

Federal Agency for Maritime and River Transportation
Maritime State University named admiral G.I. Nevelskoy

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SYSTEMIC APPROACH OF DESIGN CHARACTERISTICS DETERMINING OF MULTIFUNCTIONAL SHIPS FOR FROZEN SEAS

Textbook

The textbook is recommended by
the Far Eastern Regional Methodology Centre of Russian Ministry of Education
for multilevel training within the group
26.00.00 «Engineering and technology of shipbuilding and water transport»
for training bachelors, masters and engineers, for the post-graduates,
as well for professional retraining and skills improving of the professional directions:
26.04.02 «Shipbuilding, ocean engineering and marine infrastructure systems engineering»,
26.05.01 «Design and construction of ships and ocean engineering objects»
and 26.05.05 «Navigation»



Vladivostok
2021

**UDC 629.5.01
O35**

O35 Ogai, S. A., Voyloshnikov, M. V. Systemic approach of design characteristics determining of multifunctional ships for frozen seas : textbook / S. A. Ogai, M. V. Voyloshnikov. – Vladivostok : Maritime State University named after admiral G.I. Nevelskoy, 2021. – 448 p. — Bibliography p. 434. — ISBN 978-5-8343-1175-1.

The multifunctional ice-navigating ships are created (designed, constructed, equipped and operated) in accordance with the Shipbuilding Industry Development Strategy and with the Federal programs. The determining of design characteristics and particulars of considered ships is based on use of the systemic approach, in which the projected ship is studied as the complex system, consisting of subsystems, and, in turn, is the subsystem of the general complex object. The used approaches of project optimization cover the definition of criteria and design constraints, the objective functions and the mathematical models creation issue for their use in the determining of characteristics and particulars of these ships under design, the evaluation of considered ships structural strength, the reliability, the patency in ice and the other performances of multifunctional ships in frozen seas, the analysis of the systemic sustainability of found optimal characteristics and design particulars, the study of the impact of design constraints, including those associated with the amount of budget subsidy for construction of these ships, the constraints on ship running performances in ice, specified in the project, and the categories of the ships in the form of assigned properties in ice navigation.

The textbook is addressed to the specialists professionally engaged in determining of characteristics of ships under design for use in frozen seas, for the scientists working on the theory of ship design, and the experts involved in the development of the contracts for ships designing works and for construction of ships. The textbook is recommended by the Far Eastern Regional Methodology Centre of Russian Ministry of Education for multilevel training within the group 26.00.00 «Engineering and technology of shipbuilding and water transport» for training bachelors, masters and engineers, for the post-graduates, as well for professional retraining and skills improving of the professional directions: 26.04.02 «Shipbuilding, ocean engineering and marine infrastructure systems engineering», 26.05.01 «Design and construction of ships and ocean engineering objects» and 26.05.05 «Navigation».

UDC 629.5.01

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ISBN 978-5-8343-1175-1

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Introduction

Motivation for renewal of the fleet of merchant ships and for progress of the shipbuilding industry is the purpose of developing of marine resources, which includes any opportunities for industrial activities in the oceans related to both the service of marine freight traffics and the extraction of the offshore deposits, as well, as with the exploitation of aquatic biological resources and the ocean support of any industrial activities onshore, etc.

Marine industrial activity in freezing seas rich of indicated resources is of particular importance for the Russian Federation and for the number of states in North Hemisphere. At the same time, the batch ship construction, carried out abroad these states and well developed in the industrialized countries of East Asia, focused on the broad market demand for ships, intended for use in the temperate latitudes and tropical seas, and usually in the less degree covers the mass construction of ships assigned for the use in freezing seas.

The demand for fleet renewal and the construction of ships of innovative assignments, whose set is performed according to the Shipbuilding Industry Development Strategy for the period up to 2020 and for the future perspective /110/, which is approved by the Order # 354 on September 06, 2007 of the Ministry of Industry and Energy, is formed at the Government level, characterizes the needs of the extension of navigation in freezing seas, and the implementing of the construction of ships of the appropriate classes which allows to develop with the use of federal subsidies of national shipbuilding industry beyond the scope of competing with the mass shipbuilding in the overseas. Moreover, in addition to the development of fleet of ships of the innovation assignment, the shipbuilding yards and the plants are to be improved, as well, as the scientific and the design establishments of the industry and the profile universities.

On December 24, 2012 the Government of the Russian Federation approved the State Program # 2514–r «The shipbuilding development for the period of 2013–2030 years» /148/. The chief contractor of this State Program in accordance with the order is the Ministry of Industry and Trade of Russian Federation, and in the fulfillment of the Program the Federal Agency for Maritime and River Transportation and the Federal Agency for Fisheries are participated. The following priority tasks are envisaged: the creation of the advanced scientific and technical reserve and the technologies required for creating of promising marine and river technology;

the strengthening and the development of scientific, designing and construction potential of the industry; the ensuring of the undoubted fulfillment of the state defense order and the state armament programs; the human resources development in the shipbuilding industry, and the stabilizing of human resources to the shipbuilding yards and plants; the ensuring of the industry of domestic shipbuilding efficiency and the industry investing attractiveness, including the achievement of the level of advanced countries of the shipbuilding industry performances. The State Program will be implemented in the period of 2013–2030 years in three stages: the first stage is planned to be implemented in the period from 2013 to 2016 year; the second stage – from 2017 to 2025 year and the third – from 2026 to 2030 year. It should be mentioned that the State Program of the Shipbuilding development, which includes a number of the subprograms, characterizes planned indicators and resources in more detail than it is represented in the Shipbuilding Industry Development Strategy. The focus is on the construction of ocean and river ships of the various assignments and in the great degree the ice–navigating ships, as well, as the renewal of shipbuilding yards and plants.

The solution of the problems of shipbuilding industry development and of the fleet replenishment of ships of specified assignments, which are indicated in the Strategy, closely corresponds with the creation of methods of ships of the new classes designing, for which to determine the design characteristics the approaches are not useful enough based only on the application of analogues in view of their known limitations for ships of the innovative assignments, and it is required to develop the methods, based on the systemic approach for optimization designing of ship and the mathematical models, to the greatest extent independent of close analogues presence of the ship under design to use the approaches and methods when determining optimal characteristics and design particulars of the created multifunctional ice–navigating ship.

Among the characteristic industry features of the economy of ocean transportations, which have the greatest impact on the efficiency, profitability and on the economic payback (the self–sufficiency) of facilities of the navigation companies, the impact of investments in the replenishment and renewal of the fixed assets, that is in the fleet of ships, would be included in the first place. This follows from the analysis of balance sheet reporting, the profitability and losses of the majority of these companies, which distinguishes the economy of maritime transportation from other industries.

This fact, as well, as the accumulated depreciation and obsolescence of ships set a priority in the field of maritime transport problems. Among the top priorities

are the replacement of the obsolete and worn out fleet and the investing in construction and commissioning of new ships, which have to meet the modern requirements. In other words, it is not necessary to replace the retiring ships with their stereotyped ones, and the construction of ships of new assignments, designs and classes in accordance with the solution of problems of socio-economic development.

The other tasks of the current interest, such as the construction of individual devices, mechanisms, units, systems, instruments, technologies and etc. are subordinated to the integrated purpose of fleet of merchant ships renewal, which from the economic point of view is the dominant one in the ocean transportation industry, and the cooperation of national shipping and shipbuilding industries is needed, as well, as the cooperation at the international level.

The most important stage of creation of the innovative ship is the designing, especially its initial steps. The scientific approaches and the achievements in the initial steps of designing serve as the foundation of efficiency in the shipbuilding and shipping. The probable errors, if committed at the designing stage, are then generally unrecoverable and can cause the greatest harm, especially if the ship is of the innovative purpose, for which the analogs are not sufficiently available. The indicated reasons determine the relevance of comprehensive research and development of the approaches, methods and models for the determination of characteristics and particulars of the innovative ships under design for navigation in the freezing seas.

The Russian Federation Far East territories are located close to industrialized countries of Pacific Rim, which are characterized by mass construction of ships, aimed at satisfying demand of ships of the main types operating sea cargo traffics mostly in the middle and tropical latitudes. The prospects for shipbuilding and shipping are closely interrelated at the level of economic demand plans for the social development of coastal and continental regions, and these sectors of indicated industries are formed in the context of international competition and partnership. The geographical location of Russian Federation predetermines the special demand for the renewal of the fleet of ships suitable for use in freezing seas, in particular on the Far East of Russia and on North, in areas of interest for the development of the low populated territories, for organization of maritime transport communications, including the Northern Sea Route, and for the development of marine resources in these areas.

The demand in the Russian Federation for shipbuilding development in the context of the innovative ships creation for the freezing seas serves the strategic motivation in the context of international competition. Perhaps this feature is characteristic not only for the Russian Federation, but for some other industrially

developed states of the North Hemisphere, in particular for the USA, the EU, Canada, Great Britain etc.

This factor of demand in its turn opens the additional opportunities for shipbuilding industry, including ones of the partnership with the companies in countries of exist mass ship construction and opens the ways of the expected in the future change of the set of projects of ships under construction in the perspective as the fleet of ships for ice navigation is completed and along with the technological improvement of national shipbuilding companies. The definite similarity of the approaches probably exists on the development of the shipbuilding industry in the Russian Federation, the USA, the EU, Canada, Great Britain etc., for which the mass construction of merchant ships is nevertheless not so much characteristic as it is in the industrialized countries of the Pacific Rim, for example.

Consolidated demand for the non-typical innovative ships, which are not mass-constructed, but are constructed in single or small series can also be the driving force for merchant shipbuilding in the states of Europe and in North America. The mentioned similarity of the approaches could serve as the basis for the industrial cooperation of these countries companies. It is possible to consider the construction of single structurally diverse and technically complex ship, such as the multifunctional ice-navigating ships, or these small series as the alternative way of shipbuilding development beyond the competing with the existed mass construction of ships, where it is. These opportunities corresponded with the construction of innovative ships of the prospective classes for mastering of their construction facilities and technique are associated with the required technological level of shipbuilding, the qualification level of workers and designers, who must be able to master the construction of ships of conceptually new projects. The indicated extra-requirements primarily refer to the management of shipbuilding, to the technological facilities of shipbuilding yards and plants, as well, as to the relevance of designs.

The shipbuilding among the other high-tech industries is developed on an innovative basis. At the same time the key tasks include the construction of conceptually new ships and the mastering of those purposes of the transportation in the oceans and other maritime industrial activities, which are not yet sufficiently represented by the supply at an international markets of merchant shipbuilding industry. The innovative tasks in shipbuilding and in merchant shipping are characterized by the economic demand, since the ships of new purposes, including the new types of mass constructed ships, are in demand in the sectors of ocean resources development. This is also due to the financial supply from the investors.

Development of required approaches of research and designing of ships and the other marine engineering, their construction and operation enters in the modern ways of the improving of innovative shipbuilding and related industries for the purposes of:

1. Navigation in freezing seas, including the Northern Sea Route for cargoes transportation or for the other purposes and for ocean bottom deposits exploration, for development of aquatic biological resources and others.

2. Oil mining and deposits excavating in the oceans on the national offshores and beyond the jurisdictions, including in freezing seas.

3. Industrial fishery in coastal waters and in open ocean, including in frozen seas.

4. Defense of safety in freezing seas, as well, as of the legal development of marine resources, fishery, the fulfillment of the environmental surveillance, the transportation of cargoes surveillance and the border security.

5. Creation of modern technique and the facilities for construction of marine engineering, suitable for application in freezing seas, the construction of ship-assembling yards and shipbuilding plants, the modernization of existing plants and the creation of shipbuilding holding companies based on the partnership and the specialization of shipyards and plants.

6. Researches in the field of shipbuilding techniques, of ice-navigating ships designing, and of the ships engineering equipping.

7. Creation of qualified professional environment, of the system of education and implementation of multi-level training of specialists for solving the listed tasks.

According to the Shipbuilding Industry Development Strategy the construction of conceptually new ships intended for use in the freezing seas is contemplated, in particular the ships and the marine engineering facilities of the following classes: the tankers for navigation in freezing seas for the transportation of liquefied natural gas (LNG-tankers); the icebreakers; the container ships for navigation in freezing seas; the platforms and the equipment for the operation on the freezing seas offshores; the research of the ships for work in the freezing seas; the equipment for power generation in the freezing seas coastal areas, including the possibilities of energy generating using the renewable sources (tides, currents, winds); the equipment for processing of the natural gas in the freezing seas.

The book discovers the approaches and methods of determining of optimal characteristics and particulars at the initial stages of design of multifunctional ships for ice navigation, which creation is provided according with the Shipbuilding Industry Development Strategy and with the Federal programs. The creation of the concepts based on the systemic approach to determine optimal characteristics

and design particulars of the multifunctional ice–navigating ships allows to improve the quality and validity of design decisions, to determine logically these characteristics and particulars for contracts for these ships construction, which increases the economic efficiency of investments in shipbuilding and in shipping.

Object of the study is the multifunctional ice–navigating ship in the process of determining of it optimal characteristics and design particulars – the ship, suitable for the autonomous navigation in freezing seas, as well, as capable for servicing of and escort of other ships in these seas, that is the multifunctional icebreaking ship, which design characteristics and particulars are determined within the systemic approach for next use of their found values for ship design documenting, including the use of found design characteristics and particulars in the terms of references at the initial stages of technical project for the ship construction and in the contracts for developing of design documentation.

Terms, which can be considered synonyms: the «multifunctional ice–navigating ship» or the «multifunctional ship for the frozen seas», are used below to denote the object of study and designing. In the technical and design documentation the term is also quite common the «icebreaking support vessel» (IBSV), which has the close meaning with the indicated ones. The icebreaking support vessel is the multifunctional, because two of the purposes are indicated: the icebreaking purpose and the support one. At the same time when studying the approaches for determining of optimal characteristics and design particulars the term of «icebreaking support vessel» is not usually used below, since in accordance with the indicated term, it should be assumed that the IBSV under study for design has an icebreaking class according to the rules of a particular classification society, while a ship, considered from the standpoint of design methodology below, may not have an icebreaking class, but still have the ice or the arctic category. Thus, the used concept of the «multifunctional ice–navigating ship» (that is the «multifunctional ship for ice navigation» or the «multifunctional ship for the frozen seas») to be accurate is of broader methodological sense than the definition of the «icebreaking support vessel».

Subject of the study is the systemic approach and the set of methods for determining within the systemic approach of characteristics and particulars of multifunctional ice–navigating ship at the initial stages of designing with the use of the mathematical models of optimization, the objective functions and the functional constraints. The determination of characteristics and design particulars of ships could be done considering the economic effectiveness of the options of design characteristics and particulars sets from the investor's position, which can be the Government or that or the other sectoral or territorial administration, as well,

as the corporate investor, which is the legal entity or the physical person. When finding the optimal design characteristics, one has to compare the options of these sets, corresponding to the systemic concepts of their comparability, when design characteristics and particulars of these options are in the acceptable proportions appropriate the physical laws, the ship theory criteria, the structural mechanics and the other scientific concepts, although the key principle of optimal characteristics and design particulars of ship determining with the criterion use is the comparability of options of the characteristics sets of multifunctional ice–navigating ship under design in the frameworks of systemic approach.

It is necessary to take into account, that the approaches of conceptually new ships designing, including the multifunctional ice–navigating ships are behind the industrial needs as a rule, and they need to be developed, because the effectiveness of these ships essentially depends on the quality of designing. In addition, the traditional design methods, based on the use of statistics data and the prototypes, are of little use in determining the design characteristics of the innovative ships, for which the effective analogues of the decisions are unknown or not sufficiently enough proven and, and the statistics has not accumulated.

Development of methodological approaches for finding of optimal design characteristics of multifunctional ice–navigating ship includes the following issues:

1. Analysis of the present state of fleet of the multifunctional ice–navigating ships from the perspective of shipbuilding and navigation in the freezing seas, as well, as the considering of characteristics of new ships and planned for construction.

2. Development of the concepts of object and subject, coordinated by the methods of project optimization of multifunctional ice–navigating ship, the definitions of the concepts of options comparability in the form of the design constraints, the finding of the functional constraints, associated with the purpose of ships under designing.

3. Formulation of the balance assumptions for the design characteristics of probabilistic nature indicated by these characteristics ratios used in designing of multifunctional ice–navigating ship.

4. Finding of functional and parametric dependences of the design particulars of multifunctional ice–navigating ship or the relative values of design particulars in proportions of ship sizes with considering these particulars correlation with the seaworthy of ship and it operational properties.

5. Analysis of ship patency in the ice of definite thickness and density in the dependence on ship size and on main engines power and the propulsive properties, considering sufficient strength of the ship hull in dependence on it structural

particulars, in accordance with assigned for the ship designing data of freezing seas navigation environment.

6. Determining of dependences of the general economic indexes of multifunctional ice–navigating ship on its characteristics, on initial data (the design constraints) and on parameters (the ship design particulars).

7. Definition of the utility functions, the formulation of the economic criteria and creation of the objective functions for the determining of optimal values of design characteristics and particulars of the ship.

8. Issue of the comprehensive quality research of multifunctional ice–navigating ship design characteristics found, that is the evaluation of these characteristics sustainability, the defining of the sustainability factors of determined design characteristics and particulars of ship.

9. Approbation of the mathematical models and the algorithms in the variative calculations for finding of optimal characteristics and design particulars of multifunctional ice–navigating ship under the constraints specified in the terms of references, including the investments constraint of subsidies provided in ship construction, as well, as assigned requirements for ship patency in ice, its strength etc.

10. Definitions of concepts of the establishment and organization of shipbuilding companies that are the necessary ones for the creation of multifunctional ice–navigating ships in accordance with the Shipbuilding Industry Development Strategy and with the Federal programs.

11. Taking into account of fleet replenishment by the multifunctional ships for the freezing seas and others, constructed in accordance with the Shipbuilding Industry Development Strategy, the planning of future changes of products «line» (the sets of classes and projects of ships under construction) with the corporate investments in addition to the federal subsidies, the developing of concepts of joint participation of budget investors and the corporate ones in the subsidizing of shipbuilding developing.

12. Forming of modern professional training system for the employees occupied in the construction of the most innovative ships, in particular of the multifunctional ships for ice navigation, in shipbuilding and in related areas of the expertise, the definition of the relevant scientific tasks necessary for the improvement of the vocational training system, as well, as in the creation of assembling shipyards and in the reconstruction of shipbuilding plants.

Characteristics of multifunctional ice–navigating ship at the initial stages of designing are to be determined within the systemic approach. At the same time, the ship in all the diversity of its compared features is defined methodologically

as the set of its functional subsystems, on the one hand, and on the other one, as the element of the complex system. Among the general methodological problems, which decision is required for the formulation of the concepts of optimal characteristics and design particulars of multifunctional ice–navigating ship finding, based on systemic approach, one would include the following [40, 127, 174 and 176]:

1. Defining of multifunctional ice–navigating ship concept as the object of designing methodology, that is the element (the level) in the systemic hierarchy of design issues, as well, as the object in the conventional classification of merchant ships.

2. Formulation of the problem of optimal characteristics and design particulars of multifunctional ice–navigating ship finding in the frameworks of the objects in systemic hierarchy, associated with the ship under design, in particular the definition of the integral object concept, as the more general system than ice–navigating ship, in which frameworks the characteristics of the ship under design are determined. The certain variety of concepts of the general complex system to which the ship under design belongs is assumed.

3. Defining of constraints and formulation of set of the initial data for finding of optimal characteristics and design particulars of multifunctional ice–navigating ship, which is closely corresponded with the solution of the second issue indicated above, since the design constraints in form of the equations or the data are, respectively, the characteristics of the general integral system, which part is the ice–navigating ship under design.

4. Defining of subsystems of multifunctional ice–navigating ship, that is the objects methodologically entering as parts in the complex of this ship under design. These parts of ship at the follows stages of designing can be considered as the individual objects. The performance of multifunctional ice–navigating ship under design as the integral system consisting of subsystems, which methodologically are to be considered as individual performances of the integral ship, is also one of the consequences of the first indicated issue decision. The definitions of ship subsystems open the opportunity to determine the integral ship design particulars.

5. Definition of the set, in the other words, the vector of the multifunctional ice–navigating ship design characteristics sought in the class of independent values, characterizes the ship under optimization designing by the emphasizing of the following classes of the values: the set of constraints that serve the initial data for ship project optimization, determined under the second and third issues mentioned above, and the vector of design particulars of ship, determined accordingly the fourth one.

Listed issues to a greater extent related to the development of the methodology used at the initial stages of designing of multifunctional ice–navigating ship, namely

at stages of: the specification of the assignment and the working out the terms of references and, in the less degree, for determining of the ship particulars at the next stages of designing: at the sketch project, the technical and the working ones.

Each of the listed methodological issues from second to the fifth is systemically subordinated to the first one, and their solutions in the frameworks of the considered methodology could serve as the ground for systemic methods of optimal design characteristics finding of multifunctional ice-navigating ship. For this reason, the correct solution of the first issue is of importance – the defining of the concept of multifunctional ice-navigating ship, that is the indication of its functional and the structural inherent attributes, allowing to formulate of the design constraints in the next – the set of the initial data and the sets of: the characteristics sought and the design particulars, these in general lead to solution of the problem of optimal design characteristics of multifunctional ice-navigating ship finding.

The study deploys the following provisions corresponding the methodological foundations for determination of optimal characteristics and design particulars of the innovative multifunctional ships for ice navigation:

- concept of multifunctional ice-navigating ship in accordance with systemic approach methodology is defined for design purposes as the integral object, uniting its attributes that are the particulars, in other words, the ship individual properties, which combining when the new property arises, which is absent in other individual ones, including the patency of ship in the ice of assigned intensity, wherein the ship, as an object, being, on the other hand, the part of system the more general than the ship, and this system functions are corresponded the Shipbuilding Industry Development Strategy and the Federal programs of construction of ice-navigating ships, and each of compared options of ship when do optimization designing belongs as the subsystem (the element) to the unite general system, which serves the methodological concept of options of the ship comparability for finding the optimal one;
- mathematical values in the composition of algorithms of optimization designing of multifunctional ice-navigating ship form the following classes: the independent variables that have the greatest impact on the value of the objective function, referring to the variable characteristic of multifunctional ice-navigating ship size, in particular its design deadweight; the data for the development of the ship design, in other words, the functional constraints meaning the characteristics of the general complex system, part of which is the ship under design, referring to the set of data the assigned performances of the ship in ice of specified intensity, as well, as the characteristics of the special systems of the ship and gears in accordance with the assigned functions of multifunctional ice-navigating ship; the parameters

in the optimizing process, that is the design particulars of ship, which are the characteristics of the ship subsystems, referring to the number of particulars, for example, the dimensions of ship or their ratios, which are in the dependence on the individual properties of the integral ship;

- assumptions of multifunctional ice–navigating ship independent characteristics balance in the form of the balance equations, showing the cumulative probabilistic effect of large number of factors on the proportional ratios in the couples of the ship characteristics, varied when determining their optimal values keeping the indicated balance proportion, which allows reasonable reduction of the algorithm dimension when determining the optimal values of the characteristics, as well, as to exclude the possible methodological contradictions of the joint variation of multifunctional ice–navigating ship characteristics, which can be in the mutual interdependence;

- corresponded with the used concepts of systemic approach the functional constraints in the issue of finding of optimal design characteristics of the multifunctional ice–navigating ship its seaworthy performances and patency in frozen sea and in open water, as well, as its strength in the methodological terms are the ship subsystems, and along with some others assumed as the constraints and the individual performances of the integral ship when finding its design characteristics;

- effectiveness index of multifunctional ice–navigating ship used as optimality criterion of the ship and the objective function at the initial stages of the ship designing is determined as total generalized index of two indexes by their present values: the once invested costs in construction of the ship and the annual cash flow of operation costs, evaluating together per unit of the ship utility function in the definite proportion of both the transportation characteristic of multifunctional ice–navigating ship and its patency in ice characteristic which corresponds with the ship useful size;

- objective function used for finding of optimal design characteristics of multifunctional ice–navigating ship is the dependence of optimality criterion on independent variables (the ship characteristics sought in the optimization), on initial data (the design constraints) and on parameters (the design particulars of ship), the indicated dependence contains as well the marginal estimate of investment constraint, that is the amendment to the criterion in the form of penalty function when the investments required for the ship construction exceed the amount of provided subsidies or the appropriate premium function to the criterion, subject to compliance with this investment constraint;

– quality of optimal combination of design characteristics of multifunctional ice–navigating ship taking into account the natural error of the initial data used is characterized by the sustainability of the property of optimality when varying the initial data in relation to their specified values, the factors of sustainability of the property of ship design characteristics optimality include: the mathematical smoothness and the surface convexity of objective function in the vicinity of found optimal combination of ship characteristics; the logical classification of mathematical values in the set of the objective function used: the data, the variables and the parameters taking into account the properties of mathematical values of each of the indicated classes; the determining of the relative values of ship design particulars, which are relatively characterized more by their optimal values sustainability than the absolute values of the particulars.

Factors of the contemplated concepts and approaches novelty are due to the decisions of following obstacles and the circumstances in designing of multifunctional ice–navigating ships:

a) lacks of understood of multifunctional ice–navigating ship in the considered and used definition, as the object of design methodology in the hierarchy of functions set by Federal programs of shipbuilding development, by the Shipbuilding Industry Development Strategy and etc.;

b) changes that have occurred in the economy and industry, associated with the Federal objective projects of navigation in freezing seas, including navigation tasks for the Northern Sea Route and the tasks of oil mining and mineral deposits excavating on the offshore of freezing seas;

c) appearance of property relations in the national economy, the Federal level of the planning of new shipbuilding yards creation and the construction of innovative ships, in particular for navigation in freezing seas, which affects the determining of object and subject of the study;

d) factors of international specialization in the shipbuilding, the industrial competing and the partnership, which predetermine the logical sequence of development of national shipbuilding industry starting with the construction of innovative ships for the needs of Government especially at the shipyards and plants on the Pacific shores, which are close to the Pacific Rim of mass shipbuilding industries;

e) progress in the adjacent industries and technologies, for example in the field of offshore deposits excavating and oil mining in the freezing seas, which predetermines the characteristics of functional assignment of multifunctional ice–navigating ship, and the progress in the other spheres, associated with ships construction.

The designing provides the predominant impact on operational and economic performances as the ships, so the shipbuilding companies and serves the initial stage of multifunctional ice–navigating ship creation. In the same time the construction of innovative ships, in particular the multifunctional ships for ice navigation, requires the maximum technological level and the relevant qualifications of employees. On the other hand, it opens the possibility of competing outside the scope of serial shipbuilding and predetermines the good economic indexes in shipbuilding in view of excess of demand over supply due to limitations of supply in the construction of the multifunctional ice–navigating ships, and it corresponds with the needs of high technological level of construction of ships of these purposes.

Given study of systemic approach for determining of design characteristics and particulars of multifunctional ships for the freezing seas contains ten parts (chapters).

In the first part, the characteristics of new ice–navigating ships created as in Russian Federation, the same as in the overseas, and the new designs of these ships are analyzed. The creation of ships for the freezing seas is carried out based on budgetary subsidies, as well, as on the grounds of the federal–private partnership. Moreover, the navigation in these seas, the same as the development of the territories on the coasts are subordinated in the great degree to the solution of socio–economic problems. The ships for ice navigation suitable for self–operation in freezing seas, usually have the multifunctional assignment, and they combine the purposes of continuous ice or broken cohesive one overcoming with some of transport functions, in particular for delivery of liquid cargo, including the liquefied natural gas, or the dry cargoes, that is the general cargo, the enlarged unified and the oversized ones, for example, the blocks and modules of offshore stationary platforms and etc. The multifunctional ice–navigating ships have certain functional flexibility.

In the second part of the study, the multifunctional ice–navigating ship is analyzed from the methodological side as an object of design. The ship serves as complex probabilistic system consisting of subsystems. As the subsystem the ship considered either the integral one, considered from the standpoint of its any individual performance, in particular it this or that seaworthy property, the patency in frozen sea, as well, as the performance of its strength or other operation performance, or the subsystem is this or that structural part of ship, the gear or the mechanism and etc. When combining of subsystems of ship, that is its individual performances, which are the ship parts in the methodological definition, the new performance arises, absent in other individual parts of the ship, that is in its subsystems. The new performance of the ship, arising when combining its subsystems together, are the most important for the ship study in the design.

Study of the multifunctional ice–navigating ship as of the integral set of it subsystems indicates the ship individual performances and the additional one, arising when combining these subsystems together, serves as the prerequisite for the conclusion that in its turn the multifunctional ice–navigating ship is the subsystem of definite complex more general object, which characteristics are the input data, that is the design constraints for determining of ship characteristics in the frameworks of systemic approach. It arises the hierarchy of levels of design issues, which includes the external designing task: the determining of design characteristics of the ship, which could contain the characteristics of the ship size: the design deadweight, the cargo waterline displacement of ship, the empty/light displacement, the gross and the net tonnage, the carrying capacity, the volume of cargo and service spaces, the indexes of effective and installation capacity of the power plant, that is of main engines, the operating velocity of the ship and the characteristics of it seaworthy and the patency in ice, in particular the thickness of solid ice, which the ship can overcome by the continuous motion (this thickness in the same time can serve as the assigned design constraint and etc.), and the internal design task: the determining of ship particulars (it dimensions and of their ratios, the characteristics of the ship individual structural parts etc.).

Probabilistic features of multifunctional ice–navigating ship as the complex system in its design are to be considered outside the scope of the physical laws that describe, for example, the seaworthiness of ship (with the buoyancy, stability, propulsion, the controllability and maneuvering, unsinkability etc.), the properties of the ship general or local strength, etc. The probabilistic features indicate the ratios between the independent design characteristics of the ship and the dependent ones caused by the large set of impacting factors, when the influence of each of which on these ratios is insignificant. The use the concepts of systemic approach makes it possible to classify the numerical values entering into this model in the composition of the mathematical model of the ship under design in sets of: the sought independent on each other variable characteristics of ship, the input data, that is the characteristics of the general complex system, which subsystem is the ship under design, and the parameters of the optimization, in the other words, the particulars of ship (the characteristics of subsystems). For determining of design characteristics of multifunctional ice–navigating ship the input data and the parameters are specified as the design constraints.

Third part of the study contains the analysis of strength of the ship and it patency in ice criteria, which must be considered when accounting the assigned design constraint of thickness or the other data of the ice. The dependences for determining

of the impact of thickness of solid ice on ship cargo waterline displacement on the effective power and on the ship hull shape indicators is refined with the use of analog data: new ice–navigating ships and their design indexes, taking into account the usual similarity of the particulars of ship hull shape in the bow. The algorithm used in the mathematical model for determining of propulsive and of installation power in the dependence on design constraint of solid ice thickness as well indicates the account of constraints of the minimal velocity in open water and the reserve of installation power for the purpose of generating energy delivered to other vessels or to the shore points.

Ship hull strength in the conditions under ice impact at the level of the ice–strake of the hull shell is estimated considering the bending of the ship side overlap and this shell and taking into account that the effect of ice is more important for the strength of the plate, one of the sizes of which is equal to the framing span. It is taken into account also that on the ships assigned for ice navigation of high ice categories or the icebreaking classes at the level of ice impact on the hull of ship the additional intermediate frames can be installed. In this way, the installation of the additional framing is taken into account when determining the thickness of shell, and these assumptions are considered in the mathematical model of multifunctional ice–navigating ship used in particular for finding of cargo waterline design displacement with the account of assigned constraint of solid ice thickness.

Considering the probable inconsistencies in the performances of ship in ice and the ice categories, prescribed by the other classification societies, the comprehensive physical criterion for ships performances in the ice of assigned thickness or it other data, which covers both the safe continuous velocity of ship and the thickness of solid ice, as well, as the thickness of broken ice of the definite cohesion, overcoming by the ship with the avoidance of «ice captivity», and the thickness of solid ice, which pressure aside the ship withstands. For use in the mathematical models at the initial stages of designing of multifunctional ice–navigating ship, as well, as the ships of the high ice and arctic categories and of icebreaking classes the priority criterion of ship properties in ice serves the maximal thickness of solid ice, which the ship can overcome and withstand, also keeping into account that the index of the thickness of ice is usually in the attention of classification societies, and that this index is interconnected with the other components of indicated comprehensive index of ship properties in ice.

In the fourth part of the study the methods are of cargo waterline displacement determining in the mathematical models of multifunctional ice–navigating ship and displacement empty in dependence on the ship design deadweight, which serves

as variable characteristic in the optimization within the systemic approach using the objective function and the constraints. In the mathematical models for optimization the design deadweight characteristic is defined as maximal total of variable items of load, including the masses of: the cargo, the fuel, the ballast, the crew (with luggage and personal items), the ship stocks and its other variable summands and the constant summands of the payload specified for designing in the terms of references, that is the mass of the main equipment of the ship, for example, the modular functional equipment constructed before designing of the ship in accordance with its purpose, and the other items of the ship mass, which do not depend on the ship cargo waterline displacement in designing of multifunctional ice-navigating ship. The design deadweight can be the independent characteristic of multifunctional ice-navigating ship size sought in the optimization. The cargo waterline displacement of ship and its light displacement are in the balance dependences on design deadweight, as well, as on assigned design constraint of solid ice thickness, considered at the initial stages of ship designing in the set of rest performances of ship patency in ice. The dependence of ship cargo waterline displacement on the design constraint of solid ice thickness (or the another assigned ice category of ship under design) is of an implicit nature, in contrast to dependence of displacement on design deadweight, which part is assigned in the terms of references as the useful load. The displacement of ship with use of the balance of the displacement equation in its derivative form – the Norman factor is determined after finding of the increment of the ship hull mass depending on the necessary compliance with assigned ice thickness impacting the thickness of the ship hull shell with the account of the framing structure of hull, what is considered in the third part of the study. The use of the balance equations, established the ratios between independent characteristics of multifunctional ice-navigating ship and its dependent ones, varied in the process of optimization for the determining of their optimal values with the account of design constraints allows to reduce the dimension of the project task, as well, as the use of the parametric dependences between the characteristics of ship and its design particulars and such dependences between the particulars and their ratios.

In the fifth chapter the optimality criteria of design characteristics of multifunctional ice-navigating ship are studied. Among the main groups of the economic criteria, which can be applied for determining of optimal design characteristics of the ships of general classes such as the cargo ships the two groups are: the criteria associated with minimized costs and the criteria of maximized profit or profitability. Given that the multifunctional ship for the frozen seas are constructed usually with

the budgetary subsidies or with the involvement of budgetary and corporate investments jointly, so for the determining of optimal design characteristics of the ship of indicated purpose the criterion of the minimized costs would follow, considering the amendment by the value of the probable extra budgetary income to the costs as well. Since the general economic indexes, in correlation with which the criterion is determined, that is such indexes, as the one-time investments in ship construction, the annual operational costs and the probable corporate income (the extra budgetary one) are the functions of independent variables – the characteristics of multifunctional ice-navigating ship sought and of the design constraints, in the other words the functions of the initial data and the parameters. The resulting criterion in the form of the present worth with the specified amendment acts also as the function of the indicated mathematic values, that is the objective function, for which determining under the considered in the study assumptions, concepts and dependences the mathematical model intended for the determining of optimal design characteristics of multifunctional ice-navigating ship is being created and used.

Objective function is determined specific per unit of the useful effect in the frameworks of systemic approach, which is studied in the sixth chapter. Besides this part of the study contains the considering and determining of penalty amendment (or premium one) to the objective function for compliance of ship under design and construction with the investment constraint of provided subsidies. The characteristic the of ship transportation assignment, that is its carrying capacity, including the autonomous carrying capacity in the freezing seas, and the characteristic of multifunctional ice-navigating ship size, which indicates its capability to serve for deployment of the equipment and personnel and to provide the navigation support services in freezing seas, including laying the fairways in ice fields are considered as options of the utility function, that is the dependence of index of the effect of on the variables and on design constraints (the initial data and parameters). It is found that the size of multifunctional ice-navigating ship, in particular its design deadweight, is in the proportional relationship with the index of the ship carrying capacity, and these utility characteristics (the size of ship and its carrying capacity) can be interchanged in wide range of the data in the composition of the criterion in finding of optimal design characteristics.

The investment constraint of provided subsidies in ship construction for determining of its optimal characteristics is taken into account by introduction of penalty (or premium) amendment to the objective function, associated with the evaluation of need for the additional investment with the deficiency of subsidies or the excess of subsidized finances. The penalty (or the premium) amendment is transformed

to the comparable index with the objective function for the account of this amendment in finding of optimal design characteristics of the ship. It is taken into account the relativity of the investment constraint of the subsidized money in construction of multifunctional ice–navigating ship, since it is possible to attract the extra budgetary investments by the refund payments to the investors of market interest of the additional funds cost.

It is possible to characterize the quality of multifunctional ice–navigating ship optimal design characteristics found and they correspondence the data and the constraints by the characteristics sustainability, which is considered in the seventh part of the study. The assuming or determining of input data, which are the characteristics of general complex system (or systems, that is the methodological options of the general system), for which the ship belongs as the subsystem, affecting the optimal values of found characteristics and design particulars of ship, is the complex issue. At the initial stages of multifunctional ice–navigating ship designing, it is difficult to do the forecast of the input data accurate. That is when the optimal characteristics of ship found their sustainability is the subject are studied, that is the sustainability of the property of optimality of the ship optimal characteristics found while variation of the initial data and the design constraints. The factors of this sustainability are: the properties of the objective function in the vicinity of it optimal extremum; the logical classification of the mathematical values in the set of variables, the initial data and the parameters in accordance with the concepts of systemic approach; the finding the relative values of design particulars and not the absolute values. In the seventh part of the study the samples of variation calculus of the sustainability analysis of optimal size found of multifunctional ice–navigating ship in dependence on varied data of: the duration of annual navigation period in frozen sea; the duration of running time in the frozen sea; the utility factor of the ship design deadweight impacting the load capacity; the power installation capacity in docking when delivering the electricity to the ships, the offshore platforms or on the coast; the budgetary subsidies provided in ship construction; the index of economic risks total (the discount rate); the transport tariff per ton of cargoes for the extra budgetary customer.

Variants of the general complex system are considered in the eighth part of the study. The concept of more general system than the multifunctional ice–navigating ship under design, to which the ship belongs as the subsystem, and the attributes of options of general complex system are among the methodological definitions. Since for ships of the considered assignment the general complex system usually characterizes the ship from the points of view of the federal goals of shipbuilding development and shipping extension in the freezing seas, those determining of this

system within the options is corresponded with the budgetary subsidies provided in the ship construction.

In the frameworks of systemic approach for determining of optimal characteristics of multifunctional ice-navigating ship it is possible to consider the following samples of the general complex system: the fleet of the marine cargoes carriers, which is the characteristic example of the general complex system for external designing issue of the cargo merchant ship, providing the data and constraints for the issue; the shipping company (that is the marine enterprise as the economical self-sustainable integral complex of the assets in it), in which the ship under design enters as the subsystem; the ocean cargoes traffic of the definite intensity and the extent, serviced by the similar ships; the cluster of similar ships engaged in the development of marine resources in the definite ocean district, or the complex of ships of various types and projects, mutually complementary in it; the system of shipbuilding plants and ship assembling yards practicing the innovative methods of shipbuilding, given the assignments of ships under construction include the compliance with the applied shipbuilding technique; the national Shipbuilding Industry Development Strategy and the relevant Federal programs in shipbuilding and in shipping and etc.

Summary of examples of the general complex system, which in the multifunctional ice-navigating ship methodologically belongs as the subsystem for finding or assuming of data or the other constraints for the ship designing, allows to define the attributes of the independent purposes of budget subsidies for construction of the ships, characterizing the general complex system as the methodological concept. It is possible independently to attribute to the general complex system the purposes: the property attribute of purpose, characterizing the creation of ship (it designing, construction and operating) for the economic results; the industrial technique attribute, showing the self-containing value of the innovative opportunities in shipbuilding creation; the structural attribute, denoting the value of creating the main system of ship, that is of the innovative marine engineering facilities, which was not batch mastered in shipbuilding industry before construction of the ship, which is assigned (designed, constructed and navigated) for the indicated marine engineering facilities; the functional attribute, characterizing the ship functions of it assignment, for example with the Shipbuilding Industry Development Strategy and with the appropriate Federal programs.

Concepts of the mass modular assembling shipyard evaluation in the system of industries links is considered in ninth part of the study. When creating the new shipbuilding enterprise or improving the existing ones, as well, as the establishing

their partnership links the support of the federal administration is appropriate, provided that demand for the innovative shipbuilding production exceeds the supply for the ships of the innovative assignments, in particular for construction of multifunctional ice-navigating ships. Initially the profit of ships construction for the needs of the Government is invested in the creation of industrial facilities of these assembling shipyards or in the existing shipbuilding plants renewal, and then there has to be assumed the return of the federal subsidies and the conversion of the companies from the federal orders fulfillment to the construction of ships matching market demand. The development of the mass modular shipbuilding is carried out gradually and includes the creation of the industrial facilities of the shipyards and plants at the initial stage. The size of ships under construction is the general technological constraint in mass shipbuilding. Opportunities for cooperating of existing shipbuilding enterprises and their partnership are open up when creating the assembling shipyard which unites the involved other shipyards and the shipbuilding plants for modular assembly of large-tonnage ships. As these issues are to be solved while the working out the pilot orders of the ships construction for the federal needs and along the fulfillment of obligations to the federal investors, along the professional teams organizing, the personnel training system establishing, etc. the shipyard at the second stage assuming to operate self-sufficiently in the mass shipbuilding.

The issues of the improvement of management and the technique of innovative multifunctional ice-navigating ships construction as well, as the personnel training system of programs of these ships construction and of associated programs are in the tenth part of the study. Creation of innovative ships (designing, construction, equipping, completing, operation and maintenance) serves the subject of industrial and international cooperation and competition. The subsidies from budget in the construction of multifunctional ice-navigating ships allows to develop the industry, this extends the future opportunities of batch construction of ships of the main types, aimed at satisfaction of the market demand for new ships. The ways of the Shipbuilding Industry Development Strategy and the appropriate Federal programs fulfillment cover both the possibilities of ships construction or production of their structural parts at the national shipbuilding plants, and at the shipyards in overseas, as well, as the opportunities of investing in the creation of national assembling shipyards and shipbuilding plants. Besides the Government and the administrations (territorial and industrial) implementing the budget subsidies, the investors can be the corporate participants, including the foreign ones. The issues arise of finding of logical forms of joint participation of these investors in possession of created shipbuilding

facilities and the ships. The system of professional training of ship construction programs and the associated ones acts as the most important chain in the process of shipbuilding industry improving. Formation of multilevel continuous professional training system for the shipbuilding industry compliant with the principles of the Bologna Protocol and globally compatible by qualification estimates, having into account the required international cooperation in shipbuilding and in shipping, is consistent multifaceted priority process for the implementation of the Shipbuilding Industry Development Strategy and the Federal programs in shipbuilding and in shipping.

In the study when determining the design characteristics and particulars of multifunctional ice-navigating ship the systematic approach is used, to the creation of which Karl Ludwig von Bertalanffy an Austrian-born scientist known as one of founders of the general systems theory made a great contribution. This is an interdisciplinary practice that covers systems with interacting components, applicable to biology, cybernetics and to the other disciplines. Bertalanffy subsequently worked in Vienna, London, in Canada (in the Universities of Ottawa and Montreal) and in the United States.

Pioneering research on the application of a systematic approach to finding design characteristics and particulars of the merchant ships was carried out in the 70th and 80th by V.M. Pashin /127/, who later headed the Krylov State Research Center (in the 90th and 2000s). The concepts of the systemic approach used in determining the design characteristics of the vessel were further comprehensively presented by A.I. Gaykovich /39 and 40/.

A significant contribution to the methods of analyzing the strength of structures of ice-navigation ships is made by E.M. Apollonov and O.Ya. Timofeev /6/.

When working on the study the consulting of the ship strength assessment in the frozen sea and its patency in ice is provided by V.A. Kulesh.

The study is based on scientific concepts of ship design theory, which are discovered in known papers of L.M. Nogid /77 and 78/, V.L. Pozdyunin /131/, V.V. Ashik /9/, A.V. Bronnikov /22–24/, B.A. Tsaryov /160 and 161/.

In the methodologic grounds of the given study the impacts are of the great importance of A.N. Vashedchenko /170/, I.G. Zakharov /181/, A.I. Rakov /132/, L.Yu. Khudyakov /62/, in the issues of ice-navigating ships optimization designing the researches are of the great importance of Ye.M. Gramuzov /46–48, 182–184/, B.P. Yonov /54–56/, V.A. Zuyev /184, 185 and 56/.

For the economic evaluations and substantiations in design of ship the recommendations are used performed in the papers of V.I. Krayev /64 and 65/, L.B. Breslav /20 and 21/, V.P. Sokolov /145 and 146/, N.P. Lyubushin /72/, M.V. Voyloshnikov /174 and 176/.

Authors remember Gennady Egorov /32, 33 etc./ nice person and deep scholar, passed away in 2021. G.V. Egorov established the designing bureau of ships and was the principal of this bureau developing dozens of projects of merchant ships, including ice–navigating ones, which were built at shipyards of different states.

Checklist

1. Motivation for renewal of the fleet of merchant ships and for development of the shipbuilding industry.
2. Discrepancy between the states carrying out shipping in the freezing seas and ones carrying out the mass merchant shipbuilding.
3. The regulating decisions in the shipbuilding and shipping development, the goals of these decisions and the participating departments of administrations.
4. Importance of the systemic optimization approaches under design of the ships of the innovative types with the lack of these ships close analogues.
5. Impact of the investments in the navigation companies on their profitability and self–sufficiency.
6. Relevance of innovative ships, which satisfied the Strategies and the Federal programs of development, instead of the replenishment of retired stereotype ships.
7. Importance of the international partnership and of the industrial cooperation in merchant navigation and shipbuilding.
8. Designing as the most important step of the ship creation impacting it efficiency in construction and operation.
9. The states potentially interested in the developing of the shipbuilding industry along with the construction of the ships for the freezing seas.
10. Extra–requirements for management in shipbuilding, the technological facilities of shipbuilding yards and plants and the relevance of designs to satisfy consolidated demand for the non–typical innovative ships, which are not mass–produced.
11. Purposes of improving of the improving of innovative shipbuilding and related industries, including the required approaches of research and designing of ships and the other marine engineering.
12. Innovative ships for the freezing seas contemplated by the Shipbuilding Industry Development Strategy and by the Federal programs.
13. Multifunctional ice–navigating ship as the object of optimization designing.
14. The denotations of objects: «multifunctional ice–navigating ship» or «the multifunctional ship for the frozen seas» and «the icebreaking support vessel» (IBSV).

15. Role of the systemic approach as the concept of comparability of options of sets of the ship design characteristics and particulars when finding the optimal one set.
16. The issues which decisions are required developing of the models and the technique for finding of optimal design characteristics of the ships.
17. Issues corresponded with the development of systemic methodological approaches used at the initial stages of designing of multifunctional ice–navigating ship, the subordination of the issues under considering, the relevant designing stages.
18. Hierarchic systemic approach considering the ship under design as the complex system consisting of subsystems and as the subsystem of the more general system (the ship under design as the element of the other system).
19. Concept of multifunctional ice–navigating ship in accordance with the systemic approach.
20. Classes of the mathematic values in the composition of algorithms of project optimization of multifunctional ice–navigating ship.
21. Balance assumptions of multifunctional ice–navigating ship independent characteristics, which in the couples can be in mutual probabilistic interdependence.
22. Functional constraints of ship particulars when finding it optimal design characteristics.
23. The effectiveness index of multifunctional ice–navigating ship covering the costs for construction and the operation costs annual cash flow, as well, as the ship utility index of it capability to transport cargoes and to overcome the ice.
24. Objective function as the dependence of optimality criterion on independent variables (the ship characteristics sought), on initial data (the design constraints) and on parameters (the design particulars).
25. Factors of quality and the sustainability of found optimal values of the ship characteristic and design particulars.
26. Novelty factors of contemplated concepts and systemic approach for determining of design characteristics and particulars of multifunctional ships for the freezing seas.
27. The excess of demand over supply in the construction of the multifunctional ice–navigating ships due to limitations of the supply.
28. The multifunctional assignment (the multifunctionality) of new ice–navigating ships recently constructed, under construction and ones under designing.
29. Multifunctional ice–navigating ship as the design object – the complex system consisting of the subsystems and the object which belongs as subsystem to the more general system.

30. Particulars of multifunctional ice–navigating ship as the indexes of individual performances of the complex ship in the systemic approach.
31. The new subsystem of ship (it new individual performance) arising when combining together of the ship other individual performances (that is the subsystems).
32. Prerequisite of the assumption that the multifunctional ice–navigating ship is the subsystem of definite complex and more general object.
33. Probabilistic features of the dependences between each two characteristics of the multifunctional ice–navigating ship, or the characteristic and particular of ship.
34. The types of assigned constraints when determining the design characteristics of multifunctional ice–navigating ship, the assigned data or the assumed particular.
35. Solid ice thickness, which the ship can overcome by the continuous notion and which pressure aside the ship withstands, in the attention of other marine classification societies considering as the general criterion of ship patency in frozen sea.
36. Index of ship design deadweight characteristic as the maximal total of variable items of load and the constant summands of payload assigned in the terms of references.
37. Explicitly assigned payload constraint and the implicitly assigned increment of the cargo waterline displacement by the specified in the terms of references the thickness of solid ice.
38. Groups of the criteria appropriate for the use in the objective function for determining of optimal design characteristics of the ship: the criteria associated with minimized costs, in particular the present worth criterion with the definite amendments, and the criteria of maximized profit or profitability.
39. Options of the utility function of multifunctional ice–navigating ship, that is it navigation useful effect, covering the ship size (the deadweight, the tonnage etc.) option and the ship carrying capacity.
40. Relativity of the investment constraint, since it is possible to attract the extra budgetary investments by the market interest of the additional funds cost.
41. Quality of the optimal design characteristics found of the ship as their sustainability while varying the input data and the other constraints.
42. Factors of sustainability of optimal design characteristics found: the properties of objective function in the vicinity of it optimal extremum; the logical classification of the mathematical values; the finding of relative values of design particulars.
43. Examples of the general complex system, to which the ship under design belongs as the subsystem, for data and constraints determining when comparably varying

the design characteristics sets of the multifunctional ice–navigating ship and finding the optimal one set.

44. Attributes of the independent properties of general complex system to which the multifunctional ice–navigating ship belongs as the subsystem (the examples of the attributes).
45. Redemption of the emerged obligations of subsidies funded in construction of the assembling large–tonnage shipyard and the following conversion of it product line from servicing the needs of the Government to the construction of ships matching market demand.
46. The system of professional training of ship construction programs and the associated ones as the most important chain in the process of shipbuilding industry improving.

Chapter 1. Construction of the multifunctional ships for the freezing seas by the Shipbuilding Industry Development Strategy

Perspectives of national shipbuilding development and the corresponding demand, for which the participants of works – the researchers and the practical experts of the shipbuilding and marine engineering are oriented, are aimed for the carrying out of two economic tasks: the fulfillment of Federal programs of fleet replenishment and the satiety of international market demand for new batch merchant ships. For satisfaction of market demand the merchant ships are batch constructed usually. In the same time any national shipbuilding development have the features, predetermined by tasks issued by the Government. Russian ship-owners are usually depositing in the orders for construction of merchant ships of other assignment the amount of about 1 billion of US dollars in the overseas annually /74/. The share of national shipbuilding plants in the total of ships construction for the federal needs is about 6 %, although it could be up to 30÷40 % potentially.

The State program of the Russian Federation «The shipbuilding development for the period of 2013–2030 years» is aimed at increasing of national shipbuilding industry participation in the fleet replenishment. The implementing of this Federal program has three stages. The expected results include the creation of scientific and technical groundwork for the shipbuilding industry, the development of complexes of the industrial facilities, the implementation of the innovative projects of offshore platforms for Arctic offshore, the designs of arctic tankers for the transportation of oil and the liquefied natural gas, the arctic icebreakers and ships of the other classes, the creation of new technologies in the industries of ship machinery and the instruments production, the renewal of the production base of acting enterprises, as well, as the fulfillment of other relevant tasks, which in the expected results contribute to social issues and correspond with the improving of general economic indexes in the shipbuilding industry, and in the separate yards and plants.

The federal tasks of shipbuilding development and their carrying out, in which both could participate – the Russian shipbuilders and the foreign ones, in the most general content are in the Shipbuilding Industry Development Strategy for the period up to 2020 and for the future perspective /142/, decided by the order # 354 on September 06, 2007 of the Ministry of industry and energetics. The Strategy covers the relevant issues of the Government, which are open for participation of companies

and experts of the various specialties of the shipbuilding profession of «Naval architecture and Marine engineering» as in the Russia, so in the overseas in two general areas of works:

- in the area of ship construction in accordance with the national demand of development of conceptually new ships, which are not mastered sufficiently at the existing shipyards implementing the batch construction aimed at the satisfaction of market demand;

- in the field of new shipbuilding plants creating and the ship assembling yards, able to combine the existing shipyards to work together on the construction of conceptually new ships for the batch shipbuilding in the next matching the market demand, and to reconstruct the existing yards.

Professional training in the shipbuilding of construction processes and technique skills take place among the primary tasks, as well, as the study of ships of the innovative assignment and marine engineering designing approaches are among these tasks for the renewal of fleet and the existing shipbuilding enterprises and for the creation of new shipyards.

In the Strategy of Innovative Development of the Russian Federation for the period up to 2020 /150/ in the set of the prospective industries for the development and increasing of high-tech impact in Russian gross domestic product the shipbuilding industry is indicated, being the economy, for which the economic competition is global.

Construction and the operating of ships and the equipment of the definite assignment it is possible to attribute to the number of marine engineering and industrial technique of the follows general innovative goals developing:

- operations and the cargoes transportation in freezing seas, including in the North and in South oceans;

- industrial fishery in the ocean, including in freezing seas districts;

- mining of the natural deposits from the ocean on the continental offshore, including in freezing seas;

- protection of marine resources and the rules of law in the seas, the protection of the legitimate use of marine resources;

- creation of new shipyards for construction of ships of definite assignment;

- professional training and the scientific study of ships construction.

Information specified in the table 1.1 is relevant in definite degree and changes by the time. But this allows to indicate, that besides of Russian Federation, which has about of 50 % of icebreaking ships in the world, there are five more states having the commensurate activity in the use of icebreakers. To the number of these states the following have to be attributed: Sweden, Finland, Canada, the USA and Denmark.

Table 1

World icebreaking fleet existing, under construction and planned
(corresponds 2017, the overall set of ships, <https://alaff84.wordpress.com/>)

Russian Federation	Sweden	Finland	Canada	the USA	Denmark	Norway	China	Great Britain	Argentina	Australia	Chile	Estonia	Germany	Japan	Republic of Korea	South Africa	Latvia
Existed icebreaking ships, items																	
46	7	10	7	5	4	1	3	1	1	1	1	2	1	1	1	1	1
The icebreaking ships under construction, items																	
11			2			1	1										
The icebreaking ships planned for construction, items																	
4	3		5	3						1	1		1				

1.1. Directions of shipbuilding development in the Russian Federation

In accordance with the Shipbuilding Industry Development Strategy for the period up to 2020 and for the prospective, decided by the order # 354 on September 06, 2007 of the Ministry of industry and energetics, for the federal demand it is required the construction of marine engineering and ships of the following classes: the liquid cargoes tankers for their operation in freezing seas, including for transportation of liquefied natural gas (the LNG–tankers); the icebreakers; the container cargo ships for the freezing seas; the platforms and the equipment for operation on the freezing seas offshore; the scientific–research ships for the operation in freezing seas; the equipment for power generation in the coastal areas, including the opportunities to use of renewable energy sources (the tides, currents and winds); the floating equipment for natural gas processing in freezing seas.

One would put the attention on the fact that the specified general list covers the ships and the marine engineering equipment of the innovative nature, which construction contains the creation of the main structural or functional part that is the main system (in terms of the systemic approach), corresponding to the innovative purpose of ship according to the Shipbuilding Industry Development Strategy.

Apparently the main part could be the physical system, the gear, the machinery, the device or the separate structure of ship, specified in the terms of references for designing of ship by its characteristics, which are corresponded directly with the charac-

teristics of the purpose of ship, as well, as the main part could be defined methodologically not so much as the physical element, but as the set of the characteristics of ship innovative purpose, for example as its capability to overcome the ice field, etc.

Need to pay attention on the fact that the systemic methodological concepts have not been studied sufficiently and modern designing approaches are not developed for the ships, planned for production in accordance with the Shipbuilding Industry Development Strategy, which would require the improvement shipbuilding facilities, technique and the professional environment for designing issues of the innovative ships.

Based on planning of the construction of the ships and the marine engineering in correspondence with the Shipbuilding Industry Development Strategy as at the national shipbuilding yards, so as in the overseas, it is possible to specify the general functional goals of navigation extension in freezing seas, including in the and out of national jurisdictions, referring to the goals the follows:

- ocean cargoes transportation in freezing seas;
- fulfillment of mining of the natural deposits in the ocean and on the continental offshore in freezing seas;
- commercial fishery in the ocean, including in freezing seas;
- protection of marine resources and their legal use, etc.

Federal demand for specialized cargo ships for navigation in freezing seas is about of 90 units of total deadweight about of 4 million ton according to different estimates in accordance with the Shipbuilding Industry Development Strategy. Besides the supporting ships are required of the number of 140 units and from 10 to 12 of new icebreakers are needed. The demand for the fleet replenishment for corporate owners to navigate in freezing seas, in particular for the PJSC «Gazprom», includes the needs to replenish the follows ships and marine engineering complexes: the drilling platforms, the tankers and the LNG-tankers, the icebreakers, the supply ships, the scientific-research ones and etc.

1.2. Ships for the freezing seas constructed in the accordance with the Shipbuilding Industry Development Strategy and with the Federal programs

Given that the tasks of fleet replenishment of various assignment in the Strategy are largely associated with the construction of ships, assigned for navigation in freezing seas, then to formulate the methodological assumptions for determining of design characteristics of these ships the overview is performed below of ships

assigned for ice–navigation ordered and constructed for customers in the Russian Federation in the recent years at the shipyards in Russia and in the overseas.

Multifunctional ships of ice class: «Vitus Bering» (Fig. 1.1) and «Alexey Chirikov» for shipping company «Sovcomflot», PJSC were constructed at the shipyards: «Vyborg Shipyard», PJSC and Arctech Helsinki Shipyard, Inc. of design # R–70201, done by the Aker Arctic Technology, Inc. (Finland).



Fig. 1.1. Multifunctional arctic ship of the design # R–70201 (the «Sovcomflot», PJSC, www.scf-group.com)

Characteristics and particulars of multifunctional ship of design # R–70201: the displacement at cargo waterline 10 700 ton; the length of waterline (the load–line) 99.9 m; the breadth 22 m; the draught with cargo 7.9 m; the maximal velocity 16 knots; the capacity of the power installation 13 thousand kW. The ships of the design R–70201 are capable to overcome the continuous ice of thickness 1.7 m.

Multifunctional ships of the ice class: «Stepan Makarov» (Fig. 1.2), «Gennady Nevelskoi», «Fedor Ushakov» and «Mikhail Lazarev» for shipping company «Sovcomflot», PJSC were under construction at the Arctech Helsinki Shipyard, Inc. of Aker ARC 121 design of the bureau Aker Arctic Technology, Inc.



Fig. 1.2. Multifunctional ice–navigating ship of Aker ARC 121 design

Characteristics and particulars of the ice-navigating ship of Aker ARC 121 design are: the displacement at cargo waterline 12 984 ton; the length over all 104 m; the length of waterline (the load-line) 100 m; the breadth maximal 25 m; the breadth at cargo waterline 21.7 m; the maximal velocity 16 knots; the capacity of power installation 13 thousand kW. The number of cabins 45 items, the crew 28 men, the passengers 42 men.

Icebreakers with the diesel electric power installations are under construction in accordance with the Shipbuilding Industry Development Strategy besides of the multifunctional ships of the ice class. Need to pay attention at the multifunctionality of the icebreakers under creation (including their designing). The icebreaking ships, which are under construction according to the Federal programs and according to Shipbuilding Industry Development Strategy, besides of the usual icebreaking assignments when servicing of escorts in ice, laying fairways in ice fields, fulfilling the rescue works in ice are suitable as well for cargoes delivery, including the aggregated unified ones, and for doing cargo operations by the various techniques with the use of the own cargo gears, of helicopter, etc.

Multifunctional icebreaker «Victor Chernomyrdin» of design # 22600 (Fig. 1.3) with the diesel-electric power installation is designed in the bureau of «Petrobalt», Ltd. The ship is constructed at the shipyard of «Baltiysky zavod – Sudostroyeniye», Ltd. in the St. Petersburg.



Fig. 1.3. Icebreaker of the design # 22600 (www.rosmorport.ru)



Fig. 1.4. Icebreaker of the design # 21900M (www.rosmorport.ru)

Characteristics and particulars of ship «Victor Chernomyrdin» are: the displacement at cargo waterline 22 258 ton; the length of cargo waterline 146.8 m; the breadth 29 m; the draught loaded 9.5 m; the maximal velocity 17 knots; the capacity of the power installation 25 000 kW. Ship is able to overcome solid ice of thickness 1.5 m.

Multifunctional icebreakers of the design # 21900M: «Vladivostok» and «Murmansk» (Fig. 1.4) of the Central designing bureau «Baltisudoproject», FSUE (the Federal state unitary establishment) are constructed at the «Vyborg Shipyard», PJSC and the Arctech Helsinki Shipyard, Inc. The characteristics of ship are: the displacement loaded 14 000 ton, the length of cargo waterline 119.4 m, the breadth 27.5 m, the draught 8.5 m, the velocity in open water 17 knots, the capacity of the power installation 17 400 kW. The icebreakers of # 22600M and # 22600 designs are assigned as well for transportation of cargoes, for supply delivery and for fulfillment of handling operations, including with use of helicopter.

Multifunctional icebreakers of the design # 21900 (LK-16, «Moscow» and «St. Petersburg», Fig. 1.5) were constructed at the shipyard «Baltiysky zavod», PJSC in the St. Petersburg. The characteristics of ships are: the cargo waterline displacement 14 300 ton; the length of cargo waterline 114 m; the breadth 28 m; the draught 8.5 m; the maximal velocity 16 knots; the capacity of the power installation 16 thousand kW.



Fig. 1.5. Icebreaker of the design # 21900 (<http://fleetphoto.ru/>)



Fig. 1.6. Icebreaker of the design # 21180 (<http://nevskii-bastion.ru/>)

Multifunctional icebreaker «Ilia Muromets» (Fig. 1.6) with the diesel-electric power installation is constructed in St. Petersburg at the «Admiralties shipyards», JSC of the design # 21180, developed by the bureau «Vympel», PJSC. The characteristics and the particulars of ship are: the displacement loaded 6 000 ton; the length of cargo waterline 85 m; the breadth 19.2 m; the draught 6.6 m; the maximal velocity 15 knots; the capacity of power installation 8 000 kW. The ship is able to overcome the continuous ice of the thickness 1.0 m. On the icebreaking ship «Ilia Muromets» the possibilities of cargoes transportation and handling operations are assigned as well.

At the «Vyborg Shipyard», PJSC the icebreakers «Alexandr Sannikov» (Fig. 1.7a) and «Andrey Vilkitsky» are launched, constructed by the design of Aker

ARC 130A of Aker Arctic Technology, Inc. The multifunctional ice-navigating ships of Aker ARC 130A design are assigned for escort of ships in the Ob Bay area, for servicing of the freezing seas harbors and escorting the ships transported the liquefied natural gas.



Fig. 1.7. Icebreaker of Aker ARC 130A design (a, <https://akerArctic.fi/>); harbor icebreaker «Ob» of Aker ARC 124 design (b, <https://sdelanounas.ru/>)

Construction in Finland of ship «Polaris» of Aker ARC 130 design, which is somewhat of smaller size than ships «Alexandr Sannikov» and «Andrey Vilkitsky» and significantly different in type of power plant, as the natural gas fuel could be used on ship «Polaris», preceded the construction of ships of Aker ARC 130A design.

The engines, working as on the natural gas fuel, so on diesel fuel are used in the set of power installation. The four diesel generators of the total power of 27 000 kW and the harbor generator of the power of 1 200 kW are available.

Propulsion complex includes the azimuthal movers of the power 7 500 kW (2 items) and 6500 kW (1 items).

Ship «Polaris» is able to overcome ice field of the thickness 2.0 m (with snow cover of up to 30 cm) with the velocity of 2 knots, as well, as to move in ice slush (the broken ice) when the thickness of the ice pieces up to 7 m and up to 50 cm of freezing layer with the velocity of 4 knots and to move in open water with the velocity of 16 knots. The characteristics and design particulars of ship of Aker ARC 130A design are: the ice class Icebreaker8; the length over all 121.7 m; the length of cargo waterline 107.9 m; the breadth at cargo waterline 25 m; the maximal breadth 26 m; the design draught 8.0 m; the maximal draught with cargo 8.2 m. The crew of the ship is 35 men.

At the «Vyborg Shipyard», PJSC the harbor icebreaker «Ob» (Fig. 1.7b) was under construction of ARC 124 design of Aker Arctic Technology, Inc., assigned for servicing of ships reception in the freezing harbors, including the ships transported the liquefied natural gas.

Despite the relatively small size and the appropriate capacity of power installation, the harbor icebreaker «Ob» is able to overcome the continuous ice of thickness up to 1.5 m, moving as in front direction, so as stern. Besides of the icebreaking assignments the ship can tow. It is equipped with the cargo crane and able to transport cargoes on the aft deck of the length from the superstructure to the stern, that is the ice-navigating ship of Aker ARC 124 design is actually the multifunctional one.

Characteristics and design particulars of harbor icebreaking ship «Ob» are: the length of cargo waterline 84.3 m; the breadth 21.3 m; the draught at cargo waterline 6.5 m. The power of propulsors is 4×2.5 MW and the four rudder-propellers are for the motion with maximal velocity of 15 knots in open water. The crew of ice-breaking ship «Ob» is 18 men. The premises allow to take an extra 12 men and luggage.

It should be mentioned that Russian Federation possesses the largest fleet of the icebreakers, as it is shown in the table 1, compiled by the USA Coast Guard (www.uscg.mil/hq/cg5/cg552/ice.asp), where the nationality of fleet is performed.

1.3. Nuclear power installation as the main system under designing of multifunctional ice-navigating ship

Construction of complex ships, such as the icebreakers with the nuclear power installations, is of particular importance for the development of shipbuilding and shipping in freezing seas. The ships of this class are multifunctional and characterized by large number of functions. Methodologically to the number of principal functional parts of icebreaking ship with the power plant of this class, that is to the number the principal subsystems of ship (in the terms of systemic approach), it is possible to attribute as the ship assignment of ice overcoming and the fulfillment of the other operations, corresponded with the navigation escort in ice, and of the definite degree, the functions of cargoes and supply delivery, and moreover in the especially difficult ice conditions, as well, as the ship assignment includes the special assignment function – to has the nuclear power installation specified in the designing and itself pre-designed for use on the ship of considered project, giving the ship unlimited autonomy of energy reserves as it conceptual property, stimulating the development of the shipbuilding industry and marine engineering.

Nuclear power installation predetermines influences and changes the usual sequence of ship design within the framework of a systemic approach, starting the design process from the development of ship power plant, as opposed to the usual sequence when the power plant is to be the subject of selection and designing after the general characteristics of the ship have to be found. That is, the nuclear power

installation in the systemic approach when designing this ship is to be considered as the concept of main methodological system, which developing starts the designing of ship but not completes this process as it is in the initial designing of the ship with the organic fuel power installation with the internal combusting engines of batch construction.

In the other words, if to compare with the icebreakers equipped with nuclear power plants, for which the power installation development precedes the determining of ship design characteristics, the different designing and construction sequences are characteristic for usual icebreakers design and construction, equipped with diesel electric power installations, which are completed on the basis of the batch available mechanisms and parts of the electric equipment. Since the nuclear power installation is specified in the project of icebreaking ship, this can be considered as the analogue of functional purpose of ship, then the power installation can be methodologically considered as one of purposes of ship under creation (to have the installation of this class), along with the other purposes.

Universal double-draught icebreakers (Fig. 1.8a) of the design # 22220 (LK-60Ya, «Arctic», «Siberia» and «Ural») with nuclear power installation are designed in the «Iceberg» Central Design Bureau, PJSC. The construction of the ships is carried out at the Baltiysky Zavod–Sudostroyeniye (the Baltic Shipyard, Ltd.).

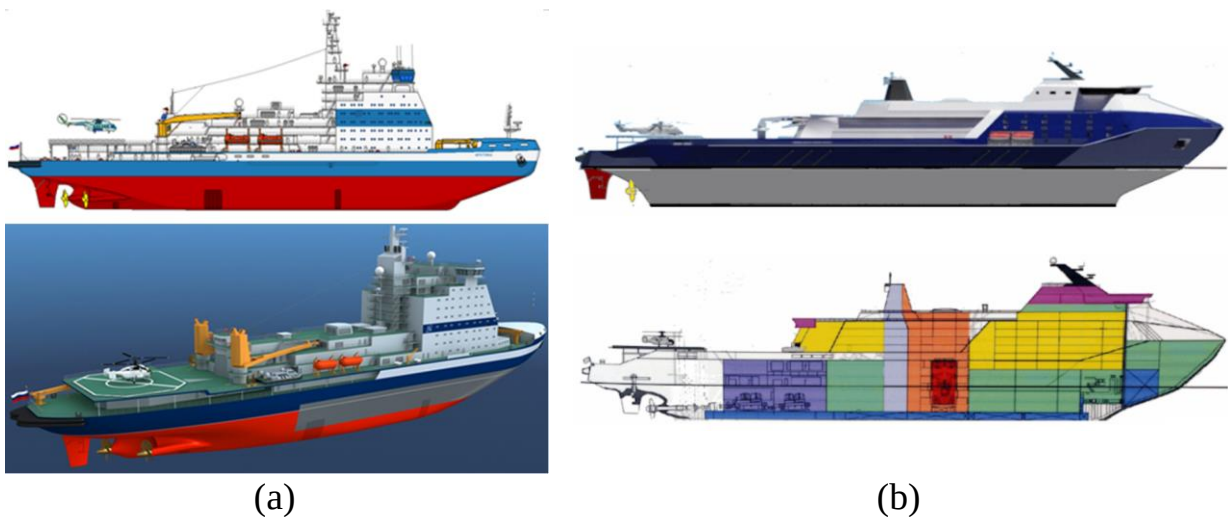


Fig. 1.8. Universal icebreakers with nuclear power: (a) the design # 22220 (LK-60Ya, «Arctic», «Siberia» and «Ural», <http://sdelanounas.ru/>); (b) the design # 10510 (LK-110Ya, «Leader», www.globalsecurity.org)

Characteristics of the ship of # 22220 (LK-60Ya) design are: the displacement at cargo waterline 25540 / 33540 ton (the values for the double bottoms are indicated); the length of cargo waterline 160 m; the length over all 173.3 m; the waterline

breadth 33 m; the maximal breadth 34 m; the draughts (two) 8.55 / 10.5 m; the velocity in open water 22 knots; the capacity of the power installation 60 000 kW. The ship of # 22220 (LK–60Ya) design can overcome solid ice of thickness 2.8 m.

Universal icebreaker «Leader» with nuclear power installation (Fig. 1.8b) of design # 10510 (LK–110Ya), planned for the construction, has the follows design characteristics and particulars: the displacement at cargo waterline 71380 ton; the length over all 209.0 m; the breadth 47.7 m; the draught at cargo waterline 13.0 m.

Power unit includes two RITM-400 reactors, 350 MW of thermal power each; the output power on the shafts is 120 MW total.

The icebreaking performances are: the thickness of solid ice maximal 4.3 m, which the ship can overcome with the velocity 2 knots and the thickness of 2.0 m with the velocity 15 knots; the width of channel in ice field – 50 m. To increase the icebreaker «Leader» patency in ice the hull of ship does not have a cylindrical insert and there are no the identical shapes of frames. The assignment of this multifunctional ship includes: the ensure of the year-round navigation along the Northern Sea Route and in the Arctic, the escort in the ice of large-tonnage cargo ships.

1.4. Multifunctional scientific–research ice–navigating ships

Scientific–research ice–navigating ships, constructed in the Russian Federation in accordance with the Federal programs and the Shipbuilding Industry Development Strategy, are the samples of the multifunctional ships as well, which is practically characteristic for any of ice–navigating ships, since besides of patency in ice and cargoes delivery functions, these ships have the opportunities of handling operations, including with use of the helicopter, the functions of the helicopter landing and service, the functions of personnel accommodation and the equipment support for scientific–researches in freezing seas, etc.

Scientific–research ice–navigating ship «Academician Treshnikov» (Fig. 1.9) is constructed in 2011 at the «Admiralty Shipyards», JSC. The design particulars of ship «Academician Treshnikov» are: the length of cargo waterline 133.6 m; the breadth 23.0 m; the velocity in open water 16 knots. Power installation includes two engines Wartsila of the power of 6 300 kW each and one of the power of 4 200 kW. The propulsive installation consists of two electrical engines of the power 7 100 kW. Velocity of ship in the solid ice of the thickness 1.1 m is up to 2 knots.



(a)



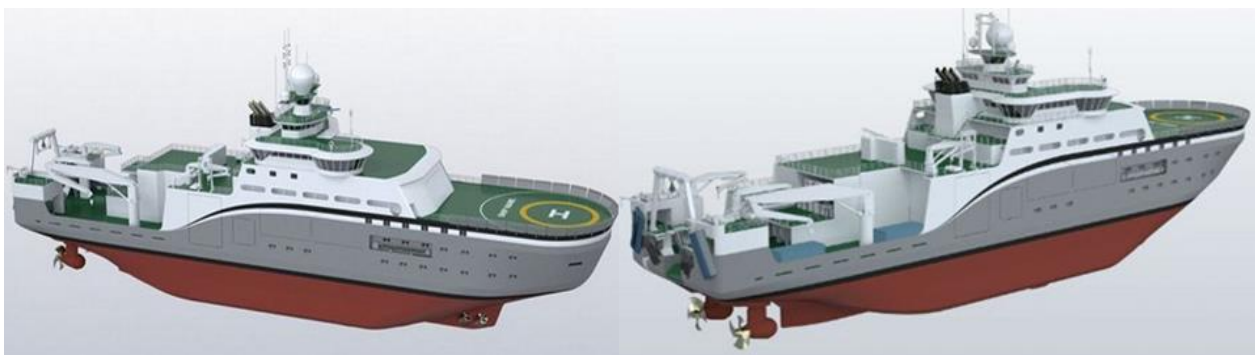
(b)

Fig. 1.9. Scientific–research ice–navigating ship «Academician Treshnikov» (<http://bastion-karpenko.narod.ru/>)

Multifunctional ice–navigating ship «Kronprins Haakon» (Fig. 1.10) is built at the shipyards Fincantieri in Genova and it is scientific ship for the Norwegian Polar Institute and is operated by the Norwegian Institute for Marine Research.

According to the rules of the International Association of Classification Societies (IACS) the multifunctional ice–navigating ship «Kronprins Haakon» has been assigned the Polar Class PC3. The ship can be operated year–round in the conditions of compressed and multi–year solid ice. The multifunctional icebreaker «Kronprins Haakon» can overcome the solid ice of thickness 1 m in the continuous motion with the velocity of 5 knots and keep the velocity of 12 knots in the ice of 0.4 m thickness.

Characteristics and design particulars of multifunctional ice–navigating ship «Kronprins Haakon» are: the gross tonnage 9 000; the length of cargo waterline 100 m; the breadth at cargo waterline 21 m; the maximal breadth 22 m; the draught at cargo waterline 8 m. The diesel–electric power installation of ship «Kronprins Haakon» includes two principal diesel–generators of the power 5 000 kW each and two ones of the power 3 500 kW each.



(a)

(b)

Fig. 1.10. Norwegian multifunctional icebreaker «Kronprins Haakon» (www.marinetraffic.com)

Two rudder–propeller electric podded azimuth thrusters of the power of 5 500 kW each are applied as movers. Two fore tunnel thrusters of power of 1100 kW each are used as the auxiliary controls. The cargo holds of the volume 1 180 cubic m are available on the ship (corresponds to 20 containers 20ft according the ISO standard). The crew of ship is 17 men, the personnel – 55 men in 38 rooms. The ship «Kronprins Haakon» is equipped with the helipad and hangar.

British multifunctional scientific–research ice–navigating ship «Sir David Attenborough» (Fig. 1.11a) for the Natural Environment Research Council is constructed at shipbuilding yards Cammell Laird in the Birkenhead (UK) and A&P Group, Ltd. in the Hebburn. The multifunctional ice–navigating ship «Sir David Attenborough» is of gross tonnage 15 000 and of 4 475 ton deadweight. The assignment includes the transportation functions, the research ones, including the personnel accommodation and the equipment support.



Fig. 1.11. British multifunctional scientific–research ice–navigating ship «Sir David Attenborough» (a, <http://www.cruisemapper.com/>) and the multifunctional icebreaker for the Institute of Polar Research of China (b, www.marinelink.com)

Diesel–electric power installation of multifunctional ice–navigating ship «Sir David Attenborough» includes two principal generators B33:45L6A of power of 3 600 kW each and two principal generators B33:45L9A of the power of 5 400 kW each. Besides of that the anchoring generator and the battery system are available. Two five-blade pitch–controlling propellers are driven in the action by four asynchronous electric motors of the power of 2 750 kW each (two electric motors at each shaft).

Multifunctional ice–navigating ship «Sir David Attenborough» has the polar class of PC4, in the same time the propulsion system of ship has the class PC5. The ship «Sir David Attenborough» can be operated year–round in the solid first–year ice with inclusions of old ice and can overcome the continuous ice of the assigned thickness 1 m with the velocity of 3 knots.

The ship velocity in open water is 17.5 knots. The economic velocity is 13 knots. The ship «Sir David Attenborough» is equipped with auxiliary controls for the maneuvering, which include four water jet thrusters of the power 1 580 kW each. The characteristics and design particulars of multifunctional ice–navigating ship «Sir David Attenborough» are: the length of cargo waterline 128.9 m; the breadth 24 m; the draught 7 m; the depth 11 m. The crew of ship is 28 men, the number of places in the rooms for personnel is for 60 men, besides two extra places are available. The helipad is available on the ship.

Design of the multifunctional icebreaker (Fig. 1.11b) for the Institute of Polar Research of China is worked out at the Aker Arctic Technology, Inc. and the ship was planned for construction in China. The ship is able to overcome the continuous ice of the assigned thickness up to 1.5 m when moving as fore and aft with the velocity of up to 3 knots. The sizes of the multifunctional icebreaker are: the gross tonnage 14 300; the length of cargo waterline 122.5 m. Two cranes are provided on the ship (of the lifting capacity 50 and 24 ton) intended to carry out works outboard with scientific equipment and for getting bottom soil samples (cores). The crew is 90 men.

Design of multifunctional ice–navigating ship (Fig. 1.12a) for the Government of Argentine is developed at the Aker Arctic Technology, Inc. The ship assigned for the transportation of cargoes and the personnel in the Antarctic, as well, as for the research purposes. The design particulars of ship are: the length over all 131.5 m; the length of cargo waterline 125 m; the maximal breadth 23.9 m; the breadth at cargo waterline 23.6 m; the draught with cargo the draught 8.3 m; the depth 13.5 m.



Fig. 1.12. Multifunctional ice–navigating ship for the Government of Argentine (<http://akerArctic.fi/>)

Multifunctional ice–navigating patrol ship «Astrolabe» (Fig. 1.13, the polar logistic ship) is built by the contract of the Administration of French Southern and Antarctic Territories and Paul–Émile Victor French Polar Institute (L’Institut

Polaire Français Paul–Émile Victor). The ship hull is constructed by the design of Aker Arctic Technology, Inc. at the shipyards Crist S.A. in the Gdynia. The completion of the ship is made at the shipyards of company Piriou in Concarneau. The «Astrolabe» is assigned for the operation as patrol ship in the French South and Antarctic Island Territories, as well, as for supply delivery to the Antarctic stations from Australia and Tasmania.

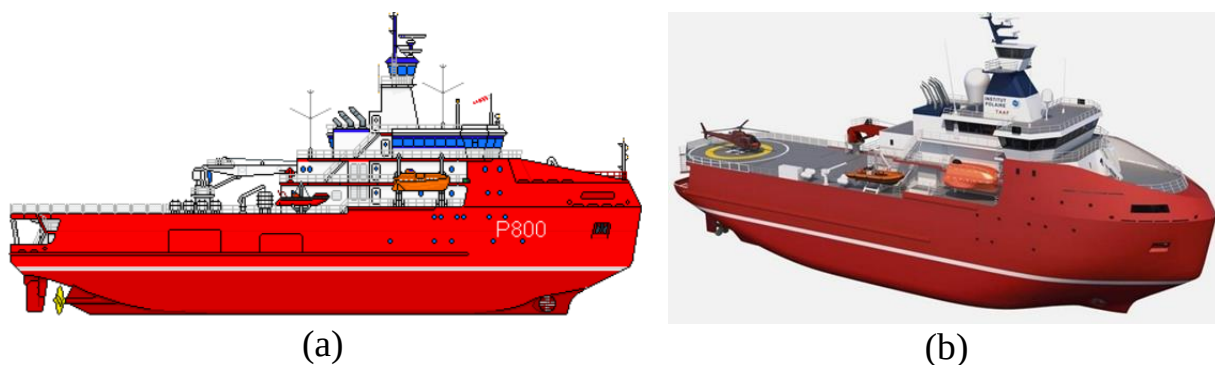


Fig. 1.13. Multifunctional ice–navigating patrol ship «Astrolabe» (<http://akerArctic.fi/>)

Ship «Astrolabe» is able to overcome the solid ice of the assigned thickness up to 1÷1,2 m, and this corresponds the class of Icebreaker 5 by the rules of Bureau Veritas. The characteristics and the design particulars of multifunctional ice–navigating ship «Astrolabe» are: the gross tonnage 2028; the design deadweight 3 000 ton; the length of cargo waterline 72 m; the breadth 16 m; the draught 5,2 m; carrying capacity 1 200 ton; the economic velocity in open water 12 knots. Power installation includes four principal engines Wärtsilä 8L20 of the power of 1 600 kW each. Two propellers of controllable pitch are used as movers. The helipad is available, as well, as the cargo gear (the 35–ton crane). Total number of crew and the personnel is 60 men.

1.5. Icebreakers under creation in Europe and in North America

Programs of fleet replenishment of ice–navigating ships, which are multifunctional usually, are implemented in some countries of Northern hemisphere. The icebreaker «Polaris» (Fig. 1.14) with the use of the natural gas as bunker fuel is constructed at the Arctech Helsinki Shipyard, Inc. with the Aker ARC 130 design of Aker Arctic Technology, Inc. for the Finnish Transport Agency.

The engines are used in the set of the power installation, operating both on natural gas and on diesel fuel. One 8-cylinder engine Wärtsilä 20DF of the power of 1 280 kW, two 9-cylinder engines Wärtsilä 34DF of 4 500 kW each and two

12-cylinder engines Wärtsilä 34DF of 6 000 kW each are available. The total power of the engines is 22 MW. The propulsion complex includes the azimuthal movers of the power 6 500 kW (2 items) and 6 000 kW (1 item).

Use of natural gas as bunker fuel opens the opportunities of refueling on site and the unlimited autonomy of ships, which are designed to work in natural gas fields. Besides of this advantage the natural gas is an environmentally friendly fuel.

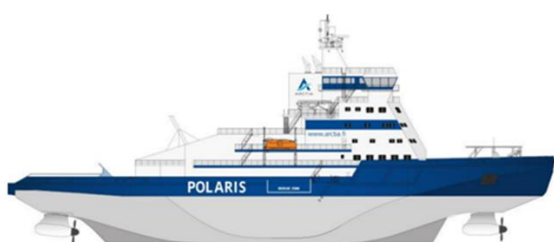


Fig. 1.14. Finnish icebreaker «Polaris» of Aker ARC 130 design using the natural gas fuel (<http://arctia.fi/>)

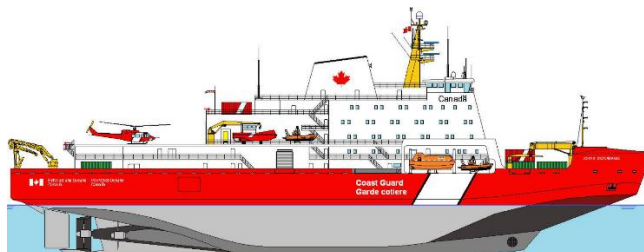


Fig. 1.15. Diesel–electric polar icebreaker CCGS «John G. Diefenbaker», Canada (www.marinelink.com)

The ship is able to overcome ice field of the assigned thickness of 1.8 m with the velocity of 3.5 knots, as well, as to lay channel of 25 m wide in the ice field of the assigned thickness of 1.2 m with the velocity of 5 knots, to serve the ships caravans in ice with the velocity of 9 up to 11 knots and to move in open water with the velocity 16 knots. The characteristics and design particulars of ship «Polaris» are: the ice class PC 4 Icebreaker(+); the cargo waterline displacement 10 961 ton; the design deadweight 3 000 ton; the length over all 110.5 m; the length of cargo waterline 97.4 m; the breadth at cargo water line 24 m; the breadth at the draught loaded 24.4 m; the draught empty 8.0 m; the draught loaded 9.0 m; the velocity in open water 17 knots. The crew of ship «Polaris» is 16 men. Additionally, the ship can accommodate 8 men.

New polar icebreaker for the Canadian Coast Guard «John G. Diefenbaker» (Fig. 1.15) of the design Vard Marine, Inc. (Canada) is planned for the construction at Vancouver Shipyards, Inc. for Canadian Coast Guard. The icebreaking class is PC2 Icebreaker(+). Six diesel engines of the total power of 39 600 MW are provided in the set of power installation. The movers are two propellers on the shafts of power of 11 MW each and the rudder column of the power of 12 MW.

Characteristics and design particulars of the ship are about: the loaded displacement 23 500 ton; the length of cargo waterline 150.1 m; the breadth 28 m; the draught 10.5 m; the depth 13.5 m; the maximal velocity 20 knots, the velocity

in ice is of 3 knots. The ship can overcome the continuous ice of thickness of 2.5 m. The helipad and hangar are available. The crew of ship is 60 men, the personnel 40 men.

Icebreaker «Aiviq» (Fig. 1.16) is built in the USA at the shipyard North American Shipbuilding in Louisiana to navigate in the Chukchi Sea on Alaska offshore, it can be used for towing and for transportation of the anchors of serviced objects.

Characteristics of icebreaker «Aiviq» are: the gross tonnage 12 892; the net tonnage 3 867; the deadweight 4 129 ton. The design particulars of the ship: the length of cargo waterline 110 m; the breadth 24.4 m; the draught 8.6 m; the depth 10.4 m. The icebreaking class is ABS A3 by the American Bureau of Shipping rules. The power installation includes four engines Caterpillar C280–12 of the power of 4 060 kW each. Two propellers of controllable pitch with the guide nozzles are used as movers. Three thrusters in the fore part are available (including two of them the «propeller-in-tube» devices, one – the propeller-rudder column), two thrusters of the «propeller-in-tube» in the aft. Velocity of ship is 15 knots in open water, 5 knots in the solid ice of thickness 1 m. The crew is 28 men, the accommodation is possible of 64 men of personnel. The helipad is available.



Fig. 1.16. Icebreaker «Aiviq» (the USA, <https://lazerone.files.wordpress.com/>)

Contract for the design and construction of polar security icebreaker (Fig. 1.17) for the Coast Guard and Navy at the Pascagoula, Miss. shipyard has VT Halter Marine Inc. by the general design of Technology Associates Inc., the design of azipod propulsion system of ABB/Trident Marine, the command and control systems of Raymarine, the joiner package of Jamestown Metal Marine, and the HVAC system of Bronswerk. The displacement loaded by 23 300 ton. The design particulars are: the length of cargo waterline 140 m; the breadth maximal 28.0 m. The Polar Class 2. The power installation includes the diesel-electric Caterpillar M32E package of the power 33 700 kW total. Velocity of ship in solid ice of maximal thickness

2.0 m is 3 knots. The accommodation is possible of 188 men (the crew and personnel). The helipad and hangar are available.



Fig. 1.17. Polar security icebreaker for the Coast Guard and Navy (the USA, www.workboat.com)

A success in the navigation in freezing seas was the construction at the shipyard Götaverken in Arendal (Norway) in 1988 of the multifunctional icebreaker «Oden» (Fig. 1.18) for Swedish Maritime Administration. The characteristics of the multifunctional icebreaker «Oden» are: the gross tonnage 9 438; the net tonnage 3 867; the displacement loaded by 13 000 ton; the deadweight 4 906 ton. The design particulars are: the length of cargo waterline 107.8 m; the breadth maximal 31.0 m; the cargo waterline breadth 25.0 m; the draught loaded 8.5 m, empty 7.0 m; the depth 12 m. The icebreaking class POLAR-20 (of DNV). The power installation includes four engines Sulzer 8ZAL4OS of the power 4 500 kW each. Two propellers of controllable pitch are used as movers. On the multifunctional icebreaker «Oden» the towing winch of 150 ton is available. The bollard pull of continuous moving forward is 250 ton. To improve the patency in ice of the ship «Oden» in it bow part the water jet system is used. Velocity of ship is 16 knots in open water, 3 knots in the solid ice of the thickness of 1.9 m. Container capacity of «Oden» is 40 TEU. The crew is 15 men, the accommodation is possible of 65 men of personnel. The helipad is available.

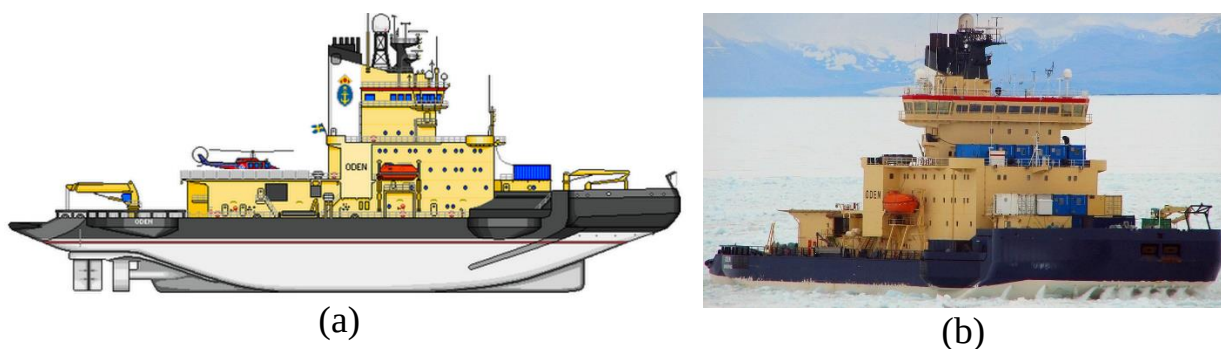


Fig. 1.18. Multifunctional icebreaker «Oden» (a);

use of water jet system to improve the patency in ice of the ship (b, www.polar.se)

Project of arctic modular towing supply vessel (AMTSV, Fig. 1.19) for the service of offshore platforms, for cargoes and supply delivery and for towing is developed in the Delft University of Technology in Netherland.



Fig. 1.19. Design of the arctic modular towing supply ship for the service of offshore platforms, cargoes and supply delivery and for towing (www.damengears.com)

Design particulars and characteristics of ship AMTSV are: the length over all 104.7 m; the length of cargo waterline 94.4 m; the breadth 21.5 m; the draught empty 8.0 m; the draught at the cargo waterline 11.1 m; the deadweight is 6 050 ton; the capacity of cargoes on the deck 4 500 ton. The ship can accept 25 TEU of standard containers in the hold and on the deck. The liquid cargoes and stocks: the bunker fuel of liquefied natural gas 1 050 cubic m; the bunker diesel fuel 950 cubic m; the fuel cargo for delivery 1 000 cubic m. The operating velocity in the open water is 14 knots. The Polar Class of ship (DNV) is 4. The ship can overcome the continuous ice of the assigned thickness 2 m, the velocity of ship in the ice of thickness 1.6 m is 3 knots. Ship power installation includes four diesel–natural gas double–fuel engines of power: 1×7.2 MW, 1×4.05 MW and 1×2.7 MW. Despite the innovative nature of design of the arctic modular towing supply ship, primarily due to the use of natural gas as the fuel, one can pay attention on the fact that shape of ship's hull with a straight fore-stem, the position of which is close to vertical, and the use on the bow section of the hull retractable rudder–propeller column as the auxiliary controls is not quite typical for ice-navigating ships of the Polar Class 4.

1.6. Experience of design modernization and reconstruction of multifunctional icebreakers

Design modernization of the icebreaker «Aiviq» (Fig. 1.20) for the needs of the Canadian Coast Guard includes the conceptual change of ship layout, the increase of premises volume for the crew with luggage and the personnel, the changes of the deck layout, the relocation of helipad and hangar behind the superstructure, the equipping of hold in the fore part and transfer one of two hydraulic cranes to the fore. The specified design modernization is implemented with no change of ship hull. The capacity of the power installation is 23 MW after the designing modernization of ship.



Fig. 1.20. Design modernization of the icebreaker «Aiviq» for needs of Canadian Coast Guard (<http://federalfleet.ca/>)

Multifunctional Chinese ship for Arctic «Xue Long» (Fig. 1.21a) is owned by the Chinese Institute of Polar Research and is the reconstructed multifunctional icebreaker of the original design # 10620, built originally in 1993 at the shipyard of Kherson shipbuilding production association (KSPA). The head icebreaking–cargo ship of the original design # 10620 is «Ivan Papanin» assigned for supply delivery.



Fig. 1.21. Multifunctional Chinese ship for Arctic «Xue Long» (a), originally is built by the design # 10620 at the shipyard of KSPA and reconstructed at the shipyard in China, the ship «Vasily Golovnin» of the same original design (b)

Characteristics and design particulars of the ship «Xue Long» are: the deadweight 10 225 ton at cargo waterline; the length of cargo waterline 167 m; the breadth 22.6 m; the draught 9 m; the total power of main engines 13 200 kW; the velocity in open water 18 knots. Ship «Xue Long» has ice class CCS B1 after the renovation at the shipyard in China.

Originally the analogue ship «Vasily Golovnin» (Fig. 1.21b) is constructed at the shipyard KSPA as well. Other samples of multifunctional icebreaker of the design # 10620 renovation is done below. The multifunctional icebreaker «Deepwater 1» is the reconstructed ship «Vitus Bering» of design # 10620 (Fig. 1.22). The additional double deckhouse is installed on the fore deck, the cargo gear is replaced and the long boom is installed.



Fig. 1.22. Icebreaker «Deepwater 1» on the basis of ship «Vitus Bering» of design # 10620 (<http://www.polarpost.ru/>)

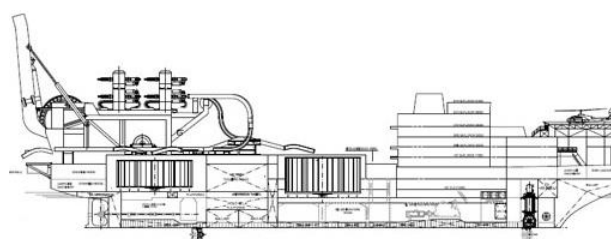


Fig. 1.23. Pre-design of icebreaking ship-cable layer on the basis of design # 10620 modernization (www.eastproject.it)

Design Deepwater Flexible Cable Lay DP3 (Fig. 1.23) of icebreaking ship-cable layer on the basis of multifunctional icebreaker of the design # 10620 renewal. By the example of icebreaking-cargo ship of the design # 10620 one can see the possibilities of reconstruction and designing modernization, which are associated with the ship original multifunctional assignment and with the general structure of the ship.

As the sample of design modernization, it is possible to indicate the multifunctional ice-navigation cargo and towing ship of the Havyard 843 ICE design (Fig. 1.24a), done on the basis of ship constructed by the design Havyard 843 (Fig. 1.24b), which not assigned to navigate in ice.

Multifunctional ice-navigating ships (cargo and towing): «Norman», «Pomor» and «Aleut» were constructed at the Turkish Cemre Shipyard and Tersan Shipyard of the Havyard 843 ICE design of the Norwegian Bureau Havyard Design & Solutions, which is the department of shipyard Havyard Ship Technology AS, at which the completion of these ships was carried out. The multifunctional cargo

and towing ships of design Havyard 843 ICE are constructed for «Rosnefteflot», JSC (the oil marine transportation company, previously «Far Eastern Marine Company», Ltd., FEMCO).



Fig. 1.24. Multifunctional cargo and towing ship of the ice class of Havyard 843 ICE design (a, www.havyard.com) and the ship Havyard 843 (b), which is the prototype for designing modernization

Assignment of multifunctional ice-navigating ships of the Havyard 843 ICE design is: the icebreaking ship for supply delivery to the offshore mining sites (drilling platforms), the firefighting, the rescue of ships and towing, the anchors transportation for floating drilling platforms, the marine pollution control. The ship could be used in the continuous ice of thickness up to 1 m. The DNV-GL class is 1A1 Fire fighter (I) Icebreaker Offshore service vessel (+, AHTS). The class of the Russian Maritime Register of Shipping is KM ★ Arc5 AUT1 OMBO FF3WS DYNPOS-1 ECO-S supply vessel. The characteristics and design particulars of ship of the Havyard 843 ICE design are: the displacement at cargo waterline 7 970 ton; the deadweight 2 871 ton; the length over all 86.7 m; the length of cargo waterline 80.24 m; the breadth 19.5 m; the depth 9.0 m; the draught at cargo waterline 7.6 m; the velocity in open water 16 knots.

Multifunctional ice-navigating ships of the Havyard 843 ICE design are equipped with diesel-electric power installations, each of which includes four principal engines: two engines B32:40L8PCD of the power 4 000 kW each and two engines B32:40L6PCD of the power 3 000 kW each. Two fore and two aft tunnel thrusters of the power 1 000 kW each are used. The ship can take cargoes 1 200 ton on the deck, including the oversized ones. The towing hook force is 200 ton. Two propellers of controllable pitch in the nozzles are used as ship movers.

Design of multifunctional ice-navigating ship Havyard 843 ICE is the improvement of the Havyard 843 (Fig. 1.24b), which is not assigned for use in the ice, and the ships of these designs differ by their ice performances, by the hull shape in the fore, by the hull structure and by the fore thrusters, which one is the electric

podded azimuth thruster (azipod) on the ship of Havyard 843. The ships of Havyard 843 ICE and Havyard 843 designs are similar functionally, besides of the patency in ice of Havyard 843 ICE, and similar in the most of other structural features, as well, as in the corresponding design characteristics and particulars.

The ship according to the original project of the Havyard 843, as well, as of the Havyard 843 ICE, has the multifunctional assignment, in particular, it performs the functions of supplying offshore drilling rigs and towing, besides of the function of Havyard 843 ICE of the navigation in ice. The sample of use as the basic prototype of the ship design, which is not assigned to navigate in ice says, that the feature of ice-navigating ship is the hull shape, necessary to overcome the ice and may not be the best from the point of view of seaworthiness of ship in open water. Besides one can attribute the characteristic elements of propellers and controls to the number of design features of ice-navigating ship.

Difference of hull mass from ship that does not have an ice category but is comparable in size with the ice-navigating one, for example the difference by design deadweight or by register tonnage, is to be attributed in the less degree to number of the features of ships of this class. That is the shape of hull, the movers and the controls types are to be considered more important attribute of ice-navigating ship design, than the displacement empty and mass of the hull, which have to match the strength requirements in ice for the assigned category and are obviously another for the comparable in size of the ship, not assigned for the freezing seas, but this is not so much important than the hull shape features, the propellers and controls.

Ice-navigating ship in one way or another is more massive in the dependence on it ice category, specified in the terms of references for designing, than the comparable ship which has not the ice category, although the massiveness of the hull does not serve the principal difference. The ice-navigating ship may be inferior by the operational performances in open water to commensurate ship, which does not have an ice category. This feature, in particular, serves the motive for designing of so-called ships DA-class (see Fig. 1.28, item 1.7), which move aft forward when overcoming ice, since the inclination of the sternpost, the theoretical buttocks lines and the keel angle in the aft end of hull, as well, as the location of the thrusters appearing vacuum under the layer of solid ice, when the ship moves by the stern, contribute to the improvement of ship performances when overcoming the solid ice, and sufficient efficiency of ship in open water is maintained in the forward motion mode. By the way, the design of multifunctional ice-navigating ship of DA-class is possible to attribute methodologically to the subject of project modernization of usual ice-navigating ship, which normally overcomes ice moving forward.

Design of large multifunctional icebreaker (the research ship) «Aurora Slim» (Fig. 1.25) was developed at bureau Aker Arctic Technology, Inc. on the basis of original design of the multifunctional icebreaker «Aurora Borealis», developed at the bureau Wärtsilä Ship Design (Finland). It is planned to build the ship by joint participation of European states, including Germany, France, Italy, Denmark, Finland, Romania, Bulgaria, Norway and the Russian Federation.

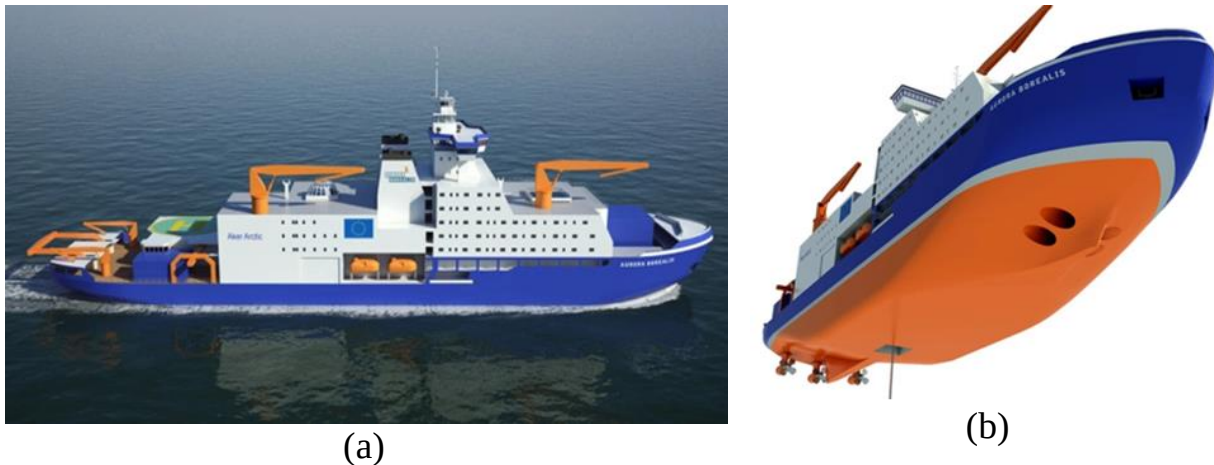


Fig. 1.25. Design of large icebreaker (the research ship) «Aurora Slim» (<http://akerArctic.fi/>)

It should be mentioned that the design «Aurora Slim» substantially differs from preceding one – the ship «Aurora Borealis» not only by estimated amount of construction financing (500 million Euros, against of previously planned 800 million Euros), but also by the composition of working equipment, planned to be installed on the ship, and the propulsion and steering complex. No rig is provided on the ship «Aurora Slim», which was on the ship of the original project «Aurora Borealis» for drilling at sea depths of more than 1 000 m. Instead of the indicated rig for underwater works, it is planned to use the mobile systems, which limits the applicability of the ship for the sea bottom drilling at the depths of several hundred meters. The indicated underwater drilling systems are supposed to be serviced through one shaft in the hull of ship «Aurora Slim» (in distinction from two shafts, which were provided in this case of the ship «Aurora Borealis»).

In addition to replacing of the three–shaft propulsion system and six retractable steering columns (three in each peak), which were planned to use on ship «Aurora Borealis», in the design of multifunctional icebreaker «Aurora Slim» the composition of the propulsion and steering complex contains three electric azimuth thrusters of power 15 000 kW each in the aft and two tunnel thrusters of power 3 500 kW each in the fore.

It is possible to characterize the running and the propulsive performances of multifunctional icebreaker «Aurora Slim» as follows: the ship can move with the velocity of 2 up to 3 knots in the solid field of multiyear ice of thickness up to 2.5 m, which corresponds to the polar class of ship PC1 by the rules of the IACS. The characteristics and the design particulars are: the cargo waterline displacement 65 000 ton; the length of cargo waterline 199.85 m; the maximal breadth 49 m; the breadth at cargo waterline 45 m; the draught loaded 13 m. Power installation includes eight principal generators of the total capacity of 97 000 kW. The maximal velocity of ship in open water is 15.5 knots, the cruising velocity 12 knots. Two helipads and hangar are available for three helicopters. The accommodation of 120 men, including the crew and the personnel, is provided on the ship.

Assignments of the multifunctional asymmetric icebreakers by the designs of: Aker ARC 100 HD (Fig. 1.26 a and b) and Aker ARC 100 (Fig. 1.26b, the icebreaker «Baltika», jointly built at the Shipyard «Yantar», JSC in Kaliningrad and at the Arctech Helsinki Shipyard) include the escort of ships in ice, the discovering fairways in ice fields, the towing in the ice, the removal of oil spill, the fires extinguishing and the other rescue works. The multifunctional ice-navigating ships of the specified designs differ principally in sizes, as well, as in the characteristics of power installations and propulsion systems.

Multifunctional asymmetric arctic icebreakers of the designs: Aker ARC 100 HD and Aker ARC 100 are indicated in the proportion to illustrate their sizes.

The ship of Aker ARC 100 HD design can move effectively fore and stern forward and sideways (at an angle). When moving fore or aft this ship is able to overcome the continuous ice of the thickness up to 2 m, and when moving in the left side (at an angle) – it can lay channel of 50 m wide in ice field of the assigned thickness up to 1.5 m. When moving in the starboard direction, the ship can efficiently gather oil spilled on the water surface. Four diesel generators: two of the power 8 000 kW each and two – of 4 000 kW each are used in the set of power installation. The propulsion complex includes three electric podded azimuth thrusters of total power 19 500 kW. The characteristics and design particulars of ship of Aker ARC 100 HD design are: the length over all 98.0 m; the length of cargo waterline 87.0 m; the maximal breadth 26.0 m; the breadth at cargo waterline 24.4 m; the depth 11 m; the draught loaded 8.5 m.

Characteristics and design particulars of Aker ARC 100 design are: the length over all 76.4 m; the length of cargo waterline 72.1 m; the breadth the draught with cargo 20.5 m; the depth 9 m; the draught loaded 7.0 m; the velocity in open water

14 knots. Class of ship by the Russian Maritime Register of Shipping: KM ★ Ice-breaker6, [1], AUT1–ICS, OMBO, FF3WS, EPP, DYNPOS–1, ECO–S, Oil recovery ship ($>60^{\circ}\text{C}$), Salvage ship, Tug, HELIDECK. The crew of ship is 24 men. In the set of power installation three diesel generators W9L26 Auxpac of the capacity 3 000 kW each are used. Propulsion complex includes three electric podded azimuth thrusters of the total power of 7 500 kW. The open deck assigned for transportation of cargoes. The cargo gear on the asymmetrical multifunctional icebreaker of Aker ARC 100 design the same as on the almost all other multifunctional ice-navigating ships is provided to the aft from the superstructure.

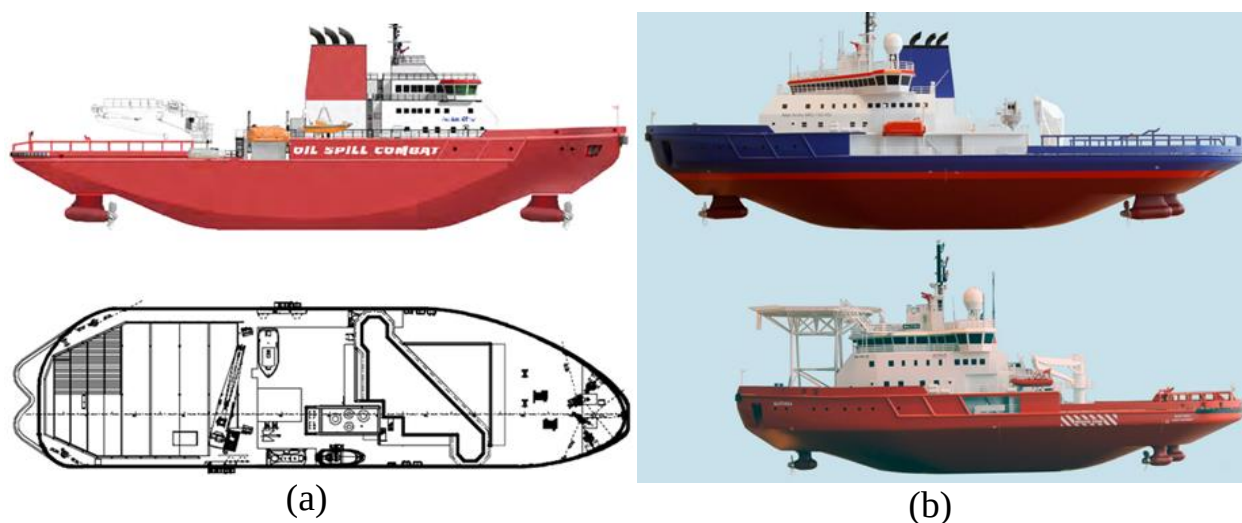


Fig. 1.26. Asymmetric icebreakers of the designs: Aker ARC 100 HD (a, b, <https://akerArctic.fi/>) and the Aker ARC 100 (b, the icebreaker «Baltika», below)

Suitability of many ice-navigating ships for design modernization, illustrated by sufficient number of examples, can be considered as confirmation of these ships multifunctionality. Besides of the purpose to overcome the ice they are usually assigned for the functions: the transportation of cargoes, the navigation servicing of other ships without ice category in the conditions of freezing seas, the towing, the rescue, the functions of scientific equipment support service, of watercrafts and helicopters and the functions of: the delivery of passengers with the cargoes, the delivery of supply to the coasts and ships in freezing seas, the accommodation of scientific and working personnel onboard the ship, etc. These ships are also suitable for modernization at various stages: in the designing, construction and in the maintenance in the operation.

1.7. Ships for cargoes transportation in freezing seas

The LNG-tankers of the «Yamal» design (Fig. 1.27) of liquefied natural gas cargo capacity 17 200 cubic m have the length of cargo waterline 299 m, the breadth 50 m, the arctic category Arc 7 by rules of the Russian Maritime Register of Shipping. The ship is able to overcome the continuous ice of the thickness 2.1 m, assigned in the terms of references. The power installations Wärtsilä can use the natural gas as the principal fuel, as well, as the heavy fuel IFO or low viscosity marine diesel fuel MDO. The installation of the couple of double fuel engines Wärtsilä 50DF is provided: 12-cylinder and 9-cylinder. The total capacity of the power installations on the ship is 64.35 MW. The ships were under construction in the Republic of Korea at the shipyards of Daewoo Shipbuilding & Marine Engineering (DSME) Co., Ltd.

Concept of LNG-tanker of arctic DA-class of 200 000 cubic m cargo capacity for the Kara Sea is indicated on Fig. 1.28. The class designation DA (Double Acting) characterizes ice-navigating ship, which shape of fore and stern is optimal for the motion stern forward when overcoming ice field and bow forward in open water. The design originally contains the main engine of power 53 MW, which is more than the capacity of power installations of most of the icebreakers, which is usually from 16 to 57 MW. The decision to reduce the design capacity of the main engine down to 40 MW (the total power of two independent double fuel internal combustion engines) was adopted in the after. The ship moving stern is able to overcome the continuous ice of thickness 2.5 m. Estimated construction cost of first ship is in the range from 300 to 350 million US dollars.



Fig. 1.27. The LNG-tanker of «Yamal» design (<http://martechpolar.com/>)



Fig. 1.28. The LNG-tanker of DA-class (<http://lngas.ru/>)

The LNG-tanker for the freezing seas (Fig. 1.29) options of the line, which are differed by cargo capacity of: 80 000, 155 000 and 215 000 cubic m, are devel-

oped at the Severnoye Design Bureau, JSC. The availability of the options line (contrary to single one decision) indicates the appropriate flexibility of the ship concept, which confirms the LNG–tanker multifunctionality – the suitability for designing modernization, besides of the ship assignment multifunctionality to overcome the ice field in the freezing seas and to transport the cargo of LNG.



Fig. 1.29. LNG–tanker of options line of Severnoye Design Bureau, JSC (www.nt-magazine.ru)



Fig. 1.30. LNG–tanker «Grand Aniva» (www.sovcomflot.ru)

Characteristics and particulars LNG–tanker «Grand Aniva» (Fig. 1.30), built according to similar design with the ships «Grand Mereya» and «Grand Elena» at the shipyard Mitsubishi Heavy Industries, Ltd. in Japan are: the deadweight at summer cargo waterline draught 71 200 ton; the displacement of ship loaded 122 239 ton; the displacement empty 36 671 ton; the velocity in open water 19.5 knots; the crew 14 men; the gross tonnage 145 000; the net tonnage 36 671; the capacity of power installation 24 MW; the length over all 288 m; the length of cargo waterline 274 m; the breadth 49 m; the depth 26.8 m; the draught loaded 11.4 m; the total capacity of cargo volumes 145 578 cubic m (4 spherical spaces).

Tanker «Captain Gotsky» for transportation in freezing seas of oil and its products, constructed in accordance with the Shipbuilding Industry Development Strategy, is indicated in Fig. 1.31. Characteristics and particulars of the ship «Captain Gotsky» are: the gross tonnage 49 597; the summer cargo waterline deadweight 72 722 ton; the length of cargo waterline 257 m; the breadth 34 m.

Arctic tanker «Yenisei» (Fig. 1.32) assigned for transportation of oil products is constructed in the 2011. Design particulars of ship «Yenisei» are: the length of cargo waterline 69 m; the breadth 23.1 m; the effective power of main engines 13 000 kW; the design deadweight 15 000 ton at winter cargo waterline 9.0 m and 20 000 ton at summer one 10.0 m. The ship is able to overcome the continuous ice of thickness 1.5 m. Ship «Yenisei» is constructed at the Nordic Yards in Germany for the owner «Nornickel», PJSC.



Fig. 1.31. Arctic tanker for transportation of oil products «Captain Gotsky» (www.sovcomflot.ru)



Fig. 1.32. Arctic tanker for transportation of oil products «Yenisei» (<http://izvestia.ru/>)

Conceptual design of an ice-class shuttle container ship of Arc7 category with a capacity of 3000 TEU (Fig 1.33) jointly developed by CNIIMF, JSC and in the Marine Engineering Bureau, JSC. The ship has the follows design characteristics and particulars: the polar class of PC3 with the arctic class Arc7; the length of waterline 220 m; the breadth 32.2 m; the depth 19.5 m; the draught of ship loaded 11.0 m; the maximal draught 12.2 m; the loaded ship displacement 65 500 ton; light displacement 24 500 ton; the design deadweight 41 000 ton; the capacity of power installation 45 000 kW; the propulsors – Azipod, 3 items; the velocity in open water 21 knots; the maximal thickness of solid ice 2.1 m, which the ship can overcome.



Fig. 1.33. Ice-class container ship of Arc7 category conceptual design of 3000 TEU capacity (www.morvesti.ru)

Promising opportunities for year-round navigation of container ships in freezing seas, for example, the possibility of all-season transportation of dry cargoes along the Northern Sea Route give rise to less confidence in practical implementation than the transportation of liquefied natural gas and oil in these seas, although the creation of container ships for the freezing seas is covered plans of the Shipbuilding Industry Development Strategy, since the demand for the transportation of liquefied natural gas and oil is associated with the geographical location of oil and natural gas offshore grounds in the freezing seas, while the transportation of dry

cargo and containers across the freezing seas is of a transit nature, and there are alternative possibilities to carry out this transportation outside the freezing seas, despite the fact that the length of the cargo line between the ports of departure and destination (in Europe and in Asia) is longer in the southern latitudes than in the freezing seas in the north.

It is possible to characterize the indicated cargo ships, assigned for the navigation in freezing seas, as the multifunctional ones, since for the creation of these ships along with their assignment of cargoes transportation the function of ice overcoming is specified as well. The function of ships seaworthiness in ice covers they performances of capability to overcome ice, the controllability in ice, the strength etc., as well, as the function of cargoes transportation, which total set affects the ship designing characteristics and particulars, such as it displacement at cargo waterline as well, as it displacement empty, the tonnages and volumes, the ice category, the capacity of the power installation, etc.

1.8. Multifunctional icebreaking ships for harbors servicing

For servicing of winter navigation on the offshore sea areas of oil and gas and in the freezing seas harbors the icebreaker «Varandey» (Fig. 1.34a) and the auxiliary tug of icebreaking class «Toboy» (Fig. 1.34b) were constructed at the shipyard of Keppel Singmarine (Singapore), by the contract with PJSC Lukoil Oil Company.

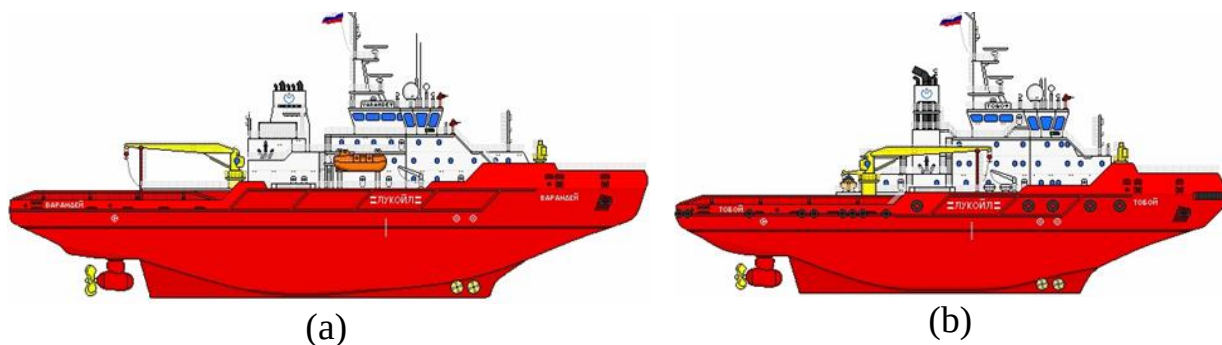


Fig. 1.34. Multifunctional icebreakers in the possession of PJSC Lukoil Oil Company (www.lukoil.ru): the icebreaker «Varandey» (a) and the harbor tug of icebreaking class «Toboy» (b)

Multifunctional icebreaker «Varandey» can be used as rescue ship, as well, as firefighting one, the bunkering ship and oil skimmer, besides of icebreaking purpose performing. The icebreaking assignment is fulfilled by ship «Varandey» and includes the safety ensuring in freezing sea when loading tankers.

Characteristics and design particulars of icebreaker «Varandey» are: the displacement at cargo waterline 10 874 ton; the design deadweight 4 643 ton; the length over all 100 m; the length of cargo waterline 88.8 m; the breadth 21.7 m; the depth 13.3 m; the draught at cargo waterline 10.6 m; the velocity in open water 15.0 knots; the class of ship by the Russian Maritime Register of Shipping is KM ★ Icebreaker7 [2] AUT1–ICS EPP tug / supply / salvage ship.

Multifunctional icebreaker «Varandey» has diesel–electric power installation, which includes four main diesel–generators 12V32 of the power 5 760 kW each, the anchoring and emergency generators are available too. Two electric podded azimuth thrusters of the power 8 400 kW each are used as movers.

Auxiliary tug of icebreaking class «Toboy» is suitable for supply delivery to the offshore platforms and drilling rigs, for marine towing, for fulfillment rescue functions and the fire fighting. The characteristics and design particulars of the tug «Toboy» are: the displacement at cargo waterline 6 533 ton; the deadweight 1 930 ton; the length over all 81.6 m; the length of cargo waterline 73.3 m; the breadth 18.5 m; the depth 11.2 m; the draught at cargo waterline 9.3 m; the velocity in open water 15.0 knots; the class of ship by the Russian Maritime Register of Shipping is KM ★ Arc7[1] AUT1 EPP supply vessel. The multifunctional ice–navigating ship «Toboy» has diesel–electric power installation, which includes three main diesel–generators 9L32 of power 4 320 kW each, the anchoring and the emergency generators are available as well. Two electric podded azimuth thrusters of the power 5 200 kW each are used as movers.

Icebreaking tug of Aker ARC 125 design (Fig. 1.35) developed at the Aker Arctic Technology, Inc combines the functions of navigation in ice, servicing and towing ships in freezing seas, as well, as oil pollutions removal, the fire control, that is the ship of Aker ARC 125 design is the multifunctional ice–navigating ship.

The ship is able to overcome the solid ice of thickness 1 m with the velocity of 3 knots and to move with the velocity of 2 knots in broken ice with pieces of 4 m thickness, or in the solid ice with the thickness of layer 0.5 m. The ship has arctic category of Arc6 by the classification by the rules of Russian Maritime Register of Shipping and category PC4 by the rules of IACS.

Characteristics and particulars of multifunctional icebreaking tug of Aker ARC 125 design are: the deadweight 270 ton; the length over all 43.7 m; the length of cargo waterline 40.0 m; the breadth at cargo waterline 14.0 m; the cargo draught 6.0 m, the draught with the protruding parts 6.5 m; the depth 7.8 m. The power installation includes two main diesel–generators of power 3 300 kW each. Two azimuths are used in the set of propulsion and steering complex.



(a)



(b)

Fig. 1.35. Multifunctional icebreaking tug of Aker ARC 125 design (<https://akerArctic.fi/>)

Variety of these classes of ships functions, among which is the transportation of dry cargoes, in particular the aggregated unified ones, the rolling cargoes, the general cargoes, etc. and the capabilities to overcome ice layer of the appropriate intensity, the additional functions of goods transportation and supplies, including the oversized cargoes on the deck, the functions of ships towing in ice, the functions of ships rescue in disasters and etc., which the icebreakers are doing besides of the principal assignment of navigation servicing in ice of ships, not having ice category, as well, as besides of the research function in freezing sea, the patrol function, the towing and others indicates the multifunctional nature of ice-navigating ships assignments.

Analysis of ice-navigating ships designs, considering the possibilities of these ships modernization, indicates the variety of they functions, this acts an integral quality of ice-navigating ships along with their specific functional assignments and with each opportunity of reconstruction or designing modernization, that is the opportunity to change any ship of this class specific assignment, and these ships uniform function in each definite option is availability of overcoming of sea ice of the assigned intensity.

1.9. Monotypes and the innovative prototypes of multifunctional ice-navigating ships under designing

Concepts of optimization designing, studied in the considered work for the multifunctional ice-navigating ships creating, associated with use of the systemic approach, the optimality criteria and objective functions, the concepts of comparability and design constraints can be used at the initial stages of innovative ships

designing, not necessarily intended for use in freezing seas, for example, the multi-purpose ship «Scandi Africa» (Fig. 1.36), created in 2015 in Norway at the shipyard of «Kværner», assigned for the support of submarine structures installation and the underwater works. Ship «Scandi Africa» is assigned for subsea operation duties with high seaworthy performances in harsh environments.

Characteristics and particulars of multifunctional ship «Scandi Africa» are: the deadweight of the ship loaded $13\,393 \div 16\,000$ ton, in dependence on operation mode; the gross tonnage 22 689; the net tonnage 6 807; the bunker fuel – up to 2 600 cubic m; the water fresh – up to 800 ton and the ballast water of up to 13 000 ton; the premises for stocks 3 500 ton; the length over all 160.9 m; the length of cargo waterline 148.8 m; the breadth 32.0 m; the depth 26.8 m; the draught of ship loaded is 9.25 m; the operation velocity is 17.2 knots. Machinery is arranged in two engine rooms and includes four B32:40L8ADC Bergen generator diesel engines of 3840 kW each and two B32:40L9 generator engines of power 4320 kW each. The propulsion are three Rolls-Royce Contaz 35 azimuth thrusters are of power 3700 kW each of contra-rotating propeller type. Besides, two ULE 255 FP retractable propulsors of power 2200 kW each are available and two RRM TT 3300 AUX CP maneuvering tunnel thrusters of power 2800 kW each. The accommodating premises are available for 140 men.



Fig. 1.36. Ship «Scandi Africa» of «Kværner» shipyard for DOF Group (www.dof.no)
The multifunctional prototype



Fig. 1.37. Ice-navigating ship of the design # 550 «Amguema» (<https://iceberg.org.ru/portfolio/2557/>)
The serial monotype

Ship «Scandi Africa» is equipped by 900-ton crane with subsea lowering system and heave compensation system for operations in 3 000 m depth. Besides it has a 650-ton tilt-able lay system for flexible pipes, and the storage equipment for 3 500 m of pipe. The ship has two ROVs launched through moonpools to 4 000 m water depth. In 2015, the innovative ship «Scandi Africa» was recognized as the Ship of the Year.

Despite the fact that the ship «Scandi Africa» has the ice category of ICE-1B and is capable to overcome solid ice of thickness of 0.7 m, nevertheless, this ice category is not significant since almost any well-built ship of this size, which strength of shell ice-strake was determined without the account of ice pressure, and considering only the water impact, accordingly its propulsive power, one way or another has at least small patency in ice by slow running.

Designing study of the innovative multifunctional ship-prototype, such as «Scandi Africa», in the frameworks of systemic approach designing methodology with the use of optimality criteria and objective functions, with the concepts of comparability and design constraints for finding of the ship optimal design characteristics minimally using the analogs or without them, due to lack of proper analogs of innovative multifunctional ship-prototype, to a certain extent close to the approaches that are relevant in the design of innovative multifunctional ice-navigating ships, and the most important basis for this conclusion is not so much the ice category of the ship under design, which may be insignificant or may not be, but the multipurpose innovative purpose of the designed ship, although ships of the ice category are usually multifunctional, because the assigned ship seaworthy and patency in frozen sea, in itself, serves the factor of purpose in addition to other functions of the ship, and its ice category assigned in the terms of references is the design constraint.

Serially created ships-monotypes could be considered specialized, referring the entire set of their repeated functions to the form of dedicated specialization, similar for all considered ships-monotypes. According to these criteria, the number of specialized vessels could, for example, include the ice navigation ships serially created in the Russian Federation and in the USSR, in particular, the ships of project # 550 «Amguema» (Fig. 1.37), which were 15 units built. Ships-monotypes of this design have the follows characteristics and particulars: the displacement of ship loaded 14 000 ton; length over all 133.1 m; the breadth 18.84 m; the depth 11.6 m; the draught 8.4 m; the installation power $4 \times 1\,365$ kW; the operation velocity 14 knots. The ship can overcome solid ice of thickness of 0.7 m. For mastered by batch construction ice-navigating ships the designing methods can be used, based not on a systematic approach and methods of design optimization, but on the correction of the prototypes specifications, for example, if it is required to have the ship project to continue its serial construction (so-called design modernization of the prototype), which would not be considered a characteristic design feature of the innovative multifunctional ship-prototype, such as «Scandi Africa». The concept of the multifunctionality of the ship under designing can be broadly applied for the ships of the innovative assignments, intended for single or small series construction.

Multifunctionality and innovation of the ship–prototype assignment, servicing as the basis for choice to use the systemic approach, the optimality criteria and objective functions, the concepts of comparability and design constraints are more important for the choice of approach and methods than the specified ice category and the assignment for the use of the ship in freezing seas as part of the terms of references for design.

Within the framework of the common classification of merchant ships, five of the most general classes are usually given, which can be considered designations of the ships specialization: the cargo ships, the fishery ships, the servicing–auxiliary ships, the ships of technical operations support and the ships of special assignment, moreover, each of these types covers a large set of subclasses for more detailed classification criteria. In particular, specialized icebreakers, serially created in the Russian Federation and in the USSR, could be attributed to the class of servicing–auxiliary ships, which are specialized for this purpose.

The last indicated of specified general five classes – the ships of special assignment, can be defined by the remainder, and the merchant ships, which are not included in the first four of the specified classes of ships, are to be referred to this fifth one and in some cases even the Coast Guard ships are to be referred. That is, within the common classification of the multifunctional ice–navigating ships studied in the considered work could be attributed to the set of the special assignment ships, created singly or in small series, that is, they are ships–prototypes, which the projects have been developed or are being developed with the optimization methods and the systemic approach, and it is assumed that in the definite prospective in the development of the serial construction of these ships as monotypes, similar in purpose, design and by construction technology, in the future, the decision of design issues will be carried out by making changes to the projects of analogs, and in this case, the ships–analogs, created in series, will be considered as the specialized ones of definite assignment, such as the purpose of initial prototype, probably the use of systemic approach, the optimality criteria, the objective functions, the concepts of comparability and design constraints will be not required in the future, and the multifunctional assignment of the initial prototype, in particular, the multifunctional ice–navigating ship, will be highlighted as the aggregate name of the form of a particular specialized purpose of the vessel.

For example, initially created multifunctional ice–navigating ship, whose purpose covers the overcoming of solid ice and the transportation of cargoes, in the next will be batch constructed as cargo ship, specialized for the transportation in freezing seas, including on the basis of design changes made to the originally created ship–

prototype without the need to use systematic approach and methods of design optimization. The examples of the multifunctional ice–navigating ships, created individually or in small series, developed initially as the innovative ships–prototypes for overcoming ice and transportation cargoes, as well, as for developing of the technology of shipyard, are considered above (item 1.7). In the transition to serial construction, these ships or other identical ships–monotypes created on their basis will be considered under designing as specialized cargo ships for transportation in the freezing seas.

That is, associated with the choice of approaches and methods of ship design, its assignment attributed to the set of innovative multifunctional ships–prototypes or to the number of the batch constructed specialized ships–monotypes depends not only on the ship functions, but also on certain technological forms of ship creating in the processes of its designing and construction, and on methods of innovative multifunctional ships designing, including the ice–navigating ones, are based on use of systemic approach, the optimality criteria, the objective functions, the concepts of comparability and design constraints.

When designing any ships, as the ships–prototypes, so as the serially created specialized ships–monotypes, the methods of design optimization can somehow be used to find of the ship particulars, if the characteristics of the ship are previously found, or by methods of design optimization within the frameworks of systematic approach, or by recalculation according to ships–prototypes specifications, as in the design of serially created specialized monotypes based on the available close ships–prototypes designs.

1.10. The functions of multifunctional ships for ice navigation, constructed for the federal needs

Functions of ships under construction according to the Strategy and the Federal programs, including the purposes of multifunctional ships for ice navigation, are of the innovative nature. This affects the choice of approach to determine the design characteristics and particulars of ships, having into account the available variety of functions. The specified thesis needs to be clarified. The batch ship construction on the contrary with the shipbuilding according to the Federal programs is of the alternative nature and aimed at the meeting of market demand. For example, the construction of ships at shipyards in the Republic of Korea, Japan or China is directed on the satisfaction of new merchant ships market, which is the basic driver of mass shipbuilding.

For the mass shipbuilding the market demand acts as the more important factor, than the Federal shipbuilding programs, and ships under construction offered for the investors are selected from the set of commercially mastered options. At the same time the ships under construction in series are completed with the standard equipment, which is selected apparently of typical materials, batch accessories in accordance with ship characteristics and function, and the standard construction methods are used.

In the accordance with systemic approach the determining of design characteristics of ship, planned for batch construction with a focus on the market demand, is usually implemented in the way «from general to specific». The constraints are determined in this sequence, the finance constraint is first of all corresponding to the valuation of the investor's complex of assets (the customer, the navigating company). In the next by the efficiency criterion by iterating over the options in the frameworks of the constraints one would find the optimal designing characteristics of ship for the mass construction.

The particulars, first of all, the ship dimensions and their proportions, which set corresponds the optimal characteristics of ship, are impacted the efficiency indexes in the lesser degree, than the design variables, and, accordingly, in the less degree depend on the constraints used for determining of optimal characteristics of ships, planned in the serial construction.

By the way, if in the frameworks of the «internal task» the particulars of ship under design can be determined by the conventional approaches with the use of data of analogs, then when finding the particulars (for the internal designing task) this assumption, which is adopted in the «external task» of the importance of ship characteristics (the variables sought) influence on it efficiency indexes compared with the influence of the particulars on these indexes, does not involve large error. The elements of ship equipment, which make up the set of serial products, for ships under design can be pre-determined by analogs.

It should be mentioned that within the concepts of systemic approach for determining of optimal characteristics of ship, assigned in the batch construction, the customer (the investor) is characterized by his own financial solvency and by the profile of industrial activities for the development of marine resources. In the other words, for the creation of serial ship the investor is not the specific entity and the methodological concept which is characterize by the couple of the indicated values (the financial solvency and the industrial profile).

In essence, in designing it is planned to build a series of ships that cover «the line» of market demand, for example in the sense the offer to construct the ships

of definite assignment corresponding the range of investors financial possibilities. It should be mentioned that the property of design characteristics optimality is related with the seriality of ship constructed, since the sustainable optimal characteristics are reproduced and a series of ships is created thus.

The sequence of design characteristics of ship determining «from general to specific» or the opposite one corresponds the concepts of the systemic approach, underlying the designing methodology, related with the definition of design constraints, that is the initial data, as well, as the set definition of independent variables – the determined characteristics of ship under design, and the definition of ship particulars sets, which are the parameters when finding characteristics at the initial designing stage.

It is possible to attribute the multifunctional ice–navigating ships (the multifunctional icebreakers) to the number of the most prospective ships of innovative classes, which are required for the federal goals of activity in freezing seas and give the ability to develop the shipbuilding enterprises out of the frames of the competing with the shipyards in Asian and European states, where in the batch construction of merchant ships of the general classes is mastered. The determining of characteristics of multifunctional ice–navigating ship under design, such as it cargo waterline displacement, the design deadweight, the capacity of the power installation etc. precedes finding of the ship particulars, which set contains the ship dimensions and their proportions, the ship layout option, it structural elements, the gears decided, the equipment under completed in designing of ship, etc.

Data for multifunctional ice–navigating ship designing, in the other words, the design constraints contain the characteristics of general system as well, to which the ship equipment belongs methodologically assigned in the terms of references. For example, the power reactors (the nuclear or ones of the organic fuel use for power generation) can be considered as the general system, which characteristics enter in the set of the ship design constraints, as well, as the technological installations for the implementing onboard the processes, such as the liquefaction of natural gas, the special systems and the equipment to overcome the ice if they are assigned, the devices for the outboard unmanned vehicles service or the helicopters, etc., that is the specifically assigned onboard equipment, developed before the multifunctional ice–navigating ship designing. By that the ship is methodologically being created for installation of this main equipment.

The ship specific functions, implicitly impacting it characteristics, such as it ability to overcome ice layer of definite thickness, methodologically can be attributed as well to the more general system than the multifunctional ice–navigating

ship itself, and these functions in designing are the subject to evaluate in units of increments: of ship load and displacement.

To determine the design characteristics of multifunctional ice–navigating ship, the approaches and the recommendations include the analysis the concepts of efficiency and optimality and the formulation of the criteria along with other concepts.

Ship utility concept, which is required for formulation of the efficiency criterion, contains the assessment of the investor access to ocean resources, that is the evaluation as the costs, so as useful result. Wherein the any properties of the ocean environment, suitable for they productive use, and not only the geological or biological ones would be attributed to the properties of ocean resources /176/ in the wide sense. In the other words, for the determining of design characteristics of multifunctional ice–navigating ship with use of the optimization approaches by economic criteria it is possible to attribute to the ocean resources any opportunities of industrial activity in the ocean on the economic payback basis, costs–accounting one or on terms of other determined utility.

For example, to the ocean resources in the economic sense can be attributed the follows:

- freight traffic in freezing seas of the liquefied natural gas or other cargoes, in particular the traffic of aggregated unified cargoes, rolling ones, etc.;
- demand of the offshore works servicing in freezing seas;
- demand of natural gas process (liquefaction);
- tasks of power generation in the considered districts;
- other industrial assignments meeting the solvent demand, including the training tasks on the terms of budget financing for the training of specialists in maritime professions for operation on the ships for ice navigation in freezing seas.

It should be borne in mind that the ship optimization designing approaches, based on the use of economic criteria for determining of design characteristics and particulars of multifunctional ice–navigating ship, may not be fully sufficient. In particular the methodological difficulties may arise due to the fact that ships of this class are intended for use in those regions for which the sufficient economic activity is not characteristic, that would be associated with the demand for shipping and other activities in the sea, in particular in the temperate and in the tropical latitudes. The indicated circumstance for determining of design characteristics of multifunctional ice–navigating ship can limit the opportunities of criteria use, based on economic indexes of income and profit.

Ships for ice navigation are to be built, first of all, for the federal issues in economic and social politics, which significantly predetermines the demand. Wherein

the financing of initial investments and operating costs is carried out primarily from the federal budget together with the private investors or without their participation, that at the stage of ship design can be difficult methodologically to use the economic criteria.

In the other words, within the systemic methodology for determining of design characteristics of multifunctional ice–navigating ship it is relevant to use the combined approaches, based as on the use of analogues data, in particular the new analogues of those ice–navigating ships, the experience of which is available, for example the icebreaking ships, so as on the project optimization of ship characteristics with the appropriate criteria taking into account the external constraints, as well, as ice–navigating ships functions in accordance with the Shipbuilding Industry Development Strategy and the Federal programs.

In the designing of ice–navigating ships it also should be mentioned, that most of they are the multifunctional ones, and it is possible to characterize the variety of assignments and the main system, specified in the design, by the mass indexes, by the tonnages and volumes, by the power, or by the other similar ones, which are in the set of ship characteristics, evaluated at the design stage by the balance equations or by the other used functional ratios.

Checklist

47. The goals of merchant shipbuilding development matching the market demand.
48. The aims of national Federal programs in shipbuilding to replenish the national fleet.
49. Characteristic innovative goals of marine engineering and industrial technique developing, construction and operation.
50. Classes of merchant ships and marine engineering, which construction is demanded by the Government.
51. Two general areas of works and partnership for the Shipbuilding Industry Development Strategy and the Federal programs.
52. The concept of ship main system as it physical element or the set of the characteristics of it innovative purpose meeting the Strategy goals.
53. The multifunctionality of the icebreakers.
54. The globality of the economic competition in the innovative sectors of shipbuilding and merchant navigation.
55. The general innovative goals in ship construction and marine engineering industrial techniques.

56. Classes of ships and marine engineering demanded by the Shipbuilding Industry Development Strategy.
57. Main system of ship as its physical element or the set of the characteristics of ship innovative purpose.
58. The general functional goals of navigation extension in freezing seas.
59. Multifunctional ice–navigating ships constructed at the shipyards of the Russian Federation or with their participation.
60. The assigned function of multifunctional nuclear–powered icebreakers under designing to have the power installation, specified in the terms of references.
61. Main subsystem of multifunctional nuclear–powered icebreaker and the feature of this ship designing sequence.
62. The hull shape cylindrical insert influence on patency in ice of the multifunctional ice–navigating ship.
63. Multifunctional scientific–research and patrol ice–navigating ships functions (besides of escort, towing, supply delivery and the rescue).
64. Known icebreaking ships under creation in Europe and in North America.
65. Use of natural gas fuel as extra advantage of the autonomy in case of opportunity re–fueling of ice–navigating ships servicing the offshore natural gas grounds.
66. The designing modernization suitability as the feature of the multifunctional ice–navigating ships.
67. Examples of the options of designing modernization of the multifunctional icebreaker of original design # 10620.
68. Options of designing modernization of usual multifunctional ships into ice–navigating one (by the examples of Havyard 843 ICE and Havyard 843 designs).
69. The most important design features of ice–navigating ship – its hull shape and the characteristic elements of propellers and controls, considering the hull strength and mass as dependent particulars on the indicated ones.
70. The improving of «Aurora Borealis» design of large icebreaker with drilling gears into the design of «Aurora Slim» (the EU and RF).
71. Multifunctional asymmetric icebreaker concept for the laying channel in ice.
72. The use of the natural gas as the fuel of tankers for the transportation of LNG–cargo in freezing seas.
73. Hull shape, propulsion and navigating modes of Double Acting (DA) ice–navigating ships.
74. Feature of design flexibility of LNG–tanker for freezing seas indicated by the line of options different by cargo volumes (the membrane volume or the number of spherical capacities).

75. Servicing of harbors (not the ships) in freezing seas as the function of multifunctional ice-navigating ship, the extra functions in these harbors, the bunkering service and the oiled waters skimming.
76. The evaluation of demand for transportation of oil and liquified gas cargoes in the freezing seas from their grounds on the offshore, and the alternative abilities of dry cargoes and containers transit transportation in the south latitudes impacting the prospective of these cargoes traffic by the Northern Sea Route.
77. The concepts of the innovative ship-prototype, designed for construction single or small serie, and the ship-monotype, covered by the batch construction or intended for this.
78. Relevance of the systemic approach, the optimality criteria and objective functions, the concepts of comparability and design constraints for determining of characteristics and particulars of any innovative ship-prototype, not necessarily having an ice category.
79. The insignificance of small ice category for big or middle-sized ship, which usually has these small categories anyway, since almost any well-built ship of these sizes, which strength of shell ice-strake was determined without the account of ice pressure, and considering only the water impact, one way or another has at least small patency in ice by slow running.
80. The importance of the ship innovative multifunctional assignment for choice of the systemic approach and the design optimization methods rather than the methods of the prototypes use relevant the designing issue of specialized ships of main classes for batch construction: the cargo ships, the fishery, the servicing-auxiliary ships, the ships of technical operations support.
81. Specialized assignment of serially created ships-monotypes, referring the entire set of their repeated functions to the form of dedicated specialization.
82. Designing methods, based on the correction of the prototypes specifications to have ice-navigating ship project to continue its serial construction (so-called design modernization of the prototype).
83. The importance of multifunctionality and innovation factor of assignment of the ship-prototype under design for the choice of design optimization methods and systemic approach rather than the ship ice-navigating factor of the purpose, which is of lesser importance.
84. Five of the most general classes of merchant ships, which can be considered their specialization: the cargo ships, the fishery ships, the servicing-auxiliary ships, the ships of technical operations support and the ships of special assignment.

85. The ship assignment belongs to the set of innovative multifunctional ships–prototypes or to the number of the batch constructed specialized ships–monotypes depends not only on the ship functions, but also on technological forms of ship creating in the processes of its designing and construction.
86. The choice of the optimization designing approach for determining of characteristics and particulars of innovative multifunctional ice–navigating ship on the contrary with the designing by prototypes of ships planned for mass construction.
87. The designing tasks levels – the «external task» of determining of multifunctional ice–navigating ship design characteristics and the «internal task» of determining of the design particulars of ship.
88. The property of design characteristics optimality in the methodological interdependence with the seriality of ship constructed, since the sustainable optimal characteristics are to be reproduced and repeated in the construction.
89. Concept of ship utility.
90. Concept of ocean resources as the composition of opportunities of industrial activity in the ocean on the economic self–sufficiency and payback basis. The examples of ocean resources.
91. The methodological difficulty to determine the economic criterion and objective function for designing optimization arising due to the fact that multifunctional ice–navigating ships are intended for use in those regions in which the economic activity is not sufficient.
92. The relevance of the combined approaches use to determine the innovative multifunctional ice–navigating ship designs characteristics combining the approaches, based as on the analogues data, and the designing optimization within the constraints.
93. The needs to characterize the variety of assignments of multifunctional ice–navigating ship and it main system, specified in terms of references, by the indexes of ship designing characteristics or in the comparable units with these characteristics.

Chapter 2. Multifunctional ice–navigating ship as object for determining of characteristics at initial designing stages

Ships for ice navigation are constructed for the autonomous work in ice and usually combine two or number of functions – besides of the overcoming ice they can transport cargoes: the liquid cargo, including the liquefied natural gas, and the dry cargo, as well, as to carry out those or the other functions, for example: the supply cargoes delivery and handling, including with use of the helicopter, the servicing of engineering works, in particular, in the process of gas or oil offshore production, the fulfillment of rescue or patrol operations, the maintenance and service of submersible equipment, the support of sub–water launching and lifting operations and the fulfillment of other special works.

In small series the specialized icebreakers could be constructed for servicing of freezing marine harbors, besides of multifunctional ships for ice navigation, created for use in freezing seas. However, these relatively small auxiliary and servicing ships for harbors usually also are doing the issues: the laying fairways in frozen waters of harbors and assisting the ships when mooring in frozen sea, as well, as tow they and rescue.

Multifunctional ice–navigating ship primarily remains in the ice area, performing the function of icebreaker, as well, as the other functions together with the icebreaking one. In this sense the multifunctional ice–navigating ship could be considered as the multifunctional icebreaker. Generally, one can indicate, that on one hand the multifunctional ice–navigating ship is the developing of concept of the multifunctional ship in the direction of seaworthiness and patency improvement in freezing seas, and on the other hand – the progress of definition of icebreaker to give it the extra functions, which opens the ability to use it on the principles of self–sufficiency and economic expediency.

Concept of multifunctional ice–navigating ship one can consider as the progress of icebreaker concept with the definite extra functions, such as the navigation function in particular the escort of ships, having lesser or insignificant ice category, on offshore grounds of mineral deposits; the function of cargoes transportation, including in the season, when the sea is free of ice; the study and training functions, including the research of the processes of navigating in freezing seas and the training of cadets; the support of the researches, conducted with the special facilities, for example the service of outboard vehicles; the industrial function, in particular,

the function of accommodation of the equipment for electricity generation in ocean or the equipment for the fulfillment of natural gas liquefaction process; the function of servicing of engineering works of construction and fixing offshore hydraulic structures, etc.

It is logical to correlate the functions of multifunctional ice-navigating ship with the list of prospective classes of ships, intended for construction in accordance with the Federal programs and with the Shipbuilding Industry Development Strategy.

To the number of prospective classes besides of the icebreakers in the Strategy are attributed to the ships for ice navigation, assigned for the operation in freezing seas, for fulfillment cargoes transportation and handling and the other functions, indicated above (Chapter 2, page 25).

Multifunctional ice-navigating ships the part of time can be used in the non-freezing seas despite the patency in frozen ones, and only the rest part in frozen sea in dependence on the geographic latitude and the seasonality. The combining of functions of ship, having ice class, such as the navigation in freezing seas and in the temperate latitudes meets the economic contradictions. In this regard the definite design issue arises of the choice from two options: the construction of multifunctional or the specialized (one-purpose) ships, for example the escorting icebreaker and the ships, not having the ice class or having insignificant one, escorted by the icebreaker.

Analysis of ships operation, which particulars satisfy the requirements of this or that ice category, shows, that for the use during the other seasons, besides of the ice season, the structure of ice-navigating ship with increased strength turns out to be too heavy, and the hull shape and characteristics of propulsion complex are not of the best choice for navigation in open water, so as the ship is designed to be operated in frozen sea. In the definite circumstances this can lead to the choice in the favor of the specialization of ice-navigating ship, including the icebreakers specialization, used in frozen sea of the maximal seasonal continuance, providing in the conditions of icy navigation of safe and effective operation of other ships, not having the ice category or having the insufficient one.

Multifunctional ice-navigating ship primarily does not leave the assigned ice area, implementing the icebreaking function and other functions. In this sense the ice-navigating ship one could consider the multifunctional icebreaker. Unlike the specialized icebreaker, which provides the safe and the effective navigation of ships of the other classes, it is supposed, that the multifunctional ice-navigating ship is the next step in terms of the specialized icebreaker design improving and this covers as well other functions with not the exclusion of the icebreaking one function.

In accordance with the Strategy and with Federal projects the budget support for construction of ships of the innovative assignment is provided. The demand of cargo ships replenishment, which assignment corresponds the Shipbuilding Industry Development Strategy, is about of 90 units of total deadweight about 4 million ton, the demand for the supply ships for operation in freezing seas is about of 140 units and from 10 to 12 units of the icebreakers are needed. In accordance with the Strategy besides of the ships of indicated classes the equipment for power generation in the coastal areas is planned to construct including on the basis of the renewable energy sources (tides, currents and winds), as well to construct the equipment for processing of natural gas in these areas.

Besides of the correlation with the plans of fleet replenishment for the Federal programs or according with the Shipbuilding Industry Development Strategy the functions of multifunctional ships for ice navigation, besides of the icebreaking one function, the other purposes can be defined considering their correspondence with the issues to serve the offshore stationary objects, the harbors, located in freezing seas, and to serve the corporative customers for their other issues. In the other words, the functions of ice-navigating ship in the indicated circumstances are the derivatives of the assignments of serviced facilities, the harbors, the ships and the offshore stationary objects.

Construction of the innovative multifunctional ice-navigating ships in the maximal degree is free from the competition with the batch shipbuilding. It should be mentioned that the multifunctional ice-navigating ships, which assignments are determined in the considered way, usually are not mastered in the countries of developed mass shipbuilding – in the Republic of Korea, Japan and in China, positioned in the forefront of shipbuilding. This segment of shipbuilding industry is prospective for developing in Russia or in the other states, washed by the freezing seas, which offshores have industrial mineral deposits and the other marine resources are available.

Practical importance of construction and maintenance of ships of this class, covering ones assigned for the transportation of cargoes in freezing seas, including the liquid cargoes and the liquefied natural gas, the aggregated unified cargoes, etc., the ships, suitable for the accommodation of equipment for generating and delivering power to consumers in the ocean, and the other ice-navigating ships of multifunctional assignment, is that these all can be the objects of contract for implementing in the shipbuilding industry out of the frames of competing to the full extent with the batch shipbuilding at shipyards in the overseas.

Special position in the methodology is occupied by training ice–navigating ship. For giving the icebreaker of the functions of training ship the minimal structural changes of the icebreaker are required, related with the difference of the particulars of ship premises, which would include the training facilities. It is required, on one hand, the accordance of this ship for the issues of the processes teaching of maintenance of the marine technology, the needs for which are provided by the Strategy, in the provision of federal social and economic policy of marine resource development, and, on the other hand, the efficiency of ship has to be achieved in terms of economic indexes.

Assignment of new training ships, including the multifunctional ships for the freezing seas, has to cover the variety of functions, referred to prospective directions of the industrial activity in the ocean. If one defines the multifunctional ice–navigating ship as the progress of icebreaker concept, which is endowed of the extra functions, then the special mention has the multifunctional ice–navigating training ship. Giving the icebreaker the functions of training ship in the technological aspect it requires the minimal design changes in relation to the original characteristics of ship, which is a project prototype in this task. It requires that the multifunctional training ship for ice navigation will satisfy the purpose of teaching of the technological processes in shipbuilding and in navigation, which corresponds to federal interests and social policy in the development of the resources of the sea, on one hand, and it would be economically be efficient on the other hand. For this reason, it is possible to attribute the multifunctional training ships for ice navigation to the number of the most structurally complex merchant ships.

Acting icebreakers or ones under designing and construction, in this or that degree practically correspond the concept of multifunctional ship, if they are additionally suitable for the cargoes transportation or passengers, the fulfillment of the engineering offshore works or the rescue, the power generation and transmission, etc.

Multifunctional ice–navigating ship fulfills the icebreaking assignment, the same as the specialized icebreaker and can be used for escort of ships, not having sufficient own properties to ensure safety and increase efficiency of their operation in ice. When using of the icebreaking ships escorted others in the ice do not need the extra strengthening of hulls of the escorted ships, which in their basic mode of navigation improves their efficiency in open water. This allows at the design stage of the escorted ship to make the choice of such a shape and structure of hull, as well, as of the particulars of propulsion complex, which are relevant the open water navigation, but in the other circumstances, in the absence of navigation escort in ice

by the icebreakers or by the multifunctional ice–navigating ships this ship, intended for open water, would have little compatibility with the required performance in ice.

Characteristic hull shape of multifunctional ice–navigating ship corresponds generally the icebreaking one, although some differences are possible of hull elements, in particular by the dimensions and their proportions, as well, as sizes differences of ships of the specified two classes are characteristic, in particular, the differences of design deadweight and of tonnage.

Considered study of approaches to determine the design characteristics and particulars refers primarily the multifunctional ice–navigating ships, which usually are equipped with internal combustion engines and the electric transmission to the propellers. The other types of power installation and the transmission, for example, the combined power installation, including as the main generators with the internal combustion engines of diesel or gas–diesel types, so as the gas turbines with the generators, can be considered methodologically as the possible options of design modernization of the basic prototypes having another installation. This is covered by the general approaches as application of the amendments to characteristics and particulars of the basic prototype, which power installation has certain differences of the ship under design.

In the frameworks of the Federal programs and the Shipbuilding Industry Development Strategy the assignments of created ice–navigating ships are of innovative nature affect the general sequence of the ships construction, in particular the sequence of designing considering the diversity of these ships functions, assigned in accordance with these documents. It would be clarified. The batch shipbuilding industry development is oriented the market demand, and one could consider an alternative direction other than the construction of ships in accordance with the Federal programs, but the mass construction of ships for the market. For example, the construction of ships series of the prevailing classes in the Republic of Korea, Japan and China, which develops on the principles of self–sufficiency for the market demand is the main factor in the batch ship construction. Wherein for batch ship construction the market demand is no less important factor, than the Federal shipbuilding programs, and the ships under construction meeting the demand are selected according of the range of ships options mastered by series. With the mass ships construction their completing is provided by the serial equipment as well, which is selected in dependence on design characteristics of the ships. The methods of mass construction of ships and the standard materials mastered by serial production are used.

Despite the prospect of the multifunctional ice–navigating ships for their construction at the shipyards in the Russian Federation and in some other states like the USA, Canada, some of the EU, etc., these ships as the designing objects in the considered definition (see the Introduction, page 14) are studied insufficiently in the distinction with the ships of adjacent classes: the specialized icebreakers and the other specialized ships, having the seaworthiness and patency in frozen seas and the corresponding ice categories by rules of the Register or by other classification societies.

Multifunctional ice–navigating ships construction is of the practical importance for shipbuilding and navigation development, and it has the methodological significance for ship design theory. Methodologically multifunctional ice–navigating ship is new object, for which the enhancement of systemic designing concepts is required, including for the determining of this ship optimal design characteristics and particulars.

2.1. Multifunctionality of ice–navigating ship

Determining of design characteristics of specialized icebreaker, not essentially endowed of extra functions, primarily is carried out on the basis of account of physical constraints of ship structural strength, the seaworthy and patency in frozen seas, with optional use of the economic criterion of efficiency evaluation mostly on the basis of costs minimization with the account as the investments, so as the operating costs.

In the accordance with the systemic approach the designing of multifunctional ships for operation in ice is provided to determine the characteristics of ship (the external designing task) and the design particulars (the internal designing task). The results of G.V. Egorov and V.I. Shtrambrsndt /33/, corresponded with the determining of ice–navigating ships particulars of hulls structures, including the project optimization of hull shape, considering the seaworthy and patency in ice, the motion resistance and the propulsion, are of the interest. In the considered paper the promising nature of the multifunctional icebreakers is indicated. To use the recommendations of G.V. Egorov and V.I. Shtrambrsndt for determining of design particulars of multifunctional ice–navigating ship it is required to specify in the set of initial data (the constraint) of those ship characteristics, as it cargo waterline displacement (or the other size specifications of ship: the deadweight, the tonnage, etc.) and the capacity of the power installation, which leads to the need to determine of these characteristics of ship size by optimization designing using the concepts of systemic

approach /127, 174/ before finding of design particulars of the ship hull shape and of its propulsion installation.

One can approach the concept of ice-navigating ship as the evolution of icebreaker definition, endowing it with extra functions. The object is the multifunctional ice-navigating ship (the multifunctional icebreaker) under the designing study, that is the ship, which can operate as the specialized icebreaker /137, item 2.2.3.1.1/ of the definite ice or the icebreaking category and can carry out the escort of the ships in ice, the overcoming of ice bridges, the channel laying in ice, the towing in the ice channel, the breaking of ice and the fulfillment of rescue, as well, as the independent operation as ice-navigating ship /ibid, item 2.2.3.1.2/ in the conditions of continuous ice, of broken ice or separate ice floes. In the particular case the multifunctional ship of ice navigation could be the ship for supply of the coast point or in the ocean.

Many of acting icebreakers, as well, as ships under construction, including under design ones, in this or that degree are the multifunctional if the fulfillment of the extra functions is assigned, such as the cargoes delivery, the passengers transportation or the participation in the rescue works, the power generation and delivery, etc. For the extra functions, besides the icebreaking one, the approaches for designing of multifunctional ice-navigating ships are usually corresponded with the determining of design characteristics of icebreakers, which one could be name the boundary task, if to reset the data or functional constraints assigned with extra function of multifunctional ice-navigating ship.

Multifunctional ice-navigating ship the same as the icebreaker is used long time annually in frozen sea, in the distinction with merchant ships of the other classes, although having the performances in frozen sea (the ice category). This is corresponded with the fact that the functions of multifunctional ice-navigating ship extra to the icebreaking one function are defined among the issues in freezing seas, while the ships of other classes having the ice category are under batch construction meeting the market demand outside any strategies of the freezing seas development. The indicated circumstance with regard of the prevailing of freezing seas as the assigned sea areas has the conceptual impact on the set of design constraints and on the optimality criterion of multifunctional ice-navigating ship under design.

From the methodological point of view the systemic approach for determining of optimal values of design characteristics of multifunctional ice-navigating ship on the contrary with the batch constructed merchant one, having the ice category, has the distinctions, despite the fact that ships of these classes contain an element

methodologically similar, – the propulsion and patency in ice. The different features of the systemic approach in designing of ships of considered classes are corresponded with the fact that for the multifunctional ice–navigating ship the motion resistance in ice and the propulsion performances in frozen sea are the constraints and belong to more general system, which part is the ship, that is the assignment belongs to complex function of ship in freezing seas in accordance with the Shipbuilding Industry Development Strategy and with the Federal programs. And for batch constructed ship, having the ice category, for optimization designing the concept of more general system in one form or another indicates the financial solvency of investor, but motion resistance and propulsion performances of batch constructed ship in ice and corresponding its structural features are not the assigned data (the characteristics of most general system to which the ship under design belongs as the subsystem), but these are the ship particulars sought in the designing study, that is the characteristics of ship subsystem of «the category and patency in ice» in the composition of internal task (the designing of ship subsystems).

The hull shape of multifunctional ice–navigating ship generally corresponds the shape of icebreaker's hull, although the certain differences of the shape particulars could be, specifically the differences of ship dimensions proportions. It is supposed, that the multifunctional ice–navigating ship, the same as the specialized icebreaker, is typically equipped with the internal combustion engines and the electrical or mechanical transmission to the movers.

The other type of the power installation and the other type of transmission or the elements in the installation and transmission composition can be, for example the complex power installation, combining the main generators with the internal combustion engines and/or the gas turbine generators, which can be methodologically considered as the option of design modernization of the basic prototype with the usual set of the power installation (the internal combustion). This corresponds with the general approach upon amendments to characteristics and particulars of the prototype, having definite distinction from ship under design by the composition of power installation. Design modernization in this case indicates the kind of the ship designing methodology using to the prototype.

Creation of multifunctional ice–navigating ships has the practical importance for shipbuilding development and navigation in freezing seas. When using the multifunctional or specialized icebreakers the escorted ships are not required in the additional amplification of structures for navigation in ice, which helps to increase their efficiency in typical conditions, – when navigating in open water. This allows

in the design of escorted ships to choose the hull shape and particulars of hull structures, as well, as the propulsion complex, etc. without their compliance with the ice navigation, which would be required without they planned escorting by ice-navigating ship.

Concept of the multifunctional icebreaker has the theoretical importance besides of the practical one for the designing methodology, since it creates the prepositions for improvement of the used approaches. The multifunctional ice-navigating ship theoretically is the new object, which can be used for the creation of system of methodological approaches, aimed at determining of designing characteristics and particulars of ship of this class.

Investor is the interested entity for creating of multifunctional ice-navigating ships. The investor can act not only as single participant, but as an establishment of two or more parties, for example as the marine company (the navigating, the fishery, etc.), which works on the self-sustaining basis, as well, as the federal departments can act as the investors, participating in the initial financing and receiving the complex or partial property rights in accordance with the shares under the partnership agreement.

The investor is not the methodological concept, which would be characteristic for determining of the batch constructed ship design characteristics, and he acts as the specific entity, carrying out the tasks with the Shipbuilding Industry Development Strategy and the Federal programs, and his point of view corresponds the optimality criterion and the objective function for determining of multifunctional ice-navigating ship design characteristics by the optimization methods. Otherwise, the investor is assumed as the methodological concept for the batch construction of ships, implemented in accordance with the market economy demand, it is just supposed that he is, and his dependence on the Strategy and the Federal programs of innovative ships construction is not important.

It should be mentioned that the construction of big series of multifunctional ice-navigating ships, which assignment would be determined according to one national strategy or to another one, not necessarily accepted in the Russian Federation, is not mastered by shipbuilding yards of the Republic of Korea, Japan and China to the extent that the construction of serial merchant ships for temperate and tropical latitudes open water navigation is provided at the shipyards in these states meeting the market demand. Therefore, the industrial segment of shipyards creation for construction of ships of the innovative assignment, including the multifunctional ships for ice navigation, is promising for shipbuilding development industry in the Russian

Federation and in the other highly industrialized states to start the improving of shipyards and the shipbuilding plants. The construction of multifunctional ice-navigating ships of the innovative assignment in the greatest degree is free of competing with the mass shipbuilding.

Multifunctional ships for ice navigation, suitable for transportation in freezing seas of liquid cargoes, including non-regime and regime cargoes, in particular the liquefied natural gas, as well, as the aggregated unified cargoes, etc., the ships, suitable for placing the equipment for power generation, the fulfillment technical processes, for example of the natural gas liquefaction, ships for the implementing of the training functions, for navigation escorting in ice of ships, not having ice category or having insignificant one, for the service of the submarine vehicles and for delivery of supply on the offshore platforms and onshore and etc., are of practical importance for shipbuilding because of fact that ships of these classes in the contracts for construction contributes to the development of innovative shipbuilding out of the frames of the competing with the batch shipbuilding.

2.2. Hierarchic systemic levels of multifunctional ice-navigating ship designing

For determining of design characteristics of multifunctional ice-navigating ship by optimization designing in the frameworks of systemic approach it is required to define the concepts: the ship under design and the object more general than the ship, to which the ship belongs as subsystem. And the characteristics of this object more general than the ship methodologically are the initial data when finding the ship design characteristics. In the other words, the characteristics of the general object are the constraints when finding of optimal design characteristics of the ship.

Besides it is required to define the subsystems of multifunctional ice-navigating ship under design, methodologically forming the ship, given that any of this subsystem is the integral ship, under the designing study considering from the point of view of the appropriate individual property of ship. In it turn the characteristics of each individual subsystem of the ship are the parameters when determining the ship characteristics. The characteristics of ship subsystems are particulars set when determining it design characteristics.

In accordance with concepts of the systemic approach of multifunctional ice-navigating ship optimization designing by it economic efficiency criterion in the composition of object more general than the ship, in particular in the composition of property complex of navigating company or of other marine enterprise,

methodologically can be defined as complex unit, consisting of parts, which combining when dialectical in the integral complex the new properties of ship arise, which had being absent in separate parts of it.

From the point of view of design methodology the individual parts of ship could be considered as follow: the subsystem of buoyancy, that is the integral ship from the point of view of it useful physical property of buoyancy (one of the seaworthy properties of ship), the subsystem of stability – the integral ship from the point of view of it physical property of stability, as well, as the subsystem of unsinkability, the subsystem of controllability, the subsystem of ship propulsion and hydro resistance properties, the subsystem of ship patency in ice, the subsystem of ship strength property, the subsystem (i.e. the design methodological property) of ship construction workability and etc.

These are the examples of the individual seaworthy and other physical properties methodological attribution to the subsystems of ship under design: the buoyancy, the stability, the unsinkability, the propulsion and hydrodynamic resistance of ship and it controllability, including the patency in frozen sea for assigned design constraint of solid ice thickness, as well, as such inherent properties of the ship hull, as it strength, reliability and etc. As the other examples, one can list the merchant ship subsystems by A.I. Gaykovich /40/ as follows: «ship hull and superstructures», «the movement», «the power», «the crew», «the maneuvering», «the stabilization», «navigation instruments, communication and signaling», «the cargoes transportation» (the methodological subsystem), «the passengers transportation», «the industrial fishery», «the automatic control and the information subsystem» and etc. All these listed are the individual properties of the integral ship.

The designing issue is finding the characteristics and particulars of the created ship. Within the concepts of systemic approach, the multifunctional ice-navigating ship under design is studied as the complex probabilistic system /127/, which cannot be studied other than consisting of parts – the subsystems. Methodologically the subsystems of ship under design are usually it individual properties, and the new property of this ship appears when the other subsystems combining together, but this new property is absent in the other individual subsystems ship (that is it other individual properties).

Figuratively, as an example, one can consider the merchant cargo ship consisting of two parts: a hull, characterized by the size and tonnage, and a propulsion system, characterized by the power and characteristics of propulsion system. When «combining» of ship hull and the propulsion complex the new property appears –

the carrying capacity, which was absent in each of both considered parts taken separately, because the cargoes transportation property is not characteristic of ship individual hull without the propulsion installation and not characteristic of the separate propulsion complex. New property arising when combining individual parts is the most valuable for determining of optimal characteristics of the ship under design.

An explanation needs to be mentioned to the example. The figurative determining of the integral ship as the composition of two parts has not mechanical, but methodological meaning. The subsystem would usually be determined not as physical part of ship, but as the integral ship studied from the point of view of one or another single property of the ship properties total composition. Continuing with the example with the regard to cargo ship, not the ship hull and its propulsion complex are more exactly be methodologically defined as the parts in each case the integral ship, studied from the point of view of this or that its individual property. The account of inexhaustibility of these properties set has to be, covering for example the number of ship seaworthy properties, its mechanical and performance characteristics, and the structural parts of ship hull, that is the floors, the modules, the sections, the items and etc.

Actually, the multifunctional ice-navigating ship under design in the terms of systemic approach one can consider in two general ways, or as the total complex of the ship properties, including the new arising property of ship when combining of its rest ones, which are the ship parts methodologically, or as the only new arising ship property, without those ones, which are in the ship individual parts. In this regard one would consider the options of definition of ship as the object under design as follows:

- the integral ship having seaworthiness and performance specifications, including the property of the functional assignment, that is the total complex of ship subsystems, including the new subsystem, that is the ship property emerging when combining the subsystems and characterizing usually the functional purpose of ship;
- the ship as the property of its functional assignment the only, arising when combining of individual parts of the integral ship, which are all its subsystems, excluding the individual properties of combined ship parts from its definition.

Dialectically the fragmentation (the deduction) can be continued in the way of ship subsystems detailing. Besides it is possible the inductive generalization and the determining of complex object, which part is the ship under design.

For example, the property complex of the navigating company, which part is the ship, could be the complex object, more general than the merchant ship, or such complex object can be the general concept, as the shipping, the shipbuilding

industry, the marine engineering, the ocean industrial fishery, etc., to which the ship under design belongs methodologically as the element.

The methodological generalizations over the ship as the object under design and its fragmentation into the subsystems give the following opportunities:

- to find the design constraints and the optimality criterion, which are required for finding of ship design characteristics;
- to define the objects hierarchy with regard to the ship under design and the models corresponding to the objects, that is the ship subsystems, used in their designing, as well, as the concepts of general objects, which include the ship under design as the subsystem;
- to order in the groups of used mathematical values entering in the compositions of objective functions for each of hierarchic levels of objects under design and the models corresponding to the objects.

These opportunities of design constraints finding, of the criteria formulation and of the mathematical values classification allow to develop systematically the objective function and the mathematical model for the determining of design characteristics of multifunctional ice-navigating ship.

With the systemic approach the data and the parameters are mathematical constants, in other words, they are the design constraints when finding the optimal characteristics of ship. The values of data and parameters are determined in the adjacent issues: the external designing task (the outer) – the determining of ship design characteristics for data of the general system, which subsystem is the ship under design, and the internal designing issue (the inner) – when finding the characteristics of ship individual subsystem.

The features of design characteristics of multifunctional ice-navigating ship allow to combine the outer and the inner issues in the composition of the multilevel systemic approach for finding of optimal design characteristic. The specified initial data in the internal designing are the optimal values of ship characteristics got in the external task, and the combinations of design particulars, especially the ship dimensions and their proportions, are specified in external designing task as well. The particulars in their turn are studied in the internal designing for determining of their optimal values for the specified characteristics of the general system – the multifunctional ice-navigating ship, which are the more general system when studying the ship subsystems, that is the data for designing of subsystems are the characteristics supposed determined in the external designing of ship.

Optimal values of multifunctional ice-navigating ship characteristics are parameters in the general system designing issue – the determining the characteristics

of this system to which the ship belongs as the subsystem. In the any the internal designing task it is possible to describe this or that general system by the characteristics of ship under design, which belongs to this complex as the subsystem. For example, one can characterize the navigating company by multifunctional ice–navigating ships entering in it; the shipbuilding yard, created in accordance with the Shipbuilding Industry Development Strategy to characterize by the ships under construction; this or that ocean cargoes traffic, for example the Northern Sea Route, to characterize by the working ships, including the multifunctional ice–navigating ones, etc.

The indicated properties of determined design characteristics of multifunctional ice–navigating ship, which are the constraints in the adjacent optimization issues, that are the parameters in the designing task of more general object, which subsystem is the ship, and the data in the designing of this or that subsystem of ship, allow in the most strict and systemic manner to develop mathematical models and methodological approaches for determining of design characteristics of multifunctional ice–navigating ship.

2.3. Sets of independent data values, characterizing the multifunctional ice–navigating ship design

Complex of the sets of independent values characterizing the multifunctional ice–navigating ship design includes follows: the characteristics (the values sought); the design constraints, that are the characteristics of the general system to which the ship under design belongs as subsystem, servicing the data for determining of ship characteristics; the design particulars, which are the characteristics of the ship subsystems and the constraints as well (the parameters) when determining the design characteristics.

Optimization of ship design characteristics with adopted criterion is the effective approach in designing of marine engineering complexes /174/, for which due to diversity of their properties, including the physical property, the structural, the manufacturability (the constructability at the available yards and plants), the functionality and the other properties, if to consider each of them separately could not be the generalized criterion, and the total set of these properties has to be generalized and transformed in to the economic property, servicing the criterion in optimization designing.

Criteria of efficiency and optimality, used in designing of multifunctional ice–navigating ship, are of the economic nature usually and are determined by the mathematical operations over the follows main economic indexes: the total income I , the operating costs C , the investments MV – the market or the other value of the investments, for example the value of the new ship which is equal the costs for it construction in the market prices, that is the ship reproduction costs RC .

Optimality criteria, which allow to separate the optimal design characteristics and particulars of multifunctional ice–navigating ship from the suboptimal ones, are the ways of efficiency criteria use, which in turn allow to order all compared options of sets of the ship design characteristics in the sequence of these options preference.

Optimality criterion represents the way of use of efficiency criterion for optimization of multifunctional ice–navigating ship design, that is for finding the optimal values in the set of design characteristics. Efficiency criterion is more general methodological concept, than the optimality one, because if one just selects the optimal options the only, than it is not required to sort all options by preference. In the same time if to order all options with the criterion of economic efficiency, then the optimal options will be found as well, assuming the constrained set of all options or the limited domain of variables determining.

Objective function is created as the mathematical model for multifunctional ice–navigating ship optimization designing, which is the sequence of dependences between composition the variables X , the parameters Y and the data Z , on one hand, and the composition of general economic indexes: the income I and the operating costs C (annual) and the investments (MV or RC), on the other one.

Besides of the indicated economic indexes (I , C and MV or RC) the economic criterion f is determined in dependence on the vectors values of variables, parameters and data (X , Y and Z) in the composition of mathematical model intended for finding of optimal design characteristics of multifunctional ice–navigating ship, the generalized variables (that are the indexes determined intermediate in the mathematical model, dependent on: X , Y and Z), are used as well. For example, if for determining of optimal characteristics the light displacement DP and design deadweight DW belong to number of the independent variables X , then the loaded displacement, which is the sum of the deadweight and the displacement empty ($D = DP + DW$), serves the generalized variable and in the set of the independent values does not enter.

Criterion in the form of the objective function f , in other words, the criterial one, is determined in dependence on the design characteristics X of ship, that is the vector or the set of values, varied in the search of sets of their optimal values, the parameters Y , that are the design particulars of ship, characterizing it subsystems,

and the data Z , that are the design constraints, in the other words, the characteristics of the general complex system, which part is the multifunctional ice–navigating ship under design. The data Z and the parameters Y are constants while varying the ship design characteristics X combinations in order to find their optimal values. The options of design characteristics X sets, that is the vectors values, are studied for optimality, and the definite value of the vector X found is optimal set of ship design characteristics.

Independent variables set X is defined methodologically as the composition of values which substantially impact the optimality criterion and the objective function f and are independent on each other variables in the set X , on parameters Y and on constants Z .

For example, the characteristics of multifunctional ice–navigating ship under optimization designing by the economic criterion for each considered option of ship among the number of the comparable ones corresponds the definite vector value of the variables X , which set could cover the options sets of ship characteristics, varied in the optimization designing, in particular: the cargo waterline displacement, the design deadweight, the tonnage, the cargo capacity, the cargo holds and spaces volume, the power of engines or the operation velocity and etc., that is the ship under the optimization designing characteristics, which sets are dependent on ship under design assignment, including the ice category.

Developing of objective function f is accompanied by the classification of the incoming it mathematical values in the follow sets: the variables X , the parameters Y and the data Z . Wherein it is supposed, that the values metrics are available, that is the logical criterion for the referring of this or that mathematical value in one of the indicated sets. For example, the metrics could be the algorithm of the independent value impact evaluation on the criterion for the study to refer any considered independent value in one of the sets: the variables X , the parameters Y and the data Z .

Practically the composition of the objective function f is created by the successive steps (approximations) and this is methodologically accompanied by the classification of the input mathematical values. Moreover, the evaluation of influence of any independent value on the applied criterion could be done at every step, and the completion of the composition of objective function f is actually to be done simultaneously with the decision of optimization designing issue.

For the choice of set of independent variables X before the determining of their optimal values using the economic criterion, it is worth to apply the recommendations in the form of following features of each value studied, which can be the indicators when attributing the variable to the set of independent ones:

- independent variable has significant impact on the optimality criterion, it is supposed, that it is available the metrics or the algorithm, fit for the evaluation of the degree of influence of the mathematical value on criterion;
- independent variable is not determined unambiguously by the other specifications, which are (or are decided to be) the independent variables;
- independent variable is to be the changeable, that is are different for the various compared options of the sets of characteristics of the multifunctional ice-navigating ship under design;
- independent variable has the metrics of real number, that is the discrete characteristics and non-numeric ones are usually not recommended to be included in the set of the independent variables of ship under design and are recommended to take them in the sets of data or parameters.

Usually the objective function in the domain of its definition is mathematical continuous, smooth and convex subject to indicated practical recommendations.

When developing the mathematical model for its use at initial stages of designing of multifunctional ice-navigating ship the number of variable values – the ship characteristics sought in the designing, are subject to the assumption of their independence, decreases usually as the developed mathematical model is improved and as the existing balance equations (see items 4.1–4.4), establishing the relations between the characteristics of the designed ship, are included in the model, thereby reducing the number of independent characteristics, and as the parametric dependences available at the initial stages of ship design (item 4.6) between the ship characteristics and particulars are included in the developed mathematical model. As a result, when developing these mathematical models, the number of independent variables is several ones, probably from one variable to three ones, and this set is commensurate with the number of the balance equations, examples of which are the following:

(1) equation of mass balance establishing the relationship between characteristics of the ship size (D , DW , PG , etc.), in this case, one of considered characteristics of the ship size can be independent;

(2) energy balance equation that establishes the ratio of useful power (the energy capacity) and consumed one, in physics, the specified ratio corresponds to the indicator of the efficiency, and in the applied issue of multifunctional ice–

navigating ship designing this balance ratio can be considered between the propulsive or effective power, on one hand, and the capacity of power installation on the other one, or between the impacting characteristics on the ship propulsive or effective power, which, in addition to the size of the ship, which is usually estimated in the assumption of the mass balance, belongs to assigned design constraint of solid ice thickness, which the ship can overcome, or varied characteristic of operation velocity in the design optimization of the ship, which is characteristic at the design optimization of the ship of big size, which has not the assigned ice category, or has the insufficient one, that is the energy balance establishes between the follows impacting and resulting indexes: (h or N_{ICE}), (v_s or Ne) and NP ;

(3) volumes balance equation establishing the ratios of useful volumes and tonnages, like cargoes holds volume or the net tonnage (NRT or W , etc.), and resulting indexes of volumes and tonnages (GRT , the volume by the hull dimensions $L \times B \times H$, the particular, characterizing the ship hull specific volume H/T , etc.) when designing the volumes balance equation like these can be used in cases, if the ship under designing is assigned to carry cargoes in the close holds or volumes – the refrigerated or frozen cargoes, the liquefied gas, etc., which imposes the minimal limit on the volume of cargo spaces and the ship's hull for definite amount of cargoes, as well, as on the other volume characteristics of definite premises, corresponded with the indicated ones, if the ship under designing carries the cargoes with a high specific loading volume that cannot be carried on an open deck, such as the processed timber cargo, if the ship accepts cargo on the inner decks within the cargo volumes of the hull – the rolling cargoes (trackless or rail), for merchant ships of some other types, as well, as for submarines with ballast water tanks, although they are not usually attributed to the set of merchant ships, etc. Merchant ships of indicated types, for which the use of volumes balance equation would be relevant, usually do not belong to the number of multifunctional ice–navigating ones, but they are specialized ships of one or another assignment.

Energy balance assumption in the designing of ship in the definite cases does not serve as a basis for introducing additional characteristics into the mathematical model, in particular, for the indicated option of the ship design optimization, not having the assigned ice category, or having the insignificant one at the great size of ship, due to the relatively narrow variation interval of the operation velocity v_s , which in this case is practically not the changeable variable, although at the same time it is an independent characteristic, then the effective power depends on the size of the ship (D , DW and PG). The conventional constant of the ship operation velocity is associated with the laws of physics (the hydromechanics) and is an observable

fact, since it is known that the operational speed of merchant ships, which is usually from 15 to 20 knots (let's say from 10 to 25 knots), varies in a significantly smaller relative interval than the interval of observed values variation of these ships size, which, as one knows, can be from several hundred tone of the ship loaded displacement practically up to 500 000 ton with the corresponded difference in ship sizes by almost 1000 times. That is the ship operation velocity in most general approximation can be studied as little varied and considerably sustainable characteristic compared to observed range of variation of the ship size characteristic. Considering this assumption at the initial designing stages in the definite circumstances the effective power of the ship would be considered dependent not on the operation velocity, which changes little by itself, and on the ship size (for large ships with small assigned ice category or insignificant one), at the same time, in accordance with the energy balance assumption, an additional searched design characteristic does not arise, instead of which the ship operation velocity is assigned, which is of design the ship particular (the parameter), specified as constraint at the initial stages and subject to refining at the next designing stages.

Moreover, the specification of solid ice thickness h , which the ship can overcome, of up to 4.0 m for the assigned arctic category Arc9, is also the data and design constraint, and not the designing optimization variable, therefore the assumption of the energy balance is usually unrelated to one or the other the ship design characteristic varied at the optimization.

The above explanations indicate that the set of the independent variables at the design optimization of multifunctional ice–navigating ship as for the external task, so as for internal one is usually not large and can be probably from one to three, when eliminating the possible contradictions of the variables mutual interdependence and the disparity of their intervals of variation.

In the same time, the designing of multifunctional ice–navigating ship even in the most generally approximal description may include several dozen elements, which in this case must be determined at subsequent design stage within the framework of the systems approach. This, i.e. limited set of the ship design optimization variables, the general appearance is predetermined of the sequence of multifunctional ice–navigating ship design characteristics and particulars finding. The most important in this sequence is the initial design stage, according to the results of which not only the ship design characteristics are to be determined, which are the data (the constraint) for next designing stage, but the rest of the design stages are also planned (the internal designing), on which the design particulars of the ship will be found.

Final stages of ship design can go beyond the professional framework of Naval Architecture and Marine Engineering and enter the field of Mechanical Engineering.

Decision of the internal designing issues (the finding of ship particulars, when the characteristics are specified) can be carried out in parallel, since within the framework of systemic approach in the internal design the subsystems of the ship are studied and design particulars are sought, i.e. an integral ship is considered individually as subsystems, from the point of view of one or another individual property of the ship, for example, one or another its seaworthiness property, or from the standpoint of individual mechanical property of the ship structures – the strength, the robustness, etc. These issues of the internal designing are decided taking into account their superposition within the framework of the systemic approach, in which the ship design particulars in the appropriate approximation can be determined individually, which serves the indicator of the ship's subsystem – the possibility of integral ship isolated study in terms of any considered its individual performance.

It should be noted that the superposition assumption is also characteristic of the ship theory (the physics of ship interactions with the marine environment), at which, in the most general approximation, the independence of individual seaworthiness properties of the ship is assumed: the buoyancy, the stability, the unsinkability, the water resistance, propulsion and controllability when finding their indexes, which to determine have to be specified the ship characteristics and particulars, and in the option of multifunctional ice-navigating ship to the indicated list of the ship physical properties in open water could also add the ship patency in ice.

In the ship designing theory (the Naval Architecture), when the issues are decided opposite to ones in the ship theory (the physics of ship in the ocean) and the ship designing particulars for specified design constraints (the data) and for previously found characteristics of the ship can be determined independent on each other in such a way that the indexes of the ship seaworthiness and its patency in ice knowingly meet the seaworthiness criteria and the assigned design constraints, and the independence of the ship seaworthiness properties and its patency in ice successively follow from their independence in the frameworks of ship theory, as well, as from the concepts of systemic approach with one of the subsystem as the integral ship considered in the internal designing consisting of the subsystems when determining its design particulars, that is of the individual or acceptable conditionally independent properties of the ship.

Conventionally acceptable independence of the ship internal designing issues, that is the superposition of independent finding of the ship designing particulars

for the assigned design constraints and previously found the ship design characteristics, helps to organize parallel independent work of several performers when determining of designing particulars of the ship, which promotes the organizing of work of the designing bureaus or groups of the graduate students, as it is for example in the work of graduate students of the Department of Naval Architecture in the University of British Columbia, independently engaged in the definition of the design elements of the ship, and this is possible when the characteristics of the ship were previously found or specified in the project in the terms of references.

The set the parameters Y , that are the design particulars of multifunctional ice-navigating ship characterizing it subsystems, is introduced as the composition of those independent values, each of which individually has not the significant influence by the appropriate metrics on the optimality criterion determined in the form of objective function f , commensurate with the impact of the characteristic. For example, to the parameters it is likely to attribute the big set of values of economically insignificant particulars of ship under optimization designing, except those, which are assigned to the variables X . Practically for determining of the best combination of variables X (the design characteristics varied under optimization) by the optimality criterion, the parameters Y (ship design particulars) can be taken conventionally, for example by the design analogue, and be considering as constants at the initial stages of designing, that is when finding the variables X , the parameters Y are considered as conventional constants, that is the parameters Y are assigned to the design constraints, as the data are Z , and at the following stages of ship design the parameters Y are subject to refining.

To the number design particulars of ship (the parameters Y), which mathematical features are characterized by degree of influence on the objective function, can be assigned the follows:

1. Dimensions of multifunctional ice-navigating ship and their proportions, as well, as the ship dimensionless specifications (like the coefficient of overall completeness of the ship hull shape, etc.).

2. This or that indexes of integral multifunctional ice-navigating ship under the study from behalf of it definite individual property, for example from the seaworthy one, such as the applied indexes of follow properties: the buoyancy, the stability, the unsinkability, the property of hydrodynamic resistance and the propulsion and the controllability, as well, as ship patency in ice, and indexes of the ship inner physical properties – the durability, the hull strength, etc.

3. Balancing ratios – the proportions in the couples of multifunctional ice-navigating ship characteristics, in particular the follows: DW/D , PG/DW , GRT/NRT , GRT/D and etc.

4. Indexes of structural elements of multifunctional ice–navigating ship, of its systems and gears, of the power installation, the electric equipment, the indexes of any structural elements.

5. Indexes of technical processes of ship construction, the specifications of the multifunctional ice–navigating ship construction technique, which are the constraints for construction of the shipyard, and etc.

Composition of the mathematical model for determining of optimality criterion and for subsequent finding of optimal design characteristics of multifunctional ice–navigating ship under the systemic prerequisite of the considered options of the ship comparability on the general level is the sequence of dependences of the criterion on the input data, determined systemically as the functional constraints, on the ship characteristics values varied in the process of iterations by the optimization designing, as well, as on the conventionally constant values of the parameters, which by optimization designing are the ship particulars, that is the characteristics of ship subsystems.

The extra benefits of automation of ship designing are the opportunities of combining with the models of automation of ship construction, as well, as the opportunities of the automatic archiving, the collection of results and their automatic use in the other processes of ship creation.

2.4. Concept of general system, which part is the ship under design

Logical systemic definition of complex object, which is more general than multifunctional ice–navigating ship under designing study, is methodologically substantial for finding of design constraints, that is the input data, and for the organizing of general sequence of design characteristics and particulars of ship determining.

In the methodological sense one can cite the examples of complex objects which are the more general systems than the ship under design, these examples in the broad sense could be like follows:

1) the fleet of the cargoes carriers at the determining of its composition and replenishment in the frameworks of the external designing task of cargo ship designing, if the demand is formed by the administrative decision /127/, wherein the external designing means the determining of ship design characteristics, and the internal issue – the finding of ship design particulars;

2) one can consider the complex (the complete set) of the marine company's (the shipping company) assets /174, 176/ as the more general system than the ship under design, in the which the ship enters, and to find the finance constraint

for the determining of optimal design characteristics of the ship by capitalization of this complex of assets in the conditions the market economy;

3) the cargoes traffic of the definite intensity and extent, serviced by the set of similar or monotype ships, which characteristics in this case are the subject of optimization designing, and besides that the number of these similarly optimal ships is among sought characteristics in the complex servicing the cargoes marine traffic;

4) the complex of similar or monotype ships, implementing the developing of ocean resources in the specified district, such as water biological resources mastered by fishery expeditions, as the offshore mineral deposits (the oil, the natural gas, the mineral resources) and etc.

In the last two examples (3 and 4) the similarity of optimal projected ships in the complexes is indicated, which follows from the concept of optimality, because if the optimal design characteristics of the ship are got, then the ships with the other specifications could not be the optimal design decisions, therefore the ships of each class in the composition of complex of the marine company have to have the similar or the closely comparable terms of references for determining of their design characteristics and particulars, which are optimal.

From the systemic point of view the multifunctional ice–navigating ship in designing could be considered in the composition of the integral complex of assets of the existing marine company, in particular the shipping one, individualized by the property rights and by the economic interests of possessor – the investor (physical or legal entity) – in the process of development of investor’s innovation strategy of access to the ocean resources. In the distinction with the serial ships, constructed in accordance with the market economy demand, on the stage of creation of multifunctional ice–navigating ship the investor could be not the single entity, but two or more parties concluding the contract, for example the marine enterprise, which acts on the basis of self–sufficiency, or the federal or other administration, subsidizing the initial investments and receiving the property rights in full or in accordance with the share of participation by the indicated contract.

For the ship of innovative assignment design, in particular the multifunctional ice–navigating ship, the more general system from certain point of view one could define methodologically but not in the property possession terms, as this is logical for the ship, assigned for batch construction, when the complex of the marine company assets is likely to consider the more general system.

The concept of «marine engineering» (ocean engineering) could be considered as the more general system (complex object) than the ship under design in the meth-

odological sense. This concept covers the ship, but the marine engineering is not reduced to ship and includes the other objects as well (the other types of objects to access the marine resources or to be applied with the others objects to access these resources).

This do not mean, that the ship is physical part of marine engineering – the general complex system. On the contrary, the marine engineering, that are the mechanisms, the gears and the systems of ship, including specifically designed for use in the marine environment (that is to access the marine resources or to be used in any way for this), for example, the marine power equipment and the electromechanical equipment, the marine instruments and the automation tools, the equipment for fulfillment of the technical processes in the ocean and etc. are usually considered as the ship equipment physically.

Standard equipment of ship as a rule is defined as the ship subsystem. In the same time the equipment of ship, directly associated with the ship functional assignment, or the atypical equipment could be methodologically considered not as the subsystem when designing the ship, particularly the innovative one, and as the more general system at determining of design characteristics of the ship.

Methodologically for the ship of innovative assignment, for example for the multifunctional ice–navigating one the more general system could be the complex of the equipment pre–developed and created specifically before the ship construction in accordance with the ship purpose defined in the Federal programs of shipbuilding developing or according with the Shipbuilding Industry Development Strategy.

As examples of the ship innovative functional equipment, specifically developed in accordance with the purpose of ship up to it designing one can designate: the new types of power installations, in particular ones used the natural gas as fuel or the natural gas mixtures with diesel fuel, the reactor and the other parts of power installations for ships under design with the nuclear power equipment, the energy generation installations of the floating power plants, the marine production installations for liquefaction of the natural gas, the special systems of the ice–navigating ships and the engineering to improve patency in ice, the propulsive devices of ice–navigating ships, the submersible devices of the any assignment and etc.

Indicated innovative engineering equipment usually is not covered by the batch industrial production and is planned for use in accordance with functional assignment of the innovative ships under design, including the multifunctional ships for ice navigation. This functional equipment is the subject of development before the ship design to specify this in the terms of references in the distinction with the batch mastered equipment for ships, such as the internal combusting engines, the diesel–generators, the boilers and the fuel equipment of boilers, the pumps,

the separators, the compressors, ship deck gears of the general assignment and their elements, the structural elements of ship piping systems of the general assignment, etc. The innovative functional equipment specifically developed in accordance with the purpose of ship does not enter in the task of the ship design, and the characteristics of this equipment pre-designed in accordance with the purpose of ship are specified in the terms of references as initial data, in the other words, as the design constraints, despite the fact that physically it is the definite subsystem of ship under design.

For construction of the ships, which functions are determined according with the Federal programs or the Shipbuilding Industry Development Strategy, the creation of new technical opportunities in shipbuilding are required, which are not characteristic for batch construction of ships for the market demand, one could consider as the creation of functional system of the innovative assignment, that is the new property the ship. The indicated functional subsystem methodologically means the new property of ship, in particular, the new created workability of this ship construction. That is in the set of data for optimization of ship design characteristics it innovative assignment contains the technological opportunities of construction of the ship or its structural elements at specifically created facilities and techniques or at they considered under creation.

For example, the significant technical characteristics of the shipyard, which predetermine the opportunities of ships of the considered assignment construction, the industrial capacities of modular construction can be realized and provided by the equipment for technical processes, if assembling shipyards are working in the cooperation with the shipbuilding plants for the output of ship sections and modules. The technical opportunities of modular construction corresponded with the specific structure of ships under construction and, accordingly, with their assignment, since the modular technique is characteristic for batch shipbuilding, as well, as it could be efficient for the single or the small-scale batch construction of ships of the innovative purposes, if the mass ship construction is planned in the prospective.

If to consider the new technical facilities in shipbuilding or ones under creation as the subject of concept of the more general system, than the ship under design, that is the system to which the ship belongs, then with the account of economic interconnection of the industries of shipbuilding and shipping, which are working and developing in the balance, the priority of these industries has the significance, since in the shipyards designing and creating the characteristics of ships, intended for construction, are to be used as the data (the constraints). This means, that the more general system, than shipbuilding yard, would be the ship, for construction of which

the shipyard is created. Exactly this priority has the place in the Strategy and in the national Federal programs of shipbuilding development, which in the types are specified of ships, planned for construction.

In the broad methodological sense, when formulating the issues (the subject and the object) in the Shipbuilding Industry Development Strategy the alternatives of the ships creation are obvious:

or the fleet renewal meeting market demand, with the assumption of this choice of two alternatives – other than creation or improvement of shipbuilding enterprises, or in the innovative ships construction, this choice will give the definition of the object, for which the more general system would be the set of the strategic objectives.

And by itself the priority selected object, would it be the innovative ship (or the batch constructed one) or the shipbuilding yard improving or creation, will serve the more general system for each other of these objects designing, wherein the characteristics of the selected object in the Strategy will be the data (the design constraints) at the developing of the other object.

In this way the concept of more general system, than the ship under design, requires formulation of the design constraints, in which the ship is included methodologically as the subsystem, is not limited to initially given four examples of the more general systems, and can contain as well one of follow objects:

- the innovative engineering equipment, that is the equipment developed in accordance with functional assignment of ship under design, which design characteristics and particulars naturally correspond the specified innovation engineering equipment;

- the innovative methods of shipbuilding existed and under creation, given that the design characteristics of ship, such as it assignment, the size, the seriality and the constructions mass, as well, as design particulars of ship, that is the characteristics of structural part of ship – it physical subsystems, for example the modules, the sections, applied at ship modular construction, one can consider as the characteristic of created shipbuilding facilities and technologies.

If this precedes the construction of multifunctional ice–navigating ship, which functional assignment corresponds the Federal programs of shipbuilding development and the Strategy, the creation of new facilities and technologies, one could consider as the creation of new functional system of ship, that is it the new property of ship not required for the other alternative – the batch construction of the monotype ships meeting market demand. That is the available technological facilities required to construct the ship are methodologically it the general system (like the part

of the ship function) if they have to be pre-created before the ship and assigned in the ship designing terms of references in its assignment – to match this technology.

2.5. Options of comparability ensuring when determining optimal design characteristics of the multifunctional ice-navigating ship

Methodological considering of multifunctional ice-navigating ship (the system) under designing as the composition of parts (the subsystems) and the dialectic defining of the ship inherent properties, absent in its individual parts and arising when combining the parts, leads to forming of the hierarchy of mathematical models used for ship optimization designing. This allows to formulate the concept of options comparability of ship under optimization designing, in other words, the concept of similarity of options compared, which are different by variable characteristics combinations and have to be similar in the rest.

Concept of the comparability of varied options of ship under optimization designing that is of their definite similarity means that when varying options of characteristics X the constant, in other words, the design constraints the similar data Z are for each compared option, which were determined previously before the ship designing for more general system as its design characteristics, and the similar parameters Y for all options of the variables X are specified as the constraints too, which were pre-determined as well or taken conventionally assumed pre-determined.

By the way for the internal designing when studying multifunctional ice-navigating ship subsystems, the set of variables X and other sets of values (Y and Z) are redefined. It has to be indicated that when fragmenting the integral multifunctional ice-navigating ship into the subsystems and the fulfilling the optimization designing of the ship individual subsystems, that is in each case the integral ship, studied in the terms of its any single function, in other words, at the level of the internal designing, the optimal characteristics X , which were determined at the upper hierarchical level by optimization designing of ship as the integral composition of its subsystems, become the data Z , that is the constraints for finding of the ship particulars, which were parameters Y at the upper level, when finding the characteristics X .

In any way, the objective function f for the project optimization of ship is determined in dependence on the variables X and specified design constraints: the parameters Y and the data Z . Wherein the varied and compared by economic criterion options of the ship are to be comparable, that is be different by the variables X and similar in the rest (Y and Z).

2.6. Accordance of the systemic levels of project optimization of multifunctional ice–navigating ships and serial merchant ships

Besides meeting the plans of fleet replenishment according with the Federal pro-grams and the Shipbuilding Industry Development Strategy the multifunction-ality of ice–navigating ships is due to demand of the other ships navigation service and escort need in frozen sea and in the points on the coasts of these seas, as well, as the demand of offshore platforms service in these seas. That is besides of the Strat-egy and the Federal programs to construct the multifunctional ice–navigating ships are the definite corporate demand. Comparison of concepts of the systemic approach in finding of optimal design characteristics of batch merchant ships intended for the construction matching market demand, what has been studied enough /9, 23, 24, 40, 127 and 174/, on one hand, and ships of innovative assignment, in particular the multifunctional ships for ice navigation, subject to creation in accordance with the Federal programs and the Shipbuilding Industry Development Strategy, on the other one, is indicated in the table 2.1.

Table 2.1

The accordance of systemic concepts at the optimization designing levels of batch constructed merchant ships and multifunctional ice–navigating ones

The object under design	The conventional merchant ship, planned for the batch construction	Multifunctional ice–navigating ship, the ship of the innovative assignment
The charac-teristic of the demand	Market demand with regard to batch merchant ships	Demand in accordance with the Federal programs and the Shipbuilding Industry Development Strategy
The char-acteristic location of yards	The Republic of Korea, Japan, China, Taiwan, Singapore, Turkey, Greece, Finland, other states with highly developed batch ships construction	The Russian Federation, the US, Canada, Great Britain, the rest of EU and the other industrialized countries in whose jurisdictions are the marine resources
The issue of the external designing – determining of ship design characteristics		
The more general complex object, which includes ship under design	Complex of the marine com-pany assets, which part is the ship under design; the fleet of carriers for deter-mining of it composition; the ocean freight traffic; the marine industrial fishery grounds and etc.	Innovative purpose of ship, specified by it function; the innovative functional element of ship; the innovative equipment – the complex of functional elements, developed for ship creation

The model directivity for determining design characteristics	Optimal characteristics of ship subject to the constraints are determined by criterion, the particulars of ship are determined in dependence on characteristics in the way «from general to specific»	Subsystem of ship, corresponding it innovative function, is worked out previously, the ship particulars and its design characteristics are determined in dependence on characteristics of the worked-out subsystem in the way «from specific to general»
The customer (the investor) in designing and construction	Customer (the investor) – the theoretical concept, characterizing the market demand (the customer availability) of ships of this or that class and design of the serial ships, offered by the «line» of options	Customer – the definite entity, interested in the implementation of the Federal programs and the Shipbuilding Industry Development Strategy; the customer can be budgetary or non-budgetary establishment and the entity
The constraints (the data for optimization designing)	Finance constraint (*) by the assessment of solvency of the investor (his property complex net worth, that is total capitalization)	Characteristic of ship function (**), corresponding the Federal programs and the Shipbuilding Industry Development Strategy, for example, the assigned patency of ship in frozen sea
The optimality criterion in the form of objective function	Used economic efficiency criteria of minimizing costs or maximizing profit for determining of optimal design characteristics; the used for purposes of optimization designing specific economic costs or the other criteria per unit of effect	Minimizing indexes: of the initial investments, of the present worth, counting the initial investments and the present value of operating costs; the loss savings index, corresponding to additional extra-budgetary income, considered as the amendment to minimizing indexes of costs
The characteristics subject to determine (the variables)	Variable values sought under optimization designing are the independent characteristics of ship sizes, of the power installation capacity, etc. like follows: the deadweight or the cargoes capacity, the volume of cargoes spaces, the tonnage, the capacity of the power installation, the propulsive power, etc. Other design characteristics determined intermediate in the mathematical model, which are dependent on the indicated independent ones are determined with the use of the balance equations Variables got optimal will become data (the constraints) in internal issue	

Internal designing issue – finding of particulars (characteristics of subsystems)	
The subsystems of ship under design	Subsystem of ship under design is its individual property, referred to the integral ship: buoyancy, the stability, the unsinkability, the ship propulsion and water resistance, the patency in ice, the controllability and maneuverability, the structures durability, their reliability and etc.; separate mechanisms of ship, the gears, the ship systems, power installations, the electrical mechanisms and etc.; structural parts of ship hull, of gears, of piping systems, of mechanisms, of engineering equipment, etc.
The particulars	Design particulars of ship are: ship dimensions and their proportions, the characteristics of ship structural elements, mechanisms, gears, ship systems, electrical mechanisms (***) Design particulars are variables studying for optimality in internal issue

Remarks:

(*) money amount by value estimate (the capitalization) of complex of assets of the investor, servicing as a liquidity guarantee of investments in construction of serial ship;

(**) icebreaking function, characterizing by assigned ice thickness (or the ice category), the other functions of multifunctional ice–navigating ship, for example the purpose of the ship main system previously created;

(***) at the previous stage in the external designing, when finding the optimal characteristics of ship, the particulars assumed to be determined conventionally, using the specifications of the analogues, or of standard equipment, or the use of pre–design studies of parts, in the external designing the particulars are used as the constraints.

Sequence of the determining of design characteristics and particulars of ships of the innovative assignment, in particular the ice–navigating ones, created according with the Strategy and the Federal programs, could be methodologically different from that sequence for ship batch constructed ships designing for the market demand, which usually corresponds the directivity of designing «from the general to specific».

The sequence of designing of ships of innovative assignment, including the multifunctional ice–navigating ships, could be opposite and have the directivity «from specific to general». In the other words, the composition of the particulars

corresponded the ship function in accordance with these programs or the Strategy has to be found and specified as the data (constraints) up to the determining of optimal design characteristics of the ship of this assignment.

It has to be indicated that the function of innovative assignment of ship under creation acts the main constraint when designing the ship. Wherein the finance constraint of the investment provided, which could serve the data (constraint) for determining of design characteristics of merchant ship, assigned for its batch construction, when moving to the model of optimization designing of multifunctional ice-navigating ship can be transformed to the objective function element (the amendment to the criterion) when using the economic criterion, associated with costs minimizing, or by index of investments close to this one, – the most appropriate the present value of all costs for the ship life cycle, including as the initial investment, so as the present value of the operating costs flow with the account of appropriate amendments with regard to costs economy subject to the availability of extra-budgetary income.

The sequence of the determining of design characteristics and particulars of ship of the innovative assignment, in particular of the multifunctional ice-navigating ship, is largely related to the features of this ship creation, for which this or that innovative element previously is to be developed corresponding the assigned ship function.

Sequence of determining of optimal design characteristics of multifunctional ice-navigating ship largely depends on the features of creating the set of the ship innovative systems, predefined as the function of ship according with the Federal programs and the Shipbuilding Industry Development Strategy. The sequence of optimal design characteristics finding in the rest is subordinated by the conventional systemic approach, including the formulation of ship as system consisting of subsystems and it as element of more general system. Characteristics of innovative elements according to the function of ship are the constraints (the data) for determining of ship design characteristics and are subject of elaboration at the other levels – when determining the characteristics of general complex system, to which the ship under design belongs as subsystem.

2.7. Probabilistic properties of the object, when determining design characteristics of multifunctional ice-navigating ship

For determining of design characteristics of multifunctional ice-navigating ship is analyzed as the complex probabilistic system, that is the integral system of the individual subsystems and the interdependences are of the probabilistic nature.

As it is indicated above (see item 2.2, page 63) the individual properties of integral ship, for example its seaworthy properties and patency in ice can act as the ship subsystems roughly: the buoyancy, the stability, the unsinkability, the propulsion and patency in ice, the controllability, etc., and when combining subsystems in the integral ship the new property of the ship appears, which is absent in the individual parts of ship.

Probabilistic properties of ship under design, as the system, methodologically includes its subsystems and the new property, arising when combining these subsystems, are indicated by the balance equations in ship designing, in particular the equation of balance of the displacement. The dependence of the displacement on directly or indirectly specified its components, for example on design deadweight or on cargo capacity is established by this equation. The practical use of the balance equations is that they allow to reduce the dimension of designing task with these equations and to reduce the number of the independent variables, that is the ship design characteristics subject to determining.

Ratio between the displacement of loaded multifunctional ice-navigating ship and the total of independent load components corresponding the design deadweight is the result of the cumulative impact of the numerous factors – the dependent components of the displacement on to this ratio. This proportional ratio between the loaded displacement and the design deadweight has the probabilistic nature and does not indicate the any single physical property of ship, for example such as they are this or that seaworthiness property, usually applied for determining of ship design particulars. In its turn the independent components of the multifunctional ice-navigating ship displacement are or specified in the terms of references for designing as the constraints or varied in the process of designing for finding of their optimal values.

In brief historical context it should be mentioned that before modern methodological approaches to determine the design characteristics of ship the probabilistic features of the ship were used in designing applying the analogues data. Probably, the determining of the ship design characteristics closing to their optimal values could be done by trial and error sequence while accumulation of experience, since the rationality of these characteristics follows not only as the conclusion in the terms of the ship theory, of structural mechanics and of the other concepts, united in designing of ship on the basis the systemic approach, and the accumulation and selection of successful decisions matters as well, which is of the probabilistic nature.

In the adjacent industrial directions, for which the mass production is characteristic, for example, in the batch construction of aircraft, automobiles and etc., there

is a gradual probabilistic accumulation and the enhancement of the results, leading to identical optimal solutions, so similar that it is difficult to find noticeable differences in characteristics of same class serial vehicles of the other brand, or aircraft of the same class, even produced by competing industrial companies.

Apparently, in the past the determining of design characteristics of ship planned for construction was done primarily on the basis the experience accumulation, which besides of the use of ship characteristics balances equations fruitful for dimension reduction in the designing issues could serve the example of ship under design properties as the probabilistic system use. In the same time the process of finding of optimal design characteristics of the ship is substantially more effective when using the systemic approach in decision of the optimization designing issues. Moreover, for the accumulation of successful design decisions and their improvement by trial and error sequences anyway the criterion is required of quality of the decisions got.

The complex automation of ship construction processes is characteristic, appropriate the level of modern shipbuilding and establishing the necessary requirements of automation in designing of ship. This leads as well to the development of the ways of analysis and the technique of design options accumulation and analysis, for example in the form of the software, archives, networks, databases (the archives with the automation of data processing and retrieval). This can open the new opportunities of use of the probabilistic properties of ship as the complex system under design. That is using the automation of ship designing processes and applying the variative methods of optimal design options selection one can see the return in the definite sense on the modern basis of digital technologies to use of ship probabilistic properties for designing in the form of accumulation of successful design decisions.

The manifestation of probabilistic properties of ship as the object under design are not exhausted by the balance equations characteristics of ship under design, in the basis of which are these properties, and the possibilities of ship design improvement by the way of the probabilistic experience and good results accumulation. If one takes into account that for the determining of design characteristics and particulars of ships of the innovative classes, in particular the multifunctional ice-navigating ships, it is logical to apply the optimization designing methods, then it is relevant to indicate as well the probabilistic nature of applied optimality criteria and of the economic indexes in the composition of these criteria. Specifically, the macroeconomic indexes have the probabilistic nature, including the indexes of investment risks, used for determining of design characteristics of ship by the optimization methods. The probabilistic nature is in the form of factor, establishing balance

between the operating costs and the investments in composition of the generalized criterion of present worth, and in the form of the interest rate index used as the basis for comparison of the criteria having the form of profitability indexes.

Need to pay attention, that probabilistic features are of considered above the multifunctional ice–navigating ship, which is the object under designing and the complex system consisting of subsystems, and these features are not the methods of calculations, based on use of random numbers, for example the extremum search methods of objective (criterial) function, which are known too.

Despite the fact that the probabilistic features of ship as object under design and the complex system are had into account in those parts of the approaches, in which this is required, nevertheless the determining of ship as the complex system for sequence of finding of design characteristics and particulars of multifunctional ice–navigating ship, apparently, is more important than focusing attention at probabilistic features of the considered object under design.

2.8. Subject of methodological approaches when determining the design characteristics and particulars of multifunctional ice–navigating ship

The general approaches and the sequence of determining of design characteristics of multifunctional ice–navigating ship have the features, corresponded with the fact that at the initial stages of designing of ships of this class and the other innovative ships, not covered by batch construction, methodologically it is difficult to find the design characteristics and particulars on the basis of ships–prototypes specifications use as the data. The use of the prototypes is basically not enough in designing of these ships, constructed or planned for construction single or in small series with the account of local specifics of the demand. Therefore, for determining of design characteristics and particulars of multifunctional ice–navigating ship the modern optimization designing approaches are relevant. When using these approaches the found design characteristics of ship and it particulars in the less degree depend on the data of prototypes.

Creation of the concepts, the methodical rules and the practical recommendations for the determining of characteristics and particulars at the initial stages of designing of multifunctional ice–navigating ship are the subject of the approaches.

The subject covers the decision of following tasks with regard of the design characteristics and particulars determining of ships of the considered class:

- the study of methodological concepts for the optimization of design characteristics of multifunctional ice–navigating ship on the basis of the systemic approach, the formulation of design constraints and the concept of the options comparability;
- analysis of cumulative probabilistic influence of diverse factors on the ratios in the couples of ship characteristics determined with the balance concepts, for example of the follows characteristics: the ship cargo waterline displacement, the design deadweight, the register tonnage, etc.;
- evaluation of functional constraints for optimization of design characteristics of multifunctional ice–navigating ship, in particular the pre–determining of constant part of the ship design deadweight, corresponding the mass of the specified equipment in accordance with functional ship assignment;
- determining and evaluation of the influence of physical constraint for assigned level of ship patency in frozen sea, for example the constraint of maximal thickness of solid ice, which the ship can overcome by the continuous motion, or the other physical constraint of patency in ice;
- the analysis of economic criteria hierarchy, the determining of multifunctional ice–navigating ship concept of utility function with account of the indexes of minimized present worth covering, as the investments, so as the operating costs, as well, as with the account of amendments, corresponding the costs savings upon possible admission of the extra–budgetary income;
- developing of the objective functions and the mathematical models for determining of optimal design characteristics and particulars of the ship according to the accepted economic criteria for the use of these objective functions and the mathematical models at the initial stages of ship designing;
- the study of properties of the design characteristics found in the vicinity of their optimal combination, including the analysis of conditional (the relative) and unconditional (the absolute) sustainability of property of the optimality of design characteristics found, given that the absolute sustainability of the optimality property is linked with the necessary of mathematically smooth and convex objective function extremum;
- probabilistic evaluation with the account of risks index of design characteristics combinations sustainability of optimal ship by the economic criterion;
- the developing of practical recommendations for the improvement of the mathematical models, used for the determining of characteristics of multifunctional ice–navigating ship at the initial stages of it designing;

– the developing of the recommendations for unification of methodological terms in the issues of multifunctional ice–navigating ship design characteristics determination at initial designing stages and corresponding the unification of concepts and terms for their implementing in practice and in the training process.

Finding of optimal design characteristics of multifunctional ice–navigating ship is performed with use of the mathematical models on the basis of calculations automation. The mathematical model used for ship optimization designing is the sequence of dependences between the assigned or the varied mathematic values, which are:

– on one hand, the initial data, that is the design constraints, defined within the systemic approach, the characteristics of ship under design, which are varied for finding of their optimal values, as well, as the conventionally constant mathematical values – the parameters, that are the particulars of ship in the issues of it design characteristics determining;

– on the other hand, the optimality criterion of ship designing, which is the used criterion of economic efficiency.

The extra benefits of automation of the processes of the ship optimal design characteristics determining are the opportunities for automatic archiving, the pre-conditions for automation of useful design decisions accumulation and at the next stages of ship creation the opportunities of the combination of the automated mathematical models and of information bases used in the designing and ones in the technological processes in shipbuilding.

Checklist

94. The duplicity or multiplicity of the ice–navigating ships functions.
95. The multifunctional ice–navigating ship definition as the developing of concept of the multifunctional ship improving it patency in ice, or the progress of specialized icebreaker concept by endowing it other functions.
96. Economic contradiction of combining of ice–navigating ship patency in ice function and the other functions.
97. The assignment of the specialized icebreaker.
98. Renewable energy sources for power generation in the seas.
99. Other functions of multifunctional ice–navigating ships, which are demanded by corporations besides of ones in accordance with the Federal programs of shipbuilding development and the Shipbuilding Industry Development Strategy.
100. Construction of the innovative multifunctional ice–navigating ships out of the competition with the batch shipbuilding.

101. Suitability of multifunctional ice–navigating ships for the assignment of cadets and personnel training.
102. The multifunctional ice–navigating ship hull shape and its correspondence with the icebreaking one.
103. The multifunctional ice–navigating ship conventional propulsive installation, the other types of power installation and the transmission.
104. Main factor in the batch ship construction on the principles of self–sufficiency in the Republic of Korea, Japan and China matching market demand.
105. Practical importance and methodological significance of multifunctional ice–navigating ships designing study and construction.
106. Priority of accounting of physical constraints of ship structural strength, the seaworthy and patency in frozen seas in the designing of the specialized icebreaker.
107. The needs to have the characteristics of size and power of multifunctional ice–navigating ship under designing before the study of particulars of the ship hull shape and its propulsive installation.
108. Evolution of icebreaker definition, endowing it the extra functions.
109. Determining of design characteristics of icebreakers as the boundary issue of multifunctional ice–navigating ship designing, if to reset the constraints assigned with extra function of ice–navigating ship.
110. The difference of the assignments of the multifunctional ice–navigating ships and ones having the ice category and batch constructed meeting the market demand outside any strategies of the freezing seas development.
111. «The category and patency in ice» as the methodological subsystem of the batch constructed ship with the ice category and not the general system, to which the batch constructed ship belongs as subsystem (not the data or design constraint).
112. Difference and the similarity of hull shape particulars and the propulsion installation of multifunctional ice–navigating ship and ones of the icebreaker.
113. Design modernization as the kind of the ship designing methodology using to the prototypes of multifunctional ice–navigating ship.
114. Theoretical importance of the designing approaches improving for multifunctional ice–navigating ship as the new designing object.
115. Options of the investor for creating of multifunctional ice–navigating ships, the likely forms of investors' entities.
116. The investor as the methodological concept for batch construction of ships.
117. Hierarchic systemic levels of multifunctional ice–navigating ship designing.

118. Characteristics of ship subsystems as particulars when determining its design characteristics.
119. Multifunctional ice–navigating ship individual subsystem as the integral ship from the point of view of its individual useful property.
120. When combining methodologically the ship individual subsystems (the parts) in the integral unit the new property of the ship arises, which had been absent in its separate parts.
121. Examples of the seaworthy and other individual physical properties methodological attribution to the subsystems of ship under design.
122. Multifunctional ice–navigating ship under design as the complex probabilistic system, which cannot be studied other than consisting of parts – the subsystems.
123. The figurative example of the merchant cargo ship as the system consisting of two parts (the subsystems): the ship hull and the propulsive installation, the new property of the ship the carrying capacity arising when combining the ship subsystems.
124. Two systemic concepts of ship under design: the all properties of the ship individual parts (the subsystems) and ones, arising when combining subsystems in the integral ship, or the arising properties, without ones in the individual subsystems.
125. The opportunities of the methodological generalizations over the ship as the object under design and of its fragmentation: the design constraints finding, the criteria formulation and the mathematical values classification.
126. The data and the parameters as mathematical constants (the design constraints) when finding optimal characteristics of multifunctional ice–navigating ship within systemic approach.
127. Opportunity to combine the outer and the inner issues in the composition of multilevel systemic approach for finding of optimal design characteristics of ice–navigating ship.
128. The characteristics determined in the external designing of ship are to be the data for designing of its subsystems.
129. Optimal values of multifunctional ice–navigating ship characteristics as the parameters in the general system designing issue.
130. Examples of the general systems characterized by the ships entering in it as the sub-systems: the navigating company; the shipbuilding yard; the ocean cargoes traffic, in particular the Northern Sea Route.

131. Complex of the sets of independent values characterizing the multifunctional ice–navigating ship under designing includes: design characteristics, design constraints and design particulars.
132. The economic property of multifunctional ice–navigating ship under designing, servicing criterion in the optimization as the generalized property, including physical property, the structural, the manufacturability one, the functionality and the other ones.
133. Economic criteria, as result of mathematical operations over the main economic indexes of income (annual), operating costs and investments.
134. Optimality criteria as the ways of use of efficiency ones, which allow to separate the optimal design characteristics and particulars of multifunctional ice–navigating ship from suboptimal options.
135. The economic efficiency criteria allowing to order all sets of ship design characteristics in the sequence of these options preference.
136. The optimality criterion equivalence with economic efficiency one if to consider efficiency criterion together with the constraints of the domain of variable ship characteristics sets studied for the optimality sought.
137. Mathematical model for the ship optimization designing, as the dependences between composition of variables, parameters and data, on one hand, and composition of general economic indexes of income, operating costs and investments.
138. Generalized variables as determined indexes intermediate in the mathematical model, dependent on variables – the independent ones, parameters and data.
139. The constant constraints assigning of data and the parameters when finding the optimal design characteristics set of multifunctional ice–navigating ship.
140. The variables set as the composition of values which substantially impact the objective function and are independent on each other variables in this set, on parameters and on constants.
141. Examples of multifunctional ice–navigating ship characteristics under optimization designing (the displacement loaded, the design deadweight, the tonnage, the cargo capacity, the cargo volumes, the propulsive or the installation power, etc.).
142. Indicators for practical attribute of variable to the set of independent ones: the significance of impact on criterion, the independence on other independent variables, the value difference for compared options, the metrics of real number of variable.
143. The number of variables of multifunctional ice–navigating ship under designing mathematical model comparability with the set of balance equations used in this model.

144. The equation of energy balance of multifunctional ice–navigating ship under designing, establishing dependence between the ship effective power (the energy capacity) in open water, or propulsive power when overcoming ice and the installation power of energy sources onboard.
145. The volumes balance equation establishing the ratios of useful volumes and tonnages and resulting indexes of volumes and tonnages in designing of ships of some types, like ones assigned for transportation of the refrigerated or frozen cargoes, the liquefied gas, the cargoes with a high specific loading volume that cannot be carried on an open deck, the rolling cargoes on the inner decks, etc.
146. Insufficient variability of operation velocity characteristic of the ship under designing, appropriate for large ship with insignificant ice category or with its absence, if to compare this with variation ranges of other independent characteristics, in particular with the range of the ship size variation, as the reason to omit the velocity from the set of variables and the energy balance equation from the set of assumptions when developing the mathematical model of this ship optimal designing.
147. The probable number from one to three of independent variable characteristics of multifunctional ice–navigating ship under designing, when eliminating the possible contradictions of the variables mutual interdependence and the disparity of their intervals of variation.
148. Importance of the initial designing stage of multifunctional ice–navigating ship for determining of the ship characteristics, which are the data (the constraints) for finding of the ship design particulars in the next, and for planning for rest designing process of the ship.
149. Opportunities of parallel decision of the internal designing issues (the finding of ship particulars, when the characteristics are specified) due to the superposition of the ship subsystems within the framework of systemic approach, in which the ship design particulars in the appropriate approximation can be determined individually.
150. The superposition assumption in the ship theory as the capability in the most general approximation to study separately the ship individual seaworthiness properties: the buoyancy, the stability, the unsinkability, the water resistance, propulsion and controllability.
151. Appropriate succession of the ship subsystems superposition within framework of systemic approach, when determining its particulars, which knowingly meet the seaworthiness criteria and the assigned design constraints in the ship designing (the Naval Architecture), which follows from ship theory (the physics

of ship in ocean) considering acceptable independent finding of ship each seaworthiness criteria, when its characteristics and particulars are specified and are not subject to determining.

152. Parameters (the design particulars) of multifunctional ice–navigating ship characterizing its subsystems, that are independent values, each of which individually has not significant influence on criterion commensurate with impact of characteristic.
153. Examples of design particulars of multifunctional ice–navigating ship (the dimensions of the ship and their proportions, the indexes of ship physical and seaworthy performances and patency in ice, the balancing ratios between the ship characteristics, the indexes of the ship structural elements and machinery and the indexes of the ship technological features of construction).
154. The substantiality of concept of more general system, than the multifunctional ice–navigating ship under optimization designing, for finding of design constraints (the input data) and for ensuring of options comparability while optimizing the ship design.
155. Examples of complex objects which are more general systems than the ship under design (the fleet of the cargoes carriers, the complex of marine company's assets, the cargoes traffic serviced by set of similar or monotype ships, the complex of similar ships, implementing the developing of ocean resources in the specified district).
156. Concept of «marine engineering» as methodological option of more general system than the ship under design, although physically the marine engineering (the machinery, devices, gears, instruments, etc.) is usually the part (the subsystem) of ship.
157. The standard equipment for the ship under design completing and the innovative equipment specifically developed in accordance with the purpose of ship,
158. Examples of the ship innovative functional equipment, which can be more general system, to which the ship belongs methodologically (the new types of power installations, including double fuel ones, the floating power generation equipment, the equipment for liquefaction of the natural gas, the devices to improve the ship patency in ice, the innovative movers, etc.).
159. Consideration of new technical opportunities in shipbuilding created for construction of innovative multifunctional ice–navigating ship as the new property of integral ship and the more general system to which the ship belongs technologically.

160. The ship under construction as more general system than the shipyard, considering the characteristics of ship, that is the serie or type intended for construction, as data for creation of the shipyard.
161. Alternatives of ships creation planning other than improving of shipbuilding yards: or fleet renewal meeting market demand, or innovative ships construction with the Shipbuilding Industry Development Strategy and the Federal programs.
162. The examples of more general system than multifunctional ice–navigating ship under designing, containing the innovative marine engineering equipment developed in accordance with functional assignment of ship and the innovative methods of shipbuilding as the characteristic of created shipbuilding facilities and technologies.
163. Concept of options comparability of ship under optimization designing, that is the similarity by all of the rest attributes of the ship options compared, which are different by variable characteristics.
164. The redefinition of mathematical values classes (the variables, the data and the parameters) when changing the hierarchical level of the optimization designing for the same object – the multifunctional ice–navigating ship.
165. Multifunctionality of ice–navigating ships following from the Federal programs and the Shipbuilding Industry Development Strategy and from the corporative demand.
166. Differences of systemic concepts at external designing issue and similarity of these at internal one at the levels of optimization designing of batch constructed merchant ships and multifunctional ice–navigating ships.
167. Directivity of designing «from the general to specific» characteristic for designing of merchant ships intended for batch construction.
168. Directivity of designing «from the specific to general» likely for innovative ship, in particular for multifunctional ice–navigating one, which for the main part (the system) is to be pre–designed or assumed pre–designed when designing of the ship.
169. Innovative assignment as the main constraint in optimization designing of multifunctional ice–navigating ship.
170. The investments constraint in optimization designing of ships intended for batch construction.
171. The deducting of investments constraint in the amendment of criterion in optimization designing of multifunctional ice–navigating ship.

172. Equation of multifunctional ice–navigating ship balance of displacement as the dependence of it loaded displacement on directly or indirectly specified the displacement components.
173. The probabilistic nature of ratio between the displacement of loaded multifunctional ice–navigating ship and the total of the independent load components as the cumulative impact of the numerous factors on to this ratio.
174. Probabilistic features of multifunctional ice–navigating ship under designing using the analogues data.
175. Possibilities of ship design improvement by the way of the probabilistic experience and good results accumulation (the trial and error methods).
176. The probabilistic nature of criteria and economic indexes used for determining of objective function for optimization designing of multifunctional ice–navigating ship.
177. The lack of enough data of ships–prototypes specifications to use these for determining of design characteristics and particulars of innovative ship, in particular, the multifunctional ice–navigating one by the conventional approaches with the data of analogues.
178. The issues of the approaches developing for finding optimal design characteristics and particulars of multifunctional ice–navigating ship: the study of methodological concepts of systemic approach use for the ship designing; analysis of the ship probabilistic properties and the balance equations; study of physical constraint for assigned ship patency in ice; analysis of economic criteria to use in optimization designing; determining of the ship concept of utility function; developing of objective functions and mathematical models; study of properties of the ship design characteristics found; analysis of sustainability of optimal ship characteristics got, etc.
179. Mathematical model used for multifunctional ice–navigating ship optimization designing is the sequence of dependences between the assigned or the varied mathematic values.

Chapter 3. Criteria of ship strength and patency in ice in determining of the design constraints

In the Russian Federation and in the overseas a lot of the experience is accumulated and the results are available of researches of merchant ships strength in ice, the property of hydrodynamic resistance, propulsion and patency in ice and of their other properties in freezing seas /6, 33, 46–48, 54–56, 83, 96, 104, 107, 126, 162, 163, 165, 166, 182–185 and etc./. It has to be noted, that the studies done of the various properties of ships in ice were carried out in accordance with one or another assigned issues, in the same time for the use of the mathematical models, intended for the determining of characteristics at the initial stages of designing of multifunctional ships for ice navigation, the systematized recommendations are required, suitable for the evaluation of hull strength indexes and the patency in ice dependences on assigned design constraints, including the design characteristics of ice environment, on parameters, that are the particulars of ship under design, which, being the characteristics of ship subsystems are the subject of decision at the next stages of designing, as well, as on variable values of the ship characteristics sought, varied when doing ship project optimization.

For the assessing of ship hull strength and the properties of ship hydrodynamic resistance and its propulsion property in ice on the stage of ship design the characteristics of ice or icebreaking category or the other assigned characteristics of ice environment, as follow: the maximal thickness of solid ice, which the ship can overcome by continuous motion, the density of the ice, the concentration of ice and so on are in the data set. It should be borne in mind that the properties of hull strength, of hydrodynamic resistance, the propulsion and the patency of ship in ice of the assigned intensity are largely interdependent, which is possible to characterize by the similarity of basic data for the evaluation of strength and the property of hydrodynamic resistance, propulsion and the patency in ice, so as by the dependence of ice loads on the structures and the floors of hull on the velocity of motion in the ice field or on the propulsive characteristics and the capacity of power installation.

When forming of the evaluation techniques used in the design calculations of the properties of hydrodynamic resistance, the propulsion and the patency in ice and the loads of ice on the hull of ship the structural features of ice–navigating ships have to be considered. At the initial stages of designing, including the determining of characteristics of ship in terms of references or in the draft design need to pay attention on the features of ship hull shape and the particulars, which must meet the conditions of ice navigation.

For overcoming of solid ice it is usually recommended the design angle of stem tilt φ to the main plane (or to waterline plane) to adopt of about 20° /32/, the design angle α of cargo waterline entry (the angle of fore sharpening of the ship waterline shape) – of about 45° , the design angle β of ship sides slope (the angle of zero theoretical frame inclination to the diametral plane) from 50 to 60° .

The ratios of particulars, specifically the proportion of ship length at cargo waterline to it breadth, are under decision as well, and the waterlines shapes in the aft part linked with account of the maneuvering performances in the curvilinear channel boundaries in ice field. The longitudinal steps or the side cheekbones in the aft can be used for protection of propellers and rudders, and the propulsors and rudders are located with the account of the shape and sizes of these steps or side cheekbones. The indicated features of fore and aft parts shapes of ship hull are attributed to the evaluation of the properties of hydrodynamic resistance, propulsion and the patency in ice and the loads on the hull of ship and do not cover the features of ship hull of the above-water part of ice–navigating ship, which are available as well, the layout of the decks and the superstructures, the features of hull framing and it single structures, gears and systems.

Need to pay attention that features of operation conditions in ice and the hull shape of ice–navigating ship suitability the conditions do not mean the mechanical increase of hull structures particulars, especially the increase of the design thicknesses of shell strakes and framing and the corresponded proportional increase of ship hull mass in dependence on the assigned in designing of ship ice category or the thickness of solid ice, which the ship can overcome. The increase of thicknesses of the structural elements and the mass of ship empty is in dependence on the design ice loads anyway. In the same time the common feature of the ice–navigating ships, created for various ice environments, impacts exactly the hull shape and the ratios of the dimensions, which correspond, first of all, the tasks of ice overcoming, although could be not the best from the point of view of property of the hydrodynamic resistance and propulsion of ship in the open water.

This characteristic feature, which says not so much about the difference of the mass of ice–navigating ship hull from the ship of similar size, for example, of the similar one by the deadweight or the register tonnage, but not having ice category, as about the differences of ship hull shape and particulars of it movers and equipment for ship control, which are chosen for ice–navigating ship with the account of operation conditions in ice of the definite intensity. Ultimately the specified feature means that in one way or another the ice–navigating ship in dependence on ice category is more massive than commensurate one, not having

the category, on one hand, and inferior to such a ship in terms of hydrodynamic resistance and the propulsion properties in open water, on the other hand. In particular, this feature serves one of the motives for creation of so-called ships of DA-class, which example is provided above (Fig. 1.26, item 1.6).

Class designation of DA indicates ice-navigating ship, the shapes of the bow and stern parts of which are optimal for moving stern forward when overcoming ice and bow forward in open water. The characteristics of DA-class ship shape in the aft, which can be considered good for the arrangement of propellers and rudders and for movement of ship in open water bow forward, in the same time correspond to recommendations with regard to the shape of the bow part, that are to the angles of: the stem tilt φ , the sides slope β and the fore sharpening α , if the ship moves stern forward when overcoming ice. Wherein the specific issue of protection of the propellers and the controls equipment of ship against broken ice arises, which is characteristic for modern icebreakers with the movers in the both ends. In the same time when ship of DA-class moving stern forward, as and for the icebreaker with the movers in the bow part, further increases the efficiency of ice forcing, since the propulsors make the hydrodynamic pressure lowering under ice layer contributing to the loss of sustainability of ice field and its destruction.

The conformity of ship design particulars of its assignment of ice crossing does not indicate itself the increase of ship displacement empty in its comparison with this of ship, not having the ice category and comparable by the size characteristics, for example, comparable by design deadweight or tonnage. The ships in this example could be commensurate by the displacement empty, if in the composition of the design constraints of second compared ship would be assigned the smaller ice category. Although these ships would have the conceptual differences of the design particulars, such as the ratios of the dimensions, the particulars of hull shape and of propulsion complex, as well, as of the indexes of hydrodynamic resistance and the propulsion in open water.

In the same time the ships for ice navigation having the identical dimensions and the characteristics of ship hull shape, as well, as conformal the particulars of propulsion and steering complex could have substantially different displacement empty in dependence on the difference of their ice category specified for the designing.

Summarizing the overview of structural and functional features of ice-navigating ship, one would note that the design constraints corresponding the assigned ice category in the terms of references of the ship or specified characteristics of frozen sea affect ship design in the issue of determining of hull particulars of the ship, such the dimensions and their ratios, as well, as particulars of hull shape,

and the choice of propulsion complex of the ship and other particulars are subordinated the ship assignment of ice field overcoming, wherein the designing decisions got in the less degree correspond the issue of ship effective operation in open water.

In the other words, the multifunctional ice–navigating ship with its structural and functional attributes is the object conceptually different from one not assigned for the operation in ice, hence, not having probably the essential differences by the displacement empty in the event, if not sufficient ice category of ship is assigned.

The differences of the displacement empty or the ratios of deadweight (or the cargoes load) to the displacement of loaded ship, or to its empty displacement could serve as the characteristic attributes in the frameworks of unite class of ice–navigating ships for the commensurate ones, different by assigned ice categories.

For the determining of optimal design characteristics of multifunctional ice–navigating ship the systematization is required of the methodic techniques for the issues of evaluation of the ship enough strength and the capacity of its power installation, providing the appropriate propulsion of the ship under designing and its patency in ice in dependence on assigned ice category.

When systematizing the methodic techniques as utilitarian criterion in the approaches it is required the orientation for the determining of those indexes, which are the generalized variables for determining of optimal characteristics of ship and ultimately impact on the design characteristics and the indexes of ship efficiency generalized in the optimality criterion. In the other words, the generalization of the having diversity as the particular methodic techniques of strength evaluation at this or that loadings of various structural parts of ship hull and different options of the conditions, evaluated for determining of ice–navigating ship motion resistance in ice and the capacity of the power installation must be done for finding those methodic guides, which are required for determining of its design characteristics. As mentioned for part of the evaluated indexes it is required to consider their mutual dependence, for example the interdependence of ship motion resistance in ice and the propulsion power, as well, as the load of the ice on sides floors of hull, impacting the design particulars and the sides floors mass, as well, as to consider the having hierarchy of some evaluations, for example of the ice loads. In dependence on the used approaches it could be the number of indexes of the ice loads criteria for those or other used methodic assumptions. However, the compliance the most critical criterion of ice loads indicates in the same time the satisfactions the rest criteria, which would be considered as the additional ones, but their evaluations have not impact on the results of characteristics of ice–navigating ship determining at the initial designing stages.

3.1. Determining of solid ice thickness affordable to overcome in dependence on characteristics of ship and its particulars

For ships of high ice and arctic categories, in particular the Arc4, Arc5 ... Arc9 and the icebreakers, intended for operation in the conditions of solid ice field of definite thickness, the critical factors of the capability to overcome ice would serve the following characteristics and particulars: the cargo waterline displacement, the capacity of power installation, the particulars of ship hull shape, the thickness of ship hull shell, the structural particulars of sides floors, for example the spacing of the transverse or the other system of the framing, the structural particulars of extremities and the protruding parts of hull, the special systems of ship, such as the trim system of icebreaking of ship.

For ships of arctic categories, capable to overcome the solid ice of the assigned thickness by continuous motion while keeping the hull strength under the compression on ice-side, one can assume, that the ship strength, determining by this way, is enough as well from the point of view of safety in case of collision with floating ice floes, if besides structural strength the safety is provided too by the navigation aids and by choosing the safe velocity of ship with the realistic assessment of ice environment, and the installation power under designing is got with the account of continuous ice overcoming ability and would be enough by the criteria of ship hydrodynamic propulsion in the broken ice. One would see the hierarchy of strength and propulsion properties evaluations of the ship in frozen sea, which means that when meeting the heaviest of seaworthiness criteria in the ice field, that is when the capacity of propulsion and of power installation is enough and the strength of ship hull for in continuous motion in solid ice of the assigned thickness specified as the design constraint in the terms of references, the rest criteria are met.

The characteristic prerequisite for ships of smaller ice categories, such as Ice1 – Ice3, or without the ones apparently would be the seaworthiness in broken ice, when autonomous navigation, or in the insufficient solid ice, or behind the icebreaker in the broken ice, in distinction with the ships of bigger ice categories, which for ships of these categories (Ice1 – Ice3) are characterized by the enough strength of structural elements and by enough capacities of their of power installations for keeping minimal required velocity for navigation safety and controllability, but not in solid ice, and the designing assignment of solid ice overcoming in this case does not advance.

Besides for the evaluation of multifunctional ice-navigating ship properties one would consider the analysis-oriented accent of marine classification societies

activity to evaluate the ice category considering importantly the ship capability to overcome solid ice, which can be characterized by maximal thickness h of smooth solid ice for corresponding ice category, in which the ship can move by stable continuous motion. Wherein the strength of ice is supposed to be equal about 500 kPa in normal bending stresses, and the layer of snow cover on ice is from 20 to 25 cm.

For approximate assessing of limiting thickness of overcoming solid ice by continuous motion the formula of L.G. Tsoy /162 and 163/, improved by S.N. Klimashevsky and A.I. Titov /63/ is known. Limiting thickness h of the overcoming solid ice by continuous motion of the ship with account of the angle of stem tilt to the main plane φ and the angle of cargo waterline entry α , as well, as the angle of ship sides slope β (of zero theoretical frame inclination to the diametral plane), can be determined as

$$h = 0.02 \times L / (F \times (D / N_{ICE} + 1.63)). \quad (3.1)$$

To use Tsoy–Klimashevsky–Titov formula one must specify the dimensions: L – the length of ship load–line, m; D – cargo waterline displacement (the ship loaded displacement), ton; N_{ICE} – propulsion power, required for f solid ice overcoming, kW; f_D – the dynamic friction coefficient of ice (of ship hull on ice), the index is equal about $f_D \approx \dots 0.10$, dependent on properties of ice; F – function of ice–navigating ship bow shape, determined with the account of the angles: of the ship cargo waterline entry α , that is bow sharpening of cargo waterline shape, for ice-breaking ship this angle recommended 45° and the angle of ship sides slope β , that is of zero theoretical frame inclination to the diametral plane, for the icebreaking ship this angle recommended by 65° . Function of ice–navigating ship bow shape looks like

$$F = \sqrt{2 \times (\cos\beta + f_D \times \operatorname{ctg}\alpha) \times \sin\alpha}.$$

The indicated angles: of waterline entry α and of sides slope β at zero theoretical frame for determining of design characteristics of multifunctional ice–navigating ship, in particular for the determining of it loaded displacement, the design deadweight, the capacity of power installation, of the thickness of shell and etc., at the initial stages of designing are possible in the general approximation to consider as the sustainable values, and in the next, for determining of the design particulars of ship these angles could be refined. Subject to the considered assumptions

of the angles: of waterline entry α and of sides slope β at zero theoretical frame the function of ship bow shape becomes

$$F = \sqrt{2 \times \cos\beta / \sin\alpha + 0.2 \times \cos\alpha}.$$

The dependence of function of ship bow shape F on the angle of ship waterline entry α and of sides slope β at zero theoretical frame with account of the indicated assumptions of these angles of the shape ship bow is presented on graphs (Fig. 3.1).

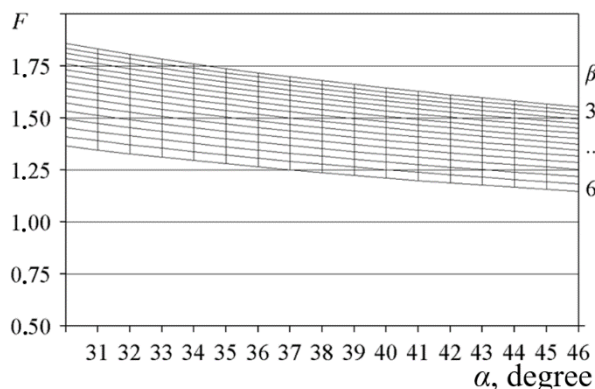


Fig. 3.1. Function of ship bow shape F in the dependence on the angles: of waterline entry α and of sides slope β at zero theoretical frame

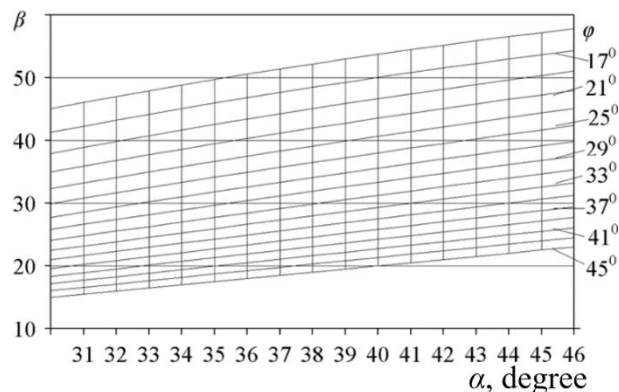


Fig. 3.2. Ratio of angles of the icebreaking ship bow shape: of waterline entry α and of sides slope β at zero theoretical frame, the angle of stem tilt of ice-navigating ship to the main plane φ

The graph shows, that the value of function of ice-navigating ship bow shape F depends on the angle of waterline entry α largely than on the angle of sides slope β at zero theoretical frame.

With the account of impact of ship cargo waterline entry angle α and the angle of ice-navigating ship sides slope β at zero theoretical frame, the close enough approximation (of the error of about 5%) the function of ship bow shape can be simplified

$$F \approx 1.41 \times \sqrt{\cos\beta / \sin\alpha}.$$

It should be mentioned that the angles of ship cargo waterline entry α and of ship sides slope β at zero theoretical frame, as well, as the angle of ice-navigating ship stem tilt φ with the account of hull shape curvature are in the geometric interdependence

$$\operatorname{tg}\varphi \times \operatorname{tg}\beta = \operatorname{tg}(\alpha/2). \quad (3.2)$$

The geometric ratio of ship bow shape angles is shown on the graph (Fig. 3.2). Provided that ship sides are smooth and with the account of the known recommendations corresponding the considered recommendations of the angle (20°) of stem tilt to main plane φ of ice-navigating ship and the angle (45°) of cargo waterline entry α than the angle of the ship sides slope β in accordance with the formula (3.2) will be equal approximately 50° . Assuming that for the extra improvement of the patency in ice field it is possible to increase appropriately the angle of ship sides slope by the adopting of shape of hull curvature at zero theoretical frame, in the further evaluations the approximal value of function of ship bow shape is adopted $F \approx 1.25$ at the corresponding angles of: $\alpha \approx \dots 45^\circ$, $\beta \approx \dots 60^\circ$. With the account of these assumptions the maximal thickness of solid ice overcoming by the ship continuous motion in dependence on variable ship size (the cargo waterline displacement D or the waterline length L) and on ship propulsion power when overcoming the ice field N_{ICE} could be determined by the formula of Tsoy–Klimashevsky–Titov after it considered transformations as

$$h \approx 0.016 \times L / (D / N_{ICE} + 1.63). \quad (3.3)$$

For the parametric equation got (4.11, item 4.7) of loaded ice-navigating ship displacement on it waterline length ($D = 0.768 \times L^{2.118}$) the parametric dependences are available for Tsoy–Klimashevsky–Titov function (3.3) argument substitute

$$L = 1.133 \times D^{0.472} \text{ (approximately } L \approx 0.840 \times D^{1/2}), \quad (3.4)$$

the approximation acceptability of argument substitute with the indicated coefficient 0.840 and the exponent $1/2$ is illustrated on the graph (Fig. 3.3).

The graph (Fig. 3.4) shows the functional constraint of cargo waterline displacement of ice-navigating ship: D_{MIN} – the minimal displacement at load-line, where the overcoming of continuous ice is possible by the continuous run without the cyclical motions of ship and without the use of the special systems (the trim, the ballast, the propellers in the bow and etc.) for ice overcoming.

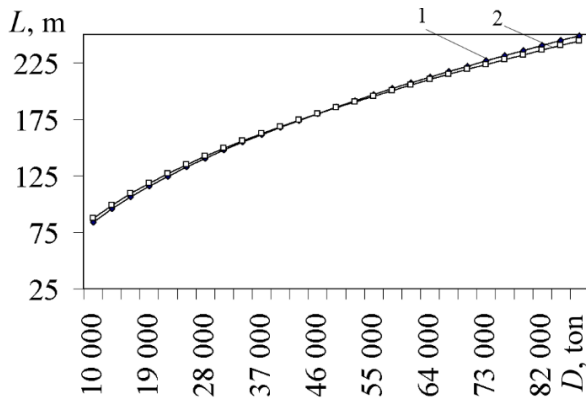


Fig. 3.3. Evaluation of approximation acceptability when replacing the factor and the exponent in composition of parametric formulas (3.4) of loaded displacement and waterline length interdependence:

- (1) $L \approx 0.840 \times D^{1/2}$
and (2) $L = 1.133 \times D^{0.472}$

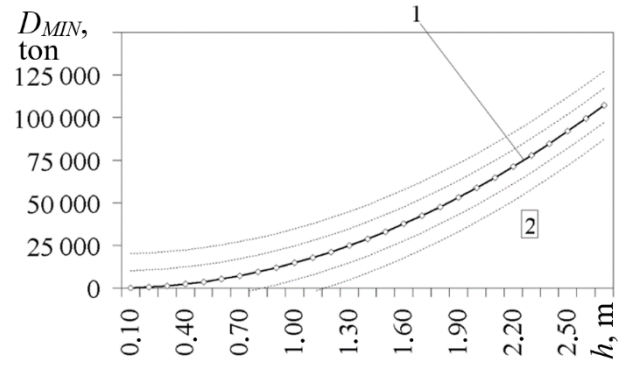


Fig. 3.4. Minimal values of displacement D_{MIN} at cargo waterline (1) in dependence on thickness of solid ice h overcoming in continuous motion and the graph area (2) of loaded displacement D at which the overcoming of solid ice is possible with use of the special systems and the ship navigation modes (cyclical motion)

$$D \geq D_{MIN} = 14709 \times h^2. \quad (3.5)$$

One would find the propulsive power N_{ICE} required for overcoming of solid ice by continuous motion of ship in dependence on it cargo waterline displacement D after the considered transformations of the formula of Tsoy–Klimashevsky–Titov (3.3) by the approximate equation

$$N_{ICE} \approx D / (0.01344 \times D^{1/2} / h - 1.63). \quad (3.6)$$

The result of determining of propulsive power N_{ICE} is indicated on the graphs (Fig. 3.5) in the form of the graphic dependence on loaded displacement D and on the overcoming thickness of solid ice h .

In the accordance with assumptions of the formula of Tsoy–Klimashevsky–Titov, outside the indicated domain of definition of ice thickness at the relatively small displacement of ship loaded or for large thickness of ice field, that is below the curve on the graph (see Fig. 3.4), it is impossible to overcome the continuous ice of corresponding thickness irrespective the ship main engines and propulsion power without the use the methods and the tools for the continuous ice destruction, such as the cyclic motions of the ship «by accelerations» or use of special systems improving the capability of ship to overcome ice. In designing of multifunctional ice-navigating ships the evaluations of power and displacement required for overcoming

the solid ice without the other methods and equipment for solid ice destruction is of practical importance.

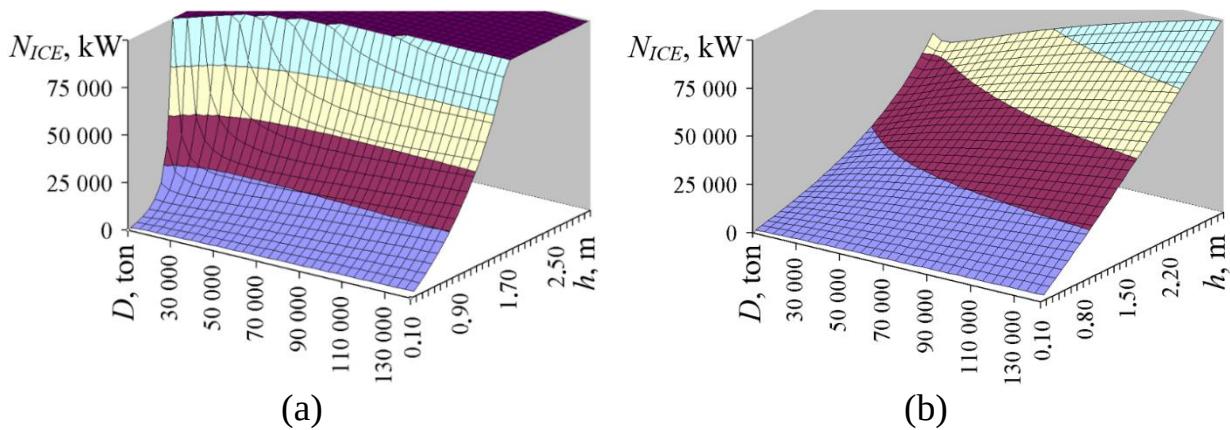


Fig. 3.5. Dependence of propulsive power N_{ICE} , required for overcoming of solid ice, on loaded displacement D and on assigned maximal thickness of solid ice h , which the ship can continuously overcome, got by formulas Tsoy–Klimashevsky–Titov: (a) in the dependence (3.6) on ship loaded displacement D and (b) the formula adjusted with the account of the analogues characteristics (3.8)

At the initial stages of multifunctional ice–navigating ship designing for finding of sets of power N_{ICE} and the loaded displacement D in dependence on thickness of the overcoming solid ice by continuous motion of ship for determining of data intervals it is advisable to obey the rules of the Register, assigned for ice navigation ships up to category of Icebreaker7 inclusive /137, item 2.2.3.2/: the category of Icebreaker6 – the fulfillment the icebreaking operations at a thickness of ice up to 1.5 m, and when the ship is capable to mote continuously in the solid ice of thickness up to 1.0 m; the Icebreaker7 – the fulfillment of icebreaking operations in winter–spring navigation at ice thickness up to 2.0 m, in summer–autumn navigation at a thickness of ice up to 2.5 m, is able to mote continuously in the solid ice of the assigned thickness up to 1.5 m, and if the total power on the propellers shafts is no less than 11 MW. The categories Arc4, Arc5, Arc6, Arc7, Arc8 are forming the arctic group. In accordance with the rules of the Register, if the arctic ship implements the icebreaking works and meets the appropriate requirements, then instead of the specification of arctic category it could be assigned one of the categories: Icebreaker6 or Icebreaker7 of ice reinforcements.

It has to be mentioned that by rules of the Register in dependence on ice category the performances of continuous motion are regulated of ship in the solid ice of the specified thickness, although the conditions of solid ice overcoming by continuous motion do not characterize to the full the icebreaking properties of the ship,

having the definite size and corresponding propulsive power. Through the use of the systems, the propellers and the motion modes the icebreaking properties of ship are practically higher, than the ability to overcome the ice field by continuous motion, which is not quite characteristic the limiting conditions for assigned ice category.

Apparently, at initial stages of the determining of design characteristics of multifunctional ice–navigating ship in used methodic and technique of ship in frozen sea hydrodynamic resistance, propulsion and patency in ice the priority would be logical to specify for the ship designing the data and constraint of overcoming thickness of solid ice besides of the other presumptions of the ship performances in ice, which would be the subject of the study at the next designing stages when determining particulars of the ship, as well, as on the stage of the constructed ship classification. In the same time, it seems reasonable at the initial stages of ice–navigating ship designing to work out the calculations by the formula of Tsoy–Klimashevsky–Titov for approximate evaluation of the required power in dependence on ship sizes (D , DW or etc.) and on the assigned design constraint – the thickness h of solid ice, considering the indicated logical initial data priority of overcoming thickness of continuous ice. Wherein for fulfillment of calculations at the initial designing stages the amendments to the coefficient and summand in this formula denominator are required by the way to reduce the discrepancies of the power indexes of known new ice–navigating ships and the results determined by considered formula with the actual characteristics of the ships capable to overcome ice in those motion modes and with the use of those equipment, which is usually provided when the ships overcome solid ice.

This compromise and the appropriate amendments lead to adjustment of summand number in the denominators of formulas (3.1 and 3.6), and the required power value got corresponds accurate enough not only the form of the initial function of Tsoy–Klimashevsky–Titov but as well the analogues data – the known new ice–navigating ships (the relative error in estimating the standard deviation is about 2.2 %, table 3.1), which for the use of special systems (the ballast system, the trim one, the movers at the ship fire, etc.) and the methods of continuous ice overcome by cyclical motion and not by the continuous motion in ice field are characteristic.

Table 3.1

Data of analogs – the new ice-navigating ships and these ships designs data, used for refinement of the subtrahend in denominator of formulas (3.6–3.8)

#	The name of ice-going ship, the design	Displacement loaded, ton	Maximal thickness of solid ice assigned for ship, ton	Propulsion power, kW	Power by the formula of Tsoy–Klimashevsky–Titov kW
1	«Vladislav Strizhov»	9 610	1.5	15 000	15 928
2	«SCF Sakhalin»	9 980	1.5	13 000	16 094
3	«Vitus Bering», design # R-70201	10 709	1.5	13 000	16 419
4	«Varandey»	10 874	1.7	16 800	19 792
5	«St. Petersburg», design # 21900	14 300	1.5	16 400	17 954
6	LK-16	15 200	1.5	18 000	18 321
7	CCGS «John G. Diefenbaker» (Canada)	23 700	2	36 000	31 203
8	«Vasily Golovnin»	20 200	1	9 300	12 353
9	LK-60	33 540	2	60 000	35 095
10	LK-110Ya	55 600	4.3	110 000	120 346
11	«Taimyr» (analogue «Vaygach»)	21 100	2	36 000	30 094
12	«50 years of Victory» (serie «Arctic»)	25 840	2.5	52 800	43 857
			Total:	396 300	377 457
	The root mean square deviation of the power estimate by the formula of Tsoy–Klimashevsky–Titov with the summand (subtrahend) in the denominator				2.2%
					0.275

Considering the appropriate refining of summand (0.275, the subtrahend – 0.275, when determining the propulsion power N_{ICE}) in the denominator of formula of Tsoy–Klimashevsky–Titov and the adjustment with the data of analogues – known new ice-navigating ships the adopted formula in the mathematical models at initial stages of multifunctional ice-navigating ships designing for use for the determining of solid ice thickness which the ship can overcome by the usual navigation mode (the accelerations, etc., not necessarily by the continuous motion as it is supposed in the original formula, 3.1) and using the available special equipment to improve patency in ice (the trim system, the fore movers, etc.) looks like

$$h = 0.02 \times L / (F \times (D / N_{ICE} + 0.275)), \quad (3.7)$$

or in the form of dependence of the propulsion power N_{ICE} of ice–navigating ship when overcoming solid ice by continuous motion on the displacement loaded D and on assigned design constraint of solid ice thickness h like

$$N_{ICE} \approx D / (0.01344 \times D^{1/2} / h - 0.275). \quad (3.8)$$

In the intervals of thickness h values of solid ice, corresponded with ice categories by rules of the Register in case of ice overcoming by the continuous motion, in the dependence of required propulsion power N_{ICE} on loaded displacement D of multifunctional ice–navigating ship and on the thickness of continuous ice h is indicated on the graph (Fig. 3.5b) for the overcoming of solid ice by the usual navigation mode not necessarily by the continuous motion (as supposed by the formula of Tsoy–Klimashevsky–Titov, 3.1) and using the available special equipment for this.

The comparison of got values of propulsion power N_{ICE} required for crossing of continuous ice shows that for bigger values of ice thickness the required values of propulsion power N_{ICE} for the new ice–navigating ships or their designs (table 3.1) are less than ones got with the formula of Tsoy–Klimashevsky–Titov (3.1, Fig. 3.5a), if without the considered adjustment of summand (0.275, the subtrahend -0.275) in the denominator to use the formula for determining of propulsion power N_{ICE} at the initial stages of these ships designing. By the way the adjusted formulas (3.7 and 3.8) in the distinction with the original one (3.1 – for the event of overcoming of solid ice by the continuous motion of the ship) correspond the conditions of the overcoming of solid ice by the ship usual navigation mode, which assumed to be characteristic for analogues (table 3.1) used for the summand refining in the denominator of formula (3.1), not necessarily by the continuous motion and using the available on the ships special equipment to improve patency in ice.

In case of ship motion in open water for evaluation of effective power Ne in dependence on the operation velocity v_s and on loaded ship displacement D at the initial stages of multifunctional ice–navigating ship designing the formula of Admiralty coefficients could be used /9 and 22/: $Ne = D^{2/3} \times v_s^{2.5} / CA$.

The parametric dependences (Fig. 3.6) of Admiralty coefficient CA on cargo waterline displacement D of multifunctional ice–navigating ship are found according with analogs in the following closely related formulas

$$CA = 0.0007 \times D + 23.1, \quad CA = 2.73 \times D^{0.2755} \text{ or } CA = 10.74 \times \ln(D) - 63.7, \\ \text{ton}^{2/3} \times \text{knots}^{2.5} / \text{kW}. \quad (3.9)$$

One would put the attention that at initial stages of cargo ships designing for navigation in the open water the slightly other formula of Admiralty coefficients is usually to be used $Ne = D^{1/2} \times v_s^{2.5} / CA$, with the other exponent of cargo waterline displacement D , although in this case the Admiralty coefficient CA have to be determined otherwise than by indicated formulas (3.9).

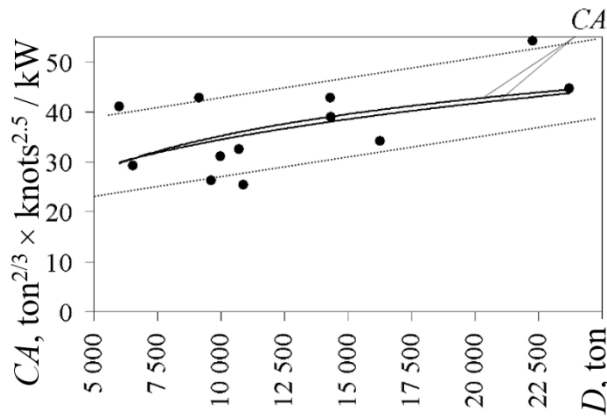


Fig. 3.6. Dependences of Admiralty coefficient CA on loaded displacement D of ice-navigating ship

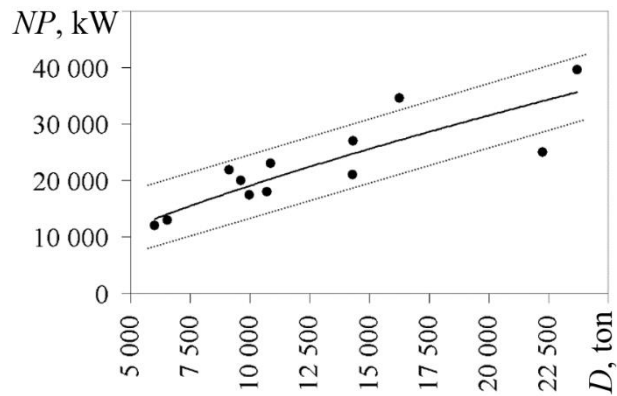


Fig. 3.7. Dependence of total power NP of energy generation sources on ice-navigating ship on it loaded displacement D

For determining of optimal characteristics at the initial stages of designing of multifunctional ice-navigating ship the operating velocity v_s in the open water is determined among intermediate values. Since the main purpose of the ship under designing is overcoming of ice field of assigned intensity when finding the design particulars of the hull shape and of propulsion complex, then the issue of operation velocity determining in open water is the dependent one on the particulars found of ship hull shape and it propulsive features corresponding the assignment of the ice overcoming. In the systemic sequence for determining of the ship operation velocity of in open water v_s one initially need to find the required propulsion power N_{ICE} necessary for ice overcoming of assigned intensity and then the velocity in the open water, if the effective power in the open water Ne at various modes of ship motion is equal the required propulsion power N_{ICE} evaluated for ice overcoming, or the effective power in the open water Ne is comparable with propulsion power N_{ICE} in the proportion of ship propulsive indexes at the various modes.

Provided that the effective power need for ship motion in the open water Ne and the required power N_{ICE} in the mode of ice of the specified intensity overcoming are proportionate ($Ne \approx N_{ICE}$), which is logical with the account of motives to the highest values of propulsive coefficients in this two modes of ice-navigating ship motion,

wherein the proportionality of the values of the effective power for the other modes of ship motion could be adopted in the first approximation at the initial stage in designing of propulsion complex including propellers and transmissions, or the other units (electric motors, Azipods, etc.), and that the proportionality of effective power indexes for the other modes achieved thanks to assuming efficient design of the propulsion device, then the dependence of operation velocity in the open water v_s on effective power and on the cargo waterline displacement of multifunctional ice-navigating ship approximately looks like: $v_s = (Ne \times CA/D^{2/3})^{0.4}$, or in the variant of the substitute of one of the parametric dependences, offered for the evaluation of Admiralty coefficient the equation for the determining of ship velocity in open water is

$$v_s = (Ne \times (10.74 \times \ln(D) - 63.7)/D^{2/3})^{0.4}, \text{ knots.} \quad (3.10)$$

Clarification is needed of proportionality of multifunctional ice-navigating ship effective power in the open water Ne and the propulsion power N_{ICE} required in the mode of ice of assigned intensity overcoming, which is used as one of assumptions for determining of operation velocity in the open water v_s . For the ships of small ice categories under designing the more critical would be assumption of priority of hydrodynamic resistance and propulsion in open water and of enough velocity v_s , at which the ship would meet the requirements of controllability and maneuverability. The determining of velocity in open water v_s from this point of view gives the effective power Ne which as well is enough for overcoming of solid ice of insufficient intensity assigned as the ship ice category and design constraint in the terms of references.

On the graphic surface (Fig. 3.8 a and b) the general dependence of operation velocity v_s of ice-navigating ship on its size, which in the considered event characterized by design deadweight DW , and on the maximal overcoming thickness of solid ice h is shown.

For definitely small value of design constraint of solid ice thickness h the operating velocity v_s of ship in open water, which is required for safe ship navigation control, corresponds the velocity lower constraint, which in the considered example assumed 12 knots. For other values of assigned design constraint of solid ice thickness h the operating velocity v_s is determined by the formula (3.10) in dependence on variable size of ship (the design deadweight DW or loaded displacement D , which are interdependent by the balance equation within the mathematical model, item 4.2) and on assigned design constraint of solid ice thickness h , wherein the effective power Ne corresponds with the required propulsion power N_{ICE} in the mode of solid

ice overcoming of the assigned thickness h , assuming the powers equivalence or proportionality ($Ne \approx N_{ICE}$). Besides in the evaluation of the ship velocity in open water v_s for methodic reasons the top constraint is introduced as well, having the conventional nature to certain extent for basic ranges of ship size and it ice category.

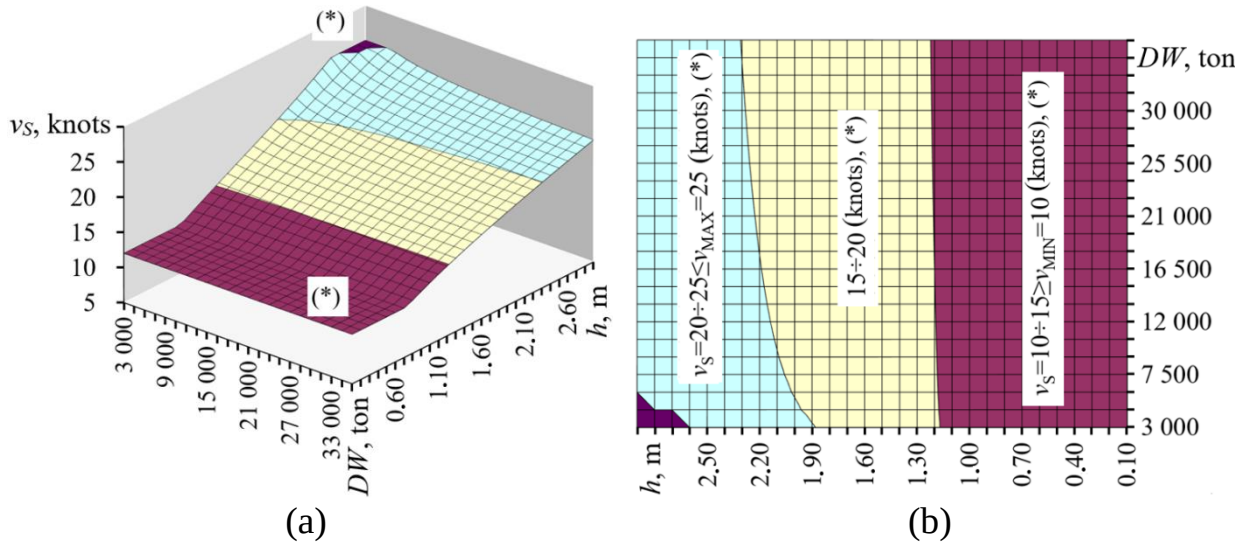


Fig. 3.8. Dependence of operation velocity v_s of ship in open water on its size (the design deadweight DW) and on assigned maximal overcoming thickness of solid ice h with the account of constraint of velocity in open water (in considered example – from 12 up to 30 knots); (*) – the areas of velocity constraints corresponding the extra power N_{ICE} , required for ice overcoming, other than the effective power Ne required for ship motion in open water (the top constraint), and for keeping velocity in the open water enough for safe ship navigation control (the lower constraint)

It should be mentioned that the assumed set of constraints when finding velocity of multifunctional ice-navigating ship in open water v_s predetermines the features of got graphic functional surface shape at the borders of these assumptions. In dependence on the lower design constraint of operation velocity in open water corresponded the propulsion power N_{ICE} , which is required for the overcoming of solid ice of relatively small thickness of 0.7 m in the considered example for plotting of the graph (Fig. 3.8), is less than the effective power Ne required for the motion in open water. The same time in the main range the design constraint of solid ice thickness h the values of effective power for ship motion in the open water Ne and the required power for ice overcoming N_{ICE} are assumed equivalent or proportional ($Ne \approx N_{ICE}$), because the required power for ice overcoming N_{ICE} serves the preposition for determining of effective power Ne and the velocity of ship v_s in the open water.

Therefore, the feature of functional surface arises, in the other words, the characteristic line of assumptions demarcation for determining of required power or the operation velocity v_s in the open water in dependence on variable index of ship size (DW or D) and on assigned design constraint of solid ice thickness h , available as well on many other graphs, plotted in the indicated coordinates (h and DW or D).

The line of assumptions demarcation on the functional surfaces got for ice–navigating ship indicates the dual–mode of the ship navigation, as in the ice, so as in the open water. The position of assumptions demarcation lines on corresponded graphic surfaces is subject of the refining at following stages of ice–navigating ship designing.

The operation velocity in the open water v_s found with the account as ship running performances in ice of specified intensity, so as the lower constraint of the velocity necessary for ship appropriate controllability in open water are used as data for determining of effective power Ne in dependence on variable ship size (DW or D) and on assigned design constraint of solid ice thickness h . The indexes of effective power (N_{ICE} or Ne) consequently got are indicated on graphic surfaces (Fig. 3.9 a and b).

Line of the assumptions demarcation when determining the effective power Ne in dependence on design deadweight DW and on the assigned constraint of solid ice thickness h one can see on the graphic functional surface (Fig. 3.9b), plotted for assumed in the example small ice category of the ship under design, at which the propulsion power and, accordingly, the power of energy generation of multifunctional ice–navigating ship under initial stages of designing depended on propulsive power, in the noticeable range of index of the design constraint of solid ice thickness h is determined in dependence on the lower constraint of operation velocity in the open water v_s . Wherein the effective power Ne required for ship motion with the appropriate controllability and with the velocity not less than this design constraint, exceeds the power N_{ICE} , which has to be required overcoming of continuous ice of small thickness (for the considered example of up to 0.7 m).

Considered graph (Fig. 3.9a) indicates that nominal power, which nevertheless is enough for the overcoming of thin solid ice, is unacceptable as design characteristic, and is insufficient for operation of the ship in open water, and inappropriate as the preposition of the lower constraint of operation velocity in the open water v_s .

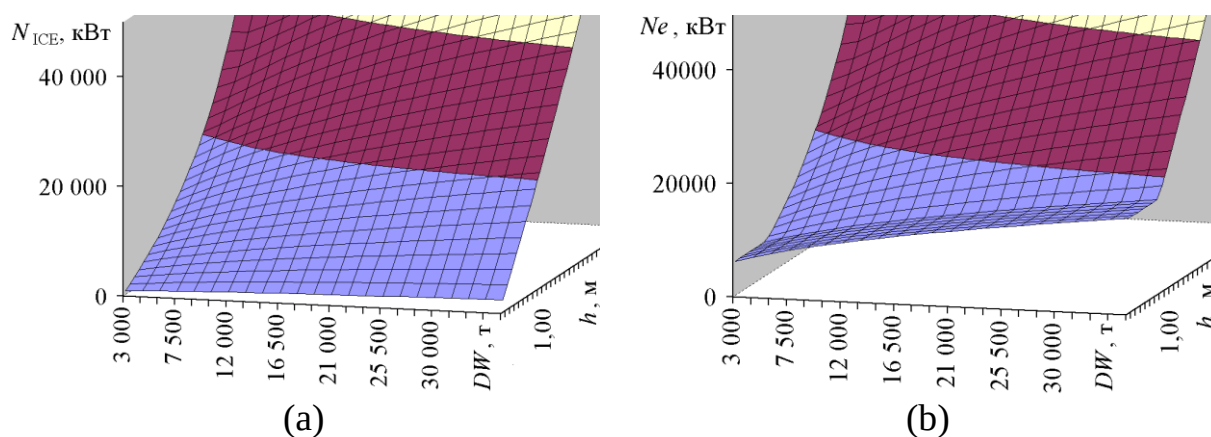


Fig. 3.9. Dependence of effective power Ne and propulsive power N_{ICE} required to overcome solid ice on the ship design deadweight DW and on maximal overcoming thickness of solid ice h for the insufficient ice categories, without account of lower constraint (a) of operation velocity in open water v_s and with account of this lower constraint (b) for multifunctional ice–navigating ship appropriate controllability

For developing of functional dependences and their use at initial stages of designing of multifunctional ice–navigating ship, in particular to determine ship size characteristic of design deadweight DW , and the characteristics depended on the design deadweight by the balance ratios (items 4.1–4.5) this recommendation is of practice nature, and the characteristic of design deadweight DW is suitable to be used as variable in the objective function, and as value assigned in the terms of references. For this reason, it is logical to use design deadweight DW of multifunctional ice–navigating ship as variable index when plotting the rest dependences, which for the size of ship serves one of the important arguments. In the same time the recommendation to use design deadweight DW as the variable characteristic does not mean that it is not possible to use other characteristics of ship size as variable of optimization designing procedure. Because the ship size is enough general index, and the various characteristics of ship size are interdependent usually, then for the study, the got conclusions are possible to attribute with other characteristics of ship size as a rule, considering the indicated interdependence of characteristics to exclude probable methodological obstacle, when the design deadweight is considered the variable characteristic of ship size.

Cargo waterline displacement D is used above (Fig. 3.5) as variable characteristic for determining of propulsive power N_{ICE} , required for overcoming of solid ice. The replacement of loaded displacement D to the design deadweight DW as characteristics of the ship size for determining of it effective power Ne in dependence on design constraint of solid ice thickness h is to be carried out for the calculation

of functional surface (Fig. 3.10). The equation of balance of multifunctional ice–navigating ship loaded displacement D is used for this variable replacing for the design deadweight DW (items 4.1 and 4.2).

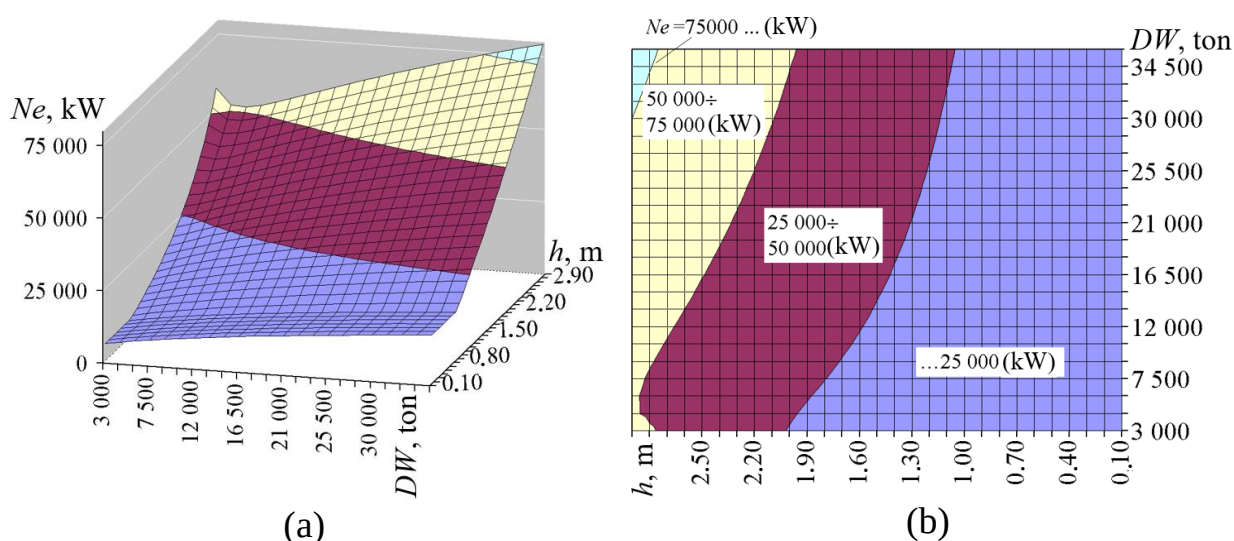


Fig. 3.10. Dependence of effective power Ne of multifunctional ice–navigating ship on design constraint of maximal thickness of overcoming solid ice h and on design deadweight DW (when replacing cargo waterline displacement D as variable to the characteristic of the design deadweight DW)

As before replacing the cargo waterline displacement D variable to the characteristic design deadweight DW , so as after this replacing the indexes of effective power for ship motion in the open water Ne and of required power N_{ICE} in the mode of ice of specified intensity overcoming one could consider the interdependent in the ratio of propulsive characteristics of ship in the considered modes: when overcoming ice and when in the open water, excluding the characteristic of power of the ship of small assigned ice category, the design constraint of solid ice thickness is probably less important when assumptions are change, which for the factor of operation velocity v_s of ship in open water constraint impacted the effective power greater than the influence of small specified ice thickness.

The specified ship velocity in the open water v_s is relative sustainable index and among the similar ships it varies in the appropriately narrow range compared to the intervals of variability of the other characteristics and particulars of ships, let say compared with an interval of variation of ship loaded displacement D .

In should be mentioned by the analysis of analogs that interval of values variation of loaded displacement D of multifunctional ice–navigating ship size or it other characteristics of size is wider substantially than the range of values of the operation

velocity v_s , which is usually from 15 up to 20 knots or about for these ships. The proportions of design particulars (the ship dimensions), determined by parametric formulas (item 4.8) have the similar property of parametric sustainability that is the values feature to be in the narrow range of variability when varying other characteristics and particulars of multifunctional ice–navigating ship or when going from analogue to analogue.

Since the operating velocity v_s and the proportions of design particulars of ice–navigating ship remain in appropriately narrow intervals than the characteristics of ship and its design particulars by their absolute value, the possibility arises to reduce the formula of the Admiralty coefficients without significant loss of accuracy at the initial stages of designing, using the characteristic of at cargo waterline displacement D the only as the variable, considering that the operation velocity in the open water v_s is in the narrow interval of the variation.

3.2. Determining of the characteristics of power installation at the initial stages of designing of multifunctional ice–navigating ship

Capacity of multifunctional ice–navigating ship power installation NP that is the total power of the energy generation sources of the ship, at the initial stages of designing would be found with the use of parametric equation in the dependence on displacement of the ship loaded D by data analysis of new ships of this class and their designs

$$NP = 24.39 \times D^{0.723}, \text{ kW.} \quad (3.11)$$

Need to pay attention on the fact that with the use of analogs data (table 3.2) the total power of energy generation sources NP , as a rule, significantly exceeds the effective power Ne , as well, as required propulsive power N_{ICE} for solid ice overcoming, which in the ratio of the efficiency factor of the transmission are associated with the power of propulsion electric motors (when using the electric transmission).

Total power of the ship energy generation sources NP is to be no less than the effective power Ne . The total power of the ship energy generation sources for determining of optimal characteristics at the initial stages of designing of multifunctional ice–navigating ship are determined in the mathematical model with the account of the specified choice. The total power of energy generation sources is in dependence on which one value is greater: the effective power ($Ne \approx N_{ICE}$) or the installation one NP got by the formula (3.11) with the account of the replace the ship

loaded displacement D variable to the variable of design deadweight DW and is in dependence on assigned design constraint of solid ice thickness h which is to overcome.

Table 3.2

Data of the analogs for determining of the dependence of energy generation sources total power of the ship NP in the form of it ratio to propulsion power ($N_{ICE} \approx Ne$), required for the ship motion in solid ice and in open water

#	The name of ice-going ship, the design	Year of construction, actual or planned	Displacement loaded, ton	Capacity of power installation, kW	Propulsion power, kW	Extra power of installation, %	Velocity, knots
1	«Ilia Muromets», design # 21180	2016	6 000	12 000	7 000	71.4%	15
2	«Toboy»	2008	6 533	12 960	10 400	24.6%	15
3	«Vladislav Strizhov»	2006	9 610	20 000	15 000	33.3%	15
4	«SCF Sakhalin»	2005	9 980	17 400	13 000	33.8%	15
5	«Varandey»	2008	10 874	23 040	16 800	37.1%	15
6	«Vitus Bering», design # R-70201	2013	10 709	18 000	13 000	38.5%	15
7	«St. Petersburg», design # 21900	2009	14 300	21 000	16 400	28.0%	17
8	«Vladivostok», design # 21900 M	2014	14 320	27 004	18 000	50.0%	17
9	LK-25, design # 22600	2012	22 258	25 000	17 400	43.7%	17
10	CCGS «John G. Diefenbaker» (Canada)	2017	23 700	39 600	33 000	20.0%	20
11	«Otso», «Kontio» (Finland)	1984	9 130	21 840	15 000	45.6%	18.5
12	«Healy» (USA)	1999	16 260	34 560	22 400	54.3%	17

Values of total power of the ship energy generation sources NP got with the considered assumptions is indicated in the projections on functional surface (Fig. 3.11 a and b). Analysis of the graphic surface shows that the total power of multifunctional ice-navigating ship energy generation sources in the wide range of characteristics depends on size of the ship (DW or D), and in a lesser degree on assigned design constraint of the overcoming thickness of solid ice h . It is possible to characterize the excess proportion of total power of the ship energy generation sources NP to the propulsion power ($N_{ICE} \approx Ne$), required for ship motion in solid ice and in the open water, in the wide range of the ship size values – it design deadweight DW . This excess of the power installation (Fig. 3.12 a and b) in the most degree is characteristic for large ships, this is confirmed by data of analogs in the table 3.2.

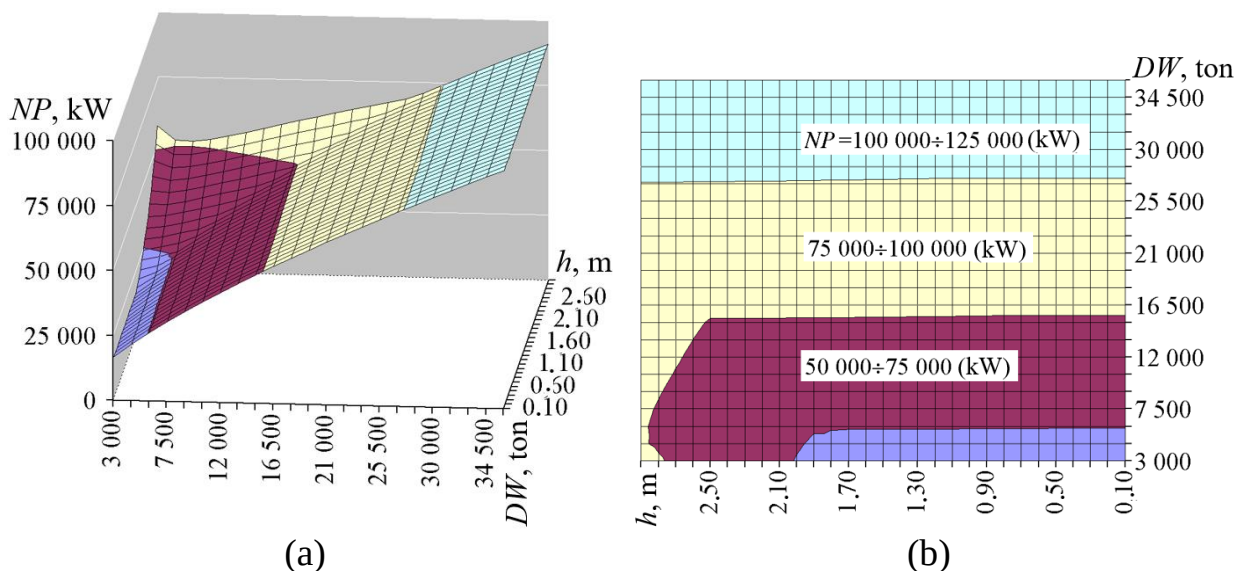


Fig. 3.11. Dependence of total power of the ship energy generation sources NP (the capacity of power installation) of multifunctional ice-navigating ship on design constraint of solid ice thickness h and on design deadweight DW of the ship

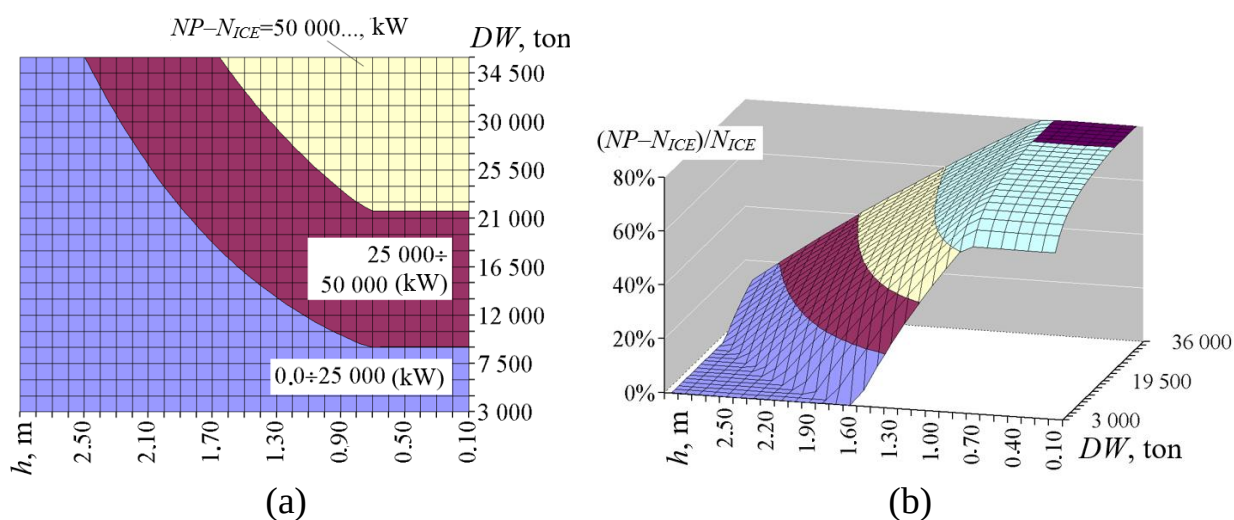


Fig. 3.12. Dependence of power installation extra capacity (the total power ship energy generation sources) over the effective and propulsion powers ($N_{ICE} \approx N_e$) on assigned constraint of solid ice thickness h and on design deadweight DW of multifunctional ice-navigating ship: (a) by the absolute value: $NP - N_{ICE}$; (b) by the relative value, that is the relation of extra capacity to the propulsion power $(NP - N_{ICE}) / N_{ICE}$

Since for ship motion in ice it is required more power in dependence on the design constraint of solid ice thickness h corresponded ice category of ship assigned in the terms of references, then the power excess of ship generation sources ($NP - N_{ICE}$) is more characteristic for ships of smaller ice categories. Besides the characteristic

line of assumptions demarcation is available on the graphic surface of dependence of extra capacity of power installation NP (Fig. 3.12 a and b) of multifunctional ice–navigating ship under design got in the form of functional dependence on design constraint of solid ice thickness h and on design deadweight DW : the feature of functional surface, meaning the dual–mode operation of multifunctional ice–navigating ship as in the ice, so as in the open water, since in dependence on the lower design constraint of operation velocity in the open water the required power N_{ICE} for overcoming of solid ice of insufficient thickness is less than effective power for ship motion in the open water N_e , in the same time in the main range of design constraint of solid ice thickness h the values of the effective power for ship motion in the open water N_e and of the required power N_{ICE} for solid ice overcoming are proportional.

3.3. The hull strength in ice field for the evaluation of structural elements at the initial stages of ship design

For determining of optimal characteristics and particulars in the composition of the mathematical model the dependence of the increment of loaded displacement of multifunctional ice–navigating ship on seaworthiness performances and patency in frozen sea is created corresponding the ship capability to overcome ice and the ship operation safety (that is enough strength of ship) in the solid ice of definite thickness, given that the other criteria of the seaworthiness and patency in frozen sea /96/, such as the safe velocity when the ship motes in broken ice, as the power enough for this motion in broken ice when keeping safe velocity and controllability of ship and etc., which are usually dependent on capability of ship to overcome solid ice and can be evaluated at the next stages of designing, in particular at the next refining of ship design characteristics found and at the determining of it structural elements and the ice reinforcements of the hull, as well, as when choosing at the design stage the modes of safe navigation of the ship.

In the frameworks of the rules of various classification societies for each of the ice categories of ship and for each section of it hull the requirements are usually attributed. The destruction is characteristic for the fore part of ship by ice impact at the highest pressures on to the hull. For aft part it is important the consideration of the maneuvers and the reverse motion mode in the ice. For ship middle part it is required the considering of hull compression in the ice.

At the initial stages of ship designing the analysis is carried out of the strength of ship hull compression, which acts on the middle part of ship's hull on the most of it length. It is supposed that the value of ice load in the rest parts of hull

by the methodology depends on this load on the middle part, and it is considered that the greatest cumulative impact on the mass of ice–navigating ship hull is influenced by the structures of most length at middle part of ship (the sides, bottom, decks, bulkheads, etc.) and its shell, which is under the load when compressing the ship by ice, and the dependence of mass of hull extremities structures has not so much significant influence on the mass of hull and on the displacement of loaded ship and empty, as the mass of structures of most length of hull influences.

Damages in the middle part are most probable in the condition of ice compression of ship. On the most length of middle part the hull is of insignificant sides slope or with the vertical ones subject the critical local strength when compressing from the sides by ice. When compressing the ship hull by ice considering at the initial stages of designing it is assumed the value of load corresponding the loss of stability of the ice layer. Formula is known for evaluation of the pressure p_{ICE} , destroying solid ice [136]

$$p_{ICE} = 0.61 \times \sqrt{h}, \text{ MPa.} \quad (3.12)$$

The limiting pressure p , which side shell can withstand with the floors of the transverse framing system, one can determine as

$$p = 4 \times \sigma_0 \times (\delta/a)^2 \times \min \left\{ \begin{array}{l} 1 + 0.5 \times \pi \times a/h \\ (1 + 0.5 \times a/h)^2 \end{array} \right., \quad (3.13)$$

where σ_0 – the yield stress of the structural steel, MPa (N/mm²); δ – the thickness of hull shell, dependent on the assigned solid ice thickness (design constraint) and on ice category of ship (or arctic) or on the icebreaking class, required for the ship strength, with the account of the wear margin, mm; a – the smaller of sides of the shell plate (equal the spacing of transverse framing), m.

For the evaluation of strength at the initial stages of designing the values of yield stresses the grades of structural steel used in shipbuilding are to be considered: St20 (Steel 20 of industrial standard of GOST 1050–88), $\sigma_0 = 245 \text{ N/mm}^2$ (MPa); St30, $\sigma_0 = 295 \text{ N/mm}^2$; St45, $\sigma_0 = 355 \text{ N/mm}^2$; St40X (the structural alloy chromium steel of GOST 4543–71), $\sigma_0 = 785 \text{ N/mm}^2$; the steel 09Г2С (09G2C, the structural low alloy steel for welded structures, GOST 5520–79), $\sigma_0 = 265 \text{ N/mm}^2$; steel 3 (the carbon steel of the usual property of the grades: St3kp, St3ps, St3sp, St3Gps, St3Gsp of GOST 380–2005), $\sigma_0 = 195 \div 235 \text{ N/mm}^2$.

In accordance with recommendations of the Register, the normative yield point and recommended grade of structural steel depends on ship waterline length

and is primarily in the interval of: $\sigma_0 = 300 \div 345 \text{ N/mm}^2$. For ships of smaller length the steel of the normative yield point of about $\sigma_0 = 235 \text{ N/mm}^2$ is recommended. The average value of the yield stresses of structures of multifunctional ice–navigating ship and its ice–strake of the shell would be adopted as 275 N/mm^2 at initial stages of its designing.

By the recommendations of the Register (the criterion of ship shell strength when ice effects) for multifunctional ice–navigating ship considering the design constraints, associated with effect of ice on the ship hull, the required thickness of shell at the initial stages of designing one can determine assuming the equality of pressure p_{ICE} , at which the destruction of solid ice occurs by the loss of the ice layer stability, and the pressure p , which the shell in the composition of side overlap of ship withstands

$$p_{ICE} \leq p. \quad (3.14)$$

The thickness of hull shell of multifunctional ice–navigating ship in dependence on design constraint of assigned thickness h of overcoming solid ice and on the spacing a one would find as

$$\delta = 390.5 \times \frac{a \times h^{0.25}}{\sigma_0^{0.5}} \times \max \left\{ \frac{\sqrt{1/(1 + 0.5 \times \pi \times a/h)}}{\sqrt{1/(1 + a/h + 0.25 \times (a/h)^2)}} + \Delta\delta, \text{ mm.} \right. \quad (3.15)$$

For the transverse framing of multifunctional ice–navigating ships in the area of ice–strake the normal spacing would have normal size in the range of 0.50 up to 1.0 m, or in case of extra intermediate frames application, the characteristic size would be of 0.25 up to 0.50 m. In the range of the critical thicknesses of continuous ice the second of two shell thicknesses, corresponded the formula (3.15), is more likely selectable at the designing by its maximal size, for which the ratio of spacing to overcoming thickness of solid ice (a/h) is less than 2.283. The dependence of limiting pressure on side overlap and the shell with the definite transformations of formula looks like

$$p = 4 \times \sigma_0 \times (\delta/a)^2 \times (1 + 0.5 \times a/h)^2. \quad (3.16)$$

Equating of the indexes: of external load (3.12) and of withstand one (3.16) with the assumption of hull strength (3.14) gives the equation

$$0.61 \times \sqrt{h} = 4 \times \sigma_0 \times (\delta/a)^2 \times (1 + 0.5 \times a/h)^2,$$

this equation one would derive to the formula

$$h^{5/2} \times 0.1525 / (\sigma_0 \times (\delta/a)^2) - h^2 - h \times a - 0.25 \times a^2 = 0. \quad (3.17)$$

Given the relative smallness of summand $(0.25 \times a^2 \sim 0.5$, this assumption is not critical, because it corresponds with some underestimation of about $0.2 \div 0.25$ m of limiting thickness of continuous ice withstood by the side overlap and shell) the criterion of shell strength when compressing the ship by solid ice of the assigned thickness h looks like

$$h^{3/2} \times 0.1525 / (\sigma_0 \times (\delta/a)^2) \approx h + a.$$

For the transverse framing system for ensuring of strength when compressing the ship hull, accounting the shell thickness margin $\Delta\delta$ for the wear, it is required to have the thickness of shell δ depended on assigned design constraint of overcoming solid ice thickness h determined as

$$\delta \approx 390.5 \times a \times \sqrt{h^{3/2} / (h + a)} / \sqrt{\sigma_0} + \Delta\delta, \text{ mm}. \quad (3.18)$$

Generally, for evaluating of strength and reliability of side shell of multifunctional ice-navigating ship one would define two typical structural failures in ice of ship hull: of the wear of shell and of residual deformations. In the considered event the evaluation of ice-navigating ship shell strength is based on the concept of failure by the residual deformation, which precede other possible damage, including the through holes.

Not only the shell, but the framing of the overlap would be used as well, as indicators of failure besides of residual deformations, although when impacted ice on the ship hull the strength of framing usually causes less concern than the shell strength in the area of ice-strake at variable load-line, as well, as the surrounding areas of the sides below and above the load-line.

3.4. Determining of extra thickness of shell and the mass of hull upon compliance of ship it assigned performances in ice

Mass empty (the light displacement) of multifunctional ice-navigating ship and it loaded displacement in case of the reinforcement to improve the ship performances in ice are in the dependence on the ship ice category assigned in the terms of references, and adopted at initial stages of designing, the dependence of the ship

hull mass on assigned design constraint of overcoming solid ice thickness is required at the initial stages of designing to use this dependence in the mathematical model of the ship design characteristics and particulars determining.

With recommendations of the Register the corrosion wear margin of the shell plate elements, which standard operation term exceeds 12 years, is to be determined: $\Delta\delta = u \times (T - 12)$. If the operation term of shell is not specified directly then would be adopted as 24 years. Average annual decrease of thickness of the outer shell of multifunctional ice-navigating ship at the initial stages of it designing would be adopted approximately as $u \sim 0.2$ mm/year. Wherein the wear margin is equal $\Delta\delta = 5.0$, mm.

Standard spacing a_0 is determined in accordance with recommendations of the Register /137/ in the interval of up to 1.0 m, in the forepeak and afterpeak – up to 0.6 m, and in the fore part (outside the forepeak) – up to 0.7 m. For determining of the standard spacing in the middle part of the ship hull the formula would be recommended: $a_0 \approx (0.002 \times L + 0.48) \pm 25\%$, m. When using the ship loaded displacement D as the variable (3.4) instead of waterline length L the standard spacing would be determined approximately as

$$a_0 \approx (0.0017 \times D^{1/2} + 0.48) \pm 25\%. \quad (3.19)$$

The dependence (3.19) of standard spacing a_0 with the variable substitute is presented on the graph (Fig. 3.13) is recommended by the Register.

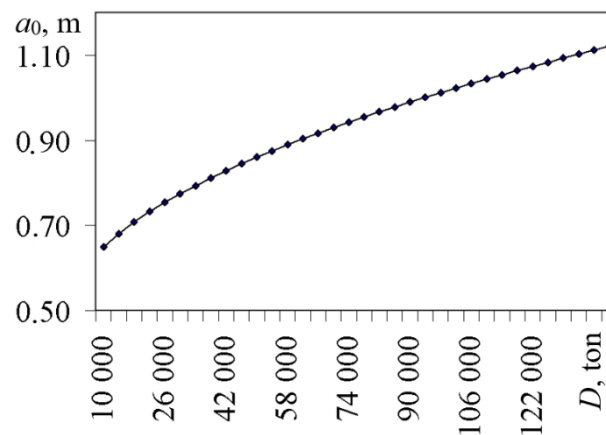


Fig. 3.13. Dependence of standard spacing a_0 on the ship loaded displacement D

Generally, the thickness of shell accordingly with recommendations of the Register is determined in dependence on the transverse load (the design pressure p) as

$$\delta = m \times a \times k \times \sqrt{p/(k_\sigma \times \sigma_0)} + \Delta\delta, \quad (3.20)$$

where m and k_σ – the bending moment and the normal stresses coefficients, the moment coefficient for the side shell is equal $m \approx 15.8$, and the coefficient of the allowed normal stresses is: $k_\sigma = 0.00283 \times L + 0.566$; $k = 1.2 - 0.5 \times a/b$ – the coefficient characterizing the ratio of sizes of the sheet structural element of shell (the shell plate of sizes: a and b): a – the smaller size, b – the bigger size, the coefficient k is practically no more than one, for the use at the initial stages of designing of ship in case of the transverse framing one can adopt approximately $k \approx 1.0$.

Given the considered assumptions and data the thickness of side shell of multifunctional ice–navigating ship in dependence on the design pressure p is determined as

$$\delta = 15.8 \times a \times \sqrt{p/((0.00283 \times L + 0.566) \times \sigma_0)} + 2.4, \text{ mm},$$

or when using the ship loaded displacement D as the variable characteristic of ship size (3.4) instead of the waterline length L the thickness of side shell is to be determined as

$$\delta = 15.8 \times a \times \sqrt{p/((0.00238 \times D^{1/2} + 0.566) \times \sigma_0)} + 2.4, \text{ mm}. \quad (3.21)$$

At initial designing stages for evaluation of influence of the ship patency in ice on the mass of hull and on the ship loaded displacement it is necessary to determine as well the thickness of shell without the account of ice load as the basis for collation.

The design pressure p without considering the ice load with only the waves impact p_w due to ship motion relative to the wave profile when finding the thickness of shell plating in accordance with the recommendations of the Register is determined as

$$p = p_w = 5 \times c_w \times a_v \times a_x \geq 3 \times c_w, \text{ kPa}. \quad (\text{the formula 1.3.2.2–1 /137/})$$

Moreover according to indicated formula the design pressure is determined at the level of cargo waterline ($p_w=p_{w0}$), that is at the level of ice if for ship of the assigned ice category, since the result could be used at the initial stages of designing as the basis for determining of influence of the ship assigned ice category, the performances and patency in ice under assigned design constraint of solid ice thickness on the mass of hull and on the loaded displacement of multifunctional ice–navigating ship.

Design pressure is determined on the basis of waves impact evaluation. The increase of the pressure on ship sides with depth within the ship draught is not included in the design load in assessing of the pressure on ship sides at the level of cargo waterline according to the considered formula.

Difference of design load by solid ice and without it impacts the determined thickness of side shell at initial designing stages and can be used attributed the integral hull as the assumption for approximal evaluation of influence of assigned in the terms of references ship ice category on it hull mass and on loaded ship displacement.

After the determining of corresponded design pressure of ice of assigned thickness at the level of ice–strake of shell for determining of the amendment to the mass of hull one would assume that impact of broken ice on side shell by the localization has the distributed nature, and this probabilistically distributed in the limits of the ship draft pressure, as well, as the pressure on the hull of ship of ice on ship bottom at the definite circumstances occurs additionally to the pressure of water on the bottom. Besides it is considered that the compression of hull by the solid ice from sides acts along most waterline length of multifunctional ice–navigating ship.

3.5. Structural strengthening of multifunctional ice–navigating ship hull

For satisfaction the ship of ice category by technical regulations of the Register the structures of multifunctional ice–navigating ship are strengthened. One would consider that of the approaches for improving of structural strength of sides overlaps of ice–navigating ship the variants are available, corresponded, at first, with the option to increase shell thickness for the improving of the overlaps, wherein the costs for construction are lower and the corrosion durability of ship hull increases, at the second, with the option to improve the strength of overlaps by improving of the main direction framing, or by the increase of the girders number when spacing reduces, or by the installation of the extra framing in the critically loaded structural areas.

The general arrangement of structural strengthening of ship hull for the first option is presented on the stretch diagram (Fig. 3.14) provided by professor V.A. Kulesh. This diagram shows the concept of ship hull strengthening. In the first option the increase of thickness of hull shell on the indicated area is provided (Fig. 3.14a). The second option of hull structural strengthening (Fig. 3.14b) is the installation of extra girders of framing (the longitudinal or transverse).

The second option could be preferable for design multifunctional ice–navigating ship, because the framing strengthening or the extra framing of sides overlaps correspond the lower mass of ship hull of the assigned ice category, compared with

the mass of hull of the same ice category ship, when the enough strength of hull is provided by the increasing of side shell (Fig. 3.14a). It should be borne in mind that in the second option increases the duration of ship operation, which was limited because of the hull corrosion wear, and reduces the costs for ice category improving.

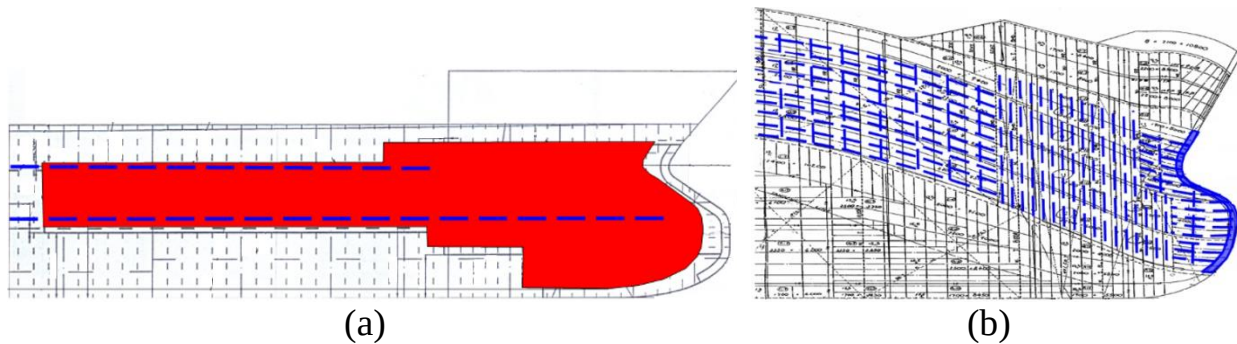


Fig. 3.14. Diagrams of arrangements of multifunctional ice-navigating ship hull ice strengthening with the increase of the shell thickness on the indicated area (a) or with the additional girders of framing (b)

In designing of structural elements of multifunctional ice-navigating ship both indicated alternatives are the subject under considering. In the same time at the initial stages of ship designing for determining of it characteristics, which are the data for determining of design particulars of the ship and its structures at the next steps of designing, one would follow the selected one of the alternatives, for example the first one, which for the ship characteristic sought is the required thickness of sides shell, or the second one, when the minimal spacing of framing is determined, corresponding the criterion of side overlap strength at the specified shell thickness.

Besides the strengthening of ice-navigating ship hull in accordance with the required category at the design stage the ice strengthening and protection of single structures is provided as well, including the protruding parts, stems, propellers, rudders, etc. (the example of structures is shown in the scheme, Fig. 3.15).

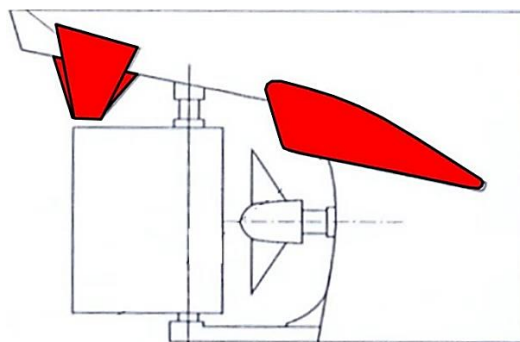


Fig. 3.15. Structural elements of additional protection of propeller and rudder in ice

Despite the fact that the strengthening and the protection of structural elements and the protruding parts of multifunctional ice–navigating ship is important issue on the designing stage, nevertheless the ensuring of shell and sides floors strength is more important issue considering the aggregate sizes and masses of the overlaps of sides, bottom, decks, bulkheads and their greater cumulative influence on the mass of hull and the ship loaded displacement at its initial stages of the ship designing.

3.6. Impact of hull structural strengthening on the mass of multifunctional ice–navigating ship

In ensuring of the ship hull strength the characteristic sought is the thickness of shell enough for operation in solid ice of the assigned thickness, this allows to determine the ship extra mass. Wherein it is considered that the other probable approach, at which the particulars of framing and the spacing would only change in dependence on the assigned design constraint of ice field thickness, and the thickness of shell would remain the same as in case of ice category absence, does not indicate the saving of ship hull mass, because the mass of framing will increase.

The choice within two considered options, at which the enough strength of ship hull is provided, serves the subject of decisions compromise at the following stages of designing – for determining of the structural elements of multifunctional ice–navigating ship. But this compromise is not so much relevant for the initial stage of designing that is for determining of ship characteristics, because the both ways of sides floors strengthening, as by the increase of thickness shell, so as by the strengthening of the main direction framing proportionally affect the mass of hull and cargo waterline displacement. When choosing any of the considered alternatives or their combinations the mass of hull increases in dependence on assigned design constraint of the ice thickness affordable to overcome.

For the structures in the area ice reinforcements the assumption is logical that the intermediate additional frames can be installed, wherein the size of the shell plate a will be twice less than the standard spacing a_0 . The dependence of the minimal thickness of shell δ of ice–navigating ship, required from the point of view of strength in the conditions of ship compression by solid ice of thickness h , on the cargo waterline displacement D is shown on the graph (Fig. 3.16, the example for ships of the ice categories: Icebreaker6, 7), illustrating of the influence on shell minimal thickness of extra frames installation at the level of waterline and ice impact.

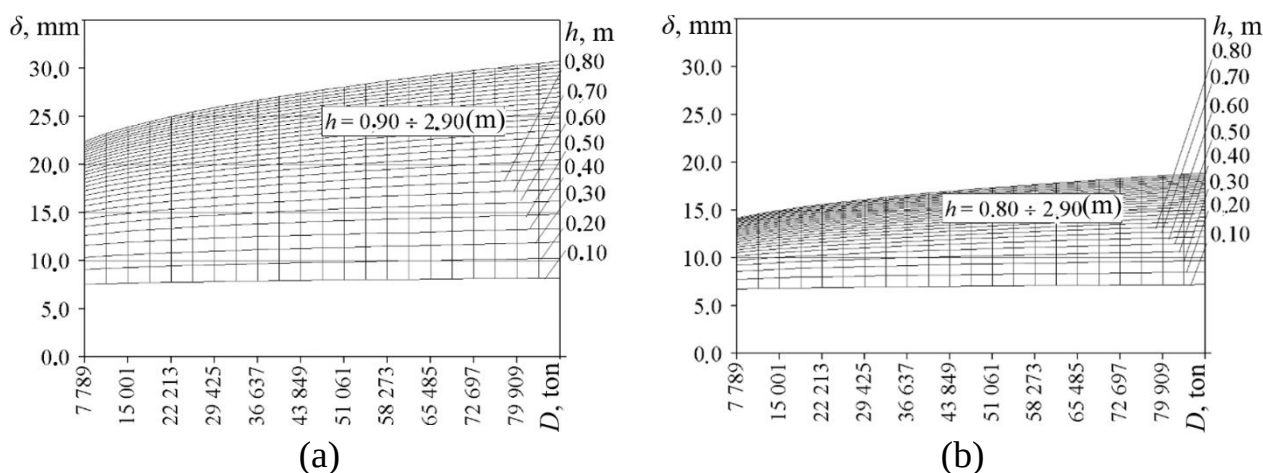


Fig. 3.16. Dependence of minimal thickness of shell δ of ship hull, at which the strength of side overlaps is provided under it ice compression, on the ship loaded displacement D and on the thickness h of overcoming solid ice for the options: (a) the standard spacing, determined in accordance with the recommendations of the Register; (b) the reduced spacing when installed the extra frames at the level of waterline and ice impact

It has sense to consider that strength of multifunctional ice-navigating ship structures largely depends on the characteristics of the individual structural elements: the stem and the sternpost, the protruding parts, the propellers and movers, the rudders and the fins, as well, as the sides framing and the framing of ship individual structural parts, wherever they are used, the keel, skegs, stiffeners, etc. Shearing importance of designing and construction issues of indicated structural elements, respecting their strength in solid ice of assigned of layer thickness, one need to account the smaller resulting impact of these structural elements on the mass of ship hull, than the impact of mass of it shell, which thickness depends on the assigned ice thickness (the design constraint).

For the assessing of design pressure p , using at the initial designing stages the recommendations of the Register (1.3.2.2–1 /137/), the coefficients could be determined as: $\alpha_X \approx 0.267$, $c_W = 10.75 - (3 - 0.01 \times L)^{3/2}$, or when using the ship loaded displacement D as the variable (3.4) instead of waterline length L the formula would be used: $c_W = 10.75 - (3 - 0.0084 \times D^{1/2})^{3/2}$.

Dependence of the coefficient c_W on cargo waterline displacement D is shown on the graph (Fig. 3.17a).

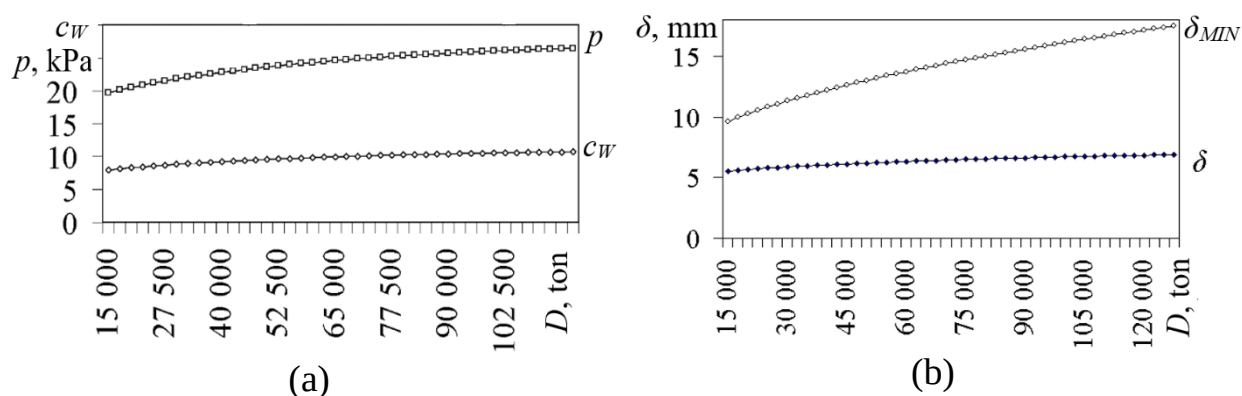


Fig. 3.17. The dependences: of coefficient c_W , of the design pressure p without the account of ice impact, on cargo waterline displacement D of multifunctional ice-navigating ship (a), of the design thickness of shell δ without the account of ice load and of minimal thickness δ_{MIN} of shell (b)

Dependence of the coefficient a_V on ship relative velocity to the wave profile (v_0 , m/s) looks like: $a_V = 0.8 \times v_0 \times (0.001 \times L + 0.4) / \sqrt{L} + 1.5$. When using the ship loaded displacement D as the variable (3.4) instead of the waterline length L , the dependence of the coefficient a_V is shown on the diagram (Fig. 3.18).

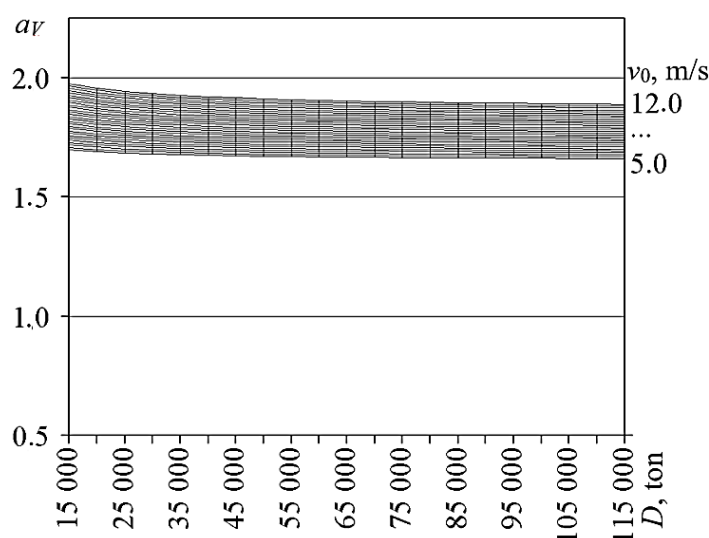


Fig. 3.18. Dependence of coefficient a_V design value on cargo waterline displacement D of multifunctional ice-navigating ship and on it velocity v_0 relative wave profile

By analyzing the graph for values range of cargo waterline displacement D from 15 000 up to 115 000 ton of multifunctional ice-navigating ship and it velocity v_0 from 5.0 up to 12 m/s relative wave profile, it is determined that the coefficient a_V is equal from 1.7 up to 2.0. Accordingly, at the initial stage of ship design for the cal-

culations the coefficient $a_V \approx 1.85$ would be adopted. Recommended at the initial designing stages the dependence of design pressure p on the ship loaded displacement D after definite transformations of the Register formula (1.3.2.2–1 /137/) looks like

$$p \approx 2.47 \times (10.75 - (3 - 0.0084 \times D^{1/2})^{3/2}).$$

The graph (Fig. 3.17 a) shows the dependence of design pressure p without the account of ice impact at cargo waterline, defined as the comparison basis without the account of continuous ice impact, on the ship loaded displacement D . The dependence of shell thickness (Fig. 3.17 b) under the design pressure p without the consideration of solid ice impact on the ship loaded displacement D (3.4, as the variable, instead of the waterline length L) could be done with the formula (3.20).

Assuming that at initial stages of designing the coefficient of mechanical properties of steel utilization is equal one ($\eta = 1.0$) the minimal thickness of the ship hull shell in accordance with the recommendations of the Register one can determine by the formula: $\delta_{MIN} = 5.5 + 0.04 \times L$, or when using the ship loaded displacement D as variable (3.4) instead of the waterline length L , which is relevant in the calculations at initial stages of the ship designing, the minimal thickness of shell one can determine as

$$\delta_{MIN} = 5.5 + 0.0336 \times D^{1/2}. \quad (3.22)$$

Dependences of the shell thickness δ without the considering of ice load and of the minimal thickness of shell δ_{MIN} on the ship loaded displacement D are shown on the graph (Fig. 3.17 b). By the graphs analyzing it is determined that at the level of cargo waterline the robust thickness of shell corresponding the design wave pressure without considering of ice load is less than the recommended minimal thickness of shell δ_{MIN} , which corresponds the minimal recommended by the Register.

The got dependence on cargo waterline displacement D of the extra thickness of the robust shell ($\delta - \delta_{MIN}$), required for overcoming the solid ice of the assigned thickness h for the evaluations of robust shell thickness at the initial stages of multifunctional ice–navigating ship designing is indicated on the graph (Fig. 3.19).

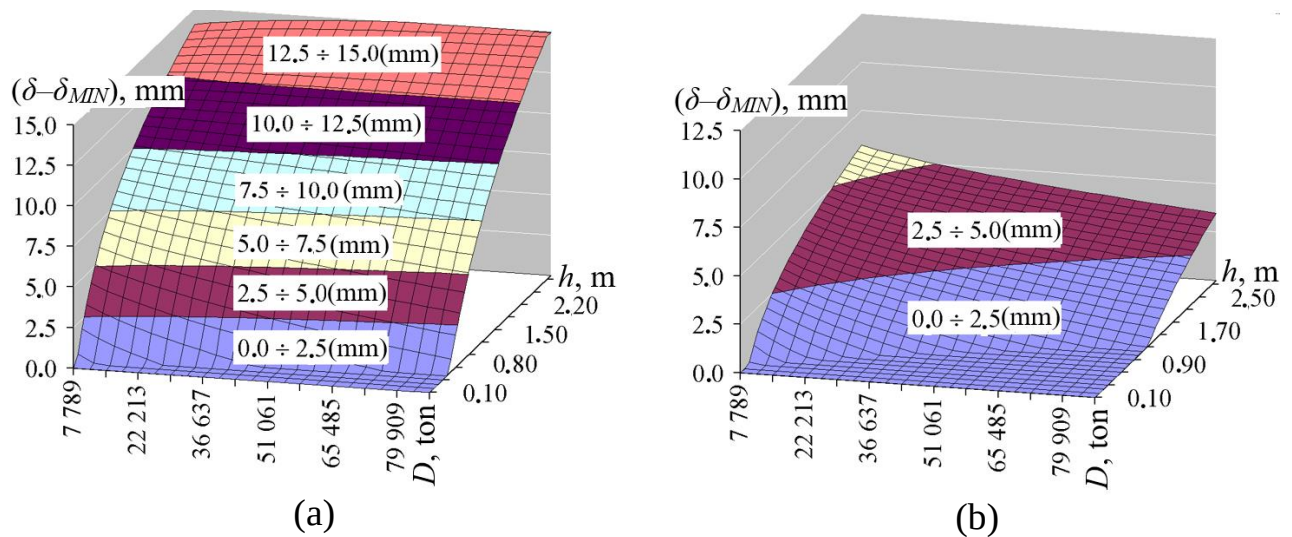


Fig. 3.19. Dependence of extra thickness of ship hull the robust shell ($\delta - \delta_{MIN}$), required for overcoming the solid ice of the assigned thickness h , on the ship loaded displacement D for following options: (a) the standard spacing, determined in accordance with the recommendations of the Register; (b) the reduced spacing when installed the extra frames at the level of waterline and the ice–strake of shell

The analysis of graph allows to conclude that for draught with cargo the extra thickness of shell ($\delta - \delta_{MIN}$) of multifunctional ice–navigating ship, which is required for the ship of smaller loaded displacement D and corresponded the assigned category and performances of ship in frozen sea, in particular, the assigned design constraint of solid ice thickness h , has less influence on the ship design characteristics and particulars than for ship of the bigger loaded displacement. Wherein the distinction of characteristics of ships, capable to overcome continuously the ice field of the assigned thickness from 1.0 to 1.5 m, is less than the distinction of characteristics of ships, capable to overcome the ice of assigned thickness from 0.5 to 1.0 m.

3.7. Evaluation of the ship patency in ice and the constraints at the initial stages of designing and in the practice of expert works

Harbors and the definite marine sea areas in the Russian Federation and in some other states of Northern hemisphere are used in frozen conditions in the navigation term from autumn to spring. In this season the intensity of navigation and the cargoes turnover in these harbors usually reduces. The lot of experience of ice navigations, including in the extremal conditions of Arctic and the Northern Sea Route is collected in shipping entirely. Systematical voyages of merchant ships in these conditions were implemented since 30th years of the twentieth century. Experience of ice navigations passed on the books /6, 39, etc./. Since this time in the various issues

the questions arise of the quantitative indexes characterizing ships seaworthiness and patency in frozen sea. The shipbuilders extend substantially their views of the ship strength and its properties of hydrodynamic resistance, propulsion and patency in ice on the basis of the theoretical, experimental and full-scale studies. The marine classification societies of the individual states are developing the national systems of the classification of ice categories of ships. The main attention of the classification societies was focused on analysis of ships icebreaking assignment – the patency in solid ice.

The academician Yu.A. Shimansky considered the indexes of ships patency in ice as «conventional» ones. Despite the known convention of various regulations of classification of ship seaworthiness in ice, it is required in designing issues the options evaluation of multifunctional ice-navigating ship from the point of view of those or other criteria: the ability to overcome solid ice of assigned thickness, the enough propulsive power for ship motion in cohesive broken ice, the appropriate controllability in these conditions, the enough strength in the conditions of solid ice overcoming and robustness of sides shell and overlaps of the hull – its extremities, the shell at the level of ice-strake under the compression of ship from sides, and the other criteria of seaworthy and patency in ice.

It is problematic to define various performances of multifunctional ice-navigating ship in ice by united integral criterion at the initial stages of the ship designing. It is possible to establish the hierarchy of indicated or the other indexes set in the frameworks of systemic approach, and in accordance with this hierarchy it is possible to adhere the most important criterion of ship performances in ice as the constraint when finding the design characteristics of ice-navigating ship. When choosing the most important index of the ship performances and patency in ice for its use as design constraint it is supposed that the rest indexes of performances and patency are to be in dependence on the chosen one the most important, or are subordinated to it in the sequence of importance, as well, as they are the subject for the determining at the next stages of designing when elaborating the particulars of the ship as the characteristics of its subsystems – of the individual structures, mechanisms, gears and etc.

It is characteristic that in the spotlight of the marine classification societies for determining of ice or arctic category the ship capability to move continuously in solid ice of the assigned thickness is usually studied. This preference of marine classification society for the choice of patency in ice index indicates in particular the hierarchy of the approaches when determining ice or arctic category of the ship.

For illustrating of the classification society approach for determining of ice and arctic categories the brief overview of the generalized characteristics of these categories and the limiting conditions of ice thicknesses by the rules of the Register /137/ are indicated below, as well, as symbols of the applied categories: the category Ice1 (LU1, that is JY1) corresponds the opportunities of autonomous navigation in crushed broken rarefied ice and in solid ice of the thickness up to 0.40 m in the fair water behind the icebreaker; Ice2 (LU2 or JY2) as well the opportunities of autonomous navigation in crushed broken ice and in the solid ice of thickness up to 0.55 m behind the icebreaker; Ice3 (LU3 or JY3) the autonomous navigation in broken ice and in solid ice of thickness up to 0.70 m behind the icebreaker, the abilities of navigation in Arctic seas are not supposed for the categories of: Ice1, Ice2 and Ice3.

The arctic categories are: Arc4 (otherwise LU4, that is JY4) corresponds the opportunities of autonomous navigation in rarefied annual arctic ice of limiting thickness of 0.6 up to 0.8 m (in dependence on season) and the navigation behind icebreaker in continuous ice of limiting thickness of 0.7 up to 1.0 m in winter–spring and summer–autumn seasons accordingly; the arctic category Arc5 (LU5, that is JY5) allows ship navigation in rarefied annual arctic ice of limiting thickness of 0.8 up to 1.0 m in the winter–spring and summer–autumn seasons, and accordingly, the navigation behind the icebreaker in arctic ice of thickness of 0.9 up to 1.2 m in dependence on season; the category Arc6 (LU6 or JY6) indicates the ability navigation in rarefied annual arctic ice of limiting thickness of 1.1 up to 1.3 m, the bigger indexes are assigned for summer–autumn season accordingly, and behind the icebreaker in arctic ice of thickness of 1.2 up to 1.7 m accordingly by seasons; the arctic category Arc7 (that is LU7 or JY7) allows navigation in cohesive annual arctic ice of limiting thickness of 1.2 up to 1.7 m (by seasons) and the overcoming of ice bridges, as well, as navigation behind the icebreaker in annual arctic ice of maximal thickness of 2.0 up to 3.2 m in dependence on the season; the category Arc8 (LU8 or JY8) allows navigation in cohesive annual and two–year arctic ice of maximal thickness of 2.1 m up to 3.1 m in dependence on season behind the icebreaker in ice of thickness up to 3.40 m; the arctic category Arc9 (that is LU9 or JY9) allows navigation in arctic multi–year cohesive ice of great congestion of moving non–cohesive ice of different types, closely grouped together, of thickness up to 4.0 m. In the indicated intervals of limiting thickness of ice the bigger indexes refer the summer–autumn season, during which the temperature decreases, and the lesser indexes for winter–spring season accordingly.

The definite similarity of the approaches when determining the categories by the Russian Maritime Register of Shipping and by the rules of the Finnish Maritime

Administration /52/ (that are the Finnish–Swedish rules) is available, which is more characteristic for the non–arctic ice categories and for smaller arctic ones.

Besides of ice categories and arctic ones, establishing the opportunities of ship safe navigation autonomously in broken rarefied or cohesive ice, or in solid ice fair water behind the icebreaker, the icebreaking categories (classes) are established by the Russian Maritime Register of Shipping as well: the icebreaking class of Icebreaker6 (that is LL6 or ЛЛ6) indicates the ability to fulfill the icebreaking operations in ice of thickness of up to 1.50 m and the ship capability to mote continuously in solid ice of thickness up to 1.0 m; the icebreaking class of Icebreaker7 (that is LL7 or ЛЛ7) allows the operations in solid ice of maximal thickness of 2.0 up to 2.50 m in the summer–autumn navigation, the ship could mote continuously in solid ice of thickness of up to 1.5 m (as well the constraint is introduced of the power transmitted to propellers, that is the power on the shafts is to be not less than 11 thousand kW); the icebreaking class of Icebreaker8 (otherwise the LL8 or ЛЛ8) permits the icebreaking operations in ice of thickness of up to 3.0 m, the ship could mote continuously in solid ice of thickness of up to 2.0 m, the power of propulsors is not to be less than 22 thousand kW; the class of Icebreaker9 (the LL9 or ЛЛ9), the icebreaking operations at a thickness of ice up to 4.0 m are allowed, the ship could mote continuously in solid ice of thickness up to 2.5 m, the power transmitted to propulsors is to be more than 48 thousand kW.

In this way the ice category, or arctic one, or the or the icebreaking class not only the characteristic of ship seaworthiness and patency in frozen sea, that is the design constraint, but the characteristic of part of the ship assignment as follows: the icebreaker motion in solid ice and it fulfillment of ice operations, while the ice categories or the arctic ones of the ship characterize it opportunity to mote safe in broken ice rarefied or of definite cohesion, as well, as to mote in the fair water behind the icebreaker in solid ice. In the same time the ability of ship of high arctic category to mote in cohesive annual ice and in two–year arctic one of the maximal thickness of 2.1 up to 3.1 m and even up to 4 m could say the conformity of this ship for the regulations of definite icebreaking class. It is in any case, that the ship satisfaction for regulations of definite category of class means not only the patency in ice, but the appropriate structural strength of the ship hull as well.

The overview of designs and specifications of innovative ships of arctic categories, created in accordance with the national Federal programs /148/ or with the Shipbuilding Industry Development Strategy, such as the tankers for transportation of liquefied natural gas (the design of «Yamal»), considered above (item 1.7), the LNG–tanker of arctic DA–class as well, the new oil tankers, such as «Captain

Gotsky» and «Yenisei», the arctic the scientific–research ships («Academician Treshnikov», item 1.4), the new arctic supply ships, as «Vitus Bering» (item 1.2) and «Alexey Chirikov», and etc. show that these ships are capable to overcome the continuous ice of the assigned thicknesses. Therefore, besides of the availability of arctic or ice category these ships satisfy the regulations of assigned icebreaking classes and they would be considered as the multifunctional icebreakers, capable to mote continuously in solid ice of appropriate thickness no less than 1.0 m (for the indicated LNG–tankers the assigned thickness of solid ice is no less than 2.0 m). Wherein the rules of icebreaking classes are also met for power, transmitted to propellers.

Design assignment of navigation in frozen sea in the terms of references of multifunctional ice–navigating ship could be taken into account in the geographic–referencing of different ice regions. The seasonal attribute could be subject of the geographic–referencing of ship operation too.

3.8. Conformity of regulations of various marine classification societies of the ship ice category assigning

In the table 3.3 the general expert review is indicated of conformity of ship ice categories applied by regulations of the Russian Maritime Register of Shipping, by the Germanisher Lloyd (GL), cooperated in 2013 with the Det Norske Veritas (DNV GL), by International Association of Classification Societies (IACS), by Lloyd's Register and by Canadian rules.

Table 3.3

The rules	The ice and arctic categories conformity (roughly)								
The Register	Ice1	Ice2	Ice3	Arc4	Arc5	Arc6	Arc7	Arc8	Arc9
DNV GL	E	E1	E2	E3	E4	Arc1	Arc2	Arc3	Arc4
IACS				PC6	PC5	PC4	PC3	PC2	PC1
Lloyd's Register	1C	1B	1A	1AS					
Arctic Class (*)	1, 1A, 2				3	4	5–6	7	8–10
CAC (**)					4		3		1–2

(*) Arctic Class, Canadian Arctic Shipping Pollution Prevention Regulations

(**) Canadian Arctic Class (CAC), Canada Shipping Act

The problem of ships ice and arctic–navigating performances determining remains relevant, as well, as evaluating of the ships strength in interaction with ice, although the large number of studies are carried out /54–56, 70, 162–166, 184, 185/ in the various institutions and more than the century of practical experience of ships operation in arctic and in the subarctic seas is available. The existing approaches

of ships reliability in ice evaluation in the general terms are attracted in the rules of the classification societies, which should be mentioned substantially differ and their unification meets the difficulties. With the account of the tendencies of international partnership in shipbuilding and navigation in freezing seas one has to have the practical approach for the objective comparison of the ships ice and arctic–navigating performances, that is the comparison of relevant regulations of various classification societies.

It should be mentioned that the classification of ice categories of DNV GL for the insufficient and smaller ice categories corresponds the regulations of Finnish Maritime Administration /52/ (that are the Finnish–Swedish rules).

3.9. Evaluation of ship running performances in frozen sea by the design indexes of the load withstood

The experimental study of the interaction mechanics of ship structures with ice forming in the reservoirs, in particular the studies of ships hulls models' interaction with ice are carried out in scientific centers of various states, in which the ships for ice navigation are created. For example, in the Russian Federation the experimental studies are carried out in the specialized laboratories of the Krylov State Research Centre /138/ and Nizhny Novgorod State Technical University named R.E. Alekseev. It is known that the experimental study of ice interaction with ships hulls models' are carried out in the laboratories of the Aker Arctic Technology Inc (Model testing facility of Aker Arctic Technology Inc) in Finland, in the Memorial University of Newfoundland and in the C–CORE Center for Arctic Resource Development of national Research Council (NRC) of Canada, in the USA, in China and in scientific centers of number of other states.

In the indicated scientific centers and in the others the set of under experimental study issues of the interaction with ice includes: the study of ice impact on the stationary and on floating platforms and on the rigs and drilling systems for mining of natural deposits on offshores of frozen sea, the evaluation of loads acting the ice–navigating ships in the various modes of navigation, as well, as the determining of indexes of ice impact on the offshore structures, the determining of general and local ice loads, the finding of the ship hull shape particulars considering the ice loads, as well, as the research of propellers action and the ship control equipment for operation in ice, the study of ship safety in frozen sea, the analysis of the opportunities of frozen sea environment control and etc.

The issue of evaluation of ice load acting the ship comes on the forefront on the step of finding of ship optimal design characteristics in forms which could be used at the initial designing stages in the composition of applied mathematical model, that by the definite way differs from the studies of objects interaction with ice, which are conducted in the indicated above research centers likely for own or fundamental scientific assignment. The set of the required ice mechanic studies and their resulting conclusions is subordinated for the assignment of the mathematical models for finding of optimal ship design characteristics, which does not deny the relevance of experimental and of theoretical research of ice impact on ships structures in frozen reservoirs, if these studies are aimed at accumulating of experimental data and at improving of approaches of the evaluation of ice loads on the ship under designing. Besides the optimal particulars of shapes of ice-navigating ships hulls, as well, as the particulars of propellers and equipment for ship control, found with the experimental works, are the parameters in the models when finding design characteristics of multifunctional ice-navigating ship. In the other words, the approaches of ice loads evaluation in the dependence on varied characteristics of ship, on the input data, including the ice category assigned in designing of ship, or on the ship running performances in ice assigned by the other way and on the design parameters used in the composition of this mathematical model, correspond the indicated particulars of propellers and equipment for ship control and the particulars of ship hull shape, which in it turn which in it turn are within results of their improvement in the experimental works, fulfilled in scientific centers and in the ice experimental tanks.

The longitudinal system of framing in shell area of ice-strake is not recommended. For determining of multifunctional ice-navigating ship optimal characteristics at the initial designing stages it is relevant to consider that following indexes of ice loads, which are governed by the Register or by the other correspondent regulations: the intensity of load (the maximal pressure); the height of the contact spot (the transverse size, that is along the transverse frame); the length of the contact spot (the longitudinal size). The indicated length of the contact spot significantly exceeds structural spacing, and in case of the transverse framing the length of contact spot practically do not impact the assumptions for determining of shell thickness. Therefore, at the initial stages of ship designing the factor of length of the contact spot of hull with ice cannot be considered.

Design pressure of ice p_{ICE} , that is the pressure in the contact area crushing the ice, in particular the pressure, which crushes the solid ice, in the evaluating of ship hull strength for the bow area is determined by the formula

$$p_{ICE} = 2500 \times k_{ICE} \times u_m \times (D/1000)^{1/6}, \text{ kPa}, \quad (3.23)$$

where k_{ICE} – the coefficient of ice category when determining the ice loads on the fore, the coefficient ice category k_{ICE} is of 0.36 up to 7.9 by the rules of the Register; u_m – the maximal value of the ship bow shape factor. The dependence of design pressure of ice p_{ICE} in the area of ship bow, determined by the formula (3.23) on ice category of ship is indicated on graphs (Fig. 3.20a), which are obtained for two of the values of ship cargo waterline displacement: 10 000 and 100 000 ton /93/.

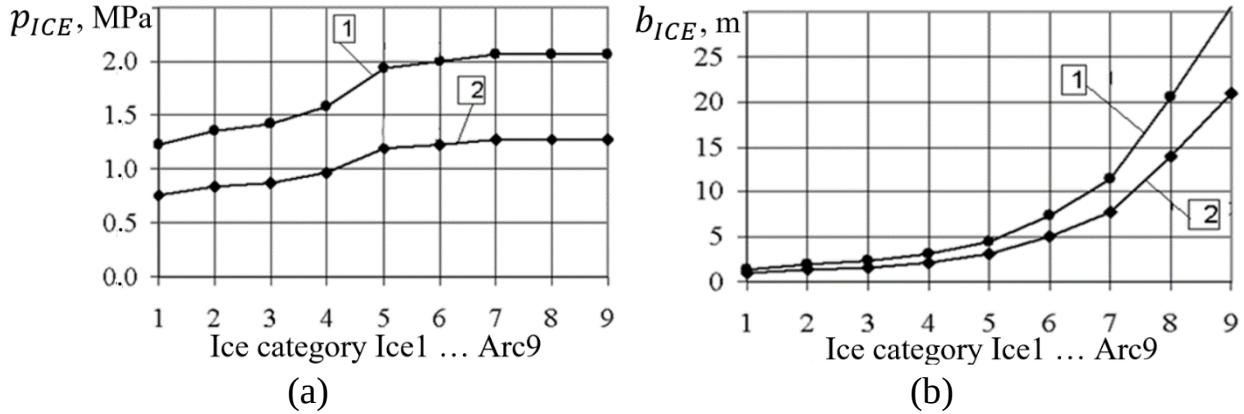


Fig. 3.20. Characteristics of ice loads: (a) the maximal pressure p_{ICE} ; (b) the height b_{ICE} (the transverse size) of contact spot in fore area in dependence on assigned ice category Ice1 ... Arc9 for the ship loaded displacement: 100 000 ton – [1]; 10 000 ton – [2]

For the characteristic shapes of ice–navigating ship fore considering the recommended angles (of stem tilt to waterline plane about 20° , of waterline entry – the fore sharpening about 45° , the angle of sides slope to diametral plane from 50 to 60°) the height of ice load distribution can be determined by the formula

$$b_{ICE} = C_1 \times u_m \times (D/1000)^{1/3}, \text{ at } (D/1000)^{1/3} \leq 3.5. \quad (3.24)$$

The height of ice load distribution b_{ICE} in area of the ship fore in accordance with the regulations in dependence on ice category factor C_1 , which is in the interval of 0.38 up to 0.64. The dependence of height of ice load distribution b_{ICE} determining by the formula (3.24) on assigned ice category of ship for two cargo waterline displacements: 10 000 and 100 000 ton is shown on the graphs (Fig. 3.20 b).

At the initial designing stages of the ship for determining of shell thickness δ of side overlap and the shell in the middle part of ship hull concerning its strength when compressing the hull by ice the assumption is logical that the contact spot height b_{ICE} is comparable to the assigned ice thickness h as the design constraint.

3.10. Joint determining of indexes of ship seaworthiness, patency and strength of hull in freezing seas

Ships with ice categories enough for autonomous navigation in ice and with corresponded structural strengthening make up relatively small part of total fleet tonnage. These ships are more expensive in the construction and they are less effective economically in usual conditions of operation – if not in frozen sea. The alternative way is available – the use of the ships of smaller ice categories for transportations in frozen sea and escorting them by the icebreakers, as well, as the use near the harbors of icebreaking tugs, which could be attributed to the set of multifunctional icebreakers. The other used indexes of seaworthiness and patency in ice, which are in the interdependence with the ship capability to overcome the solid ice, or the indexes hierarchically subordinate this function, are optionally considered below besides of solid ice of assigned thickness overcoming by the ship.

In the published article /95/ of V.A. Kulesh, S.A. Ogai and M.V. Voyloshnikov it is indicated that the various considered criteria of ship seaworthiness in solid and in broken ice could be generalized with the definite conventionality in the multiplicative structures strength criterion of ship seaworthy and patency in ice like that

$$IceQ = v_D \times \sqrt[3]{h \times h_1 \times h_2}, \text{ knot} \times \text{m}, \quad (3.25)$$

which includes as well the evaluation of three limiting thicknesses of ice (h , h_1 and h_2), characterizing capability of ship to overcome ice by acceptable safe velocity of ship v_D (knots) in the autonomous navigation in ice: h – the maximal overcoming thickness of the smooth solid ice, specified in the terms of references for designing of multifunctional ice–navigating ship of corresponding ice category, that is the limiting thickness with assumed exclusion of ship running performances loss, m; h_1 – the limiting thickness of the breakable ice, which is critical for loss of ship running performances while avoiding the danger of «ice captivity», m; h_2 – the limiting thickness of ice critical for strength of ship hull, m.

Two ships existed in the operation of related types, having the same ice category and approximately same technical condition are compared for example in the table 3.4. The compared ships have some structural differences. As it indicates with the examples, the same ice category of the ship # 1 in all respects inferior to the ship # 2.

Table 3.4

The comparison of performances in ice of the ships having similar ice category

Ship option	# 1	# 2
Ice category (1)	E	E
The wear of the ice strake, %	7.0	6.2
The power margin, % (2)	75	162
Patency in ice (assigned thickness of solid ice), m	0.45	0.58
Safe velocity of the ship in ice, knots (3)	1.56	3.02
Thickness of ice of ship running performances loss, m (4)	0.10	0.18
Limiting thickness of ice layer crushable by compression, m	0.40	0.45
Generalized criterion of ship patency in ice (3.25), knots $\times$ m	0.41	1.09

Remarks:

- (1) Ice category E in the example is indicated by rules of the Germanischer Lloyd (this approximately corresponds the category of Ice1 of the Register regulations);
- (2) for the minimal power by regulations of the Register for ship of ice category Ice2;
- (3) in the mode of autonomous navigation in the broken ice;
- (4) for the strong cohesion of ice (3 points)

Ship capability to overcome solid ice is considered above in details for determining of thickness h smooth continuous ice, which the ship considering it sizes and power (items: 3.1 and 3.2) is able to overcome. As the assumption the bending strength of ice is supposed to be equal 500 kPa, and snow layer on ice is of 20 up to 25 cm.

By the generalized criterion of the patency in ice (3.25) the evaluated distinction of compared ships is 2.66 times, that is it corresponded with definite differences of ice–strake wear indexes and the power.

3.11. Index of ship safe velocity in ice

The determining of the safe velocity v_D in ice with account of the pressure p_{ICE} , destroying ice in the contact area and the limiting design pressure p to withstand ice at the initial designing stages can be corresponded with assumption of strength of side shell in the composition of the overlap by the Register regulations (3.14).

The characteristics of ice load besides the intensity of design pressure depend on height and length of contact surface of ship hull and ice /95/. According to the recommendations of Kheisin–Kyrdyumov when using the hydrodynamic model of ship impact with motionless ice these characteristics are depended on the ship loaded displacement and it velocity. With the account of the specified recommendations

the design pressure of ice and the height of the contact spot one would find by the formulas

$$p_{ICE} = 0.66 \times D^{1/6} \times v^{13/24} \times a_p \times (2 \times R)^{-1/12} \times F \times f_{ICE}, \quad (3.26)$$

$$b_{ICE} = 1.33 \times D^{1/3} \times v^{7/12} \times a_p^{3/5} \times (2 \times R)^{-1/6} \times F \times f_{ICE}, \quad (3.27)$$

where b_{ICE} – the height of the contact spot of ship hull and ice, m; v – the velocity of ship impacted edge of motionless ice, m/s; a_p , R , F and f_{ICE} – the indexes of ice edge and the ship hull shape in the contact area.

Limiting pressure p withstand by side shell in the composition of overlap for the evaluation of structural strength could be done by the formula

$$p = 8 \times \frac{m_a \times a/b + m_b \times b/a}{(1 - 0.5 \times b_{ICE}/b) \times (a \times b_{ICE} \times (1 - a/(3 \times a_{ICE})))}, \quad (3.28)$$

where a and b – the sizes lengthwise and crosswise of the shell plate of ship hull under pressure (in the frameworks of spacing), m; a_{ICE} – the length of the contact spot (the ice pressures spot), m; m_a and m_b – the indexes of mechanical hinges resistance in the lengthwise and crosswise sections of side floors, $N \times m$.

Scope of the formula (3.28) use regarding the shell plate sizes (a and b) and sizes of the contact spot with ice (a_{ICE} and b_{ICE}) is limited by the conditions

$$a \leq a_{ICE} \text{ and } b \leq b_{ICE}. \quad (3.29)$$

Sequence (1–3) of the approximations is required for finding of ship safe velocity v_D in ice is:

1. The check of multifunctional ice–navigating ship assigned ice or arctic category accordance with the Register regulations fulfillment by it design characteristics, particulars and drawings.

2. Definition of the ship hull structural elements, which have greatest deviations from the Register regulations. The determining of loadings and stresses for these structural elements is fulfilled using, in particular the indicated equations (3.26–3.29), or by another way, for example, by the Finite Element Method.

3. The «weak» structural elements are to be revealed. The determining of the acting stresses and these elements strength by joint decision of the equations (3.26–3.29), is to be carried out for the fulfillment of strength assumption (3.14)

for the indicated elements by the successive approximation method, wherein the velocity index is varied, and the safe velocity is determined.

On the designing stage of multifunctional ice-navigating ship in assessing of strength of shell plate under the pressure with the varied sizes lengthwise and crosswise of ship (a and b) the studies aimed at the finding of safe velocity v_D could be done in the same sequence (1–3) for the data specified in the terms of references and for the varied size of the ship under designing.

It should be mentioned that the calculations of safe velocity of the ship v_D in ice, which enters in the set of offered generalized criterion (3.25) of ship seaworthiness and patency in ice, generally are of similar content with finding of the design particulars of ship structures, when the safe velocity is assigned as the data. Wherein the size of ship, which is determined at the initial stages of designing in the frameworks of systemic approach, at the next step is specified as well in the both calculations – as for determining of safe velocity, so as for finding of design particulars of the ship structures. This says that finding of design particulars of the ship structures and finding of its safe velocity in ice are carried out at the same level of internal designing having the determined ship size designing characteristic. While the particulars of the ship hull structural elements can be determined in the interdependence with determining of the ship safe velocity in ice, then size of the ship under designing is in dependence on its optimality criterion within the design constraint of overcoming solid ice thickness, assigned in the terms of references.

The issue of the finding of ship safe velocity in ice is of practical meaning not only for determining of this index in the composition of offered generalized criterion (3.25) of the ship seaworthiness and patency in ice and not only when finding the design particulars of ship structures for assigned safe velocity, as, for example, of arctic categories and the icebreaking classes of ships, for which the safe velocity would have been determined as the attainable velocity in the ice, when the ship size indexes and the power of movers are known and were found at the initial designing stages, and for the elaboration of regulations of safe operation of ship in the ice as well.

In the study of the ship navigation safety in ice the diagram can be used of the ship motion safe velocity v_D in the broken ice, which example for the ship of ice category Ice2 is shown on the graph (Fig. 3.21) for interval of relatively small ship loaded displacement of 4 000 up to 7 000 ton.

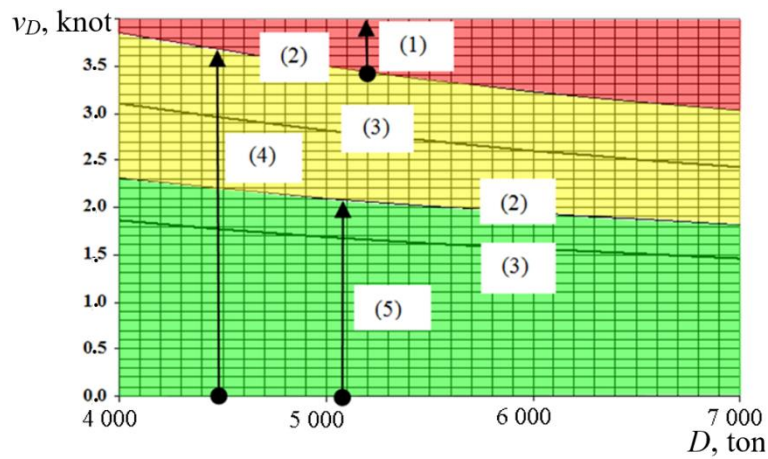


Fig. 3.21. Diagram of safe velocity v_D of the ship motion in the broken ice.

The legend: (1) the domain of dangerous velocities in ice; (2) the boundary of safe velocity values, considering the observed level of the shell wear; (3) the average values of safe velocity corresponding the wear; (4) the safe velocity of ship motion in broken ice behind the icebreaker; (5) the safe velocity of autonomous motion in broken ice

3.12. Loss of ship running performances and patency in broken ice

Capability of the ship to mote in ice with the safe velocity reduces the risk of damage, but not rule out the loss of ship running performances. The performances loss in the broken ice can lead to the «ice captivity» in autonomous navigation. Even the arctic icebreakers may lose the running performances in ice of essential cohesion.

Assuming that in the frozen sea the ship moves with safe velocity, one can determine the motion resistance with the known technique of determining of the ship running performances in the broken ice [162, 163]. The characteristics of ice varied in the calculations are: the ice thickness h , the index S of broken ice cohesion and the ice compression indexes. The determining of required power for ship motion, which corresponded with power of the movers, is carried out after finding of the velocity and in this way the index is determined of the lack of power, which characterizes the loss of the ship running performances.

The example of use of the indicated technique for evaluation of ship running performances and patency in broken ice is shown on the diagrams (Fig. 3.22 a and b).

On the basis of calculations with the indicated technique it is possible to determine the thickness of ice critical for loss of ship running performances corresponding the danger of «ice captivity» h_1 . In the example done on the diagrams this

index corresponds the boundary of the area indicated black, when the power for ship motion in the broken ice is not enough.

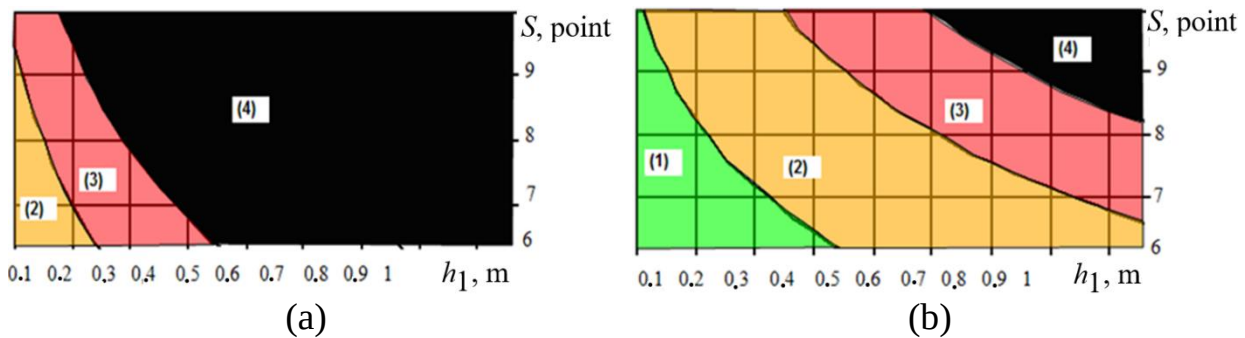


Fig. 3.22. Diagrams of movers' power sufficiency in broken ice in dependence on thickness of ice h_1 and on it cohesion S for the options: the strong compression of ice – 3 points (a), the weak compression of ice – 1 point (b).

The legend of sufficiency domains of power for ship motion in the ice:

- (1) it is required up to $\frac{1}{3}$ of power the propellers and movers for the motion;
- (2) it is required of $\frac{1}{3}$ up to $\frac{2}{3}$ of power; (3) it is required of $\frac{2}{3}$ up to 100% of power; (4) the power for motion is not enough – the loss of ship running performances in the broken ice («ice captivity»)

3.13. Evaluation of ice limiting thickness, which is to be withstand in the compression of the ship hull

Most probable damages in ice compression are in the middle part of ship hull if it is not enough strong to withstand the ice pressure. Besides, the ships not having the ice category or with the insufficient category usually have vertical sides in the middle part, which contributes the bigger ice pressure.

The load can be taken as design pressure on ship side shell assumed it corresponds the loss of solid ice layer stability. This loading of side shell is considered in details above (3.12–3.18, item 3.3). In the indicated item the pressure is used for determining that the ship shell thickness δ is strong enough to withstand the pressure of ice, given that the limiting thickness of ice at the initial designing stages assigned as design constraint h , and consistently the capacity of the power installation is enough for this ice overcoming.

In the considered example of the ship compression the dependences of pressures are indicated on graphs (Fig. 3.23) on entering the set of the structures strength generalized criterion (3.25) for the evaluation of ship in ice $IceQ$ the limiting thickness h_2 of ice field, which compression the ship is able to withstand, if one of other accounted factors in generalized criterion is assigned thickness of solid ice h , which the ship overcomes continuously.

Besides of determining of thickness of shell, which has to withstand ice pressure when compressing the ship, the similar evaluations can be performed for main direction girders, for the cross girders and the web girders. In this case for the generalized criterion (3.25) of ship patency in ice the smallest value h_2 from the set of listed indexes of limiting thickness of ice should be considered, which for the characteristic structures of side overlap most likely will match the thickness of ice, which the side shell can withstand as the element of side overlap, and it is considered above (item 3.3–3.6).

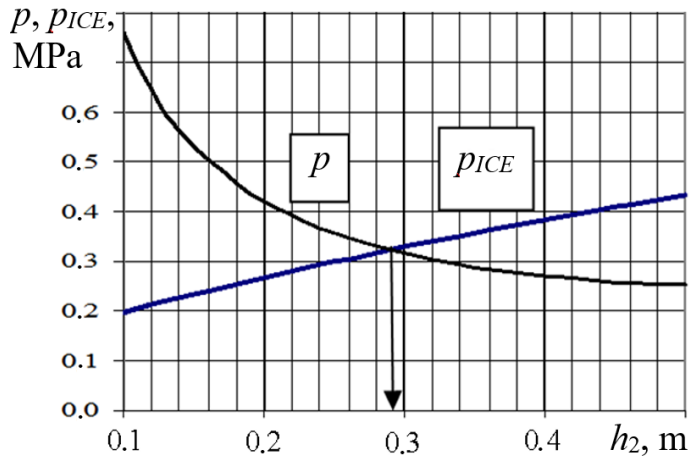


Fig. 3.23. Evaluation of limiting thickness of ice h_2 crashing when compressing ship in the condition of the excess of shell strength more than the pressure of ice destruction p_{ICE} , in assumption that limiting pressure p is withstand by side shell

At the next stages of ship design when finding the particulars of hull structures, it is required to do the analysis of strength of the cross girders, the main direction girders and the web girders, including in the conditions of ship hull compression under pressure which side shell withstands. The shell strength and of framing strength conditions when compressing the ship hull in ice are observed with this approach. For finding of mechanical stresses in the indicated structural parts the standard software packages and Finite Element Method would be used.

Despite of the practical importance of strength insuring of multifunctional ice-navigating ship hull framing, as well, as it separate structures – the stem, the sternpost, the protruding parts, rudders and the propellers and movers, – nevertheless each indicated structure has generally less influence on the characteristics of ship at the initial designing stages, than is the influence of shell – the biggest structural part of ship hull. Therefore, in the frameworks of systemic approach the design particulars of the individual structures are subject to developing at the next stages of ship designing,

and at the initial designing stages the parameters are adopted of the individual structures particulars as in the set of designing assumptions.

It should be mentioned that for the ships of arctic categories or the icebreaking classes the factors under the root in the formula of the structures strength generalized criterion (3.25) of ship seaworthy and patency in ice $IceQ$ in the frameworks of systemic approach can be considered as set of individual indexes, and the maximal overcoming thickness of smooth continuous ice h , specified for designing for corresponding ice category of ship, that is the assigned design constraint of continuous ice thickness, is in the same time the data for the evaluation of ship under ice compression.

In this case at the initial designing stages the purpose of assessing of ship strength when it compressing by ice does not contain the thickness of ice determining, which is assigned, and contains the finding of thickness of shell, corresponding the assigned ice thickness. Given that for ships of the arctic categories and the icebreaking classes the criterion (the broken ice thickness h_1) of the ship running performances lose in the broken ice is not sufficiently relevant if broken ice is not united, wherein the assumption in the formula of generalized criterion of ship seaworthy and patency in ice $IceQ$ can be simplified

$$IceQ = v_D \times \sqrt{h \times h_2} = v_D \times h, \text{ knot} \times \text{m}, \text{ at } h_2 = h. \quad (3.30)$$

In the same time the formal simplifications of generalized criterion of the ship seaworthy and patency in ice (3.25) could be not correct in some cases, because the limiting values of ice thicknesses (h , h_1 and h_2), which are under the root, in the general case are in dependence on independent assumptions describing the interaction of ship with ice, and the safe velocity v_D could be big enough, although the velocity when determining the limiting thicknesses of ice h , h_1 and h_2 is not specified and it can be the small index within the preservation of capability to overcome ice.

The similar changes of the generalized criterion of ship seaworthy and patency in ice like the indicated in formula (3.30) are possible with regard to individual ice and arctic categories and to the icebreaking classes of ship as follows:

- for the ship of ice categories of Ice1, Ice2 and Ice3 the generalized criterion could be determined in dependence on follows arguments: $IceQ(v_D, h_1, h_2)$, that is on safe speed in ice v_D , on the broken ice thickness h_1 , corresponded ice captivity assumption and on thickness h_2 of solid ice, which the ship withstands irrespectively the solid ice thickness h , which the ship can overcome;

- for ship arctic categories of Arc4, Arc5 and Arc6 the generalized criterion depends on the follows indexes: $IceQ(v_D, h, h_1, h_2)$, that corresponds the original

form of the criterion (3.25), including all the arguments as for the ship of ice categories of Ice1, Ice2 and Ice3 and considering the solid ice thickness h , which the ship can overcome as well;

– for categories of Arc7, Arc8 and Arc9 and for ships of icebreaking classes the generalized criterion $IceQ(v_D, h)$ does not depend on the broken ice thickness h_1 , corresponded ice captivity assumption and on thickness h_2 of solid ice, which the ship withstands, and moreover for these categories the index of appropriate safe velocity v_D corresponds to the achievable velocity with the account of movers' power and the ship loaded displacement for assigned solid ice thicknesses for categories of Arc7, Arc8 and Arc9.

In this way, the thickness of solid ice h enters in the set of the generalized criterion of ship seaworthy and patency in ice for arctic categories and the icebreaking classes, besides the relatively insufficient ice categories of Ice1, Ice2 and Ice3.

Besides of that for high ice and arctic categories Arc7, Arc8 and Arc9 and for the ships of icebreaking classes the allowed velocity for the safety is as well in dependence on the criterion of capability to overcome ice of ship in continuous ice, assigned as the design constraint of this ice thickness h .

Checklist

180. Relevance of multifunctional ice–navigating ship studying of strength indexes and the patency in ice in dependences on design constraints, including the design characteristics of ice environment, on parameters and on variable ship characteristics.
181. Characteristics of ice environment assigned the ship under design appropriate it ice or icebreaking category: the maximal thickness of solid ice, which the ship can over-come by continuous motion, the density of ice, the concentration of ice, etc.
182. Interdependence of the properties: of hull strength, of hydrodynamic resistance, of propulsion and the patency of ship in ice of the assigned intensity.
183. The recommended design angles of the ice–navigating ship fore shape: the angle of stem tilt to waterline plane about 20° ; the angle of waterline entry (the fore sharpening) about 45° ; the angle of sides slope to diametral plane (zero theoretical frame inclination angle) from 50 to 60° .
184. The ship maneuvering performances in the curvilinear channel boundaries in ice field depended on proportion of ship waterline length to it breadth.

185. Ice protection of movers and rudders by their location on the ship and by the longitudinal steps or the side cheekbones.
186. Relevance of the ship shape and its dimensions for the assigned ice category or thickness of ice, which the ship can overcome continuously, and contradiction of the shape and dimensions suitable for navigation in ice and ones for open water.
187. Inferiority of ice-navigating ship in open water in comparison with the ship, not having ice category and appropriate features, in terms of hydrodynamic resistance and the propulsion properties, and also in terms of massiveness, but to a lesser extent.
188. The specific issue of propellers protection in fore part of multifunctional ice-navigating ship.
189. Contributing to ice field loss of sustainability and its destruction by water pressure lowering with the use of bow movers of multifunctional ice-navigating ship.
190. The issues of designing study of multifunctional ice-navigating ship follow from its structural and functional features: the determining of the ship hull shape particulars and of propulsion complex;
191. Substantiality of multifunctional ice-navigating ship displacement empty differences within one class of the ship under designing in dependence on the difference of their ice category specified for the designing.
192. Necessity of systematization of the techniques used for evaluation of multifunctional ice-navigating ship strength, seaworthy and patency in ice in the frameworks of mathematical model for objective function determining for optimization designing.
193. Interdependence of multifunctional ice-navigating ship motion resistance in ice and the propulsion power, as well, as the load of the ice on sides floors of the hull.
194. Critical factors within the class of multifunctional ice-navigating ships of capability to overcome ice: the displacement of the ship loaded, the capacity of power installation, the hull shape, the thickness of hull shell, the structural particulars of sides, the spacing of framing, the structural particulars of extremities and the protruding parts, the special systems of ship (the trim system, the fore propulsors, etc.).
195. Criteria hierarchy of ice ship patency (the strength and propulsion) when selecting first important criterion and subordinating others, supposing they are satisfied when the first important do at initial designing of multifunctional ice-navigating ship.

196. Analysis-oriented accent of marine classification societies activity to evaluate the ice category considering importantly the ship capability to overcome solid ice.
197. Tsoy–Klimashevsky–Titov formula for rough assessing of limiting thickness of overcoming solid ice by continuous motion, the formula arguments (the length of load–line, the displacement loaded, ton, the propulsion power, the friction coefficient of ice, the function of bow shape, the bow sharpening and the sides slope angles).
198. Function of ship bow shape subject to simplification assumptions at initial stages of designing of multifunctional ice–navigating ship.
199. Minimal values of multifunctional ice–navigating ship loaded displacement which allow to overcome solid ice of definite thickness by the ship continuous motion and the lesser values of loaded displacement at which the overcoming of this ice is possible with the use of special systems and by the icebreaking navigation modes.
200. Recommendation to obey the rules of definite marine classification society at initial stage of multifunctional ice–navigating ship designing in the issue of determining of propulsive power for ice category assigned in the terms of references while use the formula like Tsoy–Klimashevsky–Titov one to find the loaded displacement.
201. The conventionality and probable lack of conformity of the ship ice category assigned accordingly the rules of definite marine classification society and the practical icebreaking performances of ship predetermine needs of developing and use of systemic physical criteria of ship patency in ice and performances.
202. Adjustment of Tsoy–Klimashevsky–Titov formula with ice–navigating ships analogues data when changing the assumptions used for indicated formula from the overcoming of solid ice by the ship continuous motion to the usual navigation mode of analogues when solid ice overcoming not necessarily by the continuous motion and with use the special equipment available on the ships to improve patency in ice.
203. The sequence of multifunctional ice–navigating ship operation velocity and effective power in open water determining considering it equal or the proportional with the ship propulsion power when overcoming the ice of the assigned intensity.
204. Prerequisite of the equality or proportionality of multifunctional ice–navigating ship propulsion power to overcome the ice of assigned intensity and the ship effective power in open water due to assumed efficient design of propulsion device which has to be efficient in each of indicated modes of the ship motion.

205. Impact on the functional dependence of velocity of multifunctional ice–navigating ship in open water of constraints for the minimal velocity enough for safe ship navigation control (the lower constraint) and for extra power, required for ice overcoming, other than effective power required for ship motion in open water (the top constraint).
206. Graphic feature of functional surfaces and the characteristic line of assumptions demarcation for determining of required power of multifunctional ice–navigating ship and its operation velocity in the open water in dependence on the ship size and on assigned design constraint of solid ice thickness.
207. Impact of lower constraint of operation velocity in the open water on propulsive power, required to overcome solid ice, on the ship design deadweight and on maximal thickness of overcoming solid ice.
208. The recommendation to use design deadweight of multifunctional ice–navigating ship as variable characteristic of the ship size along with the other characteristics of size, considering their interdependence to exclude the methodological obstacle.
209. Methodological independence (the conceptual similarity) of the ship propulsion power in ice and effective power in open water on the replacing of variable characteristics of the ship size: the loaded displacement to the design deadweight.
210. Relative sustainability of velocity in open water value of multifunctional ice–navigating ship under design compared with others design characteristics intervals of variation, in particular the characteristics of size of the ship (displacement, deadweight, tonnages, etc.).
211. The parametric sustainability of proportions of particulars of multifunctional ice–navigating ship under design (the ratios in the couples of dimensions: length, breadth, draught, depth, etc.), that is their narrow ranges of variability when going from one to another analogue, if compare with the ranges of variability of the ship sizes.
212. Excess of total power of energy generation sources (the installation power) of multifunctional ice–navigating ship over the effective power for navigation in open water, as well over propulsive power required for solid ice overcoming.
213. Power excess of ship generation sources over multifunctional ice–navigating ship effective power more characteristic for ships of smaller ice categories.
214. The feature of functional surface of power installation extra capacity, meaning the dual–mode operation of multifunctional ice–navigating ship as in the ice, so as in the open water, if the required power for overcoming of solid ice of insufficient thickness is less than effective power for ship motion in the open water.

215. Interdependence of the multifunctional ice–navigating ship capabilities to overcome ice of assigned intensity and the data for the issues of ship hull structural strength, of other ship performances in ice, like its patency in broken ice keeping safe velocity and controllability, etc.
216. Distribution of assumed destructions by the ice loads along multifunctional ice–navigating ship hull: for the fore part of ship by ice impact at the highest pressures on to the hull, for aft – the consideration of the maneuvers and the reverse motion mode in the ice, for middle – the considering of hull compression in the ice.
217. The greatest cumulative influence on the mass of ice–navigating ship hull by the structures of most length at middle part of ship (the sides, bottom, decks, bulkheads, etc.) and the ship shell, which withstand the compression by solid ice, but the influence on the ship mass of its extremities structures is not so much significant.
218. The most length of middle part the hull is of insignificant sides slope or with the vertical ones subject the critical local strength when compressing from the sides by ice.
219. Assumption of stability loss of ice layer when determining solid ice pressure on multifunctional ice–navigating ship sides.
220. Determining of multifunctional ice–navigating ship side shell thickness assuming the equality of pressure, at which the solid loses the stability, and the pressure, which the shell in the composition of side overlap withstands.
221. Characteristic ranges of 0.5 up to 1.0 m of the transverse framing normal spacing of multifunctional ice–navigating ship sides overlap in the area of ice–strake and of 0.25 up to 0.50 m in case of extra intermediate frames application.
222. Two typical structural failures in ice of the ship hull: of the wear of shell and of residual deformations.
223. The ice–navigating ship hull failure of residual deformation preceding many possible damage of hull, including the through holes.
224. The usual less concern of the frames strength of multifunctional ice–navigating ship than of sides shell.
225. Corrosion wear account when determining the multifunctional ice–navigating ships sides thicknesses.
226. The use of standard formula of the Register (or of the other marine professional regulation) for approximate determining of thickness of the sides shell at the initial designing of the ship.
227. The use of standard formula for approximate determining of sides shell thickness replacing the variable of waterline length to the ship displacement loaded.

228. Evaluating of the required thickness of hull shell at the cargo waterline of the commensurate ship without ice category as the methodological uniform collation basis to determine how much the assigned design constraint of solid ice thickness impacts the mass of the ship.
229. Assumption of probabilistic distribution of broken ice pressure on multifunctional ice–navigating ship underwater surface in the limits of the ship draft.
230. Options of strengthening of ice–navigating ship hull by increase of the shell thickness, or by strengthening the main direction framing, or by the increase of the girders number when spacing reduces, or by the installation of the extra framing.
231. The advantages of options of the ship strength in ice improving: the reduce of the ship hull mass when installing the extra framing and the duration of ship operation increase increasing the thickness of the hull shell, which was limited because of the corrosion wear, as well, as the reduce of construction costs.
232. Ice strengthening and protection of single structures, including the protruding parts, stems, propellers, rudders, etc.
233. The decisions compromise at the following stages of designing to improve the ship hull strength in ice of the alternatives choice: installing the extra framing or increasing of thickness of the hull shell.
234. Analysis of functions of the coefficients used at the initial designing stages for approximal finding of ice pressures on the ship and it shell robust thickness to determine the appropriate assumptions of these coefficients values.
235. The lesser relative influence of assigned category of ship in frozen sea, in particular, the assigned design constraint of solid ice thickness, on the shell thickness, hull mass and displacement for multifunctional ice–navigating ship of bigger size.
236. Ship patency in solid ice in the focus of attention of the classification societies, which closely corresponds the icebreaking assignment of the ship.
237. The other criteria of the ship performances in ice: the ability to overcome solid ice, the enough propulsive power for motion in cohesive broken ice, the appropriate controllability in these conditions, the enough robustness of sides shell and overlaps of the hull.
238. Methodological difficulties to define the various performances of the ship in ice by the united integral criterion at designing, the conventionality of ships indexes of patency in ice.
239. Meaning of the ship ice category, or arctic one, or the icebreaking class not only the characteristic of ship seaworthiness and patency in frozen sea, that is the design constraint, but the characteristic of part of the ship assignment.

240. Combination of the regulations of ice category assigning, the arctic one and the ice-breaking class, for which the ice patency criterion is more likely the ability of the ship to overcome solid ice by continuous motion.
241. The kind of the assigning of the design constraint of operation in frozen sea in the terms of references of multifunctional ice–navigating ship designing by this constraint geographic–referencing or the season–referencing.
242. The relevance of various classification societies regulations comparison of the ship ice category, or arctic one, or the icebreaking class assigning.
243. Scientific centers of the experimental study of the interaction mechanics of ship structures with ice.
244. Set of under experimental study issues of multifunctional ice–navigating ship interaction with ice.
245. Necessity of the of issues interaction with ice to be used in the composition of mathematical model for determining of characteristics and particulars of multifunctional ice–navigating ship under designing.
246. The use of the results of experimental studies in the dependence on varied characteristics of the ship, on input data, including the assigned ice category, or on the ship running performances in ice, on particulars of propellers, of equipment for the ship control, of ship hull shape, on other particulars of multifunctional ice–navigating ship.
247. Physical data of the ship side overlap, the shell, the contact spot and ice load intensity considering by the Register in the determining of the shell and overlap strength and the robustness.
248. Dependences of ice pressure on side of multifunctional ice–navigating ship corresponding the ice crush and the contact spot height on assigned ice category of the ship under design.
249. Assumption of the equivalence of contact spot height with assigned thickness of solid ice at the initial stage of designing of multifunctional ice–navigating ship.
250. The assumed interdependence of multifunctional ice–navigating ship capability to overcome continuously solid ice and the other performances of the ship and it patency in ice, or these indexes hierarchical subordination to this function in solid ice.
251. Option of individual criteria of ice–navigating ship patency in ice conventional generalized structures strength criterion in the multiplicative form.

252. Determining of design pressure of ice and the height of the contact spot with Kheisin–Kyrdyumov recommendations and the limiting pressure withstand by the ship side shell.
253. The sequence of approximations for finding of the ship safe velocity in ice: the check of the ship satisfaction the Register regulations for the assigned ice category, the definition of the ship hull structural elements, which have greatest deviations from the Register regulations, the determining of the «weak» structural elements within the set of ones with indicated greatest deviations, finding of the ship safe velocity by the successive approximations.
254. The methodological similarity of finding the ship safe velocity in ice and of finding of the ship robust structural particulars if the safe velocity is assigned, which correspond the level of the ship internal designing (finding of the ship design particulars), which indicates the safe velocity finding in the set of internal designing issue.
255. Safe velocity in ice of multifunctional ice–navigating ship of arctic category or the icebreaking class of ships as the attainable velocity in the ice, for specified the ship size indexes and the power of movers at the initial designing stages.
256. Multifunctional ice–navigating ship capability to mote with the safe velocity reduces the risks of damage but does not exclude the loss of ship running performances in the broken ice, so–called, the «ice captivity».
257. Determining of the limiting thickness of solid ice, which compression the ship is able to withstand, out of the assumption that it is equivalent the thickness of solid ice, which the ship can overcome.
258. Choice for the use in the generalized structures strength criterion of the smallest index of solid ice thickness of the set of solid ice thicknesses which the follows structures of the ship hull withstand: the shell, the main direction girders, the cross girders and the web girders.
259. The composition options of the generalized criterion of ship seaworthy and patency in ice for the sets of ice categories: of Ice1, Ice2 and Ice3, of Arc4, Arc5 and Arc6, and of Arc7, Arc8 and Arc9.
260. The appropriacy of the thickness of solid ice h as the characteristic of the seaworthy and patency in ice of all categories of multifunctional ice–navigating ship, besides of the small ice categories of Ice1, Ice2 and Ice3.
261. The safe velocity in ice irrelevance for the ships of the great ice categories Arc7, Arc8 and Arc9 and the icebreaking classes, as the velocity of these ship is safe if the movers' power allows this velocity for assigned solid ice thicknesses for categories of Arc7, Arc8 and Arc9.

Chapter 4. Characteristics of ice–navigating ship size and the dependences of design particulars on characteristics

The features of characteristics finding at the initial stages of designing of multifunctional ice–navigating ship of the innovative assignment are peculiar for ships not covered by batch industrial construction, for which the methods of characteristics determining on the basis the data of close of analogs (prototypes) are of little use. Just only the data of the prototypes is not enough for finding of characteristics and design particulars of the innovative ships, constructed single or small series. The determining of optimal design characteristics of multifunctional ice–navigating ship is performed on the basis of the use the mathematical models and variational calculations, in the less degree dependent on the necessity of characteristics of the prototypes used. For the reduction of dimension when doing ship design optimization of characteristics, the balance equations, establishing the conformities between the characteristics of ship would be used, in particular the mass equation of balance, which defines the balance of masses in the set of the components of ship cargo waterline displacement.

For determining of design characteristics of multifunctional ice–navigating ship and when varying their values to determine of the optimal ones the dependent characteristics are not varied individually, and they can vary only in the dependence on the varied independent ones.

There are several independent characteristics of multifunctional ice–navigating ship in the general case, the number of independent characteristics usually corresponds to the number of the used balance equations in the composition of ship optimization designing model, as it is considered (item 2.3). When using the optimization models for determining of design characteristics of multifunctional ice–navigating ship the probabilistic properties of ship as the object under design are had into account, which is possible represent as balance equations, that is the ratios between the characteristics of multifunctional ice–navigating ship, in particular equation of balance of it cargo waterline displacement. This concept is used practically for reducing of the project task dimension.

Among the characteristics of multifunctional ice–navigating ship, to which it is possible to attribute the ship cargo waterline displacement D or it design deadweight DW , only one is usually independent, and this is required to do the optimization of its value using the criterion of optimality. The second of indicated

characteristics of ship and the ship particulars can be determined by design calculation at each iteration (the designing stage) in dependence on the varied independent characteristic.

The equation of balance of cargo waterline displacement characterizes not any individual property of ship, for example this or that its physical property of the number of seaworthy properties, or the mechanical ones, such as the ship strength, its robustness and durability, usually studied for determining of ship design particulars, but the dependence between the characteristics of ship in the set of the balance equation, in particular between the set of the components of ship cargo waterline displacement, including the variable components, dependent on their total, and the constant ones, and this balance of ship cargo waterline displacement components has the probabilistic nature. The probabilistic systemic balance concept of displacement is used of cumulative influence of many factors on the loaded displacement of multifunctional ice-navigating ship, given that impact of each one factor on the ship displacement is insufficient.

The determining of balance of masses and the ship loaded displacement is carried out as part of the algorithm of ship optimal design characteristics determining. At the initial stages of designing the equation of balance is functional interdependence of ship characteristics and contains the independent component. For example, the equation of balance of the ship loaded displacement contains the total of independent summands of loaded displacement. The adjunctive «independent» means that the definite component of the ship load is independent on the value used in the mathematical model as variable. This variable for mass balance equation could be: or the designing deadweight, or the loaded displacement of the ship, accordingly how it is specified in the model, having in mind that the designing deadweight and the ship loaded displacement are usually interdependent and interchangeable as the variable in the terms of ship designing model. The total of independent components at the initial stages of the ship designing usually corresponds to the design deadweight. Although for the innovative ships in the set of the independent summands of mass balance equation the deadweight contains the mass of the specified in the terms of references the devices and gears as well, developed in accordance with the function of ship assignment.

In the practical issues the equation of mass balance is transformed to the sum (list) of independent load components as one progresses the ship design into the next stages, since the decisions made for each of the structural element of the ship, combined by this equation, means the transfer of this element in the number of independent load components at the next design stage.

In this way, the equation of balance at the initial stages of designing covers the functional dependences of independent components of balance on total of all load components (the ship displacement loaded). Finally, on the stage of the ship technical project the equation of mass balance is presented by the list of indexes of independent constant components, found at the previous designing stages. In particular, the equation of balance of ship cargo waterline displacement (the loaded displacement), which at the initial designing stages is the function on assigned deadweight of the ship load total with the other components of the load, at the final designing stage the equation of mass balance is transformed do the table of constant load components, which all are independent finally.

4.1. Mass balance of multifunctional ice–navigating ship as a form of accounting of it probabilistic properties in the designing

The dependences between the characteristics and the particulars, as well, as the internal ratios between the particulars, which characterize the proportions between these values for an efficient, reliable and seaworthy ship, safe in the operation, strong and robust in the measure in which these properties correspond to used analogs, can be used in addition to the balance equations for the dimension reduction of optimization designing of multifunctional ice–navigating ship. Perhaps the innovativeness of the ship design is not obtained from the prototypes used in designing, and the optimization methods within the systemic approach, with the use of effectiveness criteria and objective functions, the concept of options comparability and the design constraints are to be used for innovative multifunctional ice–navigating ship design characteristics determining.

In this way, it is assumed that the particulars of ship are predetermined. This allows one to focus on determining the characteristics to be optimized, assuming the particulars of ship in the form of proportional ratios constant under optimization of characteristics of multifunctional ice–navigating ship. At the next stages, when the subsystems of ship are under optimization designing, the subject is determining (the refining) of design particulars, that are the characteristics of the ship subsystems, having initially of the prototypes, when determining the ship design characteristics.

The probabilistic features of ship as complex system are manifested in the various forms, including in the form of the characteristics balance assumptions and corresponded equations, used at the initial stages of the ship designing, establishing particularly the mass balance as the dependence of the ship loaded displacement, that is the total of the components of mass of the ship (the components of load),

on total on it independent components or on individual independent component, for example on the design deadweight or the load capacity.

The ratio of multifunctional ice–navigating ship cargo waterline displacement and the total of masses of load independent components is result of the cumulative influence on this proportion of many factors – the dependence of large number of all components of the ship loaded displacement on the total of displacement independent components or on individual independent component, such as the ship cargo load.

In this way, there are no the separate, in particular, the physical properties of the ship, which would predetermine the ratio between cargo waterline displacement and the total of the ship independent components of the displacement. In the other words, the equation of balance of the ship loaded displacement characterizes not any separate property of ship, for example this or that it physical property, for example, of the set of it seaworthy ones, which are usually applying for finding of the ship design particulars, and this dependence (the balance equation) between cargo waterline displacement on the total of it independent components or on individual independent component has the probabilistic nature.

Historically one can indicate that the intuitive or deliberate use of the systemic approach the probabilistic features of ship were essentially taken before into account and used in the design tasks. Since the rationality of design characteristics of ship is not the result the only of judgment from the point of view of definite concepts, united in the ship design theory on the basis the systemic approach, then the accumulation and systematization of successful random decisions is important as well, let's say, the decisions determined by trial and error. At the same time, probably one can determine the optimal characteristics of ship by the way of the experience and the positive results collection. Nevertheless, the process to determine the design characteristics of the ship is substantially more effective when using modern methods, united on the basis of systemic approach and on use of the software.

It is possible to consider, that the structures of constructed ships in the historical past have not fundamentally changed for decades and centuries. The primarily similar generally traditional ships were built, differing in details and elements. Approach for the determining of ship characteristics on the basis the experience accumulation could serve as the sample of use of the probabilistic properties of ship as the complex system, which complements the example of the use in designing these in the form of the equation of balance of ship cargo waterline displacement as the cumulative influence of many factors on the ratio of cargo waterline displacement and it independent components. The examples of the manifestation of probabilistic properties of ship under design are not exhausted by the indicated one.

As well it is possible to attribute to these examples the definite properties of the ship under design criteria of optimality and the properties of economic indexes generalized in the criterion of optimality.

Development of integrated automation of the processes of ship construction represents the level of modern shipbuilding and establishes the necessary requirements for designing automation, that it is corresponded with the creation and use of digital and software for accumulation of the data and ordering the designing options, for example in the form of files, programs (the executables), networks, databases (the archives with the automation of search and processing). This can open up new technical opportunities of probabilistic properties use in designing of the ship as complex system.

As of ship design automation and more wide use of variation calculations one can put the attention at trial and error, corresponding the use of probabilistic properties of ship in it designing on the basis of modern digital technologies.

4.2. Characteristic size of multifunctional ice–navigating ship and the equation of balance of displacement

The equation of balance of cargo waterline displacement characterizes the probabilistic features of multifunctional ice–navigating ship as the object of design optimization, since this concept characterizes the joint impact of the great number of factors on the proportion of cargo waterline displacement and the deadweight provided that each individual factor has not the noticeable influence on these characteristics ratio.

In the set of multifunctional ice–navigating ship empty displacement DP the follows components of masses enter: the ship hull, the equipment, the systems and gears, the engines and machinery of power installation, the mechanisms and the equipment of engine room, the displacement reserve and the other components in the balance of mass dependent on the ship loaded displacement D and on the data Z (that is on data set, or the vector).

If by the use of the ship design optimization approaches with the economic criterion this or that characteristic of multifunctional ice–navigating ship, for example, it design deadweight DW is determined, then the dependent characteristic, which is in the probabilistic proportional correlation with the found one, in the considered event the ship loaded displacement D is possible to determine, using the mass equation of balance /9, 22/

$$D = DP + DW = \sum_n P(D^{A_n}, Z) + DW, \text{ or } D - \sum_n P(D^{A_n}, Z) - DW = 0, \quad (4.1)$$

where D – the ship loaded displacement (the mass of the loaded ship at the draft at the load–line); DP – the displacement of the ship empty: $DP + DW = \sum_n P(D^{A_n}, Z)$; $P(D^{A_n}, Z)$ – the summand of displacement of the ship empty; n – the ordinal number in the equation of balance summand (of ship empty displacement summand) dependent on the ship mass loaded at the draft of cargo waterline; DW – the design deadweight at the cargo waterline, including the mass of cargoes, fuel, ballast, the crew with luggage, the ship stocks and the other variable items of load, as well, as constant summands of payload assigned in the terms of references, for which the determining of characteristics of multifunctional ice–navigating ship not depends on loaded ship displacement D (on the formal side, depends on ship displacement on zero degree D^0), for example such payload components assigned in the terms of references, as the mass of equipment of multifunctional ice–navigating ship, which is created before the ship design and is supplied the ship creation; A_n – the exponent index of the ship loaded displacement for n –th summand in the mass balance equation.

Regardless the method of the balance equation obtaining the multifunctional ice–navigating ship loaded displacement characterizes the equality of the ship displacement and total of it components, which depend on ship displacement with different exponent index. In the other words, if the equation was obtained not by the summation of the loaded ship displacement items, and as the dependence on it variable components, however, the equation characterizes the total of these items.

Terminological clarification is needed. Design deadweight DW as sought characteristic of multifunctional ice–navigating ship under designing has the distinction from the usually used definition of operational deadweight, which in shipping and navigation means the total of variable components of cargoes and the stocks.

The characteristic of design deadweight DW of multifunctional ice–navigating ship in the considered mathematical models intended for design optimization consisting the maximal total of variable loads: cargoes, fuel, supply, ballast, the residual bilge water or the water on the deck, the crew with the luggage, ship stocks and other maximal of variable summands, which is usual for determining of deadweight in operation of the ship, and besides of these listed items consisting the constant summands of payload, assigned in the terms of references for designing, that is the mass of main equipment, for example, the modular equipment created before designing of the ship in accordance with the ship assignment, and the another items of mass, which in the designing of multifunctional ice–navigating ship do not

depend on it loaded waterline displacement D (in the other words, the items mass depended on displacement with zero exponent index D^0).

In the set of design deadweight DW of multifunctional ice–navigating ship the variable components of load (that is they maximal amount) enter: as the constant summands – the masses of those items, which are assigned in the designing of the ship, that are made specifically for this ship design, are not the deliveries, selected of mass–produced samples, and are the items of equipment, created for this definite construction in accordance with the ship design assignment. Formally the multifunctional ice–navigating ship is designed for installation and operation support of assigned equipment. This equipment serves the main system for determining of the ship design characteristics. The mass of the main equipment, corresponded with the ship patency in ice, for example, the power equipment or the technical one, modularly replaceable, developed not in the process of ship designing and before this, and specified in the set of ship design deadweight, along with the maximal mass of variable cargoes in the terms of references for designing of the ship, created specifically for the ship under design.

In the equation of balance of displacement (4.1) the components of design deadweight enter with zero exponent index ($A_n=0$) of the dependence of each component on the ship loaded displacement ($D^{(0)}$). In the other words, the components of design deadweight are not depending on cargo waterline displacement of multifunctional ice–navigating ship at the initial stages of it designing.

It should be mentioned that besides of the originally set design deadweight when advancing of the decisions through the stages of the ship design the mass of each element, which was finally determined at the corresponding stage of design in the next designing is considered independent on the ship loaded displacement in the composition of mass balance equation. Wherein at various stages of the design the mass of ship clarifies with the use of displacement balance, and the equation of balance itself is transformed gradually in to the load table of the ship with constant indexes of the displacement items.

It is possible to recommend giving close values of the ship loaded displacement the options of mass balance equation of multifunctional ice–navigating ship, using the data of the nowadays multifunctional icebreakers and their designs

$$\begin{aligned} D &= 0.000002 \times D^2 + 0.526 \times D + 626 + DW, \\ \text{or } 0.474 \times D - 0.000002 \times D^2 - 626 - DW &= 0, \\ \text{or } D &= 0.584 \times D + 240 + DW \text{ and } 0.416 \times D - 240 - DW = 0, \text{ ton} \end{aligned} \quad (4.2)$$

The resulting dependence of multifunctional ice–navigating ship loaded displacement D and the ship displacement empty DP on design deadweight DW are indicated on the graphs (Fig. 4.1 a) and the dependence of the ship displacement empty DP on the ship loaded displacement D is shown on the graph (Fig. 4.1 b).

The feature would be mentioned in finding of optimal design characteristics of such complex and integral engineering objects, as the merchant ships are and, in particular, multifunctional ice–navigating ships, specifically the balance equations between the ship characteristics and the parametric interdependences between characteristics and particulars of ship. For example by determining this or that ship characteristic size from the set: the design deadweight, the cargo waterline displacement of ship or the empty one, the cargoes carrying capacity, the holds volume, the gross and the net tonnages, the deck square (for ships, which transported oversized cargoes on the open deck, or the aggregated unified cargoes with large loading volume, etc.), – one will see that the rest characteristics of ship size are in the dependence on one selecting as the independent, or their proportionally in the narrow ranges with small deviation possible for their approximal values, which are found by the parametric formulas or specified with the account of the considered characteristic dependence on the independent one, which is varied for finding of it optimal value by the design optimization methods within the systemic approach, with the use of effectiveness criteria and objective functions, the concept of options comparability and the design constraints.

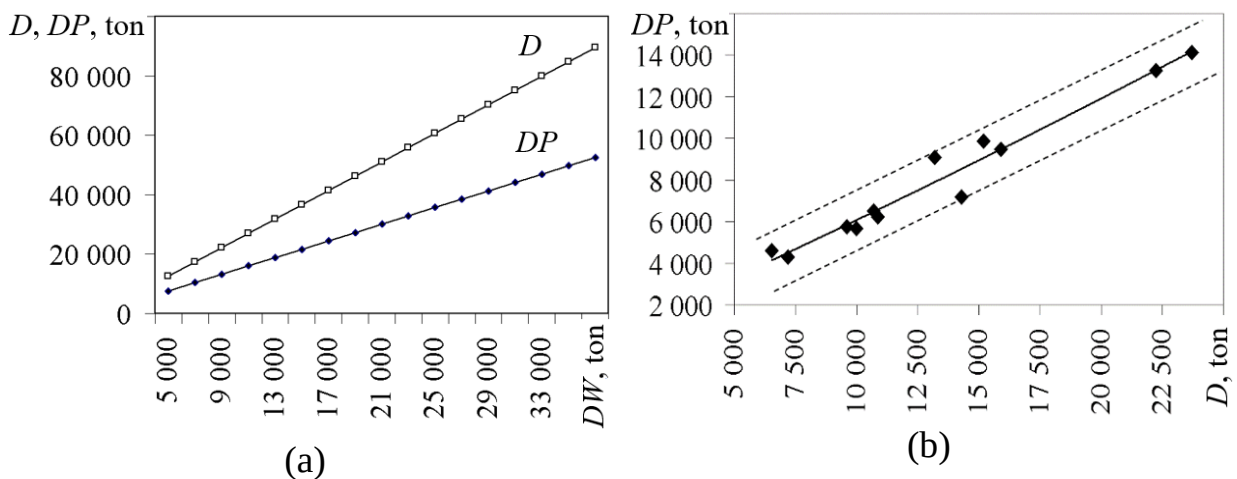


Fig. 4.1. Graphs of mass balance equation of multifunctional ice–navigating ship in the form of dependences: (a) the ship loaded displacement D and the displacement empty DP on the design deadweight DW ; (b) the displacement empty DP on the ship loaded displacement D

At proper narrow intervals of variation of the ship other characteristics, besides the project one, which is independent, and its optimal value is searched for, cannot exert the significant influence on the optimality criterion. More than that, in these narrow intervals of the variation the small influences of ship rest characteristics on the used criterion could have the opposite signs (the rest characteristics and the design particulars of ship considered independent if in these narrow intervals of deviations, then their positive or negative small influences on the criterion are generally equiprobable). Due to the ambiguity of ship characteristics influence on the criterion their cumulative impact is even less than the possible small impact of each of them in the vicinities of their deviations, besides of the characteristic, which is chosen as the independent one. The disproportion of the influence on the criterion by the independent characteristic sought (or definite number of independent characteristics, as a rule, of the small number) and rest characteristics of ship in the vicinities of their variations with the consideration of these vicinities conformity to values of the independent characteristics one could consider this in set of systemic properties of ship as the complex and integral object.

Formally the characteristic of multifunctional ice-navigating ship size when finding it optimal value could be consider the representation of relatively small number of the independent characteristics, having proportionate impact on the economic criterion used, and in particular case the single characteristic, which is linked with the rest characteristics and design particulars of ship, dependent on the considered one, and with the definite vicinities of their independent variation, for example when finding the optimal values of design particulars at the next designing stages, when the found design characteristic serves as the data (the design constraint).

At the initial stages of multifunctional ice-navigating ship designing, besides of it size, characterizing the ship opportunities to implement service-auxiliary functions, the icebreaking and navigational ones in the ice, as well, as corresponded with the carrying capacity of ship in freezing seas it is possible to indicate the index of ship seaworthiness and patency in ice as the second independent characteristic, specified in the design as, for example, the thickness of solid ice, which, servicing the design constraint, that is the data, in the same time indicating the designing characteristic of ship, since the assigned thickness of solid ice, which the ship can overcome, is linked inextricably with the design assignment of ice or arctic category of ship or with the assigned icebreaking class, as well the specified thickness of solid ice which is, first of all, the characteristic of the ship icebreaking performances predetermines largely the other ship properties in ice, such as the strength

and robustness of hull and the capacity of power installation enough for the motion in ice corresponding its density and cohesion.

The analogy is appropriate. Same, as the characteristic of ship size could be considered as combining of some set of independent design characteristics and the rest characteristics dependent on it with the definite vicinities of probable independent variation of these rest ones, so the overcoming thickness of continuous ice h could in the general approximation represent the aggregate index of seaworthy properties and patency of ship in ice, servicing the projection of some number of represented indexes, among which this or that one are independent, for example the thickness of continuous ice assigned to be independent variable and the rest indexes of ship performances in ice are in dependence on this index with some probable independent variations from their predetermined values, which could serve the subject for study at the next stages of ship designing.

In developing of methodological approaches for decision of the issues of optimal characteristics and particulars of multifunctional ice-navigating ship finding for the calculation of functional graphic surfaces and their analysis the follows indexes indicated are usually used as design characteristics, identifying as the size of ship and its seaworthiness and patency in ice – the ship design deadweight DW and the maximal thickness of solid ice h , which the ship can overcome, each of which indicates the sets of characteristics and design particulars associated with them. Selection of these indexes (like DW and h) as the arguments on graphs does not exclude the opportunity of others use.

Choice of these characteristics (DW and h) as the arguments for determining of the functional surfaces of multifunctional ice-navigating ship any indexes and the used optimization criteria on these arguments is done for the analysis of dependences by the reason of the maximal conformity of the indicated characteristics for the purpose of ship description, given that these two characteristics provide the greatest clarity, required for developing of approaches and for analyzing of results, because the indicated characteristic of the ship size (DW) could serve as the ship utility index and the component in the denominator of the used economic criterion as well (this is considered in details below, items 6.1 and 6.2), and the other characteristic, in particular the considering limiting overcoming thickness of continuous ice h , corresponded with the ice or arctic category of the ship or with its icebreaking class, is one of general characteristics of the ship performances in ice with the set of rest performances of the ship in freezing seas, and servicing the design constraint (the initial data). Therefore, the search of optimal extremum of the objective function is not provided along the axis of thickness of continuous ice h – assigned the ship

performances in ice in the terms of references, corresponded with the arctic category of ship or with the icebreaking class.

The choice of design deadweight DW as independent variable in finding of optimal design characteristics of the ship, considering at the initial designing stage the rest characteristics of ship size (D , PG , GRT , NRT , Ne , N_{ICE} , v_s and etc.) as depended, the other of which at the definite circumstances could be use as independent variable instead of the design deadweight, and which on the ship particulars (L , B , H , T , δ_w , L/B , B/T , H/T , L/H , etc.) depend, is possible to link with definite conveniences in developing of the methods and approaches for optimal characteristics and particulars of multifunctional ice–navigating ship finding, which is to be done at the next stages of designing, by the following reasons :

1. The characteristic of design deadweight DW of multifunctional ice–navigating ship covers as well the determining of indexes of payload constant components assigned for designing in the terms of references, that is the mass of main equipment, for example the modular one, created before the ship designing in accordance with the function of the ship and it main equipment assignment.

2. The design deadweight DW of multifunctional ice–navigating ship when finding it optimal value could be not only the designing characteristic sought, and the utility function as well and the denominator in the composition of economic criterion, which is to be used as objective function in design optimization.

3. In accordance with established international practice the design deadweight of ship (that is the maximal total of the deadweight items) is usually specified in the contracts for the construction and for purchase and in the certificates issued by the classification societies, so as in the data bases in the on–line and enters in the number the most applicable characteristics of merchant ships, along with the follows indexes: the tonnages (GRT and NRT), the length over all LOA , the effective power Ne (or EPS), the operation velocity v_s and some others.

4.3. Finding of direct and indirect increments of displacement of multifunctional ice–navigating ship, caused by design constraints

At developing of the mathematical model for determining of optimal characteristics of multifunctional ice–navigating ship at initial designing stages the equation of balance of the ship loaded displacement in the form of the increments can be of functional use in algorithms of the displacement determining. In this case the load increment for the ship under design can be considered the explicitly or implicitly impacted data assigned:

– the extra load of transported cargoes, if the designing of multifunctional ice–navigating ship are the progress of icebreaker concept, which is endowed with cargoes transportation function (or the other function: the cadets training ship or the scientific researches, the towing, the carrying of assigned equipment, for example – the drilling gear, the submarine equipment and launching devices, the equipment for liquefaction of the natural gas, for power generation, etc.);

– the implicitly assigned load increment, as the extra function of ship, in particular, the function of ice field overcoming, assigned as the design constraint of solid ice thickness, according the ship specified ice category, or arctic one, or the icebreaking class, the function of other ships navigation escort in the ice, or the function of autonomous work in solid ice or in the broken cohesive ice and etc., if the characteristics of multifunctional ice–navigating ship are determined as the progress of any merchant multifunctional ship concept or of the concept of ship of the other original function by the way of it endowing the ice overcoming function;

– the combination of explicitly or implicitly assigned increments of the ship load, which reflect the addition of the function to overcome the ice or it change as the complement to other existing functions of the ship.

Mass balance equation in the form of increments (the Norman factor, $\eta_N/9, 22/$), as it is known, is used in determining of the ship loaded displacement and this displacement components with use of analogs data. The set increment of multifunctional ice–navigating ship loaded displacement includes explicit part and implicit one (set indirectly). The explicit part corresponds the increment of design deadweight ΔDW , and implicit – the increment of data ΔZ (the deviation) of design constraints set, characterizing the functions of the ship and other assigned constraints like the thickness of ice, or the ice category, etc. The implicitly assigned increment of the ship load is

$$\sum_n \Delta(P(\Delta Z)) = \sum_n \frac{dP(Z)}{dZ} \times \Delta Z.$$

In this way, the total of the ship loaded displacement increment ΔD of the sum of it explicit and implicit parts is determined as

$$\Delta D = \Delta DW + \sum_n \frac{dP(Z)}{dZ} \times \Delta Z. \quad (4.3)$$

The Norman factor η_N , that is the mass balance equation in the form of increments, or the coefficient of proportionality between the caused increment of the ship

displacement, determined by differentiation of the ship displacement balance equation, on one hand, and the total of explicitly and implicitly assigned increments of load components in composition of the displacement balance equation, on other hand, looks like

$$\eta_N = \frac{dD}{\Delta D} = \frac{dD}{dD - d(\sum_n P(D^{A_n}))} = \frac{1}{1 - d(\sum_n P(D^{A_n}))/dD}, \quad (4.4)$$

where dD – the full increment of displacement, ton; $dD = \Delta D + \sum_n d(P(D^{A_n}))$;

ΔD – the assigned increment of the displacement, ton;

$\sum_n d(P(D^{A_n}))$ – the caused increment of the displacement, ton;

$d(\sum_n P(D^{A_n}))/dD$ – the derivative of caused increment $\sum_n d(P(D^{A_n}))$ of the displacement with respect to the full increment of displacement dD .

The use of the Norman factor η_N for determining of the full increment of displacement dD of multifunctional ice–navigating ship in the proportional dependence on the assigned increment of the displacement ΔD is performed, as known /9, 22/

$$dD = \eta_N \times \Delta D. \quad (4.5)$$

In the other words, the full increment of the displacement dD of multifunctional ice–navigating ship is

$$dD = \Delta DW + \sum_n \frac{dP(Z)}{dZ} \times \Delta Z + \sum_n d(P(D^{A_n})), \quad (4.6)$$

or, with the use of the Norman factor η_N the full increment of the ship loaded displacement is determined as

$$dD = \eta_N \times \left(\Delta DW + \sum_n \frac{dP(Z)}{dZ} \times \Delta Z \right). \quad (4.7)$$

It should be mentioned that when using Norman factor in the composition of mathematical models for determining of design characteristics of multifunctional ice–navigating ship the availability of analogs is considered as the methodological assumption for creation of the displacement determining algorithm.

The transformation of two of formulas (4.2) considered above gives the mass balance equation in the forms Norman factor, that are the proportions of the displacement increments – the assigned increment of displacement and the full increment

$$\eta_N = 1/(1 - 0.584) = 2.40, \text{ or } \eta_N = 1/(1 - 0.000004 \times D - 0.526). \quad (4.8)$$

Considered parametric formulas (4.8) for multifunctional ice–navigating ship shows (Fig. 4.2) that the indexes of Norman factor, determined at the initial stages of ship design are close in the interval of 2.0 up to 2.4. This says that the load increment in the sum of explicitly set increment of design deadweight ΔDW (the assigned constant part of design deadweight) and of the increment dependent the ship loaded displacement components of load set indirectly and determined as: $\sum_n \frac{dP(Z)}{dz} \times \Delta Z$ leads to corresponded ratio in average 2.20 of full increment of the ship loaded displacement to it explicitly set increment.

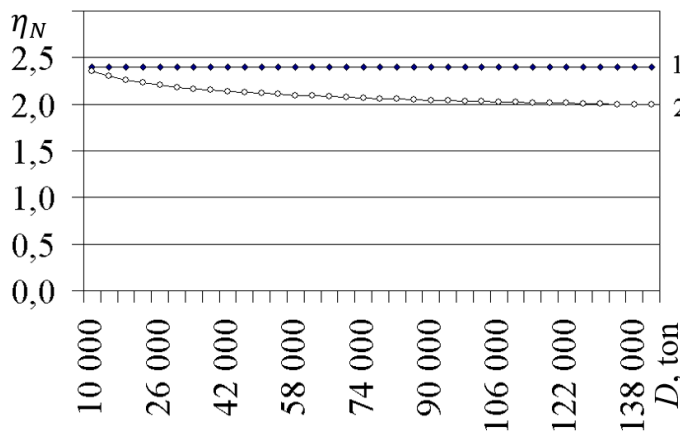


Fig. 4.2. Dependences of the Norman factor η_N on the loaded displacement D of multifunctional ice–navigating ship (1 and 2 according to the formulas 4.8)

4.4. Impact of the ship assigned performances in freezing seas on the design characteristic of cargo waterline displacement

Since the dependence of shell thickness and mass of hull on the ship performances assigned in the form of the design constraint of overcoming thickness h of solid ice, which is corresponded with the ice category or arctic one (or with the icebreaking class of the ship), in accordance with the mass balance equation the shell thickness and mass of hull determine the dependence of the ship loaded displacement on it assigned performances and patency in ice, then for the evaluation of the design constraint of affordable to overcome thickness of solid ice h or the influence on it loaded displacement D on the ship assigned ice category the following indexes are to be determined:

- the mass increment ΔP of the ship hull in dependence on assigned design constraint of the thickness h of affordable to overcome ice field, which predetermines the extra thickness of side shell ($\delta - \delta_{MIN}$);

– the balance factor η_N (the Norman factor) of the ratio of full increment of the ship loaded displacement to the indicated implicitly set load increment (the performances and patency in ice).

Then the displacement increment ΔD_P caused by a change of mass of multifunctional ice–navigating ship hull, compared with the ship studied without the considering of ice load impacting on the ship hull is: $\Delta D_{P(h)} = \eta_N \times \Delta P(h)$.

In the general approach it is possible to denote the data of assigned complex of functions of multifunctional ice–navigating ship by the vector Z (the set). To the number of the ship functions indexes the thickness of affordable to overcome solid ice h refers in particular, and, if the dependence of hull mass on the shell thickness in it turn is dependent on ice thickness, one can determine the mass increment of the ship hull

$$\Delta P = \sum_n \frac{dP(Z)}{dZ} \times \Delta Z = \frac{dP(\delta(h))}{d\delta} \times (\delta - \delta_{MIN}) \approx 0.00785 \times S_0 \times (\delta - \delta_{MIN}),$$

where $\frac{dP(\delta(h))}{d\delta} \approx 0.00785 \times S_0$ – the partial derivative of the ship hull mass in dependence on shell thickness δ and proportional to the surface area of the ship hull; S_0 – the surface area of ship hull, including wetted surface and the freeboard surface area, sq. m; 7.850 ton/cubic m – the mass density of the structural steel; $\delta - \delta_{MIN}$ – the increment of shell thickness, dependent on assigned design constraint of thickness h of solid ice affordable to overcome, as the index of one of multifunctional ice–navigating ship functions; δ_{MIN} – the minimal thickness of shell (by the Register), mm; δ – the thickness of hull shell, dependent on the assignment of the ship ice (or arctic) category or the icebreaking class corresponding the limiting index of affordable to overcome solid ice thickness corresponding the structures strength of the ship considering the wear margin to the thickness of shell, determined by the formula (3.18).

Dependence of mass increment of hull ΔP on design constraint of assigned limiting thickness h of solid ice affordable to overcome and on variable of the ship loaded displacement D before the account of impact of ice field is shown on the graph (Fig. 4.3).

Absolute value multifunctional ice–navigating ship hull mass grows as the size of the ship increases for large assigned thickness of ice (above the 0.9 m for large ships). In the same time the limiting thickness of solid ice assigned in the project for ship of smaller size has the bigger impact on the mass of hull by its relative value.

The used indexes could be determined by the next way. Surface area S_0 of shell of ship hull including the wetted surface: $\Omega \approx k_T \times \sqrt{D \times L / 1.025}$ and the total surface with the freeboard is: $S_0 \approx \Omega + (2 \times L + B) \times (H - T)$, where k_T – the factor of wetted surface area, $k_T = 2.66 \pm 0.11$ by Taylor /9, P. 211, 212/.

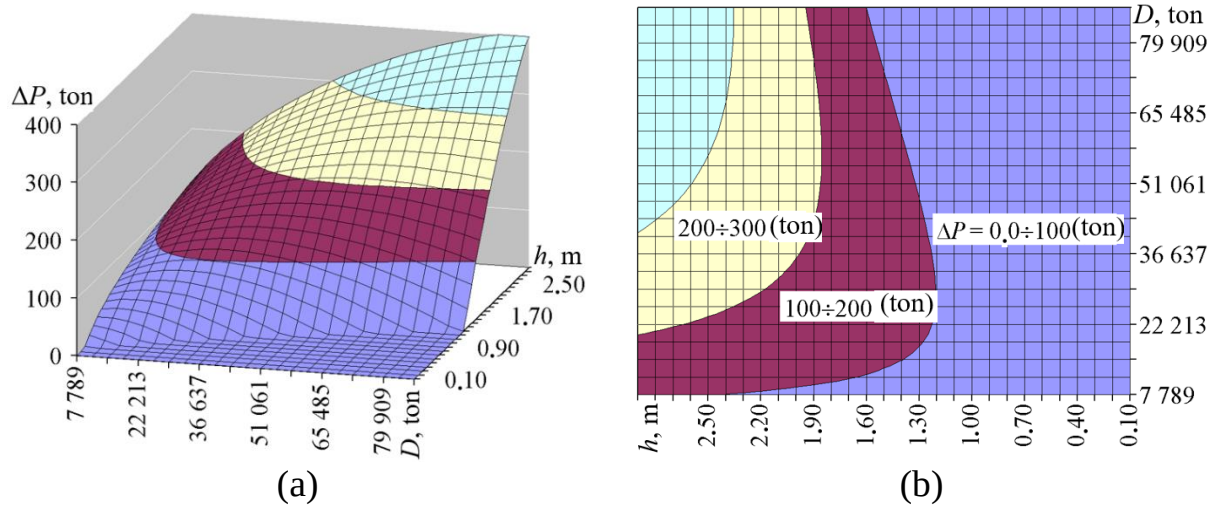


Fig. 4.3. Increment of hull mass ΔP of multifunctional ice–navigating ship with increasing of shell thickness δ in dependence on assigned design constraint of limiting thickness h of affordable to overcome solid ice and on designing characteristic of the ship loaded displacement D (before the account of ice field impact) for option of reduced spacing when installed the extra frames on side overlaps at ice impact strakes

When using the ship loaded displacement D as variable (3.4) instead of waterline length L the area of wetted surface of the ship hull is $\Omega \approx 2.408 \times D^{3/4}$, sq. m.

When substituting the data available (item 4.8) of multifunctional ice–navigating ship particulars on it waterline length L the approximal equations are:

$$B = 0.185 \times L + 5.25, H = 0.0282 \times L + 9.13, T = 0.0134 \times L + 7.55, \text{ m,}$$

the resulting dependence of surface area S_0 of hull shell on the loaded displacement is

$$S_0 \approx 0.02282 \times D + 2.408 \times D^{3/4} + 2.965 \times D^{1/2} + 8.30, \text{ sq. m.} \quad (4.9)$$

4.5. Evaluation of displacement for the training ice–navigating ship with the modular equipment

Among functions of multifunctional ice–navigating ships and icebreakers the following are specified usually /7/: the cargoes delivery in freezing seas, the crew and the personnel transportation, the cargo handling, including on an unequipped

coast and with use of the helicopter, the towing, the servicing of construction works in freezing seas, the support of mining of natural deposits in the seas and on the continental offshore, the underwater works support, the search operations in the sea, the icebreaking service, the rescue in the seas, the works of the ocean environment protection and the others works on the offshore in freezing seas, on natural gas sea grounds, including the operations of reception, processing and storage of natural gas, generation of electric power, etc.

Designing of multifunctional ice–navigating ship machinery for bunkering by the natural gas in the ocean on the production grounds, which extends the ship autonomy, is of the interest as well and it is corresponded with the retrofitting of ship devices and systems of processing and storage of liquefied natural gas (usually of 98% methane), as well the assigning of the ship power installation for partial (or full) use of the liquefied natural gas as the fuel.

Creation and operation of training multifunctional ice–navigating ship is to be intended besides of the indicated above functions to teach cadets of various maritime professions, their instruction of the ship navigation, its mechanisms control, devices, systems and instruments operation, the production technique and the processes in freezing seas and on the offshore fields refers to the considered shipbuilding area accordingly /104/.

In the frameworks of Shipbuilding Industry Development Strategy it is possible to indicate the list of the main functions of the ship to use it as analog, on the basis of which the training ship of new generation could be created. The general issue is the combining on the training ship of maximal number of functions, provided for by the Strategy. For the fields of natural gas production on the offshore in freezing seas the training ship assigned with the functions of goods supply, including the delivery of general cargoes, containers, the oversized cargoes on the deck, the fuel, transportation of passengers, the function to work in freezing seas, to fulfill rescue operations, combining the listed functions with the abilities of fuel re–bunkering in the ocean on the serviced gas production grounds. Besides of this assignment the ship implements the functions of cadets’ training of navigation and the technical maintenance of ship power equipment, operating as on diesel fuel, so as on natural gas, the maintenance and control of electric equipment, ship mechanisms, automatic devices, of operation control of natural gas processing onboard (the liquefaction) and storage of the liquefied gas.

The variant of training ship considered in the study would be used as well, as the experimental floating plant of natural gas process and the power plant for energy generation on diesel or gas fuel. Opportunity to use gas–diesel generators

and the equipment is of attention for preparing of diesel fuel and natural gas mixture on the multifunctional ice–navigating ship on the serviced offshore gas fields.

Organizing of cadets training of follows marine professional directions and specializations on considered multifunctional ice–navigating ship is assigned:

- navigation ship control, the maintenance of the ship, the operation of devices, systems, mechanisms and power installations;
- navigation in the ice, including towing operations and the rescue, as well, as skills improve of ice overcoming and control of power installation modes, the propellers and the ballast systems of ship;
- navigation when servicing the offshore grounds of natural gas, including the cargo operations control, the planning of cargoes transportation;
- operation of power equipment and machinery of various assignment, considering internal combustion engines and gas turbines, the gas–diesel equipment, the electro–mechanic engineering equipment and the facilities of automation control;
- service of natural gas processes of liquefaction, storage and use as fuel;
- power generation in the ocean for delivery of the energy to consumers, desalination and heating of water for technical use and it delivery to consumers in the ocean and onshore, etc.

The listed functions of education and training of multifunctional training of ice–navigating ship can be specified in the terms of references in addition to initial assignment: the transporting, icebreaking, towing, the rescue, etc.

Use of the combined power plant is assumed, working not only on diesel fuel, but also on vapors of the natural gas, mainly the methane, or on mixture of natural gas with diesel fuel. Universal block of premises in the hold is provided, adjacent with the engine room, which could be modularly equipped as the additional engine room. The equipment of gas process onboard (the liquefaction) and the gas energy equipment of modular design, connectable to the ship systems can be installed in these rooms in standard dimensions of the ISO containers: the natural gas reception, the exhaust system, the vapor recovery system of the natural gas, the electric power network, the automated control system, etc.

To reduce the risks of the investing in the creation of innovative ships the definite functional flexibility of their assignments in the appropriate range would be logical, as well, as the assignments adaptability at various stages, as of their creation, so as the operation of ship, at designing, refitting or renewal. This property of flexibility indicates as the suitability of multifunctional ice–navigating ship design for the exchanges and designing modernization, which samples are done above

(item 1.5), so the opportunities of the constructed ships renewal. The functional flexibility is largely linked with the use the modular concept of the ship equipping and the interchangeability of it mechanisms, mechanical and piping systems and devices.

It should be mentioned that in one way or another the basic modular concept, meaning the interchangeability of parts and the equipment standardization, is characteristic for the ship machinery. In the nowadays shipbuilding the modular equipping is possible attribute to integral assemblies of the ships, which is applicable to the full for construction of multifunctional ice-navigating ships.

Samples of the modular equipment, which are available to apply in the creation of training multifunctional ice-navigating ship, are indicated below. Characteristics of this equipment would to be assigned in the terms of references as design constraints for account of the equipment mass when finding the ship size with the use of balance equation, so as for determining of ship assignment and for the evaluation of effect index – the utility function of multifunctional ice-navigating ship in the composition of designing optimality criterion. Ship functions listed above and in the corresponding samples of ship equipment meet to the modern level of shipbuilding technology.

Engine room of training multifunctional ice-navigating ship can be equipped with the generators – the diesel or gas turbine, as well, as the piston gas generators of standard ISO container dimensions (Fig. 4.4 and 4.5). Large list of brands of the specified equipment is available besides of those shown in the images.



Fig. 4.4. Diesel-generator Cummins 1250 kVA of ISO container dimensions (<http://gensetdieselgenerator.buy.chinapackagenet.com/>)



Fig. 4.5. Gas turbine generator set Dresser-Rand of the power of 1.5÷2 MW in ISO container body (www.powercity.ru)

Trend of engines transfer on the use of natural gas as the fuel is characteristic in the shipbuilding and in shipping for the economic and environmental reasons. The advantages are possible when using the natural gas as the fuel for multifunctional icebreakers which navigation is planned in offshore servicing of natural gas production and transportation. In these conditions the use of natural gas as the fuel

allows the unlimited increase of ship autonomy all season in the respective sea area.

Gas–diesel engines could be of the use for ice–navigating ships (Fig. 4.6). Besides in the presence of vapors of the natural gas, which is transported as cargo, the converters of these vapors in the fit condition for natural gas use as the fuel would be used (Fig. 4.7).



Fig. 4.6. Gas–diesel engine Wärtsilä 20DF for ship (www.wartsila.com)

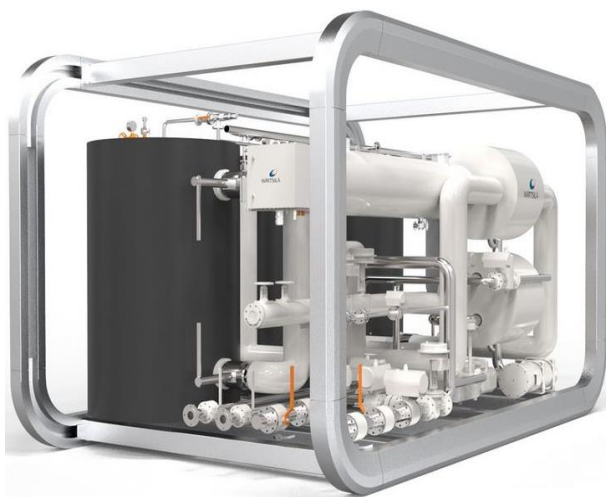


Fig. 4.7. Natural gas vapor converter Wärtsilä GasReformer in the fuel condition (www.offshore-energy.biz)

The additional engine room provides: the gas–diesel generators and fuel equipment for process of mixture of diesel fuel (75÷80 %) and of natural gas (20÷25 %), as well, as the modular equipment for gas processing (liquefaction) and for power generation using gas fuel. This modular equipment is connected to the ship systems: the natural gas reception, the fuel mixture preparing system, the exhaust system, as well, as the electric power network and the automated system of units control. The modular equipment for processing, storage and use of natural gas and for generation of power could be installed in the additionally equipped engine room in the sub–racks, which dimensions correspond the standard ISO containers of 20' and 40'.

Samples of modular equipment for processing, storage and use of natural gas by the number of units is to be duplicated for multifunctional ice–navigating ship and include for the considered example the follows:

- tank containers of capacity of one–unit up to 15 ton for liquefied natural gas (Fig. 4.8 and 4.9) – up to 20 items of total capacity 300 ton – for considered prototype of icebreaking–supply ship, which provides the autonomy of ship up to 10 days when using gas fuel, taking into account the proportion of energy content of liquefied natural gas (около 38 MJ/kg) and diesel fuel (36 MJ/kg);

- blocks of ISO container dimensions for liquefaction of natural gas (Fig. 4.10) in the volume equivalent of four 20' containers with total capacity up to 125 ton of the liquefied gas per day, providing filling of tank containers during 2.5÷3 days;
- generator sets (4 items) in the 20-ft frame containers (Fig. 4.5) each of power of 2 000 kW, assumed the power about 50 % of the ship's needs on the go without the use of diesel fuel in the mixture, as well, as to deliver power for the output of liquefied gas along with natural gas reception and for the power supply of consumers when ship operates as the floating power plant.



Fig. 4.8. Tank-container of KCM-35/0.6 (KLM-35/0.6) for liquefied natural gas (up to 15 ton) in the dimensions of ISO 40' container (www.ekip.pro)



Fig. 4.9. Tank-container for liquid cargo in the hold of icebreaking-supply ship of the design #10620

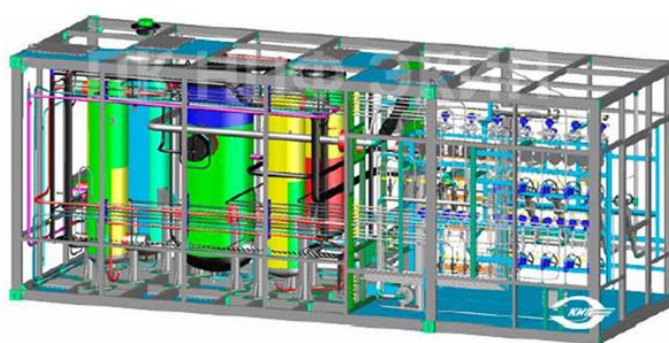


Fig. 4.10. Modulus for liquefaction of natural gas in dimensions of ISO 20' container (www.ekip-projects.ru)

Combined power installation of the considered composition of training multifunctional ice-navigating ship corresponds with the extra functions: the unlimited autonomy by fuel in the offshore field of natural gas production; the opportunities

for use of the ship as the floating power plant operating on natural gas; the training of cadets for technological processes of natural gas liquefaction, its storage and use as fuel for power generation on the ship. Equipping the post for control of processing, storage and use of the liquefied natural gas is provided in the variant of combined power plant, including gas–diesel generators, turbo generators and the equipment for liquefaction and storage of the natural gas. This control post on the training ship is combined with the laboratory for study of the processes: the heat and mass transfer, the technique processing of liquefied natural gas fuel for turbines and for internal combustion engines, as well, as control of fuel mixtures process supplied for gas–diesel engines, the collection of exhaust, the automation of control of the composition and supply of fuel mixtures, the power distribution control when generators of various types are working together in the composition of shipboard combined power installation.

Total mass of all container modules is about 1 000 ton, including the tank–containers with liquefied gas (about 300 tons). The indicated mass is additional to the operational deadweight, that is to maximal total of variable components of load. The total power of the generators, as gas–diesel ones, so the gas turbines in the composition of combined power installation in the considered variant of training multifunctional ice–navigating ship is up to 26 thousand kW, although for ship motion the power of 16 up to 19 thousand kW is used.

Opportunities of the modular equipping of the premises of variable assignment of multifunctional ice–navigating ship, indicating on the example of the conceptual design of the training ship of this class, can be characterized generally by the index of design deadweight DW in its considered definition not only as maximal total of variable items of the load, including cargoes, fuel, supply, ballast, residual bilge water or the water load on the deck, the crew with the luggage and etc., which indicates the ship operation characteristic, and in the given example, the extra to the maximal of listed components of assigned modular equipment load items, characterizing the equipment created up to designing of training multifunctional ice–navigating ship.

At the designing stage of multifunctional ice–navigating ship the determining of the ship loaded displacement D is carried out with use of mass balance equation (4.2) in finite form (the function) or in the form of load increments (4.5) in dependence on data, in other words, on design constraints assigned in terms of references for the ship, indicating the impact of more general systems, to which the ship refers as subsystem:

- design deadweight DW , including not only the maximal total of variable cargoes, and masses of all equipment specified in the terms of references as the ship design constraints in accordance with it assignment, for example the mass of the specifically created power installation for the ship or the reactor in composition of the power installation and etc., that is total load, incoming in mass balance equation in the dependence on the ship loaded displacement with zero index of the exponent;
- ship icebreaking function, which characterized, in particular, by assigned thickness h of solid ice and the assumption, that rest seaworthiness and patency indexes of ship in ice in one way or the another depend on ship capability to mote in solid ice of definite thickness, it is logical to recommend in designing of the ship to consider it performances in ice impact on the displacement in form of the displacement increment using the mass balance equation in the form of increments (the Norman factor).

In the other words, for determining of multifunctional ice–navigating ship loaded displacement D on designing stage with account of two indicated data groups, having the other impact degree on the resulting index of the displacement, it is possible to adhere the concept of the superposition of these groups of data influence and to find the both summands in the differential equation of displacement balance consistently:

$$D(DW, h) = D(DW) + dD_{P(h)}. \quad (4.10)$$

Increment of displacement of multifunctional ice–navigating ship considering assigned design constraint of the maximal thickness h of solid ice, which the ship can overcome, is: $dD_{P(h)} = \eta_N \times \Delta P(h)$, if $\Delta D = \Delta P(h)$ and $dD = \eta_N \times \Delta D$ (see 4.5).

With the use of previously got formulas (3.21, 3.22 and 4.9) for evaluation of the input indexes: δ_{MIN} , δ and S_0 in dependence on the Norman factor (4.8, Fig. 4.2) it is possible to recommend the formula $dD_{P(h)} \approx 0.00785 \times S_0 \times (\delta - \delta_{MIN})$.

Results of determining of increment of the ship loaded displacement in dependence on design deadweight DW and on assigned design constraint of solid ice thickness h are shown on the graphs: for standard spacing (Fig. 4.11a) and for reduced spacing when installed extra frames in the side area of ice impact (Fig. 4.12a).

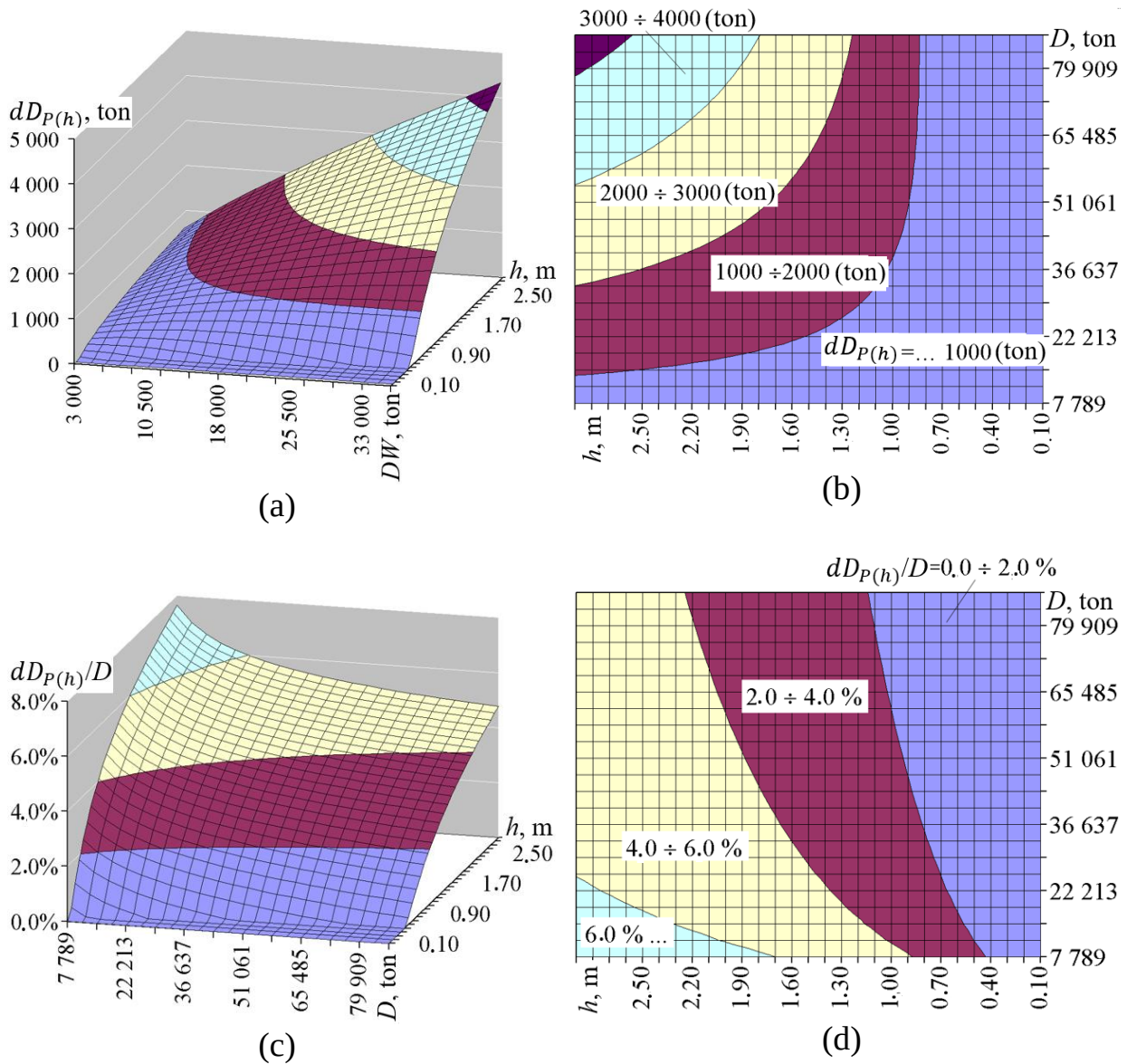


Fig. 4.11. Dependence of increment of the ship loaded displacement $dD_{P(h)}$ by it absolute value (a and b) and by the relative value (c and d, $dD_{P(h)}/D$) on assigned design constraint of solid ice thickness h and on the displacement D (without ice impact considering) and on design deadweight DW (a) for the option of the standard spacing

With use of the Norman factor in composition of the designing model the displacement increment $dD_{P(h)}$ is found in dependence on design deadweight DW and on the assigned design constraint of solid ice thickness h , it is shown in the graphs: for option of standard spacing (Fig. 4.11a) and for option the reduced spacing when installed the extra frames in the limits of ice impact (Fig. 4.12a), and on cargo waterline displacement D without the considering of ice impact (Fig. 4.11 b – d and 4.12 b – d).

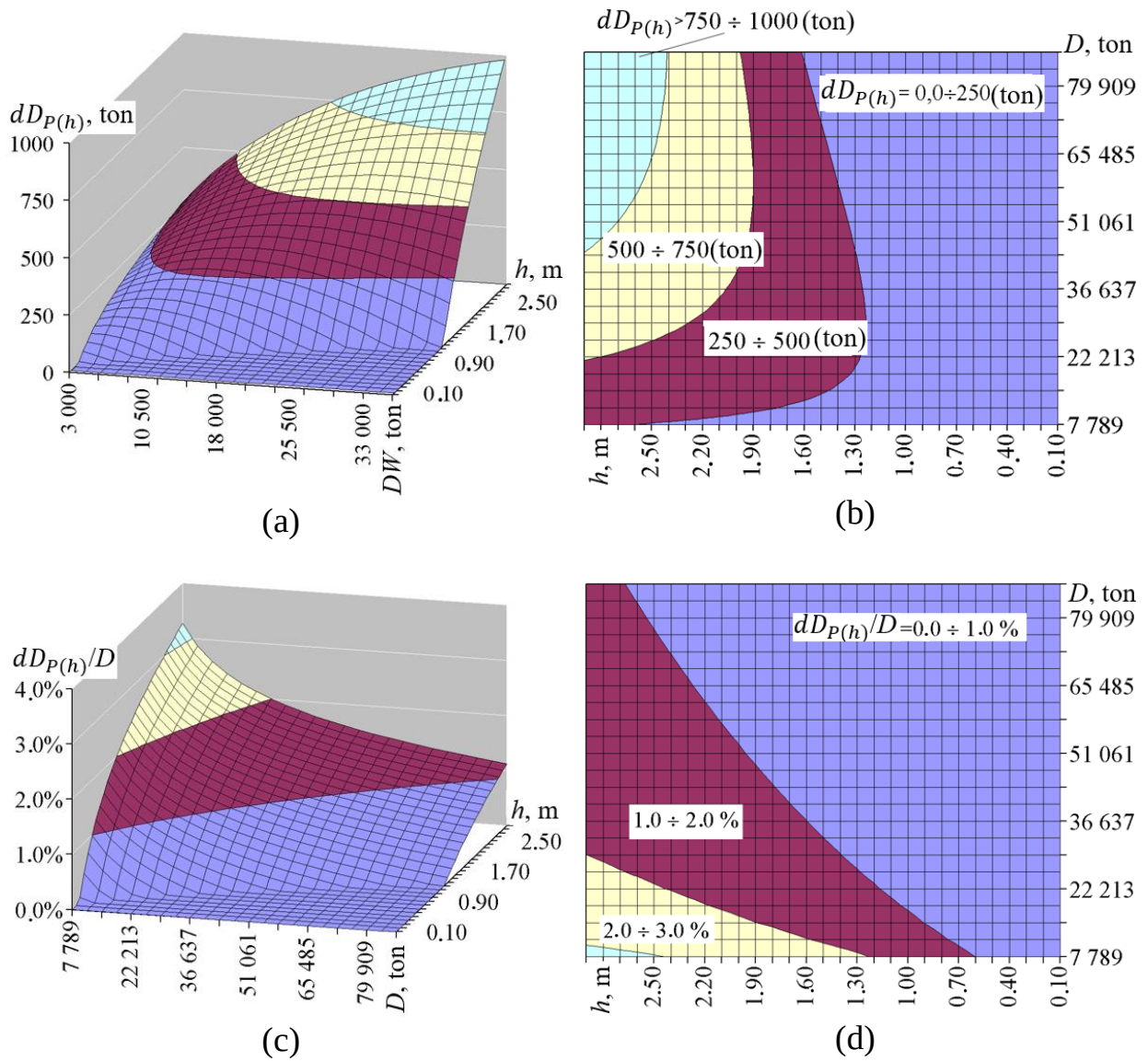


Fig. 4.12. Dependence of increment of the ship loaded displacement $dD_{P(h)}$ by it absolute value (a and b) and by the relative value (c and d, $dD_{P(h)}/D$) on assigned design constraint of solid ice thickness h and on the displacement D (without ice impact considering) and on design deadweight DW (a) for the option of reduced spacing when installed the extra frames in the side area of ice impact

Besides the design particulars of multifunctional ice-navigating ship, that is the characteristics of it subsystems, assumed at the initial designing stages as constant data, two groups of indexes are used for the determining of optimal design characteristics of the ship as methodological constraints: the first group – the mass of the assigned in design functional equipment, or the design constraint of tonnage (in particular of net register tonnage), assigned in the terms of references in accordance with the function of ship or it main system, which function corresponds to purpose of ship, and the second group of assigned indexes – the characteristics of ship

function in the ice, specified at the initial designing stages as the ship ice category, the arctic one or the icebreaking class, or as the design constraint on the ice overcoming abilities.

Considered constraints are converted to the estimates of relevant summands in the balance equations before finding of the ship characteristics dependent on the constraints, in particular they are to be converted to the values of certain components in the composition of design deadweight for determining of the objective function with the use of the mathematical model.

The graph analysis allows to conclude, that the greatest value of the increment of cargo waterline displacement $dD_{P(h)}$ of multifunctional ice-navigating ship considering assigned design constraint of solid ice thickness h corresponds the ships of smaller sizes. By the relative value the icebreaking function has less influence on design characteristics and particulars of ships of bigger displacement.

Analysis of factors impacting on the proportions of characteristics of multifunctional ice-navigating ship size (the design deadweight, displacement, holds volume, tonnages, etc.) allows to get the following conclusions:

1. Ship loaded displacement D or its design deadweight DW can act as variable characteristic when finding the optimal size of multifunctional ice-navigating ship with the account of specified design constraints, in particular, the investment constraint of subsidies, or the functional constraint, assigned as operation performances of ship in ice, for example the maximal thickness of the overcoming ice.

2. Alternatives, linked with the opportunity to improve the strength of side overlap by the shell thickness increasing or by strengthening of framing of the main direction girders, or by increase of their number by reducing of the spacing are in the approaches to ensure the side overlaps structural strength. In the first alternative the costs for ship construction or renewal are lesser and the durability of ship hull increases due to relatively lesser corrosion wear.

3. For evaluation of multifunctional ice-navigating ship performances in ice impacting the ship loaded displacement requires to determine the increment of mass of ship hull in dependence on assigned performances of the ship in ice and to find the proportion, so called the balance factor, of assigned load increment and the ship loaded displacement increment. The index of balance factor of the load increment and the ship loaded displacement increment (the Norman factor) are appropriately sustainable for the ship and makes up in the interval of 2.10 up to 2.40.

4.6. Dependences between the design particulars and characteristics of multifunctional ice–navigating ship

To reduce the dimension (the number of the independent sought variables) in the tasks of finding of optimal characteristics and design particulars of multifunctional ice–navigating the dependences between the characteristics and particulars, as well, as among ship particulars can be used besides of balance equation of the ship displacement (the mass balance equation). On the stage of determining of the ship design characteristics it particulars and their ratios are assumed known, which means the transfer of the issue of ship particulars finding to the next designing stages, and the approximal indexes of it particulars which adopted by the expert are used in the process of characteristics determining, for example, adopted according to analogs of the ship under design or the analogs of the ship subsystems or by the data of pre–design studies.

Proportions of ship design particulars and their values characterize the effective, reliable and seaworthy ship, safe in the operation, strong and durable insofar these properties correspond the analogs used.

Considered ratios of design characteristics and particulars are not attributed to the ship but to it subsystems in the frameworks of systemic approach, that is to the individual properties of integral ship. Use the data of the particulars, that are the indexes of analogues, for finding of optimal design characteristics of the ship does not come into the systemic conflict with the subject of design optimization, which is the determining of best design characteristics set by the accepted criterion, when using the constraints, assigned as the characteristics of general complex system, which part the ship under design is, and assuming the approximal values of the ship particulars.

For determining of optimal design characteristics of multifunctional ice–navigating ship the interdependence between these characteristics and the design particulars means that in the process of evaluations of options the data, in the other words, the design constraints, which are the characteristics of more general system, than the ship under design, remain constant as well, as the particulars of the ship and the proportions between these particulars. Moreover, the ratios between design particulars of the ship and it characteristics are to be assumed and considered constant when determining the design characteristics. In this case the design particulars, in the other words, the characteristics of ship subsystems, can only change in proportion to it characteristics variation, since the particulars are not considered independent under optimization of the ship characteristics.

It is supposed in this way that the particulars of ship are known usually by their relative values, and this allows to concentrate on the determining of optimal design characteristics at the initial stages of designing of multifunctional ice–navigating ship. At the following stages when doing the designing of ship subsystems, the subject is determining of the ship design particulars, and the characteristics of ship are the assigned constraints (the pre–determined).

When finding design characteristics of the ship on the bases of systemic approach the design constraints (the data), that is the particulars of ship (the characteristics of ship subsystems), in the broad sense one can initially determine among the following alternatives: the expert assumption; preliminary design study of ship structural subsystem; the use of one or few analogs, including the developing and use of parametric dependence linking the design particulars of the ship with it independent characteristics under determining by design optimization. Parametric dependences between design particulars of multifunctional ice–navigating ship and it characteristics corresponding to the last specified option of design constraint assuming when finding the ship optimal characteristics, are considered below.

Preliminary evaluation of the characteristics and particulars with the use of the dependences considered below could serve their initial approximation for use as the data when finding characteristics of multifunctional ice–navigating ship on the basis of the approaches of design optimization by the way of variation of the characteristics sought with the use of the consecutive approximations or by the other available algorithmic methods.

Equations and graphs of dependences between the ship characteristics and design particulars, as well, as actually the dependences between design particulars of the specifications of new ice–navigating ships of ice or arctic categories or the ice–breaking classes and of multifunctional icebreakers and the ships of these types under designing are generalized in the parametric formulas.

4.7. Parametric dependences of particulars on design characteristics of multifunctional ice–navigating ship

The dependences between the characteristics and design particulars of multifunctional ice–navigating ship, got by results of specifications process of the analogs – the new ice–navigating ships or their projects are given below.

Parametric dependence of the ship loaded displacement D (Fig. 4.13a) on the waterline length L of multifunctional ice–navigating ship looks like

$$D = 0.768 \times L^{2.118}, \text{ ton.} \quad (4.11)$$

Terminological clarification is appropriate. With the account of the characteristic hull shape of multifunctional ice–navigating ship at its initial designing stage the terminological difference is not so much of the indexes there: the length between perpendiculars and the length of the cargo load–line. These terms of the length dimension of ship of the considered type practically means the same. Therefore, for the purposes of the approaches presentation for determining of optimal characteristics and design particulars of multifunctional ice–navigating ship the common term the «design length» could be used for the considered index. It is supposed that this term corresponds close enough the waterline length, as well, as the length between perpendiculars of ship of this type.

Parametric dependence of multifunctional ice–navigating ship design deadweight DW (Fig. 4.13a) on the ship design length L is

$$DW = 0.10 \times L^{2.36}, \text{ ton.} \quad (4.12)$$

Parametric dependences of gross register tonnage GRT of multifunctional ice–navigating and net register tonnage NRT on its design length L looks like (Fig. 4.13b).

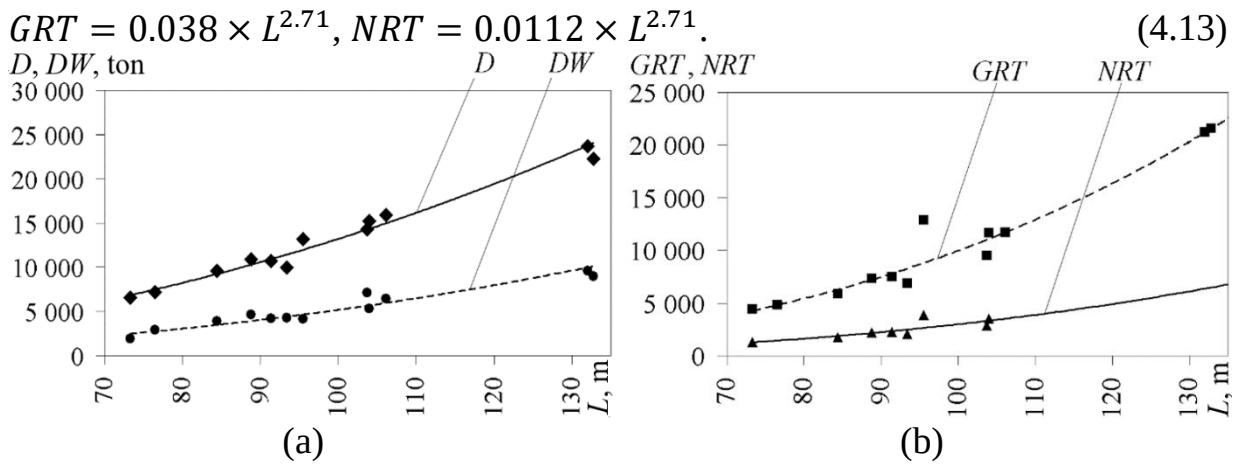


Fig. 4.13. Dependences of indexes of multifunctional ice–navigating ship design length L : (a) the ship loaded displacement at cargo waterline D and design deadweight DW ; (b) – the gross register tonnage GRT and net register tonnage NRT

Dependence of multifunctional ice–navigating ship design stock of bunker fuel onboard PFL (the maximal mass of fuel) on the ship loaded displacement D looks like

$$PFL = 23.2 \times L^{0.463}, \text{ or } PFL = 0.116 \times D + 575, \text{ ton.} \quad (4.14)$$

Parametric dependence of water ballast mass PBL (the maximal provided water ballast) on cargo waterline displacement D of multifunctional ice–navigating ship is

$$PBL = 0.0027 \times D^{1.5}, \text{ ton.} \quad (4.15)$$

Parametric equations between the design particulars of ice–navigating ship, and the dependences of particulars on characteristics of the ship give these indexes values for the effective, reliable and seaworthy ship of the considered type, safe in the operation, robust and durable to the extent that these properties are inherent the analogs, used when doing these the parametric dependences.

Parametric dependences of the particulars: the beam B , the draught T and the depth H of multifunctional ice–navigating ship on it design length L are shown on graphs (Fig. 4.14 a and b).

Parametric dependence of ratio of multifunctional ice–navigating ship design length to it breadth L/B (Fig. 4.14b) on the design length L looks like

$$L/B = 0.0043 \times L + 3.72. \quad (4.16)$$

Parametric dependence of ratio of multifunctional ice–navigating ship beam to it draught B/T (Fig. 4.14b) on the design length L is

$$B/T = 0.0161 \times L + 1.083. \quad (4.17)$$

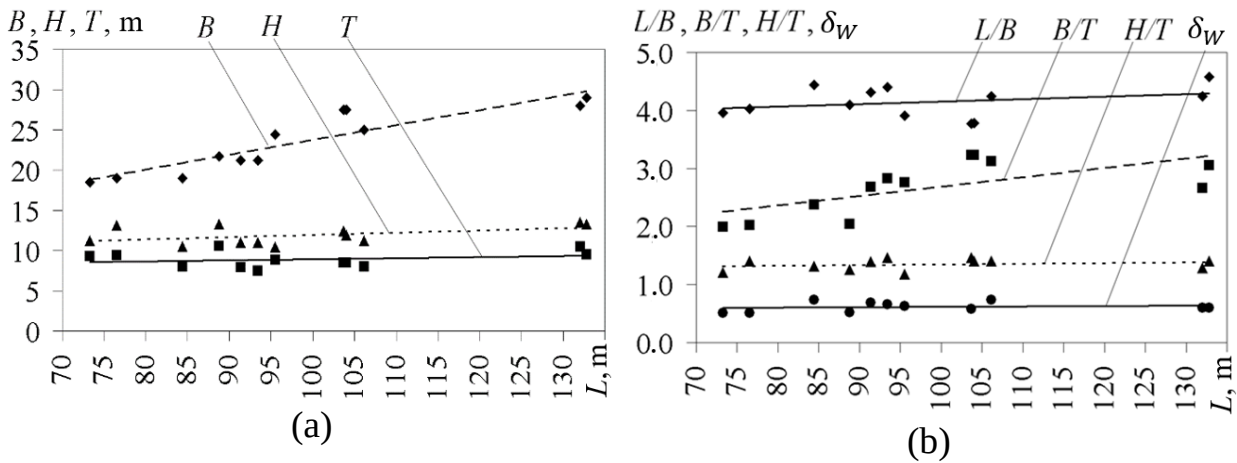


Fig. 4.14. Dependences between particulars of multifunctional ice–navigating ship on it design length L : (a) the beam B at the cargo waterline, the draught T and the depth H ; (b) the ratios of design length to breadth (L/B), of beam to draught (B/T), of depth to draught (H/T), the coefficient of hull overall completeness δ_w

Parametric dependence of the ratio of multifunctional ice–navigating ship depth to its draught H/T (Fig. 4.14b) on its design length L looks like

$$H/T = 0.0011 \times L + 1.235. \quad (4.18)$$

Parametric dependence of coefficient of multifunctional ice–navigating ship hull overall completeness: $\delta_w = D/(1.025 \times L \times B \times T)$, on ship design length L (Fig. 4.14b) is

$$\delta_w = 0.0007 \times L + 0.541. \quad (4.19)$$

The ratio of design length L of multifunctional ice–navigating ship to the length over all LOA by the results of statistic observations is approximately 0.89. The index of length over all is linked with the definite technological constraints in the ship construction. At the initial designing stages one could consider the length over all dependent on the design length as the design particulars interdependence of the ship.

Since the design particulars of multifunctional ice–navigating ship by their relative values (Fig. 4.14b) remain in the narrower intervals of their variation, than the characteristics, dependent on the design constraints, the data, and the ship particulars by their absolute value (Fig. 4.14 a and b), than using this property and the parametric dependences it is possible to reduce the dimension of the optimization task for practical reasons at the initial stages of the ship design.

When finding characteristics of ship at the initial stage of designing the use of those or other dependences between design particulars or between the particulars and characteristics correspond the initial stages of design, when the design optimization methods within the systemic approach, with the use of effectiveness criteria and objective functions, the concept of options comparability and the design constraints are applied for determining of optimal values of variable independent characteristics of multifunctional ice–navigating ship.

The use of those or other dependences between design particulars or between the particulars and characteristics is just the assumptions at the initial designing stages to find these particulars approximately and to use them as constraints in the independent characteristics optimal values determining, since at the next steps the finding of ship design particulars will themselves be the subject of use of the systemic approach and optimization methods or the other ones appropriate, if any are adopted usually for determining of those or other design particulars of ship or for clarifying of their approximal indexes adopted before by the parametric dependences at that design stage, when the characteristics of multifunctional ice–navigating ship were determined.

Wherein the particulars of the ship under design ($L, B, H, T, \delta_w, L/B, B/T, H/T, L/H$ and etc.) and its rest characteristics ($D, PG, GRT, NRT, Ne, N_{ICE}, v_s$, etc.) found approximately at the initial stages of designing and are dependent on those, which are determined by the optimization methods in the frameworks of systemic approach, for example dependent on found optimal characteristic of ship size (like the design deadweight DW) and/or on the other independent specifications, in particular, the selected one in the listed indexes of ship, besides the independent characteristics, serve to reduce using the indicated parametric dependences the possible ranges of values of design particulars and dependent characteristics of ship, which are to be exactly found at the next designing stages, when the found previously optimal values of the independent characteristics will be the data (the design constraints).

The developing of methodological approaches for finding the design characteristics of multifunctional ice-navigating ship and determining of analyzed functional graphic dependences and the necessary analysis of the results require the use of definite basic combinations of data, including the particulars and depended characteristics, corresponded the independent ones studied for the optimality.

The variant of basic combination of the data with the account of considered formulas (4.11–19) is indicated in the Chapter 5 (table 5.1, item 5.5). It should be mentioned that this combination of data can be considered as the offered design constraints for the follows graphic surfaces. Some of data of this basic combinations of one can consider as particulars, assumed by expert.

Checklist

262. Probabilistic cumulative influence of many factors on balance concept of the loaded displacement of multifunctional ice-navigating ship, given that impact of each one factor is insufficient.
263. The interchangeability of the variable characteristic of multifunctional ice-navigating ship in the mathematical model: or the designing deadweight, or the loaded displacement, having in mind that the designing deadweight and the ship loaded displacement are usually interdependent by mass balance equation.
264. Gradual transformation of the ship mass balance equation by designing stages to the sum (the list) of independent load components, since the decisions made for each of structural element of the ship, combined by this equation, means transfer of this element to the number of independent load components at the next designing stage.

265. The ship efficiency, robustness, seaworthy and other performances of the ship is consistently obtained from the prototypes used in the designing, but not the ship innovativeness is consistently obtained, for which the use of prototypes in designing is not enough relevant.
266. The absence of any separate, in particular, the physical properties of the ship, which would predetermine the ratio between cargo waterline displacement and the total of the ship independent components of the displacement, the probabilistic nature of assumption of the ship displacement balance.
267. Importance of accumulation and systematization of successful random decisions when designing of multifunctional ice-navigating ships as the independent approach, although the outdated one, besides of the systemic approach with the objective functions and the design constraints.
268. Probabilistic nature of optimality criteria of multifunctional ice-navigating ship and of economic indexes generalized in the criterion of optimality.
269. The dependence of the ship empty displacement components on the loaded displacement and on assigned design constraints (the data).
270. The mass balance equation coverage the total set of items of the ship loaded displacement irrespectively in what way this equation had got, or by the items summation, or by the other way, in particular, using the alternative data of the analogs displacements and these displacements independent parts.
271. Characteristic of multifunctional ice-navigating ship design deadweight consisting the maximal total of variable loads: cargoes, fuel, supply, ballast, the residual bilge water or the water on the deck, the crew with the luggage, ship stocks and other maximal of variable summands, which is usual for determining of deadweight in the operation of the ship, and besides of these listed items consisting the constant summands of payload, assigned in the terms of references for designing, that is the mass of main equipment, created before designing of the ship in accordance with the ship assignment, and the another items of the ship mass, which in the designing do not depend on the ship loaded displacement.
272. Zero exponent index of the design deadweight components dependence on the ship loaded displacement in the mass balance equation.
273. Gradual transformation of the mass balance equation in to the load table along the designing stages by deciding the particulars of elements entering in the equation as the summands.
274. The dependences (the balance equations and the parametric ones) of multifunctional ice-navigating ship characteristics and particulars on one selecting as the independent in design optimization.

275. When refining the dependent characteristics and particulars at the next designing stages one would consider the vicinities of their deviations from the approximal values adopted at the first designing stage, when the optimal values of independent characteristics had find, and the ambiguity of the refining characteristics and particulars in-fluence on the criterion, when their cumulative impact is even less than small impact of each individual of them.
276. Index of multifunctional ice–navigating ship seaworthiness and patency in solid ice of assigned thickness as the second independent characteristic, besides of the ship size, indicating ice or arctic category of ship or the icebreaking class and predetermining largely other ship properties in ice, corresponding it density and cohesion.
277. Hierarchy of the ship patency in ice performances with the availability of the most important one, likely the icebreaking patency in solid ice, affecting the other properties of multifunctional ice–navigating ship.
278. Choice design deadweight of multifunctional ice–navigating ship and the assigned thickness of solid ice, which the ship overcomes, for determining and analysis of the functional surfaces of the ship indexes as the arguments by the reason of the maximal conformity of indicated characteristics for the ship functional description.
279. The features of the index of assigned thickness of solid ice, which the ship overcomes, attributing the selecting of this index to the set of the ship characteristics: the dependence of the set of other performances in freezing seas on the assigned thickness of solid ice and this index correspondence with ice or arctic category of the ship or with icebreaking class.
280. The performances of multifunctional ice–navigating ship design deadweight index to chose it as independent variable in finding of optimal design characteristics of the ship: the dependence of other characteristics and particulars on the design deadweight, the coverage of assigned payload in the terms for references, the simultaneous indicating by the design deadweight of design characteristic and the utility function in the composition of the ship mathematical model and economic criterion, the specification of the design deadweight in the contracts and in the data bases.
281. Assigning of direct and indirect increments of displacement by the endowing the ship by the functions extra to existing ice category or changing the ice category to the original multifunctional ship with not the category or with the other one, or the combining of these approaches.

282. Mass balance equation in the form of increments (the derivative form) – the Norman factor, used usually to process the prototypes data when designing the ship, including the data process in the mathematical model algorithms where this factor considered the data or the function (the derivative of the mass balance equation).
283. Proportional dependence of full increment of displacement of multifunctional ice–navigating ship on the assigned (explicitly or implicitly) increment of the displacement, the use of the Norman factor.
284. The factors of multifunctional ice–navigating ship assigned performances and patency in ice influence on the ship loaded displacement: the mass increment of the ship hull in dependence on assigned design constraint of the thickness of affordable to overcome ice field, which predetermines the extra thickness of side shell, and the Norman factor of full increment of loaded displacement ratio to implicitly set load increment (the performances and patency in ice).
285. Load of modular equipment of multifunctional ice–navigating ship specified in the design deadweight.
286. The general functions of assignment of ice–navigating ships considered at their designing.
287. Multifunctional ice–navigating ship machinery assigning originally or the retrofitting for it bunkering by the natural gas in the ocean on the production grounds, which extends the ship autonomy.
288. Extra functions of the training ship under designing besides of the assigned ones of multifunctional ice–navigating ship.
289. The modularly equipped in standard dimensions of the ISO containers the additional engine room on the training multifunctional ice–navigating ship connectable to follows ship systems: the natural gas reception, the exhaust system, the vapor recovery system of the gas, the electric power network, the automated control system, etc.
290. Functional flexibility linked with use of modular concept of the ship equipping and the suitability of multifunctional ice–navigating ship for design exchanges and designing modernization, so the opportunities of constructed ships renewal.
291. The usual standardization and interchangeability of equipment of multifunctional ice–navigating ships and other ones.
292. Advantages of the trend of marine engines transfer on the use of natural gas as the fuel for the economic and environmental reasons, especially for servicing of natural gas production and transportation from the offshore grounds.

293. Determining of multifunctional ice–navigating ship displacement consisting of the summands: the displacement depended on explicitly assigned it independent components (the design deadweight) and the increment of displacement depended on assigned design constraints implicitly impacted the displacement, like the specified thickness of ice which the ship can overcome or the ice category of the ship.
294. Correspondence of greatest value of cargo waterline displacement increment of multifunctional ice–navigating ships of smaller sizes, considering assigned design constraint of solid ice thickness, which the ships can overcome.
295. Assumption of multifunctional ice–navigating ship design particulars constant when finding the ship design characteristics and adopting conventional particulars according analogs of the ship under design or the analogs of the ship subsystems or by the data of pre–design studies in the process of the ship characteristics determining.
296. The variation of the ship design particulars, in the other words, the characteristics of it subsystems, only in proportion to variation of the ship characteristics, since the particulars are assumed not independent under optimization of the ship characteristics.
297. Initial determining of the ship particulars among the alternatives: the expert assumption; preliminary design study of ship structural subsystem; the use of one or few analogs, including the developing and use of parametric dependence linking the design particulars of the ship with it independent characteristics under determining by design optimization.
298. Terminological similarity of indexes of the length between perpendiculars and the length of the cargo load–line use at the initial designing considering the hull shape of multifunctional ice–navigating ship and the consequent relevance of term of the ship design length.
299. The narrow intervals feature of design particulars of multifunctional ice–navigating ship variation by their relative values than of the intervals of absolute values variation of the design characteristics and particulars, when finding the optimal values of the characteristics.
300. The assumptions at the initial designing stages in the form of dependences between design particulars or between the particulars and characteristics which help to find these indexes approximately to use they as constraints in the determining of independent characteristics optimal values and allow to refine the particulars of the ship and it dependently found characteristics at the next designing stages.

Chapter 5. Criteria for determining of optimal design characteristics of multifunctional ice–navigating ship

Subject of study of the criteria, the objective function, the mathematical model developing includes the decision of following issues corresponded with the creation of approaches for determining of optimal characteristics and design particulars of multifunctional ice–navigating ship:

- analysis of methodological principles of the ship design characteristics optimization on the basis of systemic approach concepts, the formulation of the constraints and the concept of options comparability;
- analysis of cumulative probabilistic influence of diverse factors on ratios of the ship characteristics, assumptions of the ship characteristics balance: the ship loaded displacement, the design deadweight, the register tonnage, etc.;
- evaluation of functional constraints for optimization of design characteristics of multifunctional ice–navigating ship, in particular, the determining of constant part of the ship design deadweight, corresponding the mass of assigned equipment in the terms of references in accordance with the ship functional purpose;
- evaluation of physical constraint of assigned level of seaworthiness and patency of ship in ice, for example by criterion of maximal affordable to overcome thickness of solid ice;
- analysis of hierarchy of the economic criteria with the account of indexes of the minimized costs, both investment and operating ones, as well, as considering the relevant amendments of costs' economy upon probable admission of extra budgetary income and defining of characteristics and defining the utility function of multifunctional ice–navigating ship;
- developing the objective functions and the mathematical models for determining of optimal characteristics and design particulars of multifunctional ice–navigating ship according to the adopted economic criteria for the use of these functions and models at the initial stages of the ship designing;
- study of properties of design characteristics found in the vicinity of their optimal combination, including the research of sustainability of the property of found design characteristics optimality, given that the sustainability of these properties is linked with the necessary extremum assumption of mathematically smooth and convex objective function;

– evaluation of sustainability optimal combinations of the ship design characteristics by economic criterion considered with the risk index.

Any known economic criteria used for design optimization of the ship in the form of its objective function f , are based on the correlation of general economic indexes of ship under optimization: the total annual income of the ship I , the operation cost (annual) C and the investments RC . The optimality criterion, in the form of objective function f is a way of use of the economic efficiency criterion for determining of optimal design characteristics of the ship is the mathematic generalizations over the total annual income I , the operation costs C and the investments RC , is in dependence on the variables X , the parameters Y and the data Z , since the indicated general economic indexes of ship (I , C and RC or MV) are determined in dependence on these values (X , Y and Z). The general economic indexes of ship are monetary. As opposed to the annual income I and the operating costs C , which are characterized mathematical models and algorithms by distributed in time t cash flows and are usually determined and summarized annually, the investments (RC or MV) have one-time or discrete nature, or could be converted to the minimized criterion of comparative effectiveness (the relative one) of the present worth $(C+(RC+OC)\times i)$.

Market value MV characterizes the variant of investment index in the composition of economic criterion in the case if multifunctional ice-navigating ship is purchased at second-hand market with account of impact of existing inefficiencies of the ship on the investments value in distinction from the replacement costs RC or the reproduction costs. In the composition of the criterion and the constraints for determining of optimal characteristics of the ship under designing for the construction costs the index of replacement or the reproduction of the ship costs RC in the market economy is used, and not the market value index MV at second-hand market.

Objective function for determining of optimal design characteristics of the ship is developed and used in the form of mathematical model, besides of that, the objective function can be of the graphic form and be used as the sequences of formulas, in the form of rules, in the tables, the algorithms and etc., although the digital mathematical model is usually most convenient. The objective function is the dependence of the applied optimality criterion on characteristics of the ship X , varied in the process of finding of their optimal values, on initial data Z , which are assigned design constraints and methodologically characteristics of the more general system, than the ship under design, and on the design constraints in the form of the parameters Y , that is on the characteristics of subsystems of the ship under design, which are adopted as conventionally constant in finding of design characteristics of ship and clarified at the following stages– in designing of ship subsystems.

General economic indexes (I , C and RC or MV) do not indicate the critical judgments to select the optimal design options, and by themselves they are not the optimality criteria when doing ship design optimization, but these indexes are combined for formulation of economic efficiency criteria, which are generalized mathematically by correlating of these basic indexes. For example, it is not possible to determine if it is required to select optimal characteristics of ship by the criterion if operating costs C minimization considered separately of the follows indexes: the annual income I and the investments RC . When varying the characteristics of ship under design one need to study the joint variation of general economic indexes of ship, as costs, so the income. The math operations over the general economic indexes, in particular, the form of correlation of income and costs, when formulating the criteria and the objective functions, indicate the critical judgements, which are required for the compromise of advantages and disadvantages of options when determining optimal design characteristics of multifunctional ice-navigating ship.

Considered economic indexes in the composition of efficiency criterion for determining of design characteristics of the ship are used by their values systematically presented for the same day. Methodologically this day could be associated with the delivery of the constructed ship, or with the ship design completion, or with other day can be adopted. For the selection of design characteristics of the ship by adopted one of criteria, related with the general economic indexes (I , C and RC or MV), the simultaneous accounting of these indexes is important, and not for each date of their assessment, which in the simultaneity of their generalizing can vary with the formal financial transformations, and this will not impact the resulting design characteristics of ship, which correspond to the tradeoff of costs (C and RC or MV) and effect (or the income I), generalized for the same day. To bring the general economic indexes (I , C and RC or MV) to a comparable form of their present values for the same day the macroeconomic index of total commercial risks in the form of the discount rate i is used.

When using economic indexes as optimality criteria for design characteristics determining of multifunctional ice-navigating ship, it should be noted that economic criteria are more general in relation to other possible indicators. For example, when determining optimal characteristics of individual subsystems of the ship, own criteria can be applied, in particular, such as the efficiency of the propeller, the mass of any particular structure, etc., which in such issues of characteristics determining of individual ship structures can be the common practice.

At the same time, if the improvement of these particular criteria due to certain design or technological circumstances leads worsen of the economic indexes,

for example, when the reduce of the structure mass or an increase of propeller efficiency are associated with the use of unjustifiably expensive materials and products, then when finding the optimal characteristics should nevertheless adhere to economic criteria, which means their most general nature for design optimization issues.

5.1. Systemic interdependence of economic criteria and environmental assessments of processes of the ship creating and navigating

There is a link between economic criteria and environmental assessments, and the link is not these indexes contradiction. It is known that the terms economics and ecology have a common Greek root «eco», meaning habitat, so the term economics could be understood as habitat management, and the term ecology as the study of habitat (the environment), this is associated with the habitat protection. And the habitat is considered generally, including the industries and any resources.

If the index of the minimized costs (the present worth, investments, etc.) is used as economic criterion, then it can be seen that this index in the definite approximation indicates the purposes of environment protection, since when the costs minimizing the amount of the resources used reduces, considering total of the materials, power and labor, and for the restoration of labor the resources are required too. The resources used are pollutions of the environment, therefore, minimizing the costs and the amount of resources used in multifunctional ice-navigating ship creation (it construction and equipping) and navigation means reducing of environmental pollutions as well.

If maximized profit is used as an economic criterion, then the environmental assessments by this criterion will also be indicated in the definite case if the income index is limited, given that when it is limited the profit increase is corresponded with the added value increase, that is the costs reduce, which meet the objectives of ecology and environmental protection by reducing the use of resources.

Economic criteria in the form of profitability (the return on investments) or in the form of an internal rate of return, which corresponds to the profitability adjusted for the rate of inflation, in a certain approximation correspond the environmental assessments and environmental protection issues in the specified case when the rate of return in the numerator of profitability can increase by value added, and not due to the growth of income in proportion to the costs growth, and the indicator of investment costs in the denominator of the profitability formula, which reduces as factor of profitability increase, would also mean the decrease of resources use considered in investment costs, and this coincides with ecologic assessments to protect environment.

That is the use of economic indexes as optimality criteria when designing multifunctional ice–navigating ship is generally consonant with environmental objectives and corresponds with systematic approach, although the economic criteria are approximate for environmental assessments, since, for example, costs, both operating and investment, cover the total of various used resources, considering the materials, power and labor, and the use of resources of each type has different environmental assessment per unit of the resource.

At the same time, the use of a systemic approach makes it possible to refine the solutions at subsequent stages of designing of a multifunctional ice – navigating ship, when the ship particulars are determined, that are the characteristics of its subsystems. Taking into account the ratio of both the economic and, possibly, the ecological values of the resources, used in the creation and operation of the ship, in the subsequent stages of multifunctional ice–navigating ship designing the adjustments can be made in the characteristics and design particulars, if at the previous design stage the costs total, used as the criterion, was found reasonably minimal by the choice of the ship design characteristics the constraints. Thus, environmental assessments in the definite approximation are considered in the economic criterion when determining optimal characteristics and design particulars of multifunctional ice–navigating ship.

Moreover, the separation of problems to protect the environment from the system in which the economic and environmental issues are decided together and studying the problems of environmental protection separately from the economic ones can cause skeptical caution. For example, certain investments that do not have economic goals, but only aimed at environmental results, in particular, the creation of an installation on the shelf that would absorb greenhouse gas, methane and carbon dioxide from the atmosphere for their dissolution in water and burial in rocks under the bottom of the ocean, let say such a project is being discussed, or other similar tasks that do not have economic goals, but are aimed only at cleaning the environment, would require a large consumption of resources of various types in investment and operating costs, considering the materials, power and labor, etc., and the resources use would be corresponded with emissions of greenhouse gases and carbon dioxide from fossil fuels.

Probably, for nowadays technological level, there is a maximum justified degree of environmental cleaning. One cannot cleanse the environment without polluting it with used resources spent on cleaning, so one cannot cleanse the environment completely. This can impact the choice of the objective alternatives – which is more important: the environment cleaning or minimizing of its pollution, and the second

specified goal closely corresponds to the use of economic criteria of minimized costs, as well as profit and profitability on the concept of added value, including when designing of multifunctional ice – navigating ships.

The possible absence of economic goals and the emergence of additional factors of environmental pollution when spending resources in investments and operating costs incurred to solve environmental problems separately from economic ones, can raise doubts in projects to protect the environment outside the system of interconnection of economic criteria and environmental assessments of the processes of multifunctional ice–navigating ship creation (it designing, construction and equipping) and operation, in which approximate estimates of the reasonable use of resources economic criteria of minimized operating and investment costs are giving, which is consonant with environmental objectives, as well as the criteria of profit and profitability, determined in accordance with the concept of added value.

5.2. Criteria for determining of optimal design characteristics of merchant ship assigned for mass construction

The use of the economic efficiency criteria and the systemic approach for determining of optimal values of design characteristics is illustrated below with the example of objective functions use for merchant cargo ship under design, assigned for batch construction. Efficiency index used as the objective function, linked with costs minimization or with the maximization of the profit (or the profitability), is used usually for ship planned for serial construction on the basis of utility concept when formulating economic criterion. Economic interests are investor's motive, which are aimed to marine resources mastering. Financial estimate of corporative investor, acting on the basis of economic self-sufficiency, serves the design constraint for determining of optimal characteristics of the ship. Complex of self-sufficient corporate navigating company's assets, for replenishment of which the construction of merchant cargo ship of the series is planned, can be evaluated for finding this constraint for determining of optimal design characteristics of the ship.

Costs (the investments) and the effect are compared. At that when finding the effect of marine resources mastering to these resources in the broad sense one can attribute any properties of the ocean environment, suitable for the productive use with the serial constructed ships /171 and 176/: the concept of ocean, that is the reservoir with economic potential of coasts, with the ocean cargo traffics and etc., not limited only to the mineral resources of the sea or aquatic biological resources, and includes any legal opportunities of industrial activity in the ocean on terms of economic efficiency and self-sufficiency, or the terms of other economically defined utility.

Marine cargoes traffics, for example the liquefied natural gas transportation or the other cargoes in freezing seas can be attributed to ocean resources in the terms of economic methodology as well, as the navigation service and support of this or that industrial activity on the offshore of freezing seas, including the servicing of hydraulic engineering construction, the fulfillment of power generation in the sea or the natural gas liquefaction, or other economic activities in the ocean, in particular, the organizing in ocean of the training process of cadets in the considered professional activities.

Criterion for selection of optimal values of serial merchant ship design characteristics and particulars can be the economic index adopted of the set of two inter-related ones, the first, the minimized costs for the ship creation: it designing, construction and equipping, the ship operation and maintenance, generalized by the economic discounting to their comparable present values, and the second, the profit or the dependent index of investments in the ship creation profitability, like the internal rate of return *IRR*.

Indicated economic criteria as the result of combining of economic indexes for merchant cargo ship planned for batch construction, generalized by the economic discounting to their comparable present values, are: the investments for ship construction *RC*, the annual operating costs of ship *C*, the working assets for the ship equipping and operating costs prepay *OC*, the macroeconomic index of investment risks total *i* (the discount rate, or the index of the cost of capital use a year) and the annual cargoes carrying capacity Q_G on the marine cargoes traffic of the specified extent (the characteristic of economic effect, in the other words, the index of utility function of merchant cargo ship) it is possible to submit of specific present worth (PW/Q_G) per the unit of economic effect Q_G

$$PW/Q_G = (C + (RC + OC) \times i)/Q_G, \quad (5.1)$$

or in the form of the internal rate of return *IRR* index, which does not contain the index of the effect Q_G , but has the index of the income *I*, the cash flows (*I* and *C*) are considered comparable and synchronous, as well, as the investments (*RC* and *OC*), and they generalizing by the economic discounting to their present values is no need, and the index of the internal rate of return looks like

$$IRR = (I - C)/(RC + OC). \quad (5.2)$$

Given the characteristic international partnership in shipbuilding and in ocean navigation and cooperation in these industries, as well, as world markets competing

of marine batch shipbuilding, it is logical to apply the US dollar as monetary unit for determining of economic indexes in the estimates. This monetary unit is usual for the indicated markets estimates, and for transformations of indexes in the US dollar in to the units of other national currencies the data of state banks would be used of any countries on the exchange rate of national currencies. On the other hand, used frequently monetary units of US dollars in the international transactions, depend on market fluctuations of appropriately small degree, and their appropriate sustainability is convenient for US dollars use in a long-term investment, such as the ship construction. The indicated property of appropriate sustainability of US dollars purchasing power could serve the reason for neglecting the amendment to the index of the internal rate of return *IRR* of the consumer price index growth rate, since the indicated amendment is small due to appropriate sustainability of US dollars, and with the account of the purpose of criterion of the internal rate of return the amendment would not have the significant influence on values of optimal design characteristics of the ship got.

Criteria of the present worth or the specific present worth are of comparative nature (the relative) and they indicate the preferences in sets of compared options of multifunctional ice-navigating ship. Absolute economic nature has the internal rate of return economic efficiency criterion, or others ones, depended on the specified – they indicate as the preferences in sets of compared options of multifunctional ice-navigating ship, so as the preference of investing in the ship creation compared with the macroeconomic index of costs for capital use. To decide about the ship optimality, it is required to know, that the selected variant of the ship is the best compared with others and is this option effective in the macroeconomic environment. Because of that if the comparative nature (the relative) criterion is used in the ship design optimization, there are to be any extra index of the ship absolute efficiency, or the assumption that it is.

When using the minimized criterion of comparative (the relative) effectiveness of the specific present worth (PW/Q_G) and the maximized criterion of overall efficiency (the absolute) of internal rate of return *IRR* for finding of optimal characteristics in case of mass construction of merchant ships or at developing of the terms of references for the contracts for construction of these ships it is possible to consider, that for new batch constructed merchant ship the investments for it construction *RC* exceed significantly the working assets *OC* for prepayment on operating costs *C* with the account of the characteristic periodicity of income and the required costs to pay for the fuel and the supply. Therefore, in the formulas of the economic

criteria (5.1 and 5.2) for determining of optimal design characteristics in total with investments for the ship construction RC the working assets OC are omit

$$PW/Q_G = (C + RC \times i)/Q_G, \quad (5.3)$$

$$IRR = (I - C)/RC. \quad (5.4)$$

With the use of the developed mathematical model for the example of determining of optimal design characteristics of the LNG–tanker the criteria: the specific present worth (PW/Q_G) per unit of economic effect Q_G and the internal rate of return IRR are determined by the formulas (5.3 and 5.4) respecting the concepts of systemic approach in dependence on the design constraints and on the varied characteristics – the operation velocity v_s and the design length L of the ship and these objective functions are indicated in the form of graphic surfaces (Fig. 5.1 a and b), and in the projections to the base plane of LNG–tanker characteristics sought (Fig. 5.1 c and d). Since the transactions of the participants of other states by the international contracts are provided usually on the basis of international cooperation, then the monetary indexes on the graphs are indicated in the US dollars.

These monetary indexes could be transformed in the national currencies by official rate of US dollar, set by national banks. Considering the exchange rate proportionality, the use of certain monetary units does not affect the shape of graphic surfaces and the optimal values of the ship characteristics and design particulars got relevant the minimal or maximal values of objective function.

For illustrating of methodological approach when selecting optimal design characteristics two options of the batch constructed LNG–tanker different by the size (the displacement, tonnages, the cargo volume, etc.) and by number of tanks for the liquefied natural gas are compared for example. The tanks and cargo systems, as well, as the power installation are the main functional subsystems of ship of this type, which refers to the number of the most complex structural merchant cargo ships.

Compared options (1 and 2) of LNG–tanker have the following characteristics: option 1 (Fig. 5.1e): cargo waterline displacement – 122 239 ton; light displacement – 36 671 ton; gross tonnage – 145 000; net tonnage – 367 00; cargo capacity (98 %) – 145 600 cubic m; length over all – 288 m; length between perpendiculars (the design) – 274 m; the breadth at draught with cargo – 49.0 m; draught – 11.40 m; the hull of ship doubled; cargo tanks – spherical, 4 items; class +100A1 2G; power of main engine – 24 100 kW; operating velocity – 19.0 knots; option 2 (Fig. 5.1f): cargo waterline displacement – 145 000 ton; light displacement – 42 000 ton; cargo

capacity – 174 700 cubic m; length over all – 330 m; length between perpendiculars – 316 m; the cargo tanks – 5 items.

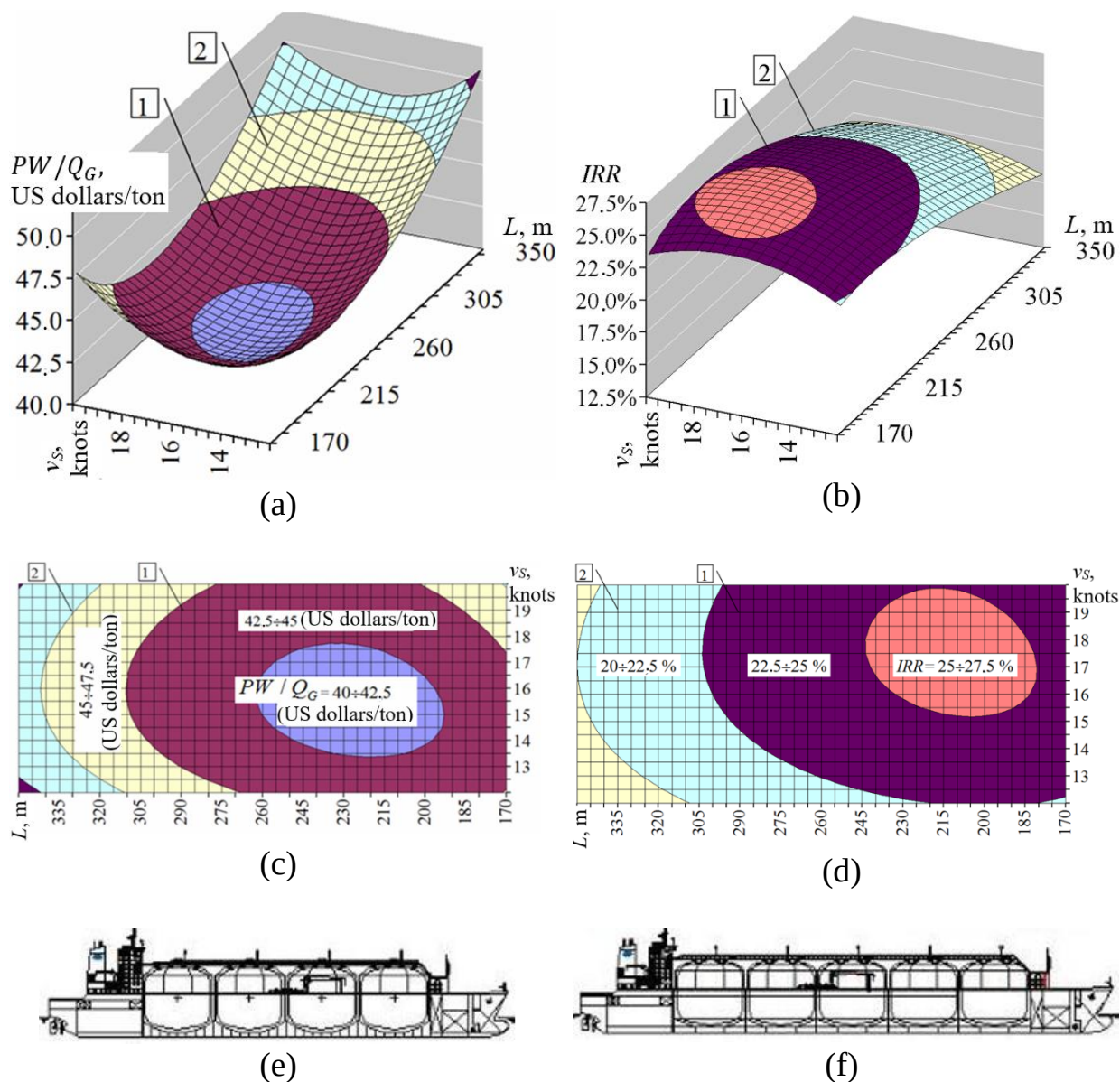


Fig. 5.1. Objective function and the options comparison (1 and 2) of batch constructed LNG-tanker by minimized criterion of specific present worth (PW/Q_G , a and b) and by maximized criterion the internal rate of return IRR (b and d), the ships general arrangement: options 1 (e) and 2 (f)

Considered options of LNG-tanker besides of indicated characteristics and design particulars differ the other characteristics dependent on listed ones.

It is indicated for criteria of the specific present worth (PW/Q_G) and the internal rate of return IRR the objective functions in the forms of graphic surfaces (Fig. 5.1 a and b) and in the form of projections on the basic plane of variables (Fig. 5.1 c and d) for the considered data: the line extent between point of departure

and port of arrival 5 000 nautical miles, the day capacities of cargo handling in the both harbors 20 000 ton/day, the total of investment risks, that is the discount rate 15 % in the considered example the smaller ship (option 2) has the benefit (the option 1, Fig. 5.1e).

In the same time the best values of both economic criteria would correspond the smaller ship, for example, such an LNG–tanker, which is indicated on general arrangement scheme (Fig. 5.2), having the following approximal characteristics and design particulars: cargo waterline displacement – 105 000 ton; light displacement – 31 000 ton; cargo capacity – 145 600 cubic m; length over all – 245 m; the design length – 232 m; cargo tanks – 3 items; capacity of power installation from 15 000 to 20 000 kW; operating velocity from 15 to 17 knots.

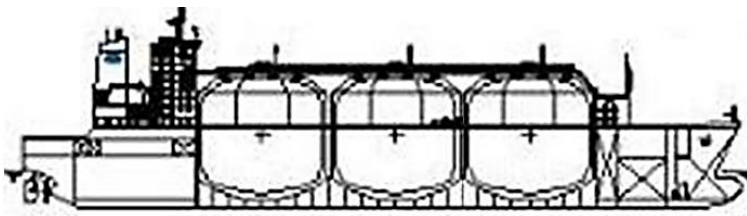


Fig. 5.2. Option of LNG–tanker, having maximal advantages by considered criteria of the specific present worth (PW/Q_G) and the internal rate of return IRR

Design constraints (the data) are used, assigned in the terms of references, characterizing the more general system in the frameworks of systemic approach, which subsystem is the ship under design, besides the particulars adopted conventionally at the ship initial designing stages, when determining it optimal characteristics. The indexes of cargo traffic, in particular such as extent of marine cargo line, specified 5 000 nautical miles in the considered example, and the intensity of cargo handling in the harbors (for the cargo of liquefied natural gas the intensity of cargo handling in considered example assumed 20 000 ton/day) can be considered as the data of general system for cargo ship designing intended for batch construction.

Analysis of the influence of initial data deviations, which are possible from their specified values, on corresponding variations of optimal design characteristics of the ship is of the interest when assigning these data values, for example, to answer the question will those or the other deviations of data lead to the conclusion change in the considered example of the optimal values determining of the ship characteristics and corresponding recommendations change of the relevance of more compact LNG–tanker, let's say if the extent marine cargo line will practically be bigger, that

is not the 5 000, but the 8 000 nautical miles. The results of determining of the economic criteria for specified changed option of data are presented on the graphic surfaces of objective functions and on the projections (Fig. 5.3 a – d).

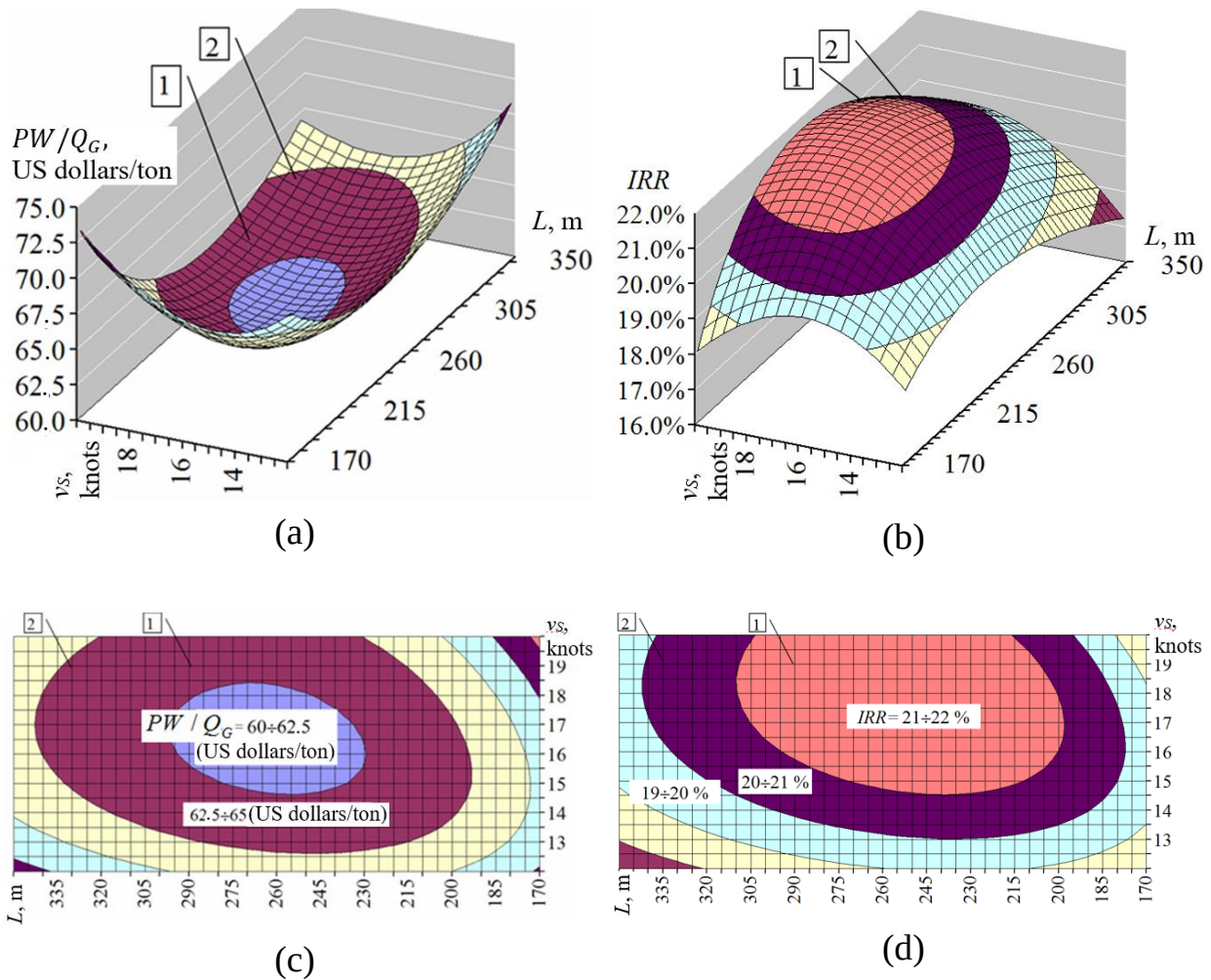


Fig. 5.3. Objective function and comparison of considered options 1 and 2 of LNG-tanker assigned for the batch construction by minimized criterion of specific present worth (PW/Q_G , a and c) and by maximized criterion of internal rate of return IRR (b and d) for the data of marine cargo line extent 8000 nautical miles

If the intensity of cargo handling in the harbor of cargo departure and in the harbor of it delivery as well will be bigger, that is not 20 000, but 30 000 ton/day, than the results of determining of the economic criteria is indicated on the graphic surfaces of objective functions and on the projections on the basic plane (Fig. 5.4 a – d).

Data (assigned design constraints) change in indicated ranges by graphs of objective functions it is possible to characterize as noticeable tendency of the ship optimal size (in particular case – it design length) and it velocity increase, although

when varying data in these ranges the general conclusion of economic relevance of more compact LNG–tanker, which general characteristics are indicated above, is not change.

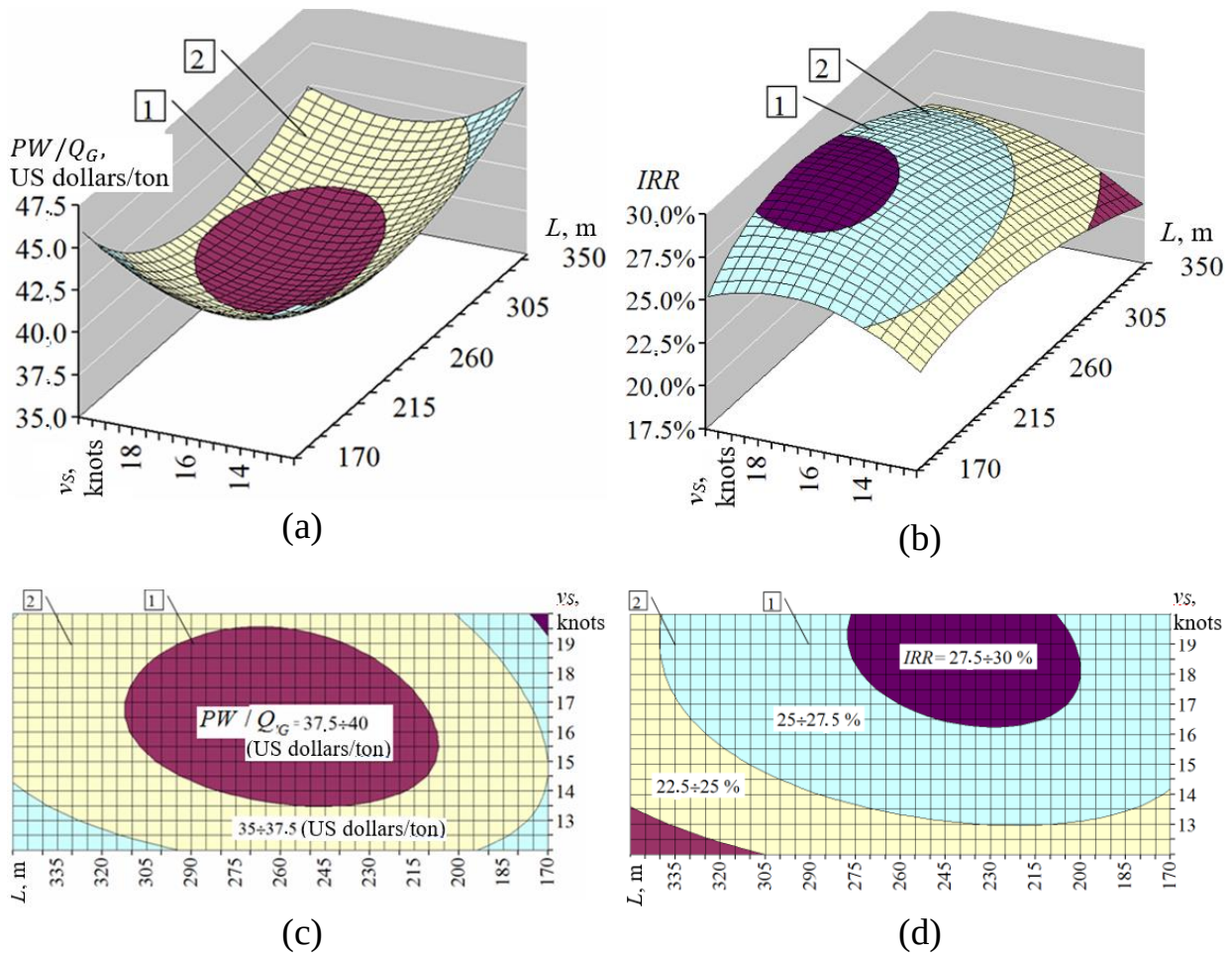


Fig. 5.4. Objective function and comparison of considered options 1 and 2 of LNG–tanker assigned for the batch construction by minimized criterion of specific present worth (PW/Q_G , a and c) and by maximized criterion of internal rate of return IRR (b and d) with account of cargo handling intensity in harbors of departure and arrival assumed 30 000 ton/day

The considered example illustrates the general methodological approach of the economic criteria use in the form of objective functions and shows the importance of assured determining the design constraints (the data) impacting the results of finding of optimal design characteristics of the ship, assigned in the batch construction, that is the importance of characteristics of the general system (in the considered example – the marine cargoes traffic), to which the ship belongs as the subsystem.

Use of the economic criteria in the form of the objective functions within the systemic approach and the use of mathematical models are relevant for determining

of optimal design characteristics of the ships of innovative types, which creation is provided according to the Shipbuilding Industry Development Strategy, according to the Federal programs of shipbuilding, by plans of navigation in freezing and Arctic seas as well. In the same time the methodological features are available, arising, in particular, when defining the concept of general complex system, to which the ship of innovative assignment belongs as subsystem, which optimal design characteristics in it turn are subject of the determining.

For the ship, intended for batch construction in accordance with demand in the relevant sectors of navigation the concept of general system, associated with the definition of design constraints when finding characteristics of the ship, which enters in this system, is of more formal nature, than concept of this system for innovative multifunctional ship, assigned for navigation in frozen sea. The considered above definition of utility function is quite obvious in the developing of mathematical models for determining of optimal design characteristics of merchant ships of the main classes, such as cargoes transporting or fishery ones, etc., and the utility function of ice-navigating and multifunctional ship has significant methodological differences.

5.3. Optimality criterion for design optimization of multifunctional ship for the frozen seas

Complex issues for determining of optimal characteristics of multifunctional ice-navigating ship in the process of it designing includes formulation of the adequate criterion of optimality as the use of the efficiency criterion in the frameworks of the systemic approach, which indicates the preferences of federal or corporative investor implementing the financing in ship construction. Efficiency criterion covers all costs, linked with the ship construction, it commissioning and operation, so as the economic effect of ship, characterizing by it utility function.

It would be considered, that corresponded with the fact that ships for frozen sea are constructed usually for the use in those districts, in which the economic activity is not characteristic besides the implementing of the federal tasks the methodological difficulties may arise of the ship efficiency evaluation. These circumstances can limit the applicability of the economic criteria based on the indexes of income and profit for determining of optimal design characteristics of the ships of these classes. The multifunctional ice-navigating ships can be created in accordance with the federal policy issues, which predetermine the federal demand. In the same time the starting investments and the financing of operating costs can be carried out jointly on the basis of federal subsidies and the participation of private investors or without

them, which can be a methodological difficulty on the stage of determining of ship design characteristics required for economic estimates. This methodological obstacle is not usual for determining of design characteristics of ships, planned for batch construction in accordance with the market demand: the cargo ships, the fishery ones, the service–auxiliary ships and the ships of the technical fleet to support offshore construction works.

Characteristic feature, when finding the economic indexes of multifunctional ice–navigating ships, which are created for the federal demand with not enough in the open market, which corresponded with batch constructed merchant ships, as from the point of view of those or other socio–economic issues in freezing seas for development of mineral deposits on the offshore, for improving of the activity on the coasts, for servicing of cargoes traffics and escorting of the ships with insufficient ice category in frozen sea and, considering the typical of federal financing of multifunctional ice–navigating ships construction and operation maintenance, the dependence arises between general economic indexes of costs and incomes: $I(C, RC)$, that is the dependence of federal subsidies, which correspond the index of income I , on the reasonable costs (RC and C). In case of the insufficient capabilities of financing of multifunctional ice–navigating ship creation (the construction, equipping, commissioning and operation maintenance) by private investors, perhaps, the activity in the indicated marine districts would be impossible without the federal subsidies offer available. In the other words, for construction, equipping, commissioning and maintenance of multifunctional ice–navigating ships it is supposed the federal participation as in the shipbuilding so as in the navigating companies, and as in the investments funding in the construction of ships RC , so in funding of the ships operation C . Wherein the dependence arises of the indexes of funds subsidized in the considered segment of shipbuilding and navigating in freezing seas of cumulative annual income I on the reasonable amount of investments (RC and C).

Multifunctional ice–navigating ship’s purpose of the navigation in freezing seas comes to the fore and the auxiliary purposes of navigation servicing in these conditions and the escort of ships of smaller ice categories and the insufficient categories. This assignment of the ship is usually subject of federal subsidies funding, which indicates the assumption of federal ownership of the ship or the joint ownership with the federal control. Then the extra budgetary funding of income, associated with servicing of the corporate customers, for example the funding of multifunctional ice–navigating ship service of cargoes transportation, or the extra budgetary funding of navigation service and the escort in ice, of the electric power supply of other ships, or the onshore consumers, the service of maintenance of offshore

platforms, the service of onshore sites, etc. could be considered as the annual budgetary costs saving CD . Therefore, make sense to clarify the indexes set in the criteria of efficiency of multifunctional ice-navigating ship, considering the amendment to income index I as the costs savings CD .

Need to clarify as well, that some of economic indexes in the compositions of efficiency criteria can act as constraints (the data) in the tasks of the determining of optimal design characteristics of the ship. In particular, the investment constraint RC^* can be attributed to the number of these constraints, that is limiting value of federal subsidies in construction of the ship, which consequently serves the federal property, or the joint property with federal participation or control. However, the investment constraint when funding the construction of multifunctional ice-navigating ship is relative to certain extent, since besides the federal subsidies it is possible to attract the additional corporative finances by the cost of capital i , corresponded with total of investment risks.

Having the seaworthiness and patency in frozen seas, the ships of various purposes can be used the part of time in the open water, and the other time – in frozen sea in dependence on the geographic latitude and the seasonality. The combining of functions of the ship having ice category, such as the function of navigation in frozen sea and in the temperate latitudes (in open water), meet the economic contradictions, which is not characteristic particularly for specialized ships, planned for the batch construction. In this regard the specific design issue arises to select of two alternatives: the construction of multifunctional ice-navigating ships, or to create the set of specialized ships, for example the icebreaker and the ships, not having the ice category or having the insignificant one, escorted by the icebreaker. It should be mentioned that the multifunctional ice-navigating ship is methodologically more general object (complex one), than the specialized icebreaker, because this multifunctional assignment covers the icebreaking functions as well. Therefore, the conclusion of multifunctional ice-navigating ship preference or the specialized icebreaker in each definite case would be resulted from the determining of ship optimal design characteristics in the dependence on assigned design constraints, in particular on it size – the design deadweight and the sizes dependent on the deadweight, depending on what degree these sizes correspond to other functions of ship, besides of the icebreaking one.

For the options of multifunctional ice-navigating ship efficiency assessing at the initial stages of designing when varying the value of this or that designing characteristic from the systemic point of view by criterion of the present worth PW would be determined not by absolute and by specific value per the unit of economic effect.

Annual cargoes carrying capacity Q_G of merchant cargo ship is considered example of optimal characteristics LNG-tanker determining is used above as the economic effect index, in other words as it utility index, or the ship functional efficiency. This choice of utility function is obvious for merchant ships of main types, such as cargo ships, or fishery, or others, and the utility function of multifunctional ice-navigating ship is of significant methodological difference.

Variants of concepts of multifunctional ice-navigating ship utility indexes are:

- ship characteristic of annual turnover of cargoes transportation Q_G in the units of mass, the cube units or in the aggregated unified cargoes (ISO containers), etc., that is the characteristic of the ship working;

- characteristic of ship size, which indicates the ship suitability for fulfillment of the service-auxiliary functions, the navigation servicing and the escort of other ships, not having ice category or having the insignificant one, in conditions of frozen sea, the ship suitability for carrying onboard of the special equipment, assigned for the implementing of those or other functions in freezing seas, which correspond with the ship icebreaking performances and patency in ice and with working characteristic.

The potential characteristics of multifunctional ice-navigating ship, subject to select independently as utility function or the index of effect, are among the characteristic of the ship size within the follow set: displacement of the ship loaded D , design deadweight DW , cargoes capacity PG , tonnages (gross GRT or net NRT), etc., – as well, as this or other characteristic of the ship energy generation considered not only as design characteristic sought in the design optimization, but as the utility function as well: effective power Ne , required power in ice N_{ICE} , total capacity of ship power installation NP and etc.

It should be mentioned that listed and other characteristics of the ship size, as well, as the characteristics of it energy generation are interdependent and are in the balance proportions /111/, so, if any of them is used as utility function it has to be selected individual with not the other listed or other characteristic use as this function.

The ship size from the considered set of the indexes can be used as economic effect index in the composition of economic criterion when finding the design characteristics of multifunctional ice-navigating ship, since the size can characterize the useful potential properties of multifunctional icebreaker and indicates, on one hand, the index of navigation and escorting performances, which the ship provides in ice of definite intensity (the assigned), in particular indicates the channel size (the width) made in solid ice, on the other hand, the size characterizes the room for arrangement of the ship structural parts and the payloads, assigned in the ship design as constraint in the terms of references.

Methodological feature of multifunctional ice–navigating ship size is of the interest, as the ability of index of the ship size to be used as the variable designing characteristic of ship when finding its optimal value, so as the index of the economic effect in the composition of optimality criterion. For example, the design deadweight DW or the other characteristic of ship size can be as the of utility function and the denominator for finding the efficiency criterion by the specific value, and as the design characteristic sought in optimization.

Interdependence of indexes of carrying capacity and of the size of multifunctional ice–navigating ship is analyzed below the more detail (item 6.1 and 6.2) when studying the preferences for choice of the ship utility function in composition of efficiency criterion, used as the optimality one. It was found that with an increase (or the decrease, i.e. the any variation) of the ship size, in particular, its carrying capacity has tendency to increase (or decrease) in the certain proportional ratio, which says about probable interchangeability of these indexes of the ship size and economic effect of the ship carrying capacity in the definite intervals of these values variation.

General economic indexes ($C-CD$, RC and i), as well, as the economic criteria, in particular the specific present worth (PW/Q_G and PW/E), or the other forms of criteria within the systemic approach, which are the mathematical operations over the economic indexes, are the dependences on the values, used in the mathematical model of multifunctional ice–navigating ship: the characteristics, varied when finding of their optimal values, the design constraints – the data, that is the characteristics of general complex system, the part of which is the ship under design, and the parameters – the ship design particulars, in the other words, the characteristics of its subsystems.

It is characteristic that both considered options of utility function, the ship working characteristic and its potential one – the size of ship or the ship annual carrying capacity of cargoes – the effect per unit of time. Although the working nature is not so visible in the first option when using the characteristics of ship size as the economic effect index. Nevertheless, characterizing by the ship size its suitability for fulfillment of the service–auxiliary functions of navigation servicing and escort in frozen sea of other ships, not having ice category or having the insignificant one, of the accommodation of the required personnel and the arrangement onboard of special equipment, assigned for fulfillment of those or other purposes in frozen sea characterizes these opportunities during a year, because the effect in the considered examples is correlated with annual index of present worth PW .

Objective function $f(X, Y, Z)$ in the form of the mathematical model for determining of optimal design characteristics of multifunctional ice–navigating ship is, in this way, the sequence of dependences between values affecting the objective

function: variables X , parameters Y and data Z , on one hand, and main economic indexes (C , CD and RC), which generalization is economic criterion, on the other hand:

$$f(C, CD, RC) = f(X, Y, Z). \quad (5.5)$$

Mathematical model for determining of optimal design characteristics of multifunctional ice–navigating ship, which is based on determining of the objective function on mathematic values of variables X , parameters Y and data Z is practically developed in the spreadsheets of Microsoft Excel, which is appropriately convenient, or with the use of other standard software. The scheme (Fig. 5.5) shows that depending on the listed values of variables, parameters and data (X , Y and Z) of general economic indexes of annual income I , to be more correct, the annual budgetary costs saving CD , associated with servicing of the corporate customers in case of multifunctional ice–navigating ship, of operation costs C and of the investments RC are generalized in the objective function f .

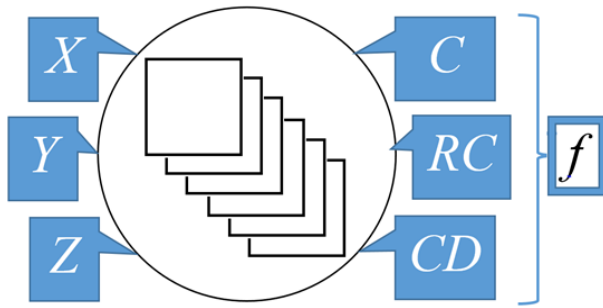


Fig. 5.5. Scheme of the objective function f dependence on annual budgetary costs saving CD , associated with servicing of the corporate customers, on operation costs C , on investments RC , which in turn depend on variables X (the multifunctional ice–navigating ship design characteristics sought or its particulars), on parameters Y (the assumed characteristics of ship subsystems) and on data Z (the assigned constraints, that is the characteristics of general system, to which the ship belongs as the subsystem)

Economic criterion for multifunctional ice–navigating ship could be used of specific present worth PW per unit of effect (the utility function), that is in the form of the present value of all costs deducting their probable saving corresponding with probable extra budgetary income, when services are provided to the corporate customers, besides of the federal issues fulfillment, this objective function looks like

$$f = PW/E = (C - CD + i \times RC)/E, \quad (5.6)$$

where the index of the present worth PW of multifunctional ice–navigating ship with the account of budgetary costs savings CD can be used in the mathematical model for finding of optimal design characteristics of the ship, assigning the constraint of effect

$$PW = C - CD + i \times RC. \quad (5.7)$$

5.4. Investments evaluation for finding of objective function when determining the design characteristics of ice–navigating ship

For determining of multifunctional ice–navigating ship optimal characteristics at initial stages of designing in the composition of criteria the reproduction costs RC of total expenses for the ship construction in the market prices, including the profit and taxes, which approximate equations were derived from available costs of analogs construction and systematized in forms of dependences on characteristics of the ship size, in particular on the follows: on design deadweight DW , on the ship displacement empty DP , on it gross register tonnage GRT and on the design length L (Fig. 5.6)

$$\begin{aligned} RC &\approx 0.0323 \times DW - 25.5, \\ RC &\approx 0.023 \times DP - 38.8 \approx 0.023 \times DP, \\ RC &\approx 0.010 \times GRT + 42.2 \approx 0.010 \times GRT, \\ RC &\approx 2.08 \times L - 67.23 \approx 2.08 \times L, \text{ million US dollars.} \end{aligned} \quad (5.8)$$

The cost indexes are indicated below in the US dollars since the construction of the ice–navigating ships usually is carried out on the basis of international cooperation, and these indexes can be converted in any currencies by the exchange rates of US dollar set by the state bank of any country for the definite day.

Costs for construction of the ship «Aurora Borealis» of bigger size than the analogues is indicated additionally (Fig. 5.6b) for assessing of applicability of projected values of costs for creation of multifunctional ice–navigating ship (that are the ship designing, construction and equipping) outside the interval of analogs sizes on one of the graphs, which confirms the applicability of projected investment costs got by the formulas (5.8) at initial stages of designing of multifunctional ice–navigating ship.

Dependence of projected reproduction costs of multifunctional ice–navigating ship in market prices RC is indicated on the graph (Fig. 5.7a) with account of design constraint of maximal thickness of affordable to overcome solid ice h on the variable characteristic, which varying when do design optimization, represented by the ship

characteristic of design deadweight DW and on rest characteristics and particulars of the ship in the mathematical model, that is on the generalized variables. As well the dependence of the reproduction costs by relative value RC/DW per the unit of ship size is shown on graphic surface (Fig. 5.7b).

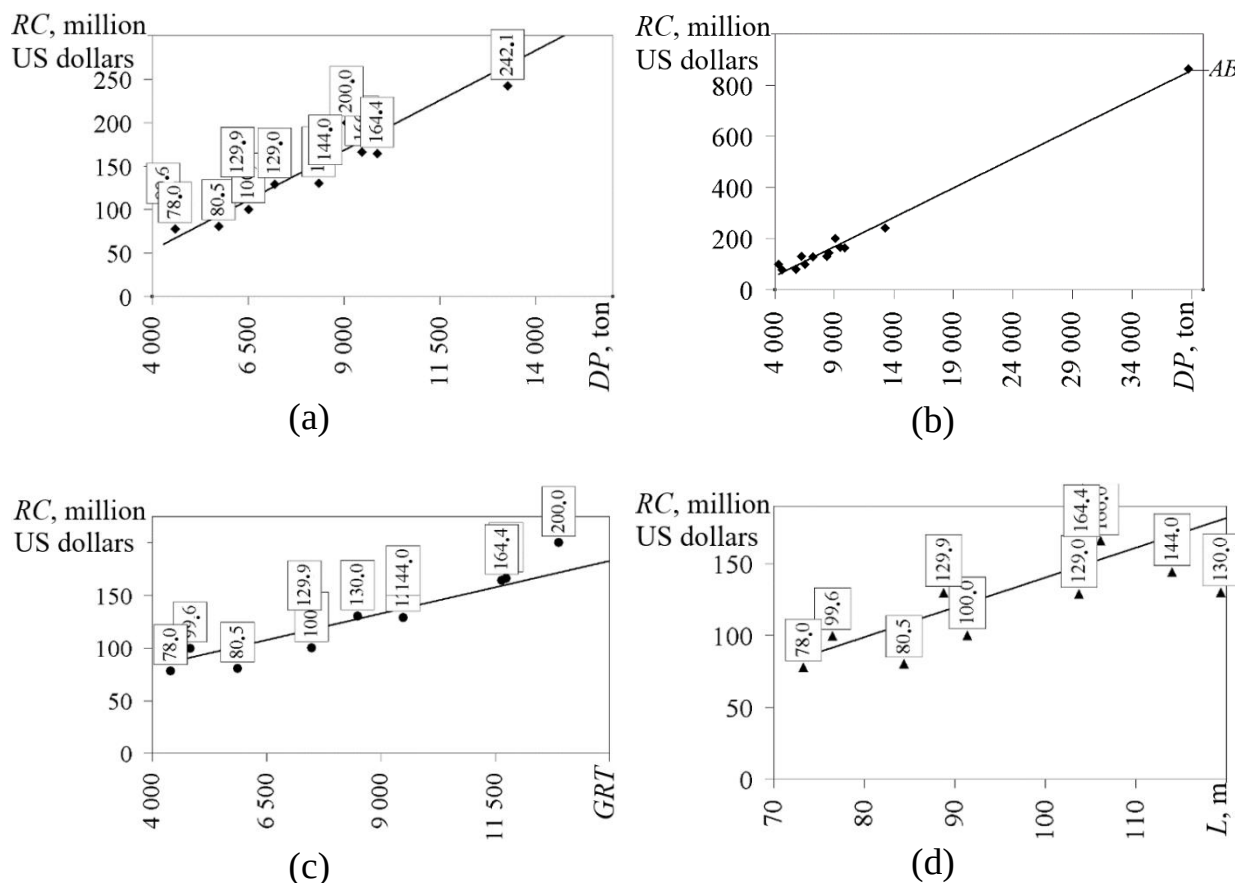


Fig. 5.6. Dependence of evaluated by the analogs required costs for construction RC (the reproduction) of multifunctional ice-navigating ship with the diesel-electric power installation (a) on it displacement empty DP , (c) on gross register tonnage GRT and (d) on ship design length L ; AB – the index of costs for construction of ship «Aurora Borealis» (of biggest size, on the graph – b)

Since the costs are assessed for new constructed ship, then the amount of working assets OC , corresponded the prepayment of operating costs C for the billing period, is substantially less, than the reproduction costs RC . For this reason, the need for the costs of replenishing the working assets is not included in the total investments for construction of ship with the reproduction costs RC , used for the objective function at initial designing stages. Wherein it is considered that subject is the determining of optimal design characteristics under given constraints and not the economic indexes as they are. It is assumed that at the other stages of multifunctional ice-navigating ship creation the possible clarifications of investment indexes,

the operating costs and the income will be of uniform nature and these possible clarifications will not have the noticeable influence on the validity of design characteristics found of ship.

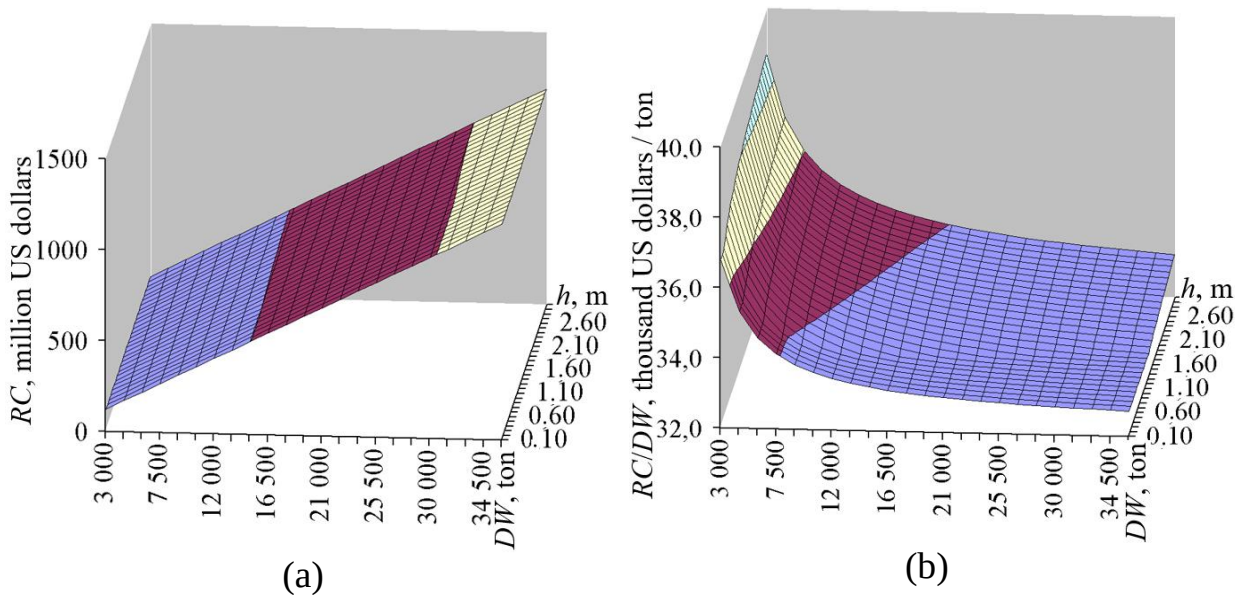


Fig. 5.7. Dependence of reproduction costs RC on design deadweight DW of multifunctional ice-navigating ship and on assigned design constraint of thickness of solid ice h (a) and dependence of specific reproduction costs per unit of the ship size RC/DW (b)

5.5. Index of operating costs for multifunctional ice-navigating ship used in the composition of efficiency criterion

Annual operating costs C of multifunctional ice-navigating ship for use of this index in the composition of the efficiency criterion at the initial stages of multifunctional ice-navigating ship designing can be determined by summing the terms

$$C = (C_{CR} + C_{FCR} + C_{DCR} + C_{TXCR}) + C_{FL} + C_{SP} + C_{RM}, \quad (5.9)$$

where $(C_{CR} + C_{FCR} + C_{DCR} + C_{TXCR})$ – total of annual costs, associated with the crew support: C_{CR} – costs for crew salary; C_{FCR} – costs for crew supply (food, accommodation, work clothes, appliances and etc.); C_{DCR} – costs for crew delivery with luggage; C_{TXCR} – payments to budget and employees' taxes, if the employer pays over the salary these taxes separately to the budget; C_{FL} – costs for fuel; C_{SP} – costs for the ship supply; C_{RM} – the annual costs for ship repairs and maintenance. The suitable dimension of listed operating costs is in the account per year (in particular, million US dollars / year).

Forms of classification and grouping of the operating costs by items are possible, differing in the degree of detail and approximation of the resulting index. The criteria in the approach for choice of the items set of operating costs can be: the proper accuracy of cumulative index of costs determining and adequate account of main factors influence on the index.

Costs of the crew salary annual are: $C_{CR} = n_{CR} \times c_{CR} / 1000$, where n_{CR} – number of the crew, men; c_{CR} – average annual salary costs per crew member, thousand US dollars / year.

Components of multifunctional ice–navigating ship operating costs, as well, as the amendment to operating costs with the account of possible commercial income is logical to determine in accordance with ship operation mode by the seasons – in freezing seas and on open water during the annual navigation period ($T_{EXP} = T_1 + T_2$):

1. The repair and maintenance of the ship during definite time in a year (around 30 days, to be more exact the days of repair and maintenance of merchant ships of various types were previously published /64, the tables in the Appendix to the indicated book/).

2. T_1 – the period during a year of fulfillment of navigation servicing in frozen sea and escort of other ships, having lesser performances and patency in ice, including the following functions:

- navigation servicing and escort of ships, having lesser performances in frozen sea (the escort of ships, laying the fairway, the rescue works, the auxiliary services, the training and etc.);

- laying of channels in ice, including to the berths or to other stationary objects;

- power supply to serviced ships, to offshore platforms or to onshore consumers.

3. T_2 – period during a year of the navigation functions fulfillment in open water: $T_2 \approx 365 - 30 - T_1$, including the following:

- transport purposes, including the transportations in frozen sea for the extra budgetary customers, the delivery of cargoes on the offshore platforms;

- power supply to serviced ships, to offshore platforms or to onshore consumers.

Given considered explaining and taking into account the grouping of terms, the annual operating costs C of multifunctional ice–navigating ship one can determine as

$$C = C_{CR} \times k_{C1} + (C_{FL1} + C_{FL2} + C_{RM}) \times k_{C2} - CD, \quad (5.10)$$

where the generalized coefficients the operating costs k_{C1} and k_{C2} are:

$$k_{C1} = 1 + (C_{FCR} + C_{DCR} + C_{TXCR}) / C_{CR} \text{ and } k_{C2} = 1 + C_{SP} / (C_{FL} + C_{RM});$$

C_{FL1} – costs of fuel during the operation period T_1 of navigation functions fulfillment in frozen sea; C_{FL2} – the costs for fuel during the operation period T_2 in open water.

Costs for fuel during the operation period T_1 of navigation functions fulfillment in frozen sea one can determine as

$$C_{FL1} = T_1 \times ([T_{R1}/T_1] \times q_1(N_{ICE}) + (1 - [T_{R1}/T_1]) \times q_2(NP)) \times c_{FL}, \quad (5.11)$$

where $q_1(N_{ICE})$, or $q_1(Ne)$ – daily fuel consumption on the go (when implementing the navigation functions in frozen sea and in open water), ton/day; $q_2(NP)$ – the daily fuel consumption of the ship docked, ton/day; c_{FL} – the cost of fuel used by the power plant per ton; T_{R1} – the running time of multifunctional ice–navigating ship in frozen sea, day; $[T_{R1}/T_1]$ – the relative duration of running time in frozen sea within the duration of period of the navigation functions fulfillment in frozen sea during a year, including maneuvering, navigation service and escort of ships, having lesser performances and patency in ice, including the channels laying in solid ice, in particular, to the docks or to other stationary objects, the fulfillment of rescue tasks in frozen sea, the support works, cadets training, etc.

Daily fuel consumption by seasons: in frozen sea and in open water for evaluation of economic indexes at initial stages of designing can approximately be determined as: $q_1(N_{ICE}) \approx 0.008 \times N_{ICE}^{0.95}$, or $q_1(Ne) \approx 0.008 \times Ne^{0.95}$ – the daily fuel consumption on run in frozen sea and in open water, ton/day.

Daily fuel consumption of the ship docked considering its own needs and the power supply of serviced ships, the offshore platforms, or the onshore consumers is: $q_2(NP) \approx 0.008 \times ((x_Q + y_Q) \times NP)e^{0.95}$, ton/day, where x_Q and y_Q – the relative values of load (in proportion to the installation power), consumed for own needs of the ship docked x_Q and for power supply of serviced ships, offshore platforms or onshore consumers y_Q .

Costs of fuel during the period T_2 of the ship navigation in open water is

$$C_{FL2} = (T_{R2} \times q_1(Ne) + (T_2 - T_{R2}) \times q_2(NP)) \times c_{FL}, \quad (5.12)$$

where the running time in open water is: $T_{R2} = (2 \times LR / (24 \times v_S) + \Delta T_{R2}) \times n_{R2}$, LR – the extent from departure to the destination, nautical miles; ΔT_{R2} – duration of the ship maneuvering during the round trip when fulfilling the cargoes transportation in open water, day.

Number of round trips during the period T_2 of ship navigation in open water is: $n_{R2} = T_2 / (2 \times LR / (24 \times v_S) + \Delta T_{R2} + T_{PR2})$, where T_{PR2} – berth time of the ship in harbors during the round trip (the sum of time of the ship berth in points of departure and arrival), day, and the duration of one round trip in open water is:

$$2 \times LR / (24 \times v_S) + \Delta T_{R2} + T_{PR2}.$$

It is logical to determine the costs of supply at initial approximation in dependence on fuel costs and costs for the ship maintenance.

Annual carrying capacity of multifunctional ice–navigating ship depends on the part of design deadweight DW , since in the used definition the design deadweight includes the assigned in the terms of references payload components of the ship functional equipment besides of total mass of variable components of deadweight: the cargoes capacity of the ship PG , the fuel PFL , the ballast PBL , the crew with luggage, the ship stocks and the other variable items of the load. The functional part of the design deadweight DW of it constant loads include the masses of equipment, created before the ship designing, which do not depend on the ship loaded displacement D , that is they depend on the displacement in zero degree (D^0). Design deadweight works the characteristic sought in design optimization of multifunctional ice–navigating ship and differs from the operation deadweight definition, which means the total of variable loads.

Amount of transported cargoes during the period T_2 of ship navigation in open water is equal the total of annually transported cargoes (the annual carrying capacity), because the rest part of year, that is in ice, the multifunctional ice–navigating ship does not carry cargoes itself, but serviced and escorted other ships, which have no ice category or have the insufficient category. Annual carrying capacity can be determined as

$$Q_G = n_{R2} \times [PG/DW] \times DW \times (1 + k_G), \text{ ton}, \quad (5.13)$$

where $[PG/DW]$ – coefficient of design deadweight utilization by cargoes capacity of multifunctional ice–navigating ship; k_G – coefficient of the ship loading in reverse direction of round trip. It is supposed that in the direct trip the ship is fully loaded, to be more exact, the ship is loaded full in one of two directions, and reverse one is of partial load of the ship.

Dependences of annual fuel consumption FL and the amount of transported cargoes Q_G by multifunctional ice–navigating ship in the season of open water

are determined by the mathematical model with account of generalized variables – the characteristics of the ship, which are dependent on the independent ones, in particular, on design deadweight DW characteristic, and on index corresponded with the ship ice category, that is the assigned design constraint of thickness of solid ice h (affordable to overcome by the ship in the other season)e, and are shown on the graphic surfaces (Fig. 5.8 a and b).

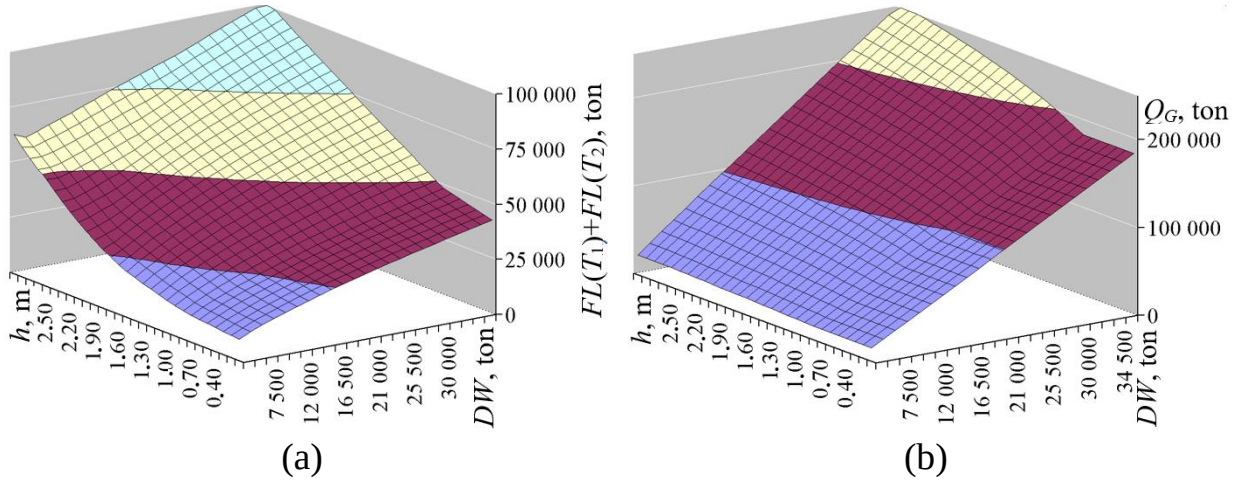


Fig. 5.8. Dependences of annual fuel consumption FL (a) and annual cargoes carrying capacity Q_G (b) in the season of open water operation of multifunctional ice–navigating ship on assigned design constraint of thickness of solid ice h (affordable to overcome by the ship in other season) and on the ship size variable characteristic of design deadweight DW

Extra budgetary income, counted as costs saving in the composition of efficiency criterion and objective function of the ship at its initial designing stages, for considered functions of multifunctional ice–navigating ship one can represent by the sum

$$CD = CD_1 + CD_2, \quad (5.14)$$

where CD_1 – annual extra budgetary income, corresponding the fulfillment of marine transportation of cargoes in open water for the corporate customers; CD_2 – annual extra budgetary income, corresponding power supply for the corporate customers on the serviced ships, on offshore platforms or onshore,

$$CD_1 = i_{CG} \times Q_G, \quad (5.15)$$

$$CD_2 = i_E \times T_1 \times (1 - [T_{R1}/T_1]) \times y_Q \times NP, \quad (5.16)$$

where i_{CG} – the price of transportation of one unit of cargo (load, volume or container) for extra budgetary customer (cargo owner) on the line of specified extent LR , thousand US dollars / ton (or other cargo unit); i_E – the price of the power supply to the serviced ships, the offshore platforms or the onshore for extra budgetary consumers per the unit of power, thousand US dollars per kW×hour.

Dependence of annual operating costs C of multifunctional ice–navigating ship deducting the budgetary costs savings CD is presented in the form of functional surface and in the projection on basic plane (Fig. 5.9 a and b) on design constraint of maximal thickness of affordable to overcome solid ice h and on variable characteristic of the ship size – it design deadweight DW , determined with the account of rest characteristics and particulars of ship in the mathematical model, that is the indexes of constraints and the values of generalized variables, dependent on the independent ones.

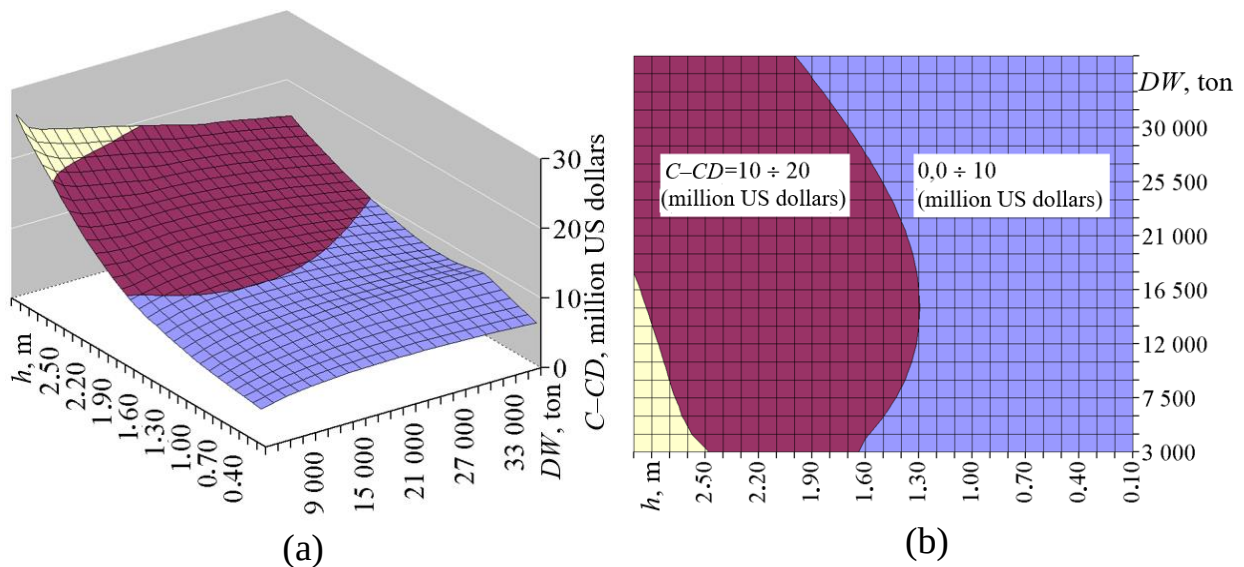


Fig. 5.9. Dependence of annual operating costs C deducting the budgetary costs savings CD of multifunctional ice–navigating ship on assigned design constraint of solid ice thickness h and on the characteristic of the ship size – it design deadweight DW

5.6. Choice of base combinations of data for determining of design characteristics of multifunctional ice–navigating ship

Assumed base combination of data is used for determining of graphic functional dependences of objective function and the indexes, and for analysis of studied methodological approaches for determining optimal design characteristics of multifunctional ice–navigating ship. The assumed data combination is specified

in the table 5.1. One can consider some of specified constraints – the data and parameters (the particulars) from the base combination as the approximal ones to refine them at the next stages in the designing the ship subsystems, defined methodologically in each case as the integral ship, considered from behalf it definite individual performance.

And the other data of table 5.1, for example the cargo line extent or the prices for service, depended on cargoes traffic extent, by the intensity of cargoes handling operations, that are the prices for the services for the corporative customers (the extra budgetary), etc., apparently, would be considered in the next as variable design characteristics sought, with the otherwise defined object, supposable, if the designing object would be not the multifunctional ice–navigating ship, but more general than the ship system, which would cover as well the transportation of cargoes and the other services for the extra budgetary customers. This general system could have the form of individual complex of company assets, including the ships in this complex, to which are assigned the indicated tasks of the transportation and services. In the more detail the options of general system appropriate for multifunctional ice–navigating ship under designing are considered in Chapter 2.

Table 5.1

Example of initial data for objective function and the mathematical model for determining of design characteristics of multifunctional ice–navigating ship

The index name, the dimension	The index example
Duration of the ship navigation in frozen sea during a year T_1 , day	180
Relative running time in frozen sea $[T_{R1}/T_1]$ during annual operation period (likely in the interval from 10 to 90 %)	50 %
Duration of the ship maneuvering ΔT_{R2} in the round trip when fulfilling the cargoes transportation in open water, day (corresponds from 1 to 3 days per trip)	2
Coefficient of the ship loading in reverse direction of round trip k_G (likely in the interval from 0.25 to 0.75)	0.50
The utilization coefficient of design deadweight by cargoes capacity $[PG/DW]$ (likely in the interval from 0.25 to 0.75)	0.50
Relative value of load x_Q (in proportion to the installation power) for own needs of the ship docked (likely in interval from 0.0 to 10 %)	5.0 %
Relative value of load y_Q (in proportion to the installation power) for power supply of serviced ships, offshore platforms or onshore (likely in the interval from 10 to 90 %)	50 %
The berth time during the round trip of ship T_{PR2} , day (likely corresponds from 5 to 10 days per trip)	7

End of the table 5.1

The index name, the dimension	The index example
Constraint of minimal safe velocity of ship v_{SMIN} in open water, knot (subject to clarification in designing of equipment for ship control)	12.0
Constraint of maximal effective velocity v_{SMAX} in open water, knot (subject to clarification in designing of propellers and hull shape)	25.0
Discount rate i (the macroeconomic index of total risks; for the US dollars the rate could be about 5 % and less than 10 %)	5.0%
Expert factor a_F of the amendment (penalty or premium) to the criterion of specific present worth with the account of compliance with investment constraint of the subsidies in the ship construction	50%
Costs for repair and maintenance of ship during the year by the relative value, in relation to the costs for ship construction (make up in the interval from 1.5 to 3.5 %)	2.5%
Constraint of the investment RC^* in the multifunctional ice-navigating ship creation (the maximal budget funding provided for ship design, construction and equipping), million US dollars	500.0
The extent from departure to destination LR , nautical miles (*)	2 000
Fuel price c_{FL} , used by power plant, thousand US dollars/ton (**)	0.40
Generalized coefficient of operating costs, associated with the crew salary k_{C1} (is in the range from the 1.4 up to 1.6)	1.5
Generalized coefficient of operating costs, associated with bunker fuel consume k_{C2} (approximately is equal 1.1)	1.1
Price of transportation of one unit of cargo for extra budgetary customer (the sea transport tariff on the specified line) i_{CG} , thousand US dollars / ton	0.25
The price for power supply i_E to the serviced ships, the offshore platforms or on the onshore for extra budgetary consumers, US dollars /(kW×hour)	0.15

Remarks. (*) The cargoes line extent approximately corresponds the distances from the harbors of the Northwest Region of the Russian Federation, or from the Yamal Peninsula to the offshore fields, or from the harbors of the Far East to the relevant fields on the offshore, is used in the examples of data set, when elaborating the approaches and methods for determining of objective function and functional graphic surfaces.

(**) Since contracts for the international marine transportations and the construction of ships under international contracts are likely concluded by the participants from other states, the monetary units are used the US dollars. These indexes could be converted in any national monetary units by exchange rate of US dollar, establishing by the states banks for the definite day. Considering the proportionality

by the specified rate, one or the other monetary units do not impact on the formulas, on graphic functions and on optimal values of the characteristics and design particulars of the ship.

Indicated opportunities of redefinition of object under design and consequent change of the set of design constraints, transferring some of the constraints in the category of variables, are mentioned above for the explaining of definite relativity, which can be referred the specified base combination of data, used below for the study of developed methodological approaches of multifunctional ice–navigating ship optimal design characteristics determining, and in each case the graph legends contain descriptions of deviations from the specified data, which are summarized in the table 5.1.

Checklist

301. Subject of study of criteria, objective function and mathematical model includes the issues: the formulation of the constraints and systemic concept of options comparability; analysis of assumptions of the ship characteristics balance; evaluation of functional constraints and determining of constant part of the ship design deadweight; evaluation of physical constraint for assigned level of seaworthiness and patency in ice; analysis of hierarchy of the economic criteria and defining the utility function; developing the objective functions and the mathematical models; study of mathematical properties of design characteristics in the vicinity of their optimal set; evaluation of optimal ship design characteristics sustainability.
302. Economic indexes in the sets of criteria: the total annual income, the operation cost (annual) and the investments.
303. The comparative effectiveness (the relative one) of multifunctional ice–navigating ship criterion of the present worth of the annual nature.
304. Investments index of the ship replacement or reproduction costs for construction in the market economy and equipping of multifunctional ice–navigating ship, other than the investments to acquire the ship at the second–hand market for its market value.
305. Objective function as dependence of applied optimality criterion on characteristics of the ship, varied in process of finding of their optimal values, on initial data, which are assigned design constraints and are methodologically the characteristics

- of more general system, than the ship under design, and on design constraints adopted as particulars, that is on characteristics of subsystems of the ship.
306. The necessity of math generalization of economic indexes of income, costs and investments to indicate the critical judgments when finding optimal design characteristics of multifunctional ice–navigating ship.
 307. In the composition of efficiency and optimality criterion, when efficiency one is used with the constraints and within the considered options domain for finding of the ship characteristics optimal values, general economic indexes systemic presenting for one same day.
 308. The use of macroeconomic index of total commercial risks in the form of the discount rate to generalize the economic indexes of income, costs and investments in the composition of economic criteria.
 309. Independence of characteristics of the ship under design optimal values on selecting of day of economic indexes of income, costs and investments generalization, the systemic rule to generalize these indexes for any one day, which could be associated with the delivery of the ship, or with it design completion, or with other day.
 310. Indexes, linked with costs minimization or with the maximization of the profit (or the profitability) for use as objective function for determining of the ship optimal design characteristics.
 311. Financial estimate of corporative investor, acting on the basis of economic self–sufficiency, as the design constraint for determining of optimal characteristics of merchant ship assigned for batch construction.
 312. The evaluation of complex of the self–sufficient corporate navigating company’s assets for finding of the constraint for determining of optimal design characteristics of merchant cargo ship for replenishment of this company complex of assets.
 313. The conceptual attribute of any ocean environment properties to marine resources, not limited only to the mineral ones or aquatic biological resources, but of any legal opportunities of industrial activity in the ocean on terms of economic efficiency and self–sufficiency, or the terms of other economically defined utility, considering the concept of ocean with it economic potential of coasts, with cargo traffics, etc.
 314. Economic index adopted to use as optimality criterion of the set of two interrelated ones: of minimized costs for the ship creation, generalized by the economic discounting to their comparable present values, and the second, the profit or the dependent index of investments in the ship creation profitability.

315. The ship creation components, subject to it economic evaluation: the ship designing, construction and equipping, it operation and maintenance.
316. Recommendation and the conveniences to use US dollars as monetary units for determining of the indexes in the criterion of economic efficiency and optimality of multifunctional ice–navigating ship.
317. Relative nature of present worth economic efficiency criterion – indicates the preferences in sets of compared options of multifunctional ice–navigating ship.
318. Absolute nature of internal rate of return economic efficiency criterion – indicates as the preferences in sets of compared options of multifunctional ice–navigating ship, so as the preference of investing in the ship compared with the macroeconomic index of costs for capital use.
319. The assumption to omit the working assets in the total with the reproduction costs for construction of merchant ship in the optimality criterion due to small value of working assets compared with the reproduction costs.
320. Methodological difficulties of definition of the utility functions for ice–navigating and multifunctional ship, other than merchant ships of the main classes, such as cargoes transporting or fishery ones, etc.
321. Efficiency criterion covering all costs, linked with the ship construction, it commissioning and operation, so as the economic effect of ship, characterizing by it utility function.
322. Methodological difficulties to define economic efficiency concepts and criteria for the ships, assigned to navigate in low populate districts with not enough economic potential of territories and coasts, which leads to the necessity of states participation in the federal subsidizing of investments corresponded with federal issues in freezing seas, particularly in the creation of multifunctional ice–navigating ships.
323. Dependence of index of income in the composition of economic efficiency criteria on the costs indexes of multifunctional ice–navigating ship creation (the construction, equipping, commissioning and operation maintenance) in the case of the federal subsidizing of investments.
324. The federal ownership of the ship or the joint private ownership with the federal control in case of the federal participation in funding of multifunctional ice–navigating ship creation and navigation maintenance.
325. Extra budgetary (the corporate) funding of income linked with amendment to income index, as the costs saving of multifunctional ice–navigating ship for cargoes transportation for corporate customers, the navigation service

- and the escort in ice, the electric power supply of other ships, or the onshore consumers, the maintenance of offshore platforms, the service of onshore sites, etc.
326. Relative nature of the investment constraint when funding the construction of multifunctional ice–navigating ship, since besides the federal subsidies it is possible to attract the additional corporative finances by the cost of capital.
 327. Obstacle of the ship functions combining and two alternatives: to construct multifunctional ice–navigating ships, or to create the set of specialized ships – the icebreaker and the ships, not having the ice category or having the insignificant one, escorted by the icebreaker.
 328. Systemic hierarchical level of multifunctional ice–navigating ship the more general, than the level of specialized ship, in particular, the specialized icebreaker.
 329. Conclusion of preference of multifunctional ice–navigating ship or the specialized icebreaker as one of results of the ship optimal design characteristics determining in the dependence on assigned design constraints, in particular on its size – depending on what degree these sizes correspond to other functions of ship, besides of the icebreaking one.
 330. The systemic approach to determine economic efficiency criterion by specific value per the unit of economic effect.
 331. Variants of concepts of multifunctional ice–navigating ship utility indexes: the ship working characteristic of annual turnover of cargoes, etc., or the ship potential characteristic of size, which corresponds with the ship icebreaking performances and patency in ice and with working characteristic.
 332. Potential characteristics of multifunctional ice–navigating ship, subject to select as utility function or the index of effect, within the set: displacement of the ship loaded, design deadweight, cargoes capacity, tonnages (gross or net), etc., – and the ship energy generation characteristics as utility function options: effective power, required power in ice, total capacity of ship power installation and etc.
 333. Methodological feature of multifunctional ice–navigating ship size as its ability to be used as the variable designing characteristic, so as the index of the economic effect (the utility function) in the composition of optimality criterion.
 334. The tendency of definite proportional variation of the ship carrying capacity when the ship size varied allowing to assume the interchangeability these indexes to use as utility function in the composition of optimality criterion.
 335. Dependence of economic efficiency criteria on the general economic indexes, depended on values, used in the mathematical model of multifunctional ice–navigating ship: the characteristics (the data), the design constraints – the data and the parameters – the ship design particulars.

- 336. The annual correspondence of the ship potential utility function like the ship size any characteristic, because considered potential opportunities of the ship in the efficiency criterion attributed with the annual general economic indexes.
- 337. Systemic options of the present worth economic criterion use for determining of optimal design characteristics of multifunctional ice–navigating ship in form of the specific present worth per unit of effect (the utility function in the composition of the criterion), or in the form of present worth with the assigned constraint of the effect.
- 338. The analogues data use for determining of projected reproduction costs to create multifunctional ice–navigating ship in the mathematical model of optimal design characteristics determining.
- 339. The set of multifunctional ice–navigating ship operation costs items to fit the total index in the mathematical model.
- 340. Dependences of the ship operation costs items in the mathematical model on variable sought design characteristics, on assigned design constraints (the data) and on assumed parameters (the particulars when finding the design characteristics).
- 341. Determining of fuel consumption of the ship, considering the modes of it navigation: in frozen sea and in open water and, in respect that the ship characteristics satisfy the assigned constraints to navigate in frozen sea.
- 342. The items of extra budgetary income, consisting the cargoes transportation and power supply services of the corporate customers, counted as costs saving in the composition of efficiency criterion and objective function of the ship.
- 343. The relativity of assumed data combination (the constraints) by the opportunities of redefinition of multifunctional ice–navigating ship under design and consequent change of the set of design constraints, transferring some of the constraints in the category of variables.

Chapter 6. Utility function and its use in composition of design optimality criterion of multifunctional ice–navigating ship

Issue of optimal design characteristics of multifunctional ice–navigating ship determining includes the statement of the economic criterion, objective function and the mathematical model, which indicates the preferences of federal or corporate investor of the ship construction subsidizing. The economic criterion covers as costs, linked with the ship construction, its equipping, commissioning and operation, so the expected economic effect, characterized by the utility function of the ship.

Systemic defining of utility function is required for formulation of objective function and for elaboration of the mathematical model for determining of optimal design characteristics of multifunctional ice–navigating ship. In the process of ship optimality criterion formulation at initial stage of ship designing one needs to decide the following issues: the ship utility function composition of its independent components in their definite proportional correlation, such as the ship size performances in ice, other characteristics of the ship and its design particulars, dependent on size of ship and on assigned design constraint of ice category or the icebreaking class, and the economic effect performances of the ship rest functions, as well, as determining of design constraints corresponded with utility function in the form of the penalty amendments to optimality criterion, when characteristics of the ship size are derived in the constraint, in particular, dependent on investment one.

6.1. Utility function in compositions of optimality criteria

Utility function, which characterizes the economic effect of multifunctional ice–navigating ship, is an integral part of the economic criterion, applied for the determining of optimal design characteristic, and this effect characterizes the ship functions, like the navigation in the freezing sea and escort of the ships, not having the ice category or having insignificant one, so as the transportation of the cargoes by the multifunctional ice–navigating ship itself or its another work.

The index of cargoes carrying capacity of batch constructed merchant ships on the considered lines (Chapter 5) is usually the effect index, or, for example, the annual amount of the produced water biological resources for the fishery vessels and etc. It was considered, that for the ships of some types, like the service–auxiliary ones, the icebreaking ships, the harbor tugs, the rescue ships or others, the effect may

not be determined by one or another index of the work per unit of time, in particular, per year, and characterizes by potential opportunities of the functions fulfillment during the definite period, for example the opportunities of the ship navigation in ice of assigned thickness, carrying on board the set of functional equipment and cargoes within the design deadweight or volume of premises, assigned in the terms of references, or the opportunities of the escort service of ships not having ice category or having the insignificant one by multifunctional ice–navigating ship, which size is correlated with the sizes of escorted ships in the ice. Wherein the size of multifunctional ice–navigating ship in the composition of utility function is possible to characterize, for example by design deadweight DW , the cargo waterline displacement D or the other the characteristic of ship size (PG , GRT , NRT and etc.).

Characteristic of multifunctional ice–navigating ship size of above listed set of could be used as index of the economic effect in composition of the economic criterion when finding the ship design characteristics, since it size can indicate the ship performances in the ice: on one hand, the amount of provided navigation services by the ship in ice of assigned intensity, in particular the width of laying channel in ice field, on the other hand, the ship size characteristic determines the room for arrangement of functional parts of the ship, which are indicated in the terms of reference.

Index of present worth PW with account of budgetary costs saving CD of multifunctional ice–navigating ship in the mathematical model for finding of it optimal design characteristics under given constraints is determined by the formula (5.7, chapter 5). This index PW with account of the saving CD dependence on design constraint of solid ice thickness h and on variable sought, representing the ship size characteristic of design deadweight DW , determined with the account of the rest characteristics in the mathematical model and is shown on functional surface and in the projection (Fig. 6.1 a and b).

Analysis of graphic dependence of present worth PW deducting budgetary costs saving CD on the ship variable size DW and on design constraint of solid ice thickness h says that the specified economic index in the systemic attitude is not the criterion for finding of optimal design characteristics of the ship, and the functional surface of the present worth PW has not the relevant optimal extrema along the axis of sought variable of design deadweight DW , and the present worth PW by with the increase of the ship size DW . This means that for conformity the systemic comparability of multifunctional ice–navigating ship options, differing by the size DW , it is required to determine the criterion per unit of economic effect E (as the utility function), which depends on the ship size as well.

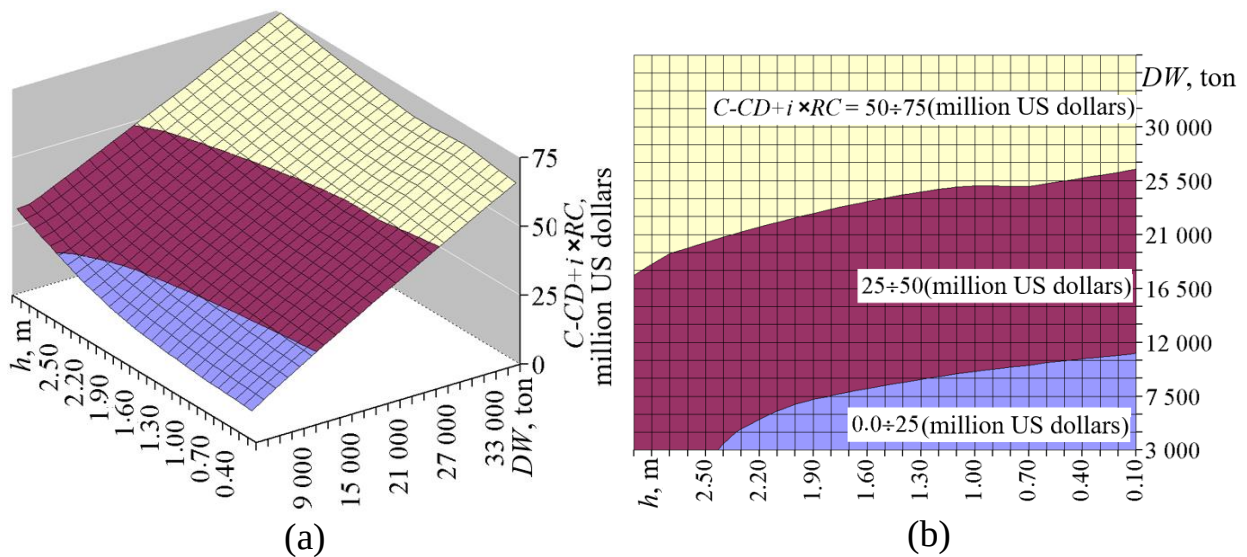


Fig. 6.1. Dependence of present worth PW deducting the budgetary costs saving CD of multifunctional ice–navigating ship on design constraint of solid ice thickness h and on characteristic of design deadweight DW sought as the ship variable size

In the composition of mathematical model used for determining of optimal design characteristics of multifunctional ice–navigating ship the investments and the other costs (RC , C and PW) as well, as the economic effect E are the functional dependences on the ship characteristics X , varied in the process of their optimal values search, and on specified design constraints, to which the data Z and the parameters Y (the design particulars of ship) are assigned.

When using the independent characteristic of multifunctional ice–navigating ship size (DW or other) as the index of the economic effect E it is of the interest the methodological feature of this index, which as well is the variable designing characteristic of the ship when finding the optimal value of this characteristic.

The characteristic of the ship size, which correlates with the ship carrying capacity, is considered below and influences the composition of objective function and the mathematical model. Characteristic of ship size in the appropriate interval of it variation can be used as the index of economic effect E of multifunctional ice–navigating ship in the denominator of specific present worth (PW/E) criterion with the account of the appropriate interchangeability of the ship size characteristic and annual cargoes carrying capacity, when using these indexes in the composition of it economic criterion for design optimization of multifunctional ice–navigating ship. Optimal values of the ship design characteristics got corresponding the optimum (the optimal extremum) of objective function, that is the minimum of specific present worth in each option of effect in the criteria denominators (PW/Q_G ,

or PW/DW) within constraints, will be similar because of indicated appropriate interchangeability of the economic effect index options (Q_G and DW) for multifunctional ice–navigating ship.

Criterion of specific present worth (PW/DW) deducting the budgetary costs saving CD of multifunctional ice–navigating ship per unit of the ship utility function index, which in this case is adopted the ship design deadweight DW

$$PW/DW = (C - CD - i \times RC)/DW. \quad (6.1)$$

Dependence of efficiency criterion of multifunctional ice–navigating ship under design of specific present worth (PW/DW) deducting the budgetary costs saving CD per unit of the index of ship utility function (6.1), as which the design deadweight DW is considered, on design constraint of assigned thickness of solid ice h affordable to overcome, and on variable characteristic of design deadweight DW , determined with the account of rest characteristics in the mathematical model, is shown in the form of functional surface and in the projection on basic plan (Fig. 6.2 a and b).

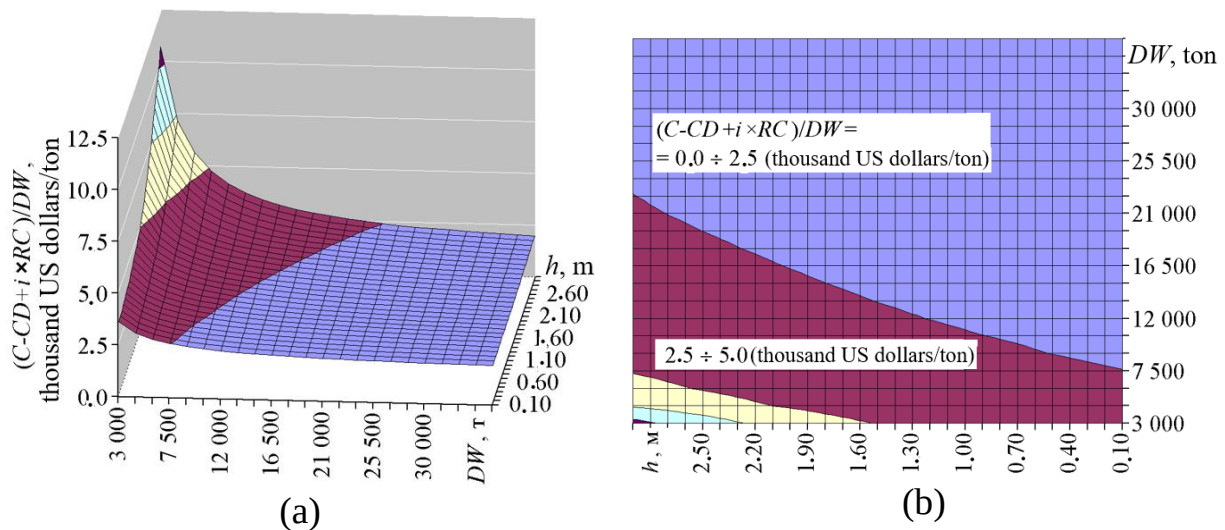


Fig. 6.2. Dependence of specific present worth (PW/DW) deducting the budgetary costs saving CD per unit of multifunctional ice–navigating ship utility function index, as which the design deadweight DW is considered, on design constraint of assigned thickness of solid ice h affordable to overcome and on variable sought characteristic of design deadweight DW

Given the duality or multiplicity of multifunctional ice–navigating ship assignments, including as ice field overcoming and the escorting of other ships, not having essential ice category, and has the cargoes transportation purpose as well, besides of ice overcoming one, the economic effect is dependent on size of the ship

and on capacity of the power installation, but the powers (of installation and effective) are as well in dependences on size of the ship in the definite degree, considering the less velocity than the ship size relative variation ranges.

Use of index the annual carrying capacity Q_G of multifunctional ice-navigating ship is considered as an alternative option of the economic effect index E , which is usual for determining of utility function for operation in open water of cargo ship, assigned in the batch construction. The specific present worth (PW/Q_G) deducting the budgetary costs saving CD of multifunctional ice-navigating ship per unit of the ship utility function index, which in this case is adopted per unit of transported cargoes – the ship annual carrying capacity Q_G (during period T_2 in each year, when using the ship in open water) are determined as

$$PW/Q_G = (C - CD - i \times RC)/Q_G. \quad (6.2)$$

Dependence of specific present worth (PW/Q_G) deducting the budgetary costs saving CD per unit of mass of transported cargo of period T_2 in each year, when using the ship in open water, on design constraint of the thickness of solid ice h affordable to overcome in frozen sea in the mode of navigation servicing and escorting T_1 , and on variable characteristic of design deadweight DW , determined with the account of rest characteristics in the mathematical model, is presented in the form of functional surface and in the projection on basic plan (Fig. 6.3 a and b).

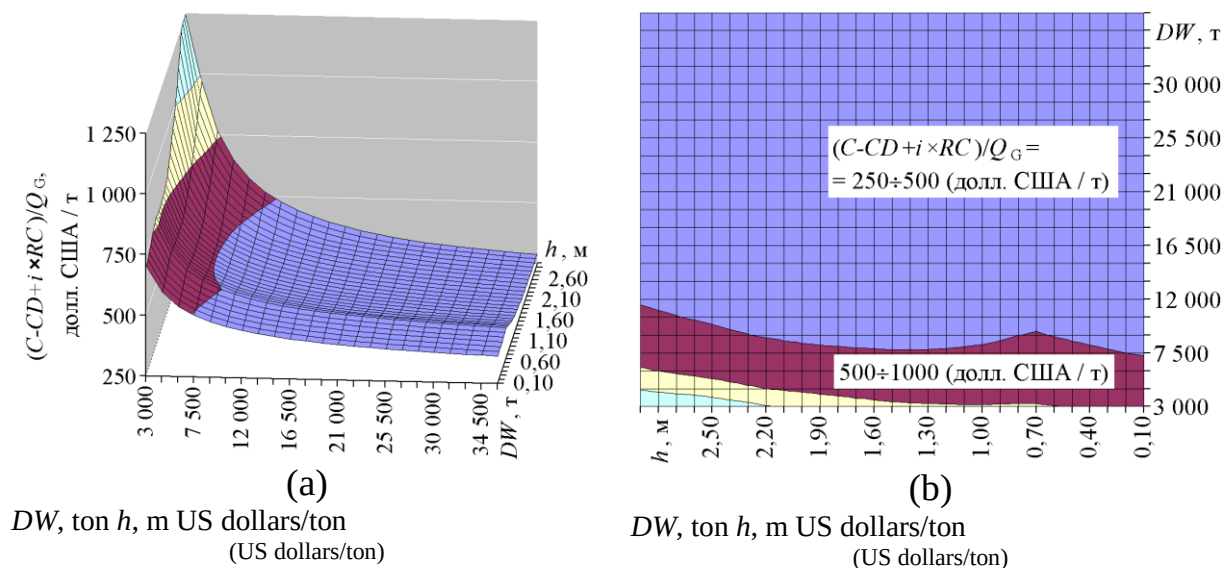


Fig. 6.3. Dependence of specific present worth (PW/Q_G) deducting the budgetary costs saving CD per unit of utility function, which is considered the annual carrying capacity Q_G (during period T_2 in each year, when using the ship in open water), on design constraint of solid ice thickness h affordable to overcome in the mode of navigation servicing and the escort of other ships T_1 and on variable characteristic of design deadweight DW

The graphic surface of this objective function of the specific present worth, as it is shown on charts (Fig. 6.3 a and b), is characterized by non-uniform smoothness for the specified thicknesses of solid ice in the considered example relevant of about 0.70 m. Indicated non-uniform smoothness of the surface of objective function is linked with the assigned constraint of minimal velocity of ship in open water.

For the graphs plotting it is assumed, the required velocity in open water in the examples of calculations assumed no less than 12 knots from the point of view of the ship appropriate controllability. This constraint affects the evaluation of the objective function for determining of the effective power Ne , which is likely enough to satisfy small specified constraint of thickness of solid ice affordable to overcome, at which the lower constraint of velocity in open water impacted more sufficient on the effective power Ne than the ice layer thickness of small value. The impact of the combination of constraints (the assigned thickness of ice and the minimal appropriate velocity in open water) on capacity of the power installation NP and on the effective the power Ne leads to the visible surface irregularity of the objective function (PW/Q_G). This indicates the boundary of the conditions change of the propulsive and the effective powers evaluation (N_{ICE} or Ne), which, on one hand, depends on assigned design constraint of solid ice thickness h (at large values of thickness) and on the other hand – on assigned constraint of the minimal velocity appropriate from the point of view of the ship controllability in open water, if ice thickness affordable to overcome is assigned small.

For the assumed constraint of the ship velocity in the open water no less than 12 knots (although it is possible the other assumed this lower constraint of the velocity) the boundary index of thickness of ice thickness affordable to overcome, as it is determined and indicated on the graphs, for multifunctional ice-navigating ship is about 0.70 m (Fig. 3.8 item 3.1). If the assigned design constraint of solid ice thickness h exceeds this limiting velocity of ship in the open water, then the factor impacting the index of ship power installation capacity is the design assignment to overcome ice, which is most close to the icebreaker's assignment. In the other case the power corresponds the requirement of the ship motion in open water with the velocity no less than the assigned minimal velocity required for the ship control, and this power is to be enough for the overcoming of ice, which thickness h is no more than indicated boundary index of solid ice thickness.

In the same time the indicated non-uniform smoothness of the objective function surface (Fig. 6.2) has not the significant influence on conclusion of preference of the bigger size of multifunctional ice-navigating ship in assessing its efficiency by

the specific present worth per unit of transported cargoes (PW/Q_G). A similar conclusion of the preference of ship of the bigger size it is possible to have by the analysis of the graphic surface (Fig. 6.3) of the objective function of specific present worth (PW/DW) per unit of the ship size (the design deadweight). However, the indicated forms of efficiency criteria shown by graphic surfaces of objective functions as costs indexes are reducing indefinitely by increasing the ship size, and these criteria do not cover the investment constraint influence of subsidies provided for creation (the designing, construction and equipping) of multifunctional ice–navigating ship. The financial constraint impact on the forms of criteria and on resulting values of optimal design characteristics is considered below.

6.2. Choice of utility function option for the multifunctional icebreaker

Almost any new icebreaker, including one considered under design before constructing, in the definite degree corresponds the concept of the multifunctional ice–navigating ship, if additionally the icebreaker is suitable for cargoes transportation, as well, as for fulfilling of the engineering or rescue works, for the generation and the delivery of power and for other purposes in freezing seas, these are characteristic by the icebreakers specifications and their general arrangements (items 1.3–1.5).

In the same time, besides of the icebreakers as they are, many of ice–navigating ships for example the new LNG–tankers, the supporting (the supply delivery) ships, the scientific–research ones and the others, besides of fulfillment of their appropriate purposes are suitable for the motion in ice as well, and the ship patency in solid ice predetermines its navigation performances in other conditions, in particular, in broken ice of various degree of cohesion, as well, as enough power to run in open water with no less velocity than economically feasible one, so the velocity in open water likely is the operation performance, depended on patency in solid ice, rather than design one.

Given the mentioned duality or plurality of functions of assignment of multifunctional ice–navigating ship the economic effect could be determined as the working (operating) index of the ship annual cargoes carrying capacity, or the potential (the design) characteristic of the ship size and particulars dependent on the size, characteristics of the ship structural parts, the mechanisms, the energy generation machinery, the gears, the systems and etc., which is considered above in detail (item 6.1).

Choice of the alternatives of economic effect index (the utility function) is required for its use in the composition of economic criterion when selecting optimal design characteristics of the ship. The alternatives of utility function are considered

of the ship of cargoes transportation purpose or it use for the navigation service in frozen sea implementing the other ships escort in ice environment. The possible strict preference with specified combination of data (the design constraints), considering the alternatives of ship cargoes transportation purpose and the navigation function of the other ships escorting, would mean the choice of type of multifunctional ice–navigating ship of two indicated alternatives of the specialized assignment, given that the specialized ships are usually batch constructed merchant ones of various types, having insufficient ice category or without it, acts the adjacent type of the multifunctional ice–navigating one, as well, as the specialized icebreakers not having other purposes are of adjacent type too, in particular, the icebreaker assigned for patrolling in frozen sea with not transportation cargoes or other purpose.

Formal indicator of the option selection within the alternatives of multifunctional or specialized icebreaker in dependence on assigned design constraints could be the result of the determining of optimal design characteristic, depending on degree to which the other purposes of the ship, besides of the icebreaking, correspond the found optimal characteristic of ship size like it design deadweight or other characteristic of size in specific case if design deadweight is dependent on other characteristic of the ship size considered the independent variable and got optimal.

In the same time, the evaluation of options of utility function (Q_G or DW) interchangeability in the denominator of the criteria of specific present worth (PW/Q_G) and (PW/DW) is of the interest – what could be or is it the difference (or the deviation) of multifunctional ice–navigating ship optimal sizes found, each of which corresponds minimal extrema of indicated objective functions. The analysis of the dependence of annual carrying capacity relation to the design deadweight (Q_G/DW) on size of multifunctional ice–navigating ship observing assigned design constraint of solid ice thickness h (Fig. 6.4 a and b) affordable to overcome got with the use of the considered mathematical model, shows that indicated proportional relation of the carrying capacity to the ship size is generally sustainable when varying the size of ship and proportionally depends on assigned design constraint of solid ice thickness h affordable to overcome, and minor difference of the dependence from the proportionality is noticeable for the ships of lesser size and lesser assigned ice category (the design constraint of solid ice thickness h affordable to overcome).

Therefore, the annual carrying capacity Q_G of the ship for assigned design constraint of solid ice thickness h affordable to overcome at the initial stages of designing it is possible to consider proportional the ship size (the design deadweight DW or this or that other variable dependent on size) in the wide range of the ship size variation, and the selection of one option utility function to the other of two considered

options (Q_G and DW) in the denominator of the economic criterion practically does not impact the got value of the ship size, which attributes optimal extremum of objective function.

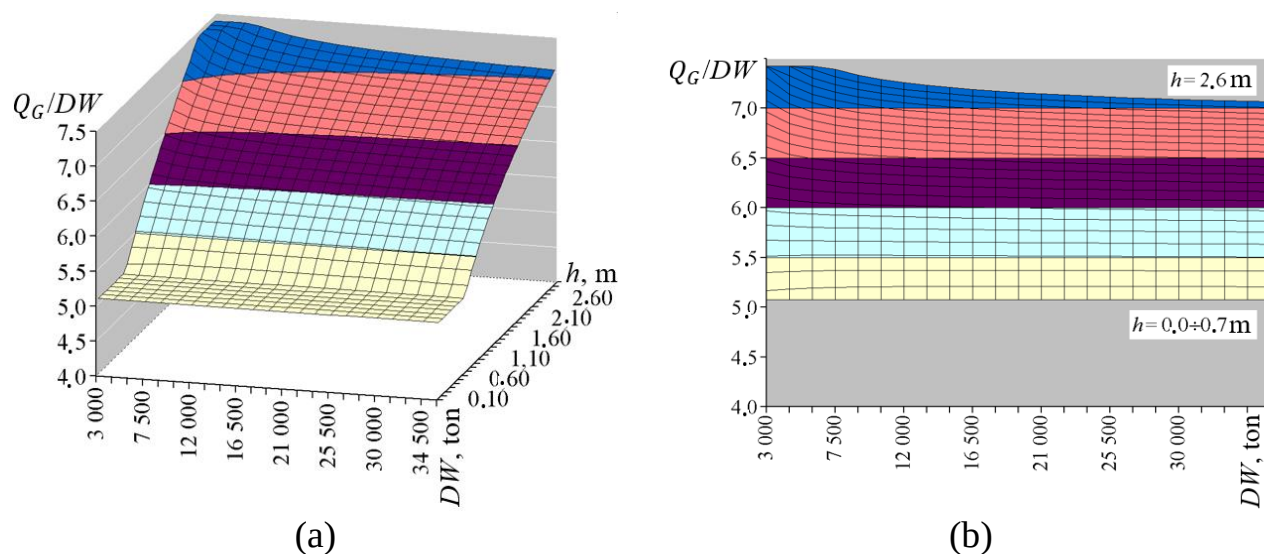


Fig. 6.4. Dependence of relation of multifunctional ice-navigating ship annual carrying capacity to its design deadweight (Q_G/DW) on design deadweight DW and on assigned design constraint of solid ice thickness h affordable to overcome

Because of general similarity of the ship size got by criterion of specific present worth in both of considered options of utility function one of these options can be used in the next, for example the utility function of the ship potential characteristic of design deadweight DW in the denominator of specific present worth (PW/DW), which is more consistent with evaluation of the ship navigation in the freezing sea, the fulfillment of escorting in ice and the auxiliary support functions of other ships, although, considering the proportionality of the ship size with the operating index of the ship annual carrying capacity, which for multifunctional ice-navigating ship is indicated by functional surface of relation of the ship annual carrying capacity to its design deadweight and by the projection on the graph (Fig. 6.4 a and b), therefore the criterion of specific present worth per unit of ship size (PW/DW) proportionally characterizes its efficiency of cargoes transportation (PW/Q_G) as well.

6.3. Provided subsidies investment constraint in ship construction accounting as penalty amendment to the objective function

The analysis of graphs (Fig. 6.2 and 6.3) of objective functions of the specific present worth criteria (PW/Q_G and PW/DW) indicates the unilateral nature of both variants of considered criteria efficiency of two options of utility function (Q_G and DW),

meaning by these two options of criteria the wrong preference of the ship of indefinite big size, corresponding with that the considered criteria themselves do not attract the impact of constraint of the subsidies, provided in the ship construction RC^* , which is the ship size systemic constraint of the implicit nature.

It should be borne in mind that the subsidies constraint in the ship construction RC^* is definitely relative, because of availability to have the extra budgetary finances (the corporate ones), besides of the budgetary ones, at the interest proportional the total of commercial risks (the capital cost), that is the discount rate i .

It should be borne in mind that ships construction for freezing seas, or for the other sparsely populated regions with the harsh climate can be of socio-economic goals and for development of these regions industries and navigation in these seas, so the prospective issues of creation and the improvement of national shipbuilding industry, which at the stages of it establishing and original developing needs the special economic conditions, for example, the appearance of demand of the replenishment of multifunctional ice-navigating ships, which are not mastered by the batch shipbuilding and which construction needs the federal funding.

Besides of finding of utility function considering as the ship performances and patency in ice, associated with the ship size and with other its characteristics and design particulars, dependent on the size, or associated with the ship carrying capacity, it is required to study the design constraints, as well, and the penalty amendments to optimality criterion for needs of extra financing (or the premiums for subsidies economy) at the initial stages of multifunctional ice-navigating ship designing, if, for example, the characteristic of subsidized ship size depends on the investment constraint.

The investment constraint RC^* is the provided budget subsidies in multifunctional ice-navigating ship creation, including its designing, construction and equipping for the operation, corresponding the ship size (particularly the design deadweight DW^*), which is dependent on the subsidies provided.

Using the parametric formula (5.8, item 5.3) of dependence on size of multifunctional ice-navigating ship of subsidies required for the ship creation at initial designing stage it is possible to transform the investment constraint /116/ of provided budget subsidies RC^* in the ship creation to constraint of subsidized index of design deadweight DW^* , dependent on provided subsidies

$$DW^*(RC^*) \approx 30.96 \times RC^* + 789.5, \text{ ton.} \quad (6.3)$$

Federal possession of the ship or the joint property of the corporate and federal participation with the federal control or without it indicates the full or the partial

funding of multifunctional ice–navigating ship creation (it designing, construction and equipping) by federal budget subsidies.

To bring the flows and one–time financial indexes to the comparable form the index of the total commercial risks, that is the index of discount rate i can be used, what is known in the economy. In the same time for determining of the investment constraint by the index of subsidies RC^* provided in the ship creation it is required to make the amendment of the present value of future operating costs flow to the general index of the finances required for the construction, since the used economic criterion of the present worth PW exactly accounts as the flow of operating costs $(C - CD)$ deducting the budgetary costs saving CD , so as the one–time financial index of the investments capital cost, which is investments index transforming comparable with cash flow $(i \times RC)$.

6.4. Objective function with the account of penalty or premium amendment for compliance with the budget subsidies constraint in construction of multifunctional ice–navigating ship

For the creation of multifunctional ice–navigating ship (it designing, construction and equipping) the investment constraint of provided budget subsidies is conventional to a certain extent, since in addition to the subsidies it is possible to raise funds from the other sources by the market cost of capital under reasonable interest, correlated in the similar estimates with the total of investment risks, that is with the discount rate i . These corporative finances (the extra–budgetary) can be funded as to subsidize the investments RC in the ship creation and it commissioning in the operation, so to fund the operating costs C deducting the budgetary costs saving CD , which is equal the probable extra–budgetary income for year or for the corresponding time. These extra investments, if they are required, can be obtained annual at the financial markets for the cost of capital in the monetary units, corresponding the present worth of cash flow, equivalent the annual operating costs C , deducting the budgetary costs saving CD , together with the product of discount rate i (the total risks index) on one–time investment RC for creation of the ship and it commissioning in operation.

If corporate finances (the extrabudgetary) are required in the case of the budgetary investments shortage, that is, if the subsidies, provided in multifunctional ice–navigating ship creation and assigned in the terms of references, are not enough for the creation, including it designing, construction, etc. of the ship of optimal size, then to obey the financial constraint RC^* of the subsidies, provided in creation

of the ship, the penalty amendment is of the positive value, when applied to any criterion like costs, in particular, the present worth (PW/Q_G and PW/DW), or the specific present worth. It has to be considered that the ship of bigger size and more expensive in the construction is usually of the lesser costs (the construction, operation and others) per unit of the ship size, that is why the financial constraint RC^* is relevant.

By the way, the same feature of ship of bigger size, that is it the lesser costs per unit of the ship potential characteristic (the size, the power of installation), that is per any of the independent design characteristic of the ship size or capacity, or per unit of that or other characteristic of the ship operation, like its annual carrying capacity of cargoes, or the power generated and delivered to consumers, if it is of the ship assignment, or per unit of annually produced liquified natural gas, etc. leads to the introduction of concept of so-called «green ship» (the environmentally friendly ship). The potential indexes (the design) and the operation ones of the ship have to be bigger as possible, because these indexes values considered factors of the ship ecological cleanliness, along with some other characteristics and particulars of the ship, besides of its size, such as its type of fuel, as safety of transportation of goods, including liquid chemicals, oil, gas, etc. Any way at the initial designing stages the potential and operation indexes corresponded with the ship size are of the attention not only by the economic reasons, but by ecological ones too, and these are quite understandable, because the costs amount spent per unit of indexes proportional with size generally indicate the environment resources use and the impact of the ship construction and operation on the environment per unit of the ship utility effect of its assignment. Ecological cleanliness factors of multifunctional ice-navigating ship corresponded with the economic criteria of minimized costs, as these criteria corresponded with reduce of the resources use and, finally, with reduce of interference in the environment per unit of effect got (the ship utility function), on the contrary, the economic criteria of maximized profits may result the increase of resources use per unit of effect.

Thus, investing more money and increasing the ship under creation sizes and its effect in operation absolute, one reduces costs and impact on the environment specific, that is per unit of effect, in particular, the unit of the ship size. But the investment constraint arises, as of provided federal subsidies limits, so because of the capital cost (the interest paid to the corporate investor) for affordable corporate extra – financing.

Given the symmetry of approach use at multifunctional ice-navigating ship design optimization, the premium amendment to the minimized criterion of specific present worth is of negative value upon compliance of ship sizes the provided subsidies RC^* or in case of the provided subsidies excess. That is if it is possible to create the more compact multifunctional ice-navigating ship for the lesser subsidies

than are provided, and the ship which would nevertheless meet the design constraints, including will obey of the investment constraint RC^* , that is the ship size got is optimal by the economic criterion with the use of specified premium amendment, which reduces the value of the specific present worth by the economy of subsidies for the ship creation. For account of the investment constraint by matching variable sought of the ship size, in particular it design deadweight DW the subsidized index DW^* , the criterion is used, combining the economic criterion of specific present worth (PW/DW) with the penalty amendment (or the premium one) for compliance of the ship size (DW) and it subsidized index of design deadweight DW^* , assuming expert factor a_F of the amendment (penalty or premium) influence the criterion of specific present worth by compliance of provided and required subsidies in the ship construction with investment constraint.

When subsidies saving arises subject the compact ship creation meeting the design constraints, it is possible to evaluate the present worth savings Δ_{PW} in the form of cash flow equivalent of the corresponding subsidies RC^* (the investment constraint) saving, which is to be the extra result for the investor, that is the amendment (penalty or premium) to the objective function for compliance of ship under design of the varied ship size (DW) to subsidized index of design deadweight DW^* , when designing multifunctional ice-navigating ship. Absolute value of penalty (or premium) amendment to objective function of specific present worth (PW/DW) per unit of utility function, in particular per unit of design deadweight DW , is

$$\Delta_{PW/DW} = (PW/DW) \times a_F \times ((RC/RC^*) - 1), \text{ US dollars / ton}, \quad (6.4)$$

and the objective function f of specific present worth (PW/DW) with account of penalty (or premium) amendment $\Delta_{PW/DW}$, is

$$f = PW/DW + (PW/DW) \times a_F \times ((RC/RC^*) - 1), \text{ US dollars / ton}. \quad (6.5)$$

Considering the dependence (6.3) of the subsidized index of the ship design deadweight DW^* and the assigned investment constraint RC^* the approximately proportional subsidies RC required for the ship construction are

$$RC/RC^* \approx DW/DW^*, \text{ or } DW^*/RC^* \approx DW/RC, \quad (6.6)$$

in the wide range of values of assigned constraint of subsidized index of the ship design deadweight, or of the amount of subsidies provided in the ship creation (DW^* ,

or RC^*) with some deviation from the proportionality more likely for small subsidies, which are not so much characteristic for multifunctional ice–navigating ships. By replacing of the variables, it is possible to transform the objective function to use the ratio of variable size of the ship DW and the subsidized index of the ship design deadweight DW^* instead of the determining amendment in dependence on the ratio of the required investments RC associated with the ship construction to the provided subsidies RC^* .

The objective function of specific present worth (PW/DW) with account of the penalty (or premium) amendment, determined by absolute value $\Delta_{PW/DW}$, or by relative one $\delta_{PW/DW}$, looks like

$$f = PW/DW + \Delta_{PW/DW}, \text{ or } f = PW/DW \times (1 + \delta_{PW/DW}), \quad (6.7)$$

where the penalty (or the premium) amendment in the objective function f , determined by absolute value $\Delta_{PW/DW}$ and by the relative one $\delta_{PW/DW}$, are

$$\Delta_{PW/DW} = (PW/DW) \times a_F \times ((DW/DW^*) - 1),$$

$$\text{and } \delta_{PW/DW} = a_F \times ((DW/DW^*) - 1), \quad (6.8)$$

or

$$f = PW/DW + (PW/DW) \times a_F \times ((DW/DW^*) - 1) =$$

$$= PW/DW + PW \times a_F \times (1/DW^* - 1/DW), \quad (6.9)$$

in these formulas it is visible that the amendment to the objective function (penalty or premium): $PW \times a_F \times (1/DW^* - 1/DW)$ is proportional to the index of present worth PW by the absolute value within the scale: $(1/DW^* - 1/DW)$.

The graphic surface shape indicated previously (Fig. 6.2 a) of function of specific present worth (PW/DW), deducting the budgetary costs saving CD , per unit of utility function, considered the size of ship (DW), on assigned design constraint of solid ice thickness h affordable to overcome and on variable sought of characteristic of the ship design deadweight DW is shown on the graph (Fig. 6.5a) in projections correlation with the dependence of present worth PW , deducting the budgetary costs saving CD . The second considered functional surface (Fig. 6.5b) indicates the form of dependence on listed arguments of amendment to the objective function for the compliance of the variable characteristic of the ship size (DW) with the subsidized index of it design deadweight DW^* , corresponded the assigned investment constraint RC^* of funding of multifunctional ice–navigating ship creation (it designing, construction and equipping) by federal budget subsidies.

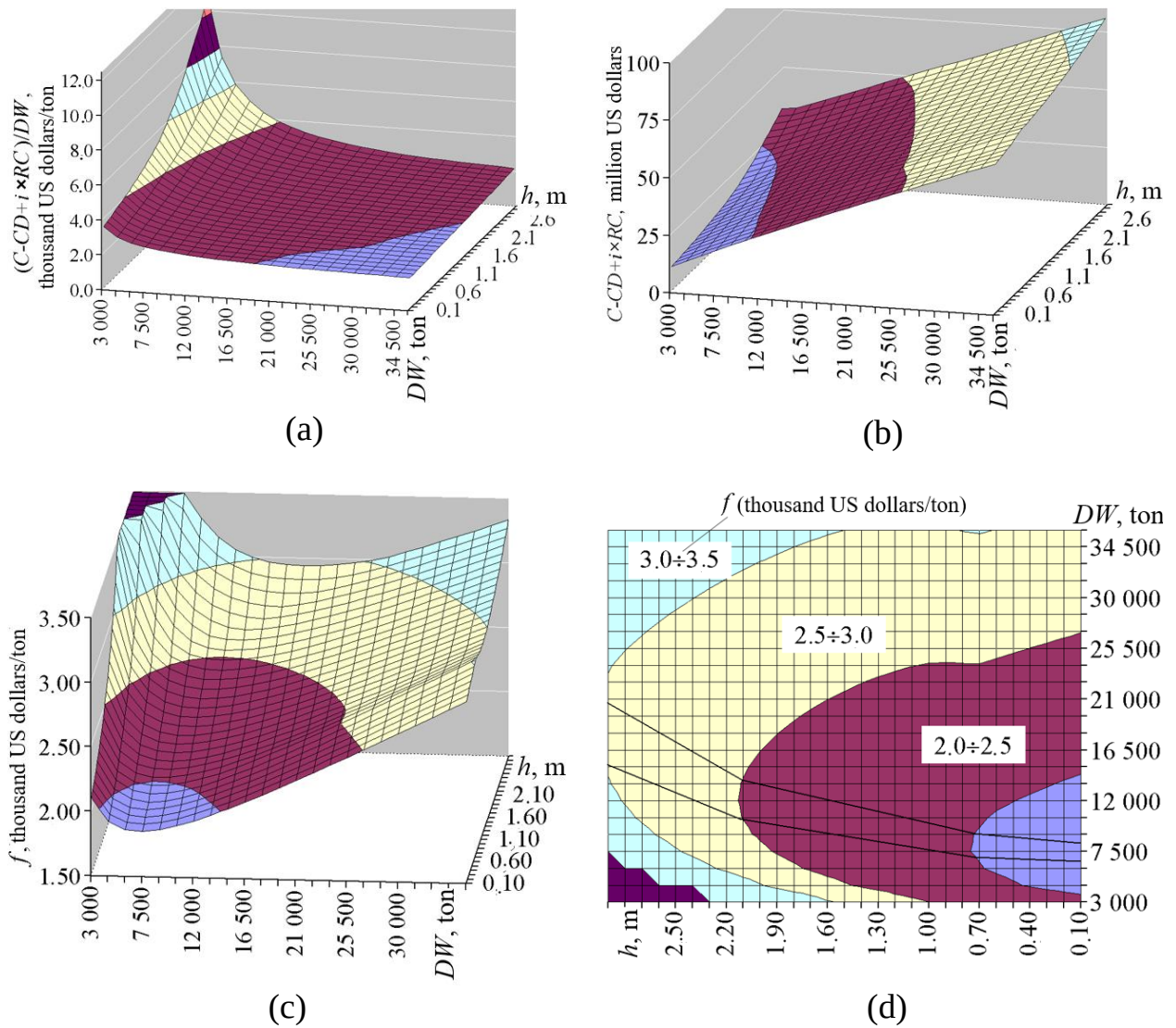


Fig. 6.5. Dependences on size of multifunctional ice-navigating ship (on it design deadweight DW) and on assigned design constraint of solid ice thickness h affordable to overcome of indexes: (a) specific present worth per unit of the ship size (PW/DW); (b) present worth PW by it absolute value proportional the amendment to the objective function for the ship size (DW) compliance the subsidized index of it design deadweight DW^* ; (c and d) the generalized criterion combining the specific present worth and the amendment (penalty or premium) for the ship size DW compliance the subsidized index of the ship design deadweight ($DW^* = 16\,270$ ton) for the assigned financial constraint of the provided subsidies ($RC^* = 500$ million US dollars) and for the rest data of the listed set (see table 5.1)

When combining the indicated functions: the economic criterion and the amendment (Fig. 6.5 a and b) – in accordance with the formula (6.9) the resulting dependence is got in the general form (Fig. 6.5 c and d), covering together the economic

criterion of specific present worth (PW/DW) and the amendment (penalty or premium) for the ship size (DW) compliance the subsidized index of its design deadweight DW^* with the account of expert factor to the amendment. For indicated graphic surface of generalized criterion the expert factor a_F is assumed equal $\frac{1}{2}$.

On the graphic dependence of objective function f in the form of the generalized criterion with the account of penalty (or premium) amendment for the ship size compliance with the investment constraint of subsidies in the ship construction on the assigned design constraint of solid ice thickness h affordable to overcome and on the variable characteristic of ship size (DW) for the base combination of data (see table 5.1), with the account of rest characteristics and particulars of ship in the mathematical model, that is the values of generalized variables (the depended on independent ones), one can determine the area of values of multifunctional ice-navigating ship size by, in particular, of its design deadweight DW . The value of design deadweight DW determined are associated by the balance equations with the rest characteristics of ship (the dependent ones). Besides, it is possible at the initial approximation to find the design particulars, using the available parametric dependences.

Need to pay attention on the fact, that the size of multifunctional ice-navigating ship, when using this index as variable for determining of the objective function corresponded investor's motives when selecting the ship size, and, accordingly, the design particulars of ship dependent on its size, are characterized by the appropriate sustainability in the interval of variation of assigned ice category constraint in the terms of references, that is the index of the ship seaworthiness and patency in ice, specified solid ice thickness h affordable to overcome as the ship design constraint of.

In the analyses of the graphic surface of objective function it is visible, that interval of the optimal values of the design deadweight of multifunctional ice-navigating ship from 6 000 to 20 000 ton corresponds the range of variation of assigned values of solid ice thickness from 0.10 to more than 2.5 m, that is the ship optimal size varied in the interval of approximately ten times narrower relatively the range of assigned design constraint of solid ice thickness variation.

6.5. Relative and absolute amendments to optimality criteria for the investment constraint compliance

Graphs of relative amendment $\delta_{PW/DW}$ (Fig. 6.6 a – c) and of absolute one $\Delta_{PW/DW}$ (Fig. 6.7 a and b) in the form of functional surfaces in dependence on ship size by its design deadweight DW and on the factor a_F of amendment (penalty or premium) to criterion of specific present worth considering the compliance

of the ship under design size with assigned investment constraint of subsidies in the ship creation (it designing, construction and equipping) are indicated in projections for base combination of the data (see table 5.1).

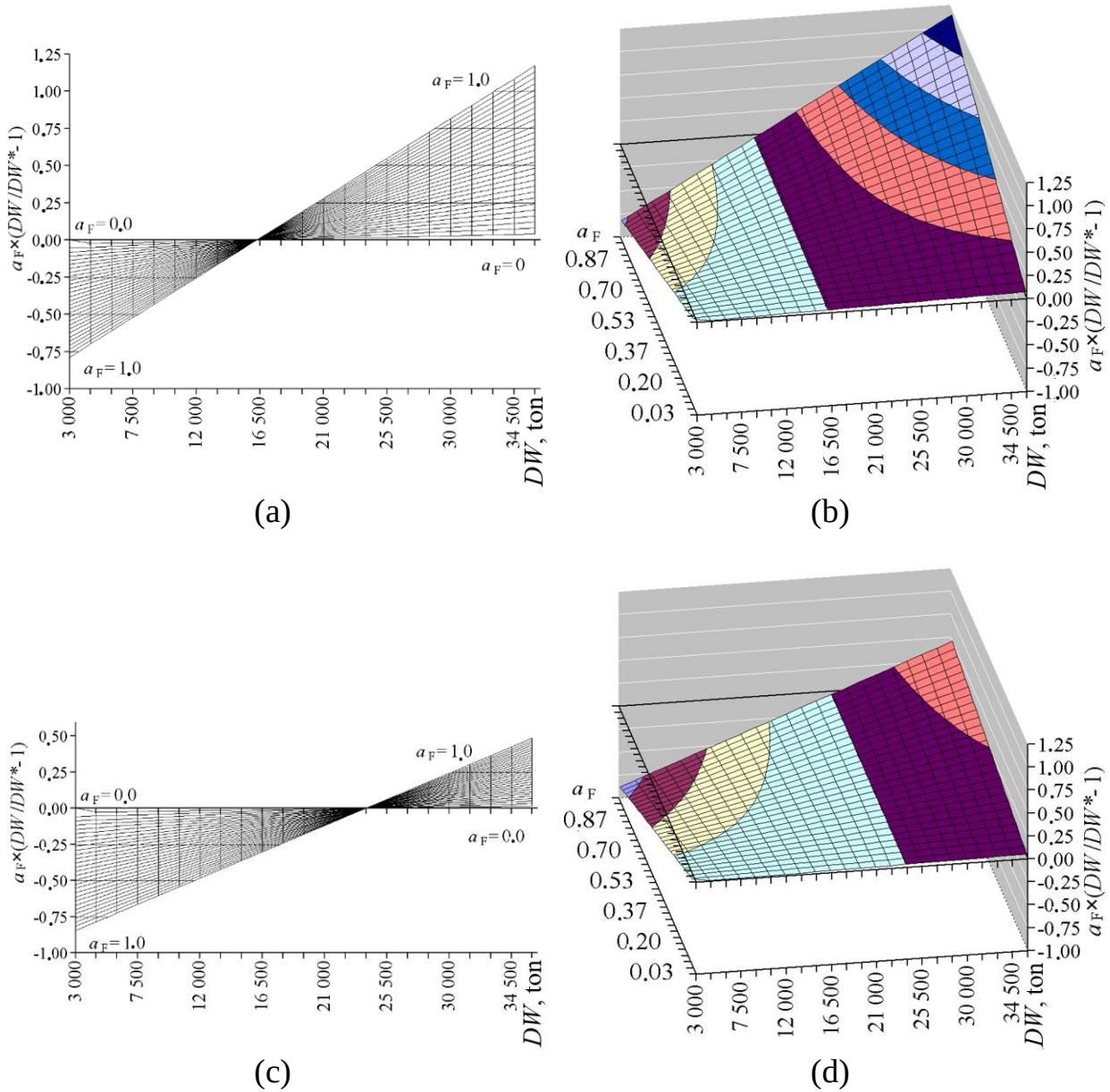


Fig. 6.6. Relative amendment (penalty or premium) $\delta_{PW/DW}$ to the objective function of specific present worth (PW/DW) for the ship compliance with assigned investment constraint of subsidies RC^* , associated with multifunctional ice-navigating ship creation, in dependence on ship size (DW) and on the factor of account of amendment a_F to criterion of specific present worth for options of constraint:

(a and b) the ship size subsidized index of design deadweight $DW^* = 16\,270$ ton for assigned investment constraint of subsidies $RC^* = 500$ million US dollars;
(c and d) the ship size subsidized index of design deadweight $DW^* = 24\,010$ ton for assigned investment constraint $RC^* = 750$ million US dollars

It is visible on the functional surfaces of amendments ($\delta_{PW/DW}$ and $\Delta_{PW/DW}$) to the objective function f of specific present worth (PW/DW) that in the vicinity of assigned constraint of subsidies RC^* of the costs associated with the ship creation, to which the ship size subsidized index of design deadweight DW^* corresponds, the factor a_F of the amendment has small impact on this amendment.

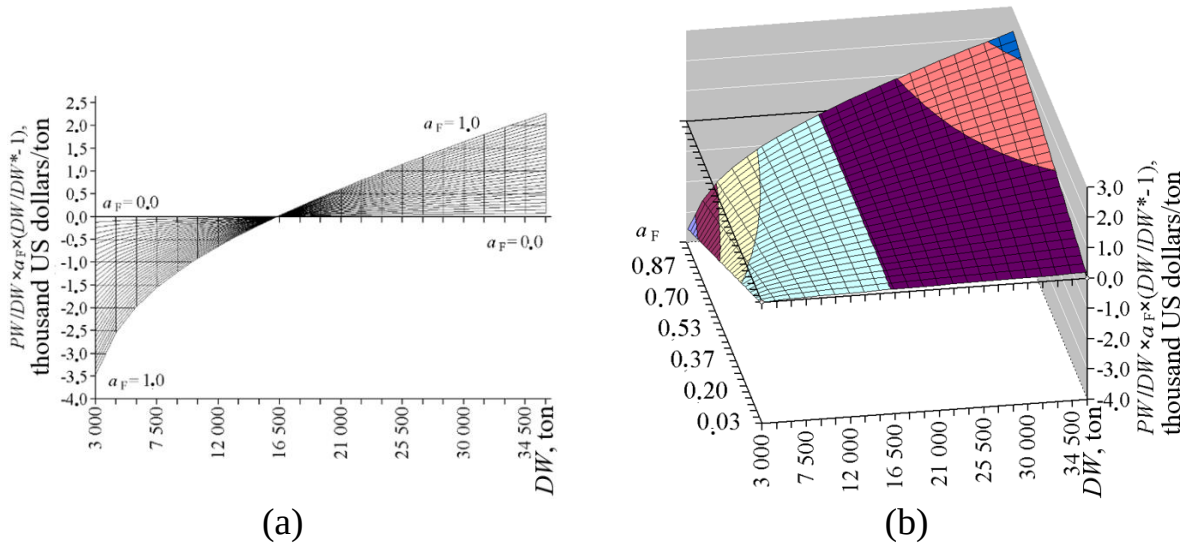


Fig. 6.7. Absolute amendment (penalty or premium) $\Delta_{PW/DW}$ to objective function of specific present worth (PW/DW) for compliance with assigned investment constraint of subsidies RC^* , associated with multifunctional ice-navigating ship construction, in dependence on ship size (DW) and on factor a_F of amendment account to criterion of specific present worth for option of constraint of the ship size subsidized index of design deadweight: $DW^* = 16\,270$ ton for assigned investment constraint: $RC^* = 500$ million US dollars (provided subsidies)

Along the deviation or investment constraint from the assigned subsidies RC^* associated with the ship construction transformed in the form of subsidized index of design deadweight DW^* the amendment to the objective function f , as by it the relative value $\delta_{PW/DW}$ (Fig. 6.6 a – c), so as by absolute one $\Delta_{PW/DW}$ (Fig. 6.7 a and b) the more than bigger factor a_F of the amendment of the investment constraint $DW^*(RC^*)$ compliance in account to the criterion of specific present worth (PW/DW) in the composition of generalized criterion.

6.6. Dependences of objective function with account of amendment of investment constraint of provided subsidies

By graphic functional surfaces (Fig. 6.8 a – c and Fig. 6.9 b and c) the dependences of objective function f (the dependence of the criterion on the variables,

on the data and the parameters) considering the investment constraint by the amount of provided subsidies RC^* and the amendment (penalty or premium) to the criterion of the specific present worth on multifunctional ice–navigating ship size by its design deadweight DW and on the factor a_F of amendment account, it is visible on the graphs that optimal value of ship size DW corresponding minimal of objective function f has the tendency to decrease as increases the factor a_F of the amendment account in the composition of the criterion f .

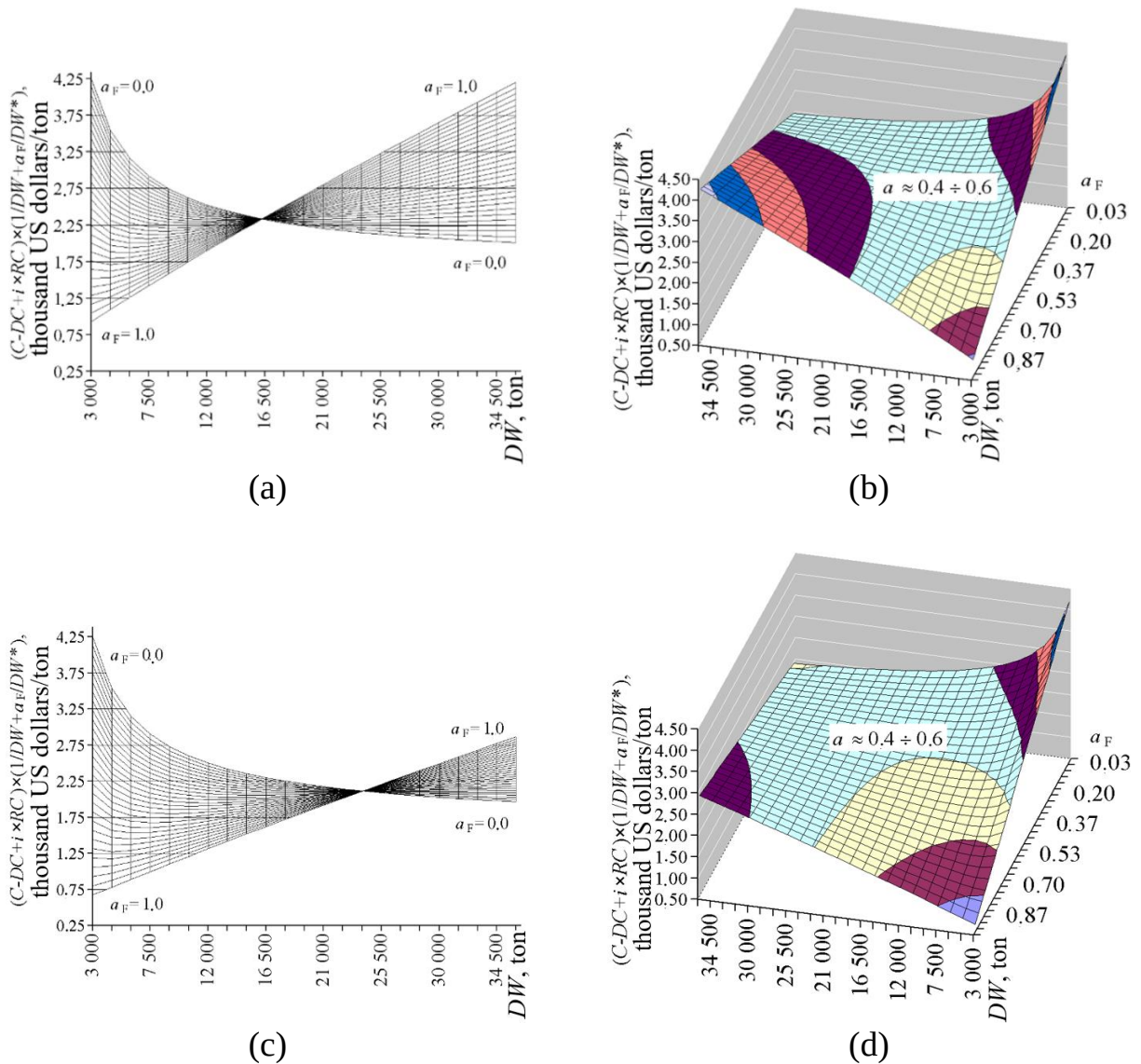


Fig. 6.8. Dependence of objective function f with account of amendment (penalty or premium) for investment constraint compliance on multifunctional ice–navigating ship size DW and on the factor a_F of amendment influence to the criterion of specific present worth, for data options:
(a and b) the ship size subsidized index of design deadweight: $DW^* = 16\,270$ ton for assigned investment constraint of subsidies: $RC^* = 500$ million US dollars;
(c and d) the ship size subsidized index of design deadweight: $DW^* = 24\,010$ ton for investment constraint: $RC^* = 750$ million US dollars (provided subsidies)

This indicates the expecting tendency of multifunctional ice–navigating ship optimal size DW to decrease along the degree of the amendment influence on objective function increases by signification of account of assigned investment constraint of subsidies RC^* , associated with the ship creation (it designing, construction and equipping).

Formally the graphs (Fig. 6.8 a – d, Fig. 6.9) indicate, that objective function f has the optimal extremum along the axis of the ship size DW value for average values of the factor a_F , which are approximately from 0.4 to 0.6, of account of the amendment (penalty or premium) to the objective function for compliance the assigned investment constraint of subsidies RC^* , associated with the ship creation (it designing, construction and equipping) account to the criterion of the specific present worth.

If assume the factor a_F of 0.5 or by that, then there is no the significant relative deviation in finding to optimal ship size independently on this factor from the indicated range. The smaller indexes of the factor a_F of the amendment account to the objective function (less than 0.4) would correspond the resulting indefinitely big optimal size of the ship, which is obtained when using the criterion of specific present worth without the investment constraint, but the unlimited ship size found, which would say of systemic incompleteness of the assumptions and could not lead to the optimal size of the ship under design.

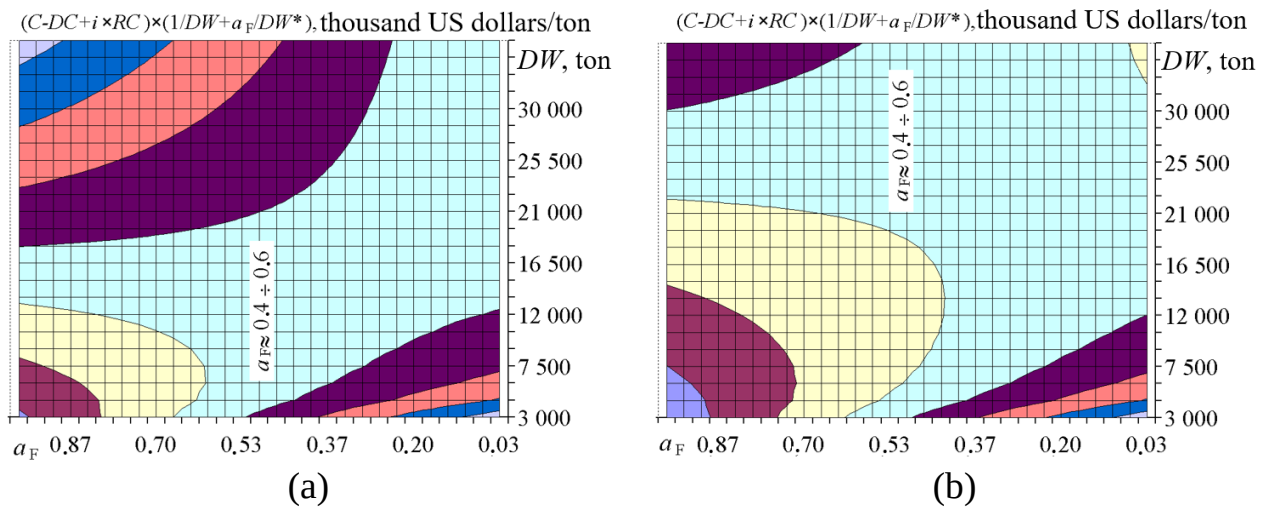


Fig. 6.9. Dependence in the form of projection on ship size DW and on the factor a_F of the amendment (penalty or premium) account in the criterion f of specific present worth with the account of assigned investment constraint of the provided subsidies RC^* associated with the ship creation, for the data specified:

(a) the ship size subsidized index of design deadweight: $DW^* = 16\,270$ ton
for assigned investment constraint: $RC^* = 500$ million US dollars;

(b) the ship size subsidized index of design deadweight: $DW^* = 24\,010$ ton
for the investment constraint: $RC^* = 750$ million US dollars (provided subsidies)

The bigger indexes of the factor a_F of the amendment account for the objective function (more than 0.6) indicate the overvaluation of the investment constraint of subsidies RC^* , associated with the ship creation (it designing, construction and equipping), since in this case the impact of the specific present worth economic criterion on the choice of optimal design characteristics of the ship is underestimated, and the resulting ship size is extremely reduced under the influence of the investment constraint RC^* of the subsidies. In the other words, the variation of factor a_F of the amendment account to objective function one could consider the ensuring of recommendations adopted above of this factor a_F assume in the range from 0.4 to 0.6, or $\frac{1}{2}$.

Two variants of formula of the objective function of specific present worth with the account of amendment (penalty or premium) of the investment constraint of subsidies RC^* , associated with the ship creation (it designing, construction and equipping), besides of the equation (6.5), represented above, are:

$$\begin{aligned} f &= PW \times ((1 - a_F)/DW + a_F/DW^*), \text{ or} \\ f &= PW/DW \times ((1 - a_F) + a_F \times DW/DW^*). \end{aligned} \quad (6.10)$$

Substitute in an equation of index $\frac{1}{2}$ of the factor a_F of the amendment (penalty or premium) account to the criterion of specific present worth it is possible to characterize as the formal equivalence of the impact on objective function as variable ship size DW sought under optimizing, so the ship size subsidized index of design deadweight DW^* , and objective function with account of considered factor ($a_F = \frac{1}{2}$) of the amendment looks like:

$$f = PW \times (1/DW + 1/DW^*)/2. \quad (6.11)$$

Study of methods of multifunctional ice-navigating ship optimal design characteristics determining in the frameworks of systemic approach with the use of objective function and the mathematical model, and with the account of design constraints leads to the following conclusions:

1. Efficiency concept of multifunctional ice-navigating ship, required for finding the criteria, closely corresponds the definition of the utility functions, characterizing the potential (the design) or the working (operational) economic effect, given that the purpose of ship of this class are: as the navigation servicing and the escort in freezing sea of ships of the other classes, not having the ice category or having the insignificant ice category, so as self cargoes transportation or the other assignments, including in the open water season.

2. Criteria of specific present worth for considered options of utility function of the ship, as per unit of transported cargoes in a year (PW/Q_G), so the potential utility function corresponding size of the ship is considered (PW/DW), unilaterally characterize multifunctional ice–navigating ship under design, which indicates the preference of the ship of indefinite maximal size because of the systemic obstacle of the underestimate of impact of the investment constraint RC^* of provided subsidies, associated with the ship creation (it designing, construction and equipping), which predetermine the ship size subsidized index of design deadweight DW^* .

3. Utility function, which potentially can be characteristic of multifunctional ice–navigating ship size at initial stages of designing, on the other hand corresponds with approach of account of investment constraint of subsidies provided for the ship creation, wherein the constraint of subsidies for it use in the determining of optimal design characteristics can be transformed to ship size subsidized index.

4. Besides of the budgetary subsidies in construction of multifunctional ice–navigating ship the finances from the other sources can be involved by the cost of capital, proportionate with the index of total commercial risks, that is the discount rate index. This means that the investment constraint, that is the subsidies provided for the ship creation (it designing, construction and equipping), is conventional to certain extent and optimal size of the ship when determining it by the criterion may exceed the investment constraint of ship size subsidized index, although this corresponds with the use of the penalty amendment, entering the objective function, corresponding the cost of extra investments involved besides of provided subsidies.

5. Systemically the amendment to the objective function can be of the penalty nature, for the investments required for creation of multifunctional ice–navigating ship, which size is bigger than ship size subsidized index, so as of premium nature – for the saving of investments to be spent for the creation of more compact multifunctional ice–navigating ship of lesser size than the subsidized size, although complying the design constraints, assigned in the terms of references.

Checklist

344. The issues of the ship utility function composition of independent components, such as the ship size performances in ice, other characteristics of the ship and it design particulars, dependent on size of ship and on assigned design constraint corresponded with ice category, as well, as the economic effect performances of the ship.

345. Design constraints, which are corresponded with utility function in the form of the penalty amendments to optimality criterion, when characteristics of the ship size are derived in the constraint, in particular, dependent on investment constraint.
346. The need to determine the criterion per unit of the effect of multifunctional ice–navigating ship, that is per unit of the ship size in case of potential utility function, to omit the obstacle of considered options incomparability, when the objective function has not the relevant optimal extrema, and the present worth unilaterally reduces while increase the ship size.
347. Methodological feature of multifunctional ice–navigating ship size independent variable characteristic, when it is used as index of the economic effect and not only the variable.
348. Influencing the composition of objective function and the mathematical model the appropriate interchangeability of economic effect index options: of multifunctional ice–navigating ship size, which correlates with the ship carrying capacity and this means the similarity of resulting optimal characteristics found in both options of the optimality criteria denominators, as the ship size characteristic, so it carrying capacity of cargoes.
349. Criterion of specific present worth deducting the budgetary costs saving of multifunctional ice–navigating ship under design per unit of the ship utility function index of the ship design deadweight.
350. Dependence of the economic effect of multifunctional ice–navigating ship on it size, not only for the purpose to overcome ice, but for cargoes transportation as well, considering as the patency in ice dependence on the ship size, so as the amount of cargoes onboard the ship and the powers (of installation and effective) dependences on the size.
351. The non–uniform smoothness of graphic surface of objective function of specific present worth per unit of the annual carrying capacity, considering the assigned design constraints of minimal velocity of ship in open water and the solid ice thickness affordable to overcome, arising demarcation line of these constraints.
352. The more sufficient impact on the effective power of the lower constraint of the ship velocity in open water than the ice layer thickness of small value, especially for multifunctional ice–navigating ships of bigger sizes (and of small assigned ice categories in terms of references).

353. The conclusion of the preference of the bigger size of multifunctional ice–navigating ship using the specific present worth criteria as per unit of transported cargoes so per unit of the ship size (the design deadweight or the other).
354. The systemic obstacle of lack of consideration of the investment constraint of subsidies provided for creation (the designing, construction and equipping) of multifunctional ice–navigating ship leading to indefinite reducing of the efficiency criteria of costs by the increase of variable size of the ship under designing.
355. Ship patency in solid ice predetermines its navigation performances in other conditions, in particular, in broken ice of various degree of cohesion, as well, as enough power to run in open water with no less velocity than economically feasible one, so the velocity in open water is likely the operation performance rather than the design one.
356. Conformity of utility function in composition of design optimization criterion the potential characteristic (the design one) of multifunctional ice–navigating ship size rather the working (operating) index of the ship annual cargoes carrying capacity, assuming the dependence on the ship size of other design characteristics and working ones corresponded the multifunctionality, characterizing the ship utility optionally.
357. Two alternatives of specialized assignment – the specialized batch constructed and merchant ships of various types, having insufficient ice category or without it, acts adjacent type with multifunctional ice–navigating one, and the specialized icebreakers not having other purposes are of adjacent type too, in particular, assigned for patrolling in frozen sea with not transportation cargoes or other purposes.
358. The choice of the multifunctionality or the specialization of ice–navigating ship assignment considering the results of optimal design characteristics determining observing the assigned constraints, in particular studying the resulting payload of the ship or its design deadweight, or the ratio of net and gross tonnages.
359. Study of utility function interchangeability of options of annual cargoes carrying capacity or the ship design deadweight by study of difference of multifunctional ice–navigating ship optimal sizes, each of which corresponds the use of indicated utility functions in the compositions of criteria.

360. Recommendation to use the utility function of multifunctional ice–navigating ship potential characteristic of design deadweight in the denominator of specific present worth, because this criterion per unit of ship size proportionally characterizes its efficiency of cargoes transportation as well.
361. Systemic prerequisite to have constraint of the subsidies, provided in the ship construction, in the composition of economic efficiency criterion use for design optimization of multifunctional ice–navigating ship to exclude the wrongly preference of the ship of indefinite big size.
362. Relativity of subsidies constraint, provided in the ship creation (the designing, construction, equipping and operation), because of availability to have the extra budgetary finances by their capital cost (the interest proportional the total of commercial risks, that is the discount rate).
363. Socio–economic goals of states regional development and the needs of shipbuilding industry improvement correspond, in particular, with appearance of demand of the replenishment of multifunctional ice–navigating ships, which are not mastered by the batch shipbuilding and which construction needs the federal funding.
364. The penalty amendments to optimality criterion for needs of extra financing (or the premiums for the subsidies economy) besides of provided subsidies for multifunctional ice–navigating ship creation (it designing, construction and equipping).
365. Federal possession of multifunctional ice–navigating ships or joint property of the corporate and federal participation correspondence with federal subsidies of multifunctional ice–navigating ship creation (it designing, construction and equipping).
366. Indexes of the investments transforming comparable cash flow to generalize them in the present worth criterion with the other indexes and to determine the amendment (penalty or premium) for the conformity of subsidies provided for the ship creation (it designing, construction and equipping) the needs of investments.
367. Equivalence the macroeconomic index of discount rate and the capital cost of subsidies in the ship creation (it designing, construction, equipping and operation), which part exceeds the provided funding (the financial constraint).
368. The monetary equivalence of the cost of capital and the cash flow, consisting of the annual operating costs, deducting the budgetary costs saving, together with product of one–time investment for creation of the ship and its commissioning in operation on discount rate (the total risks index).

369. Concept of the environmentally friendly «green ship» of affordably big size and of other maximal potential indexes and operation ones, because the lesser costs and the lesser environment resource use per unit of the ship utility effect got corresponded bigger size of the ship.
370. Ecological cleanliness factors of multifunctional ice–navigating ship correspondence with the economic criteria of minimized costs, with reduce of the resources use and with reduce of interference in the environment per unit of effect got (the ship utility function).
371. Correspondence with premium amendment of negative value to the costs – to the specific present worth criterion of the economy of subsidies for compact multifunctional ice–navigating ship creation, which meets the design constraints of the terms of references.
372. Sustainability of the ship size characteristic and it other characteristics and particulars, depended on the ship size, corresponded the optimal extremum of objective function, when varying assigned design constraint of solid ice thickness affordable to overcome.
373. Use of assumed factor of amendment to the objective function of investments constraint compliance of provided subsidies of costs, associated with multifunctional ice–navigating ship creation, and the check of this factor of amendment harmony (the factor subjectivity degree of influence on the objective function).
374. The tendency of multifunctional ice–navigating ship optimal size to decrease along the degree of the amendment influence on objective function increases by signification of account of assigned investment constraint of subsidies, associated with the ship creation (it designing, construction and equipping).
375. The mathematical extremal of objective function contained the amendment for compliance of assigned investment constraint of subsidies, associated with the ship creation (it designing, construction and equipping), that is the equivalence zero of the partial derivative of the objective function availability for values in the range approximately from 0.4 to 0.6 of the factor of account of the amendment (penalty or premium) to the objective function for compliance the assigned investment constraint.
376. The indefinitely big optimal size of the ship resulting from systemic incompleteness of the assumptions for small indexes of the factor of the amendment account to the objective function (less than 0.4) for compliance of assigned investment constraint of subsidies, associated with the ship creation.

377. Overvaluation of investment constraint of subsidies, associated with the ship creation (it designing, construction and equipping), and the extremal reduce of the ship size found by the bigger indexes (more than 0.6) of factor of amendment account for the objective function, and underestimation of impact of the specific present worth economic criterion on the choice of optimal design characteristics of the ship.
378. The recommendation of the balanced value $\frac{1}{2}$ of the factor of account to the objective function of amendment for compliance assigned investment constraint of subsidies, associated with the ship creation (it designing, construction and equipping).

Chapter 7. Factors of optimal values sustainability of the ship characteristics and design particulars

It is possible to characterize the optimal characteristics found and design particulars of multifunctional ice–navigating ship by their property of sustainability, in the other words, by the sustainability of the characteristics optimality.

For determining of optimal design characteristics X of multifunctional ice–navigating ship with use of the design optimization methods and the systemic approach the correct evaluation of the input data is of the great importance, that are the design constraints, including the characteristics Z of the general system, to which the ship under design belongs an integral part, and the parameters Y , in the other words, the design particulars of ship (the characteristics of it subsystems), assumed as the constants too on initial stage of the ship design characteristics determining and are subject of the clarifying at later stages of the ship design.

In the same time, it is possible to attribute the merchant ship, in particular, the multifunctional ice–navigating one, to the number of the objects, for which the data (in the other words – the constraints) for design optimization determining are of great difficulty, wherein the data errors may occur. Practically the impossibility to be confident to the full at the initial designing stage in data assumed for the ship created for decades, for example, to be confident for sure of assigning of the ship functional purpose, which in particular has to comply with the assigned design constraints of ice environment, the district of the ship operation in this or that distant perspective, the economic conditions, which will be characteristic in the future. At the design stage it is not even possible to know definitely national attribute of the ship after a long–time period. By this reason, the optimal characteristics of multifunctional ice–navigating ship, got at it initial designing stages, have to have the sufficient sustainability. In the other words, the anticipated changes in the future of conditions of the ship use (the constraints assigned in the design) will not negate the choice of it optimal design characteristics.

To assess the sustainability of optimal characteristics at design stage of multifunctional ice–navigating ship it is possible to perform the variant calculations by changing the data and the parameters and correlating the intervals of variation of these indexes with an interval of optimal values of the ship design characteristics change, for example to compare these intervals by their relative values. Graphic form

of the objective function surface in dependence on data and design characteristics can be used for this analysis.

Factors of sustainability of optimal characteristics and design particulars studied with the variant calculations checking the sustainability of optimal design characteristics of multifunctional ice–navigating ship, which were determined with use of the appropriate objective function and respecting design constraints in accordance with concepts of systemic approach, are:

1. Mathematical properties in the vicinity of optimum point (the optimal extremum) of the objective function f and the properties of its arguments: the variables, the parameters and the data (X, Y, Z) , on which the objective function is depended.

2. The balancing ratios between the characteristics X (in their couples) of multifunctional ice–navigating ship, as well, as the parametric dependences between the characteristics of the ship and its particulars (X and Y), at that the design particulars of the ship Y are more sustainable by their relative values.

The required property of sustainability of optimal characteristics and particulars of multifunctional ice–navigating ship corresponds the property of their found optimal values to remain in the narrow intervals of variation, with account of approximate nature of data and design constraints, and of the data anticipation errors at initial stages of ship designing and considering possible variation of data in perspective.

In broad sense one can dually assess the sustainability of optimal characteristics and design particulars of multifunctional ice–navigating ship: on one hand, as the property of the optimal values found to remain in the narrow intervals, with the account of possible variability of data in the perspective, on the other hand, as the ability of these characteristics to remain in the narrow range of their relative values in the set of analogs of the multifunctional ice–navigating ship.

As one can see, the indefiniteness of anticipated values of design constraints, servicing the data in the terms of references for designing of multifunctional ice–navigating ship is the factor of optimal design characteristics and particulars variability in the first case, and the factor of variability is the set of analogs, in the other words, their probabilistic sampling, in the second case. Correlation of determined design characteristics variability interval or design particulars of the ship with the interval of variability of assumed or anticipated design constraints serves the criterion of sustainability in the first case, and both of indicated variability intervals are evaluated by their relative indexes. In the second case the sustainability of the statistical sampling of analogs serves for evaluation of characteristics and design particulars variability intervals by their relative values.

Need to pay attention on the fact that in both cases the sustainability of the property of optimality of design characteristics and particulars of multifunctional ice–navigating ship, as sustainability of intervals of values with the account of possible variability of the data assumed or anticipated for designing, so as the limiting of dispersion characteristics in the samplings of analogs, are methodologically interconnected by similar causes of characteristics and design particulars variability and the values of the analogs data dispersion. Those or other deviations from the interdependence of the systemic levels when determining design characteristics can be attributed to general causes of variability and dispersion of values, for example the deviations in the form of no very explicit dependence of optimality criteria on design constraints, as well, as lack of clarity of the criteria of optimal characteristics choice of the various analogs used in the designing and etc.

It should be mentioned that the sustainability of found design particulars of multifunctional ice–navigating ship is dependent property on the optimal characteristics sustainability, which, in its turn, is linked with the composition of the objective function used, especially with the classification into groups of mathematical indexes from this composition impacting the objective function. In particular, the property of optimal characteristics and design particulars sustainability on the stage of objective function forming and creation of the mathematical model is predetermined by the answers on the following questions:

- according to which formal or other concept the index that or the other one is attributed to the number of varied characteristics under optimization designing of ship;
- in accordance with which attributes that or the other mathematical index is included in the number of parameters, that is in the set of design particulars, which means the characteristics of subsystems of the ship under design optimization;
- by what attributes the any mathematical index of ship under design optimization is to be attributed to the set of data, that is to the design constraints.

7.1. Sustainability of optimal design characteristics of the ship in the vicinity of objective function extremum

In the vicinity of point (the set, or the vector) of optimal design characteristics of multifunctional ice–navigating ship respecting given constraints the objective function by zero values of its partial derivatives are insensitive to variation of the constraints – the data and parameters, as well, as to the deviations of design characteristics of the ship from their optimal values found. Insensitivity of the objective

function to variation of constraints results in the sustainability in the vicinity of optimal extremum of property of design characteristics optimality. The varying the design constraints affects the objective function equivalently on each point in the vicinity of optimal design characteristics, but not so much impacted on the exchange of choice of optimal design characteristics because of indicated equality zero of these partial derivatives.

Necessary prerequisite of the objective function f extremum (equality to zero of the partial derivative) with respect to variable x – characteristic of the ship, for example the sought design deadweight DW of the set of variables X looks like: $\partial f / \partial x = 0$. It is possible to re-determine the necessary prerequisite of objective function extremum by the mathematical transformation considering the differential dependence of data on variable ($\partial z / \partial x$)

$$\partial f / \partial x = (\partial f / \partial x) \times (\partial z / \partial z) = (\partial f / \partial z) \times (\partial z / \partial x) = 0. \quad (7.1)$$

Formally it is possible to clarify the considered property of sustainability of smooth differentiable parabolic function: $f = (x - (z + 8.5))^2 + x + z$ on a demo example of the graphic surface (Fig. 7.1).

It is represented on the graph that in the wide range of data z variation (or the parameter y , that is any of assigned constraints) the property of optimality of characteristic x remains because of equality to zero of the partial derivative: $\partial f / \partial x = 0$. This is illustrated on the graphic surface (Fig. 7.1) by the horizontal lines, which are practically parallel to base plane of graphic surface along the entire segment in the vicinity of data z (or the parameter y , that is the constraint) and vicinity of the minimal extremum with respect to variable x of considered function f .

The example illustrates that sustainability of the property of optimality can result from continuity and doubly differentiability of convex objective function and corresponding necessary prerequisite of the extremum: $\partial f / \partial x = 0$, with respect to variable x , which corresponds with the sought characteristic of the ship. Considered illustrative functional surface is used for explaining of the property of multifunctional ice-navigating ship design characteristics sustainability, in particular the ship design deadweight optimal value DW sustainability indicated above on graphic surface of objective function (Fig. 6.5 c and d), as well, as in the follows calculations of sustainability of optimal characteristics study when varying the data (the design constraints), which are considered below.

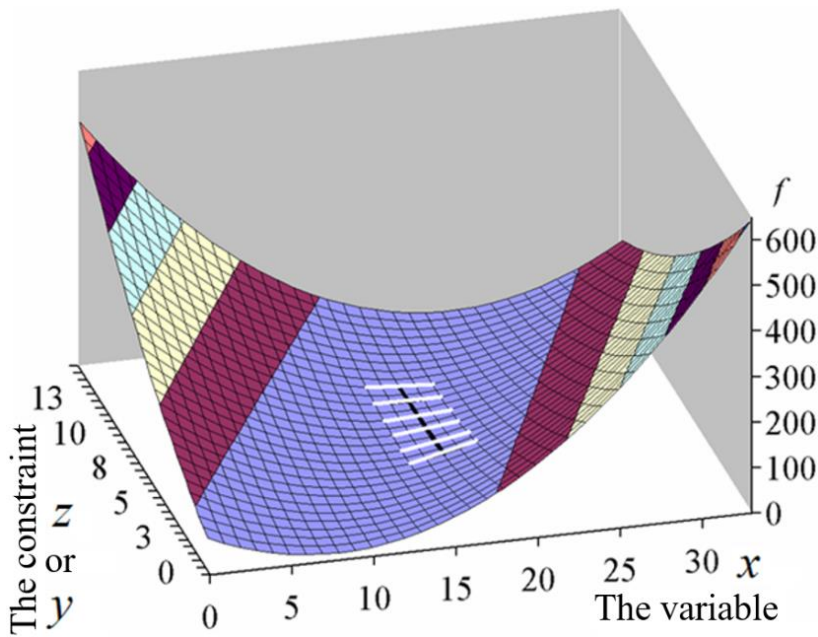


Fig. 7.1. Graphic surface of a smooth differentiable function with the partial extremum with respect to variable x

In indicated example the sufficient prerequisite of extremum of a function of two variables: $(\partial^2 f / \partial x^2) \times (\partial^2 f / \partial z^2) - \partial^2 f / (\partial y \times \partial z) > 0$ is not directly applicable, since one of these of variables is data z and it is not required the finding of the extremum of the objective function with respect to data z . Data z in the finding of optimal design characteristics of multifunctional ice-navigating ship can be, in particular, the design constraint of the assigned maximal thickness h of solid ice affordable to overcome or it can be the other index, for example of the set represented above (table 5.1).

Similar transformations like the considered one (7.1) correspond the partial increments for any data z or the parameters y , including the design particulars of the ship, specified as the constraint for determining of it optimal characteristics and subject for clarifying at the following stages of designing.

Provided (7.1) that if partial derivative of objective function with respect to data z is not equal zero: $\partial f / \partial z \neq 0$, this leads the conclusion, that the partial derivative of the constraint z with respect to variable x is equal zero: $\partial z / \partial x = 0$ (the variable sought sustainability prerequisite, the independence of the variable on data in the vicinity of point, in which the necessity prerequisite of continuous smooth objective function is respected) or, accordingly: $\partial y / \partial x = 0$ at $\partial f / \partial y \neq 0$.

Under the conditions of continuity and differentiability of the objective function $f(X, Y, Z)$ in the definite range of variation of data z of the set the data Z (the con-

straints) the optimal values of variables x found are sustainable, for which the necessary prerequisite of the extremum is respected: $\partial f/\partial x = 0$, characterizing the preference of the characteristics x sought by used criterion, in other words, the prerequisite of mathematical fixed point, in which the partial derivative with respect to variable x is equal zero: $\partial f/\partial x = 0$, and the second partial derivative is not equal zero: $\partial^2 f/\partial x^2 \neq 0$, which is possible to observe on the illustrative graphic surface (Fig. 7.1), provided that in the optimum point the partial derivative of the objective function with respect to data z is not equal zero: $\partial f/\partial z \neq 0$. Also, the optimal values of variables found are sustainable in the range of the variation the parameter y (that is the constraint of parameters set Y), accordingly, provided that in the optimum point the partial derivative of the objective function with respect to parameter y is not equal zero: $\partial f/\partial y \neq 0$.

When partial derivative with respect to variable x is equal zero: $\partial f/\partial x = 0$ and the second derivative is equal zero too: $\partial^2 f/\partial x^2 = 0$, then there may be an interval of optimal values of ship design characteristic in the limits of equality to zero of both derivatives. This is also the kind of the sustainability of ship design optimal results.

If in fixed point in the respect of the prerequisites: $\partial f/\partial x = 0$, $\partial^2 f/\partial x^2 \neq 0$, the partial derivative of objective function with respect to data z is equal zero as well: $\partial f/\partial z = 0$ (or with respect to parameter y : $\partial f/\partial y = 0$), then for defining of fixed point to associate it to the set of sustainable optimal characteristics of ship the additional study of the mathematical convexity of objective function $f(X, Y, Z)$ is required. Practically for the analysis of sustainability of optimal design characteristics of the ship and the convexity of objective function it makes sense to perform by graphic functional surface.

7.2. Analysis of the sustainability of optimal design characteristics studying the objective function of multifunctional ice-navigating ship

Dependence of the objective function f in the form of generalized criterion of specific present worth (PW/DW) per unit of utility function, as which the deadweight DW of multifunctional ice-navigating ship is considered with the account of the penalty (or premium) amendment to the specific present worth for compliance of the ship under design with investment constraint of the subsidies provided for multifunctional ice-navigating ship creation (it designing, construction and equipping), on design constraint of thickness of solid ice h affordable to overcome and on sought variable characteristic of the ship size, possibly represented by design

deadweight DW , is indicated on graphic functional surface and its projection (Fig. 7.2 a and b), considering the geographical latitude of works district, which impacted the period T_1 of the ship navigation in frozen seas during a year, when reducing the ice nautical period to 90 days compared with the duration of 180 days in the variant of the example data (table 5.1), used above graphic functional surface and its projection (Fig. 6.5 c and d), with the account of the generalized variables, which were determined by the used mathematical model, that is with account of the dependent characteristics and particulars of the ship.

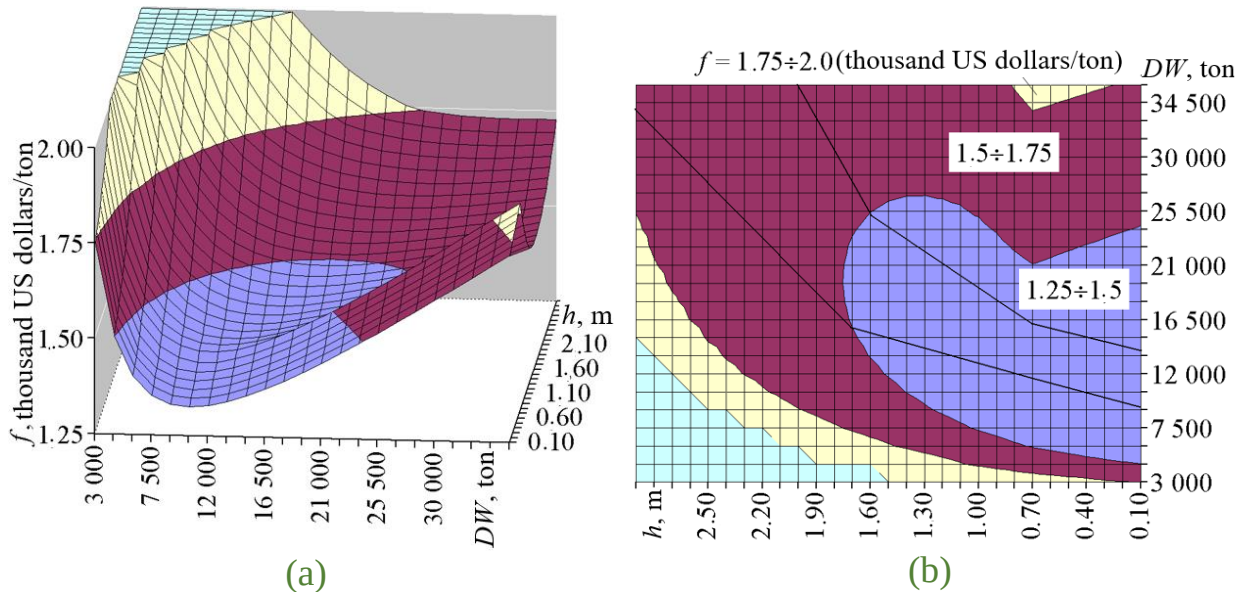


Fig. 7.2. Dependence of objective function f (the generalized criterion of specific present worth) on design constraint of maximal thickness of solid ice h affordable to overcome and on sought variable characteristic of design deadweight DW , considering the geographical latitude of works district, which impacted the period T_1 of the ship navigation in frozen seas during a year, when reducing ice nautical period to 90 days compared with the duration of 180 days in variant of the example data (table 5.1), used for graph above (Fig. 6.5 c and d)

On the graph of objective function surface and on the projection (Fig. 7.2b) the area of the optimal values of multifunctional ice–navigating ship size is between solid lines, by which one can judge about the dependence of ship optimal size on the design constraint of solid ice thickness affordable to overcome. The graph shows that at reduction of the period T_1 of ice navigation to 90 days, compared with the duration of 180 days in the variant of example data, the size of multifunctional ice–navigating ship and the set of the ship design particulars dependent on ship size increase, it is understood that, with reduce of period of the ship navigation in frozen seas during a year.

The reduction of period of ship navigation in freezing sea and with the appropriate increase of the duration of it navigation in open water are impacted on the optimal size increase of ship under optimization designing having the extra opportunities of the ship use for the cargoes transportation, including the delivery of cargoes for the corporate customers.

In the same time the size of multifunctional ice–navigating ship is characterized by appropriate sustainability in respect to the varying of assigned design constraint of the ice thickness, at least if the specified design constraint less than 1.6 m. Generally, the dependence of ship optimal size on the design constraint of maximal thickness of solid ice affordable to overcome h , indicated on the graph by solid bounding lines, as well is of sustainable nature (the steady regular increase in the designed vessel as the constraint increases).

Dependence of objective function f in the form of generalized criterion of specific present worth (PW/DW), with the account of penalty (or premium) amendment for compliance of multifunctional ice–navigating ship under design with the investment constraint of subsidies associated with the ship construction, on design constraint of maximal thickness of solid ice h affordable to overcome and on sought characteristic of the ship size, represented by the design deadweight DW , is indicted on functional graphic surface and on it projection on the base plan (Fig. 7.3 a and b) with the assumption of the relative reduction to 25 % of running time $[T_{R1}/T_1]$ during period T_1 in a year of navigation in frozen seas other than the relative duration 50 % in variant of the example data (table 5.1) and with account of generalized variables, which are determined by the mathematical model, that is of dependent characteristics and particulars of the ship.

On graph of objective function surface with the assumption of relative index of running time $[T_{R1}/T_1]$ during period T_1 in a year of navigation in frozen seas reduction to 25 %, compared with the relative running time in frozen seas 50 % in the example data (table 5.1), this is visible that optimal size of multifunctional ice–navigating ship and, it is understood that, the ship design particulars dependent on size change little for the indicated variation of running time in frozen seas, that is the characteristics and particulars are sustainable to this variation of data. It is possible to do this conclusion if compare the graphs (Fig. 6.5 c and d, Fig. 7.3 a and b).

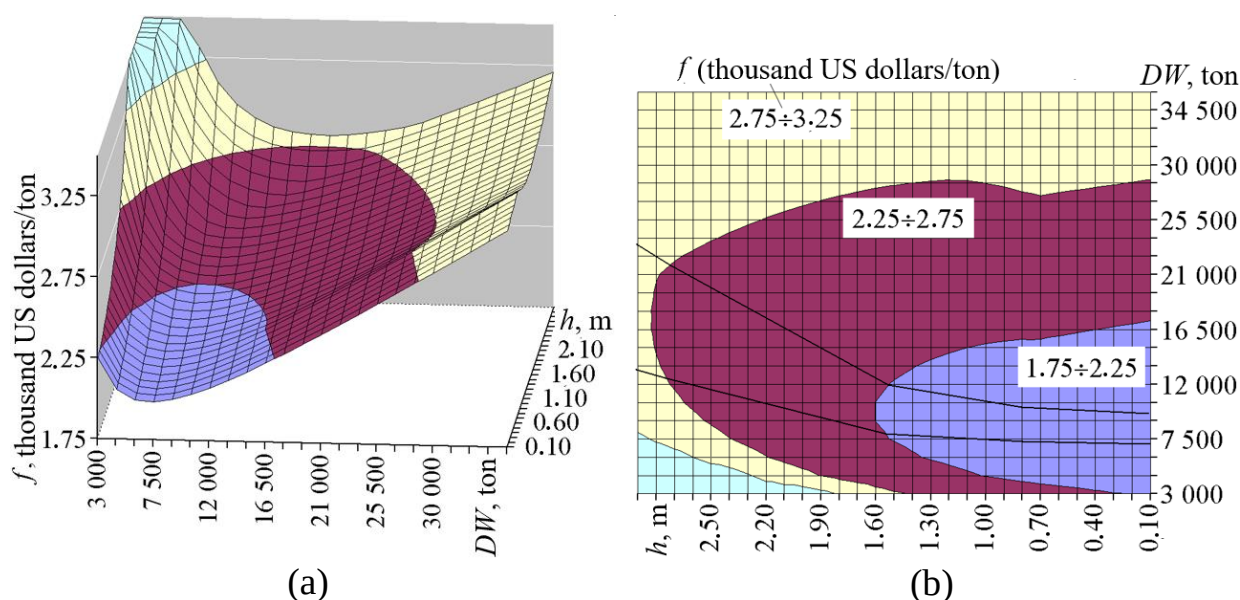


Fig. 7.3. Dependence of objective function f (the generalized criterion of specific present worth) on design constraint of assigned maximal thickness h of solid ice affordable to overcome and on sought variable characteristic of the design deadweight DW with the reduction to 25 % of relative running time $[T_{R1}/T_1]$ during period T_1 in a year of navigation in frozen seas compared with the relative running time in frozen seas of 50 % in the example data (table 5.1)

Dependence of objective function f of generalized criterion of specific present worth (PW/DW) with account of penalty (or premium) amendment for compliance of ship under design with the investment constraint of provided subsidies in the construction of multifunctional ice-navigating ship on specified design constraint of the maximal thickness of solid ice h affordable to overcome and on variable sought, represented the characteristic of design deadweight DW , is presented on functional graphic surface and on its projection on the base plan (Fig. 7.4 a and b) in the increase of utilization factor of multifunctional ice-navigating ship design deadweight of its load capacity $[PG/DW]$ to 75 % compared with the factor of 50 % in variant of the example data (table 5.1), and with account of the generalized variables, which are determined by the mathematical model, that is of dependent characteristics and particulars of the ship.

On the graph of the objective function surface with increase of design deadweight utilization factor of multifunctional ice-navigating ship of its load capacity $[PG/DW]$ up to 75 % compared with the utilization factor of 50 % in the example data (table 5.1) it is visible that optimal size of the ship and, it is understood that, the dependent on ship size its design particulars set are appropriately increased in dependence on increase of utilization factor of multifunctional ice-navigating ship design deadweight of its load capacity.

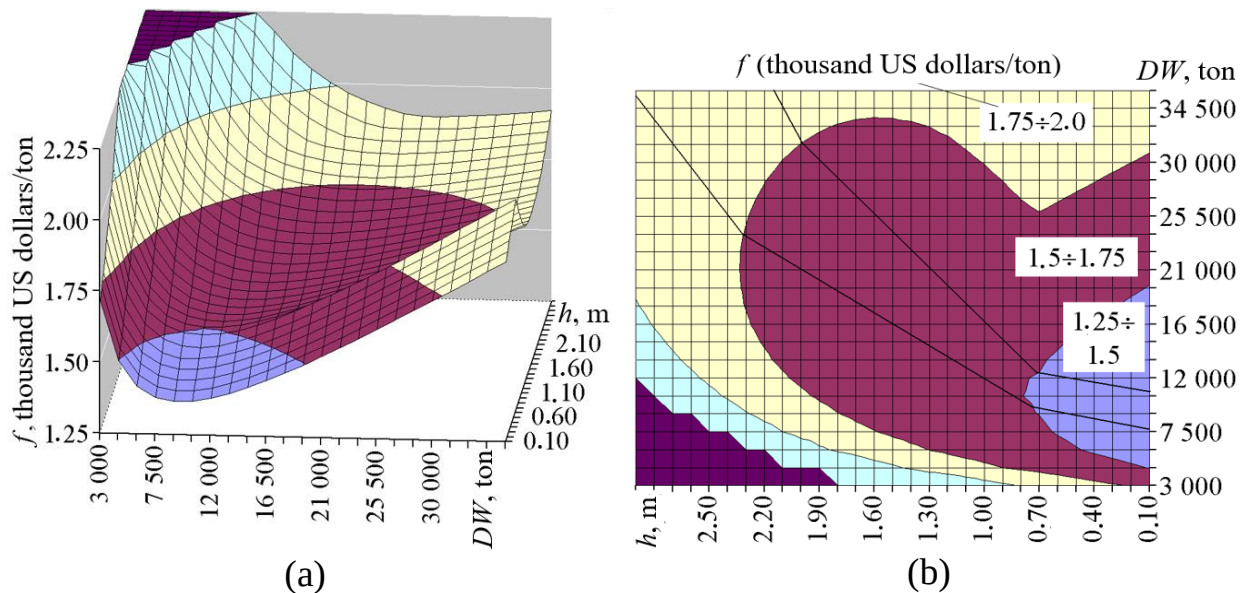


Fig. 7.4. Dependence of objective function f (the generalized criterion of specific present worth) on design constraint of assigned maximal thickness h of solid ice affordable to overcome and on sought variable characteristic of the design deadweight DW in case of increase to 75 % of utilization factor of multifunctional ice–navigating ship design deadweight of it load capacity $[PG/DW]$ compared with the utilization factor 50 % in the example data (table 5.1)

It is possible to compare the graphs (Fig. 6.5 c and d, Fig. 7.4) with the account of differences of used indexes of utilization factors of design deadweight by the ship load capacity. In the specified calculations the additional purposes to use ship as cargo, including, for the delivery of the cargoes for corporative customers (the extra budgetary) have the impact on increase of optimal size got. Factor of load capacity of the ship increase by the relative value affects the optimal size in the appropriate similarity with the factor of reduction of the ice navigation during year, for example with latitudinal change of the area of work, which is studied above (Fig. 7.2 a and b).

In the same time the ship size is characterized by the sustainability with respect to variation of the assigned design constraint of continuous ice thickness in considered range of values from 0.10 to 2.90 m along the axis h of design constraint of the maximal thickness of ice affordable to overcome. In the other words, optimal size of the ship (the deadweight) steady regular increases along with the specified constraint increases.

On functional graphic surface and on it projection on the base plan the dependence is shown (Fig. 7.5 a and b) of objective function f of generalized criterion of specific present worth (PW/DW) on design constraint of maximal thickness of solid ice h affordable to overcome and on variable sought by optimization of characteristic of multifunctional ice–navigating ship design deadweight DW , with

the account of penalty (or premium) amendment for compliance of the ship under design with investment constraint of provided subsidies for the ship creation in case of reduction to 25 % of the installation power NP of load on installation of the ship docked by the load relative value y_Q for power supply of ships, offshore platforms or onshore, compared with the load on power installation of 50 % in variant of the example data (table 5.1), with the account of the generalized variables, determined by the mathematical model, that is of dependent characteristics and particulars of the ship.

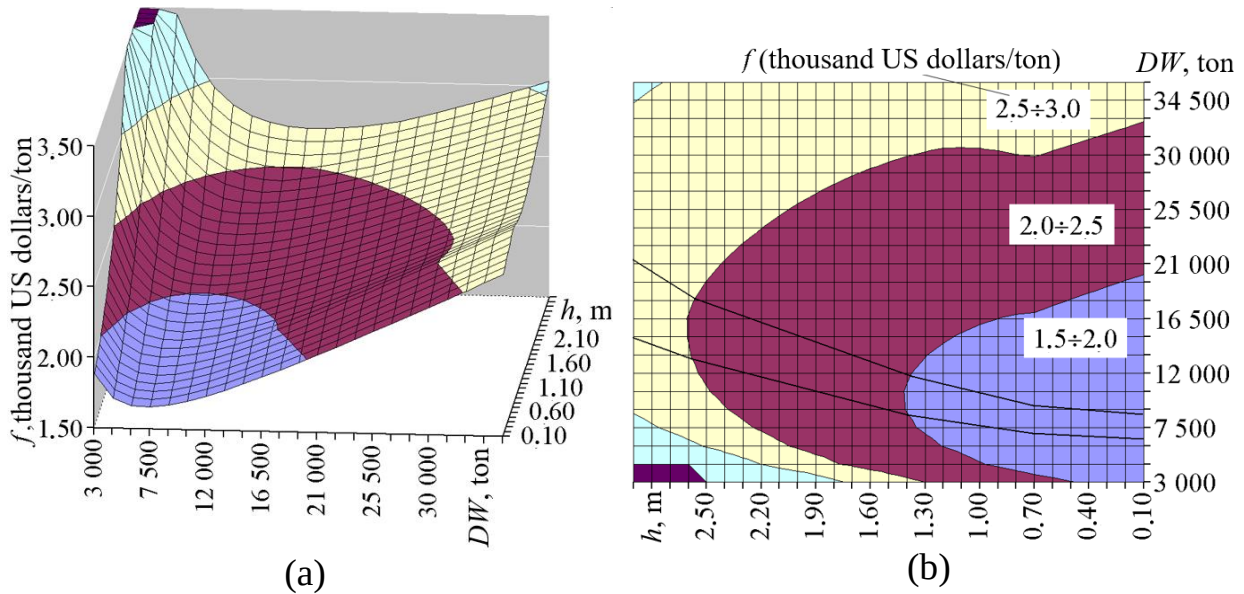


Fig. 7.5. Dependence of objective function f (the generalized criterion of specific present worth) on design constraint of maximal thickness h of solid ice affordable to overcome and on sought variable characteristic of multifunctional ice-navigating ship design deadweight DW in case of the ship docked reduction of power load to 25 % by relative value y_Q of the installation power NP of the power supply on ships, offshore platforms or onshore, compared with the load on power installation of 50 % in the example data (table 5.1)

On the graphic surface of objective function in case of load reduction to 25 % of the installation power NP of multifunctional ice-navigating ship docked by the load relative value y_Q of the power supply on ships, offshore platforms or onshore compared with the load on power installation of 50 % in the example data (table 5.1) it is visible that optimal size of the ship and, it is understood that, the dependent on the ship size it design particulars change little for the indicated variation of data, that is design particulars of the ship are characterized by the sustainability. It is possible to do this conclusion if compare the graphs (Fig. 6.5 c and d, Fig. 7.5).

7.3. Sustainability of optimal design characteristics of multifunctional ice–navigating ship, when economic data change

The study is of the interest of sustainability of found optimal design characteristics of multifunctional ice–navigating ship if possibly economic data change: the investment constraint, the risks index, the transport tariff and etc.

Dependence of objective function f in the form of the generalized criterion of specific present worth (PW/DW) is shown on functional graphic surface and on its projection on the base plan (Fig. 7.6 a and b) with the account of penalty (or premium) amendment for compliance of ship under design with the investment constraint of provided subsidies, associated with the ship construction, on design constraint of maximal thickness h of solid ice affordable to overcome and on variable sought, represented by characteristic of design deadweight DW , in the case of provided budgetary subsidies reduction, associated with the construction of the ship, to 250 million US dollars, compared with the investment constraint corresponding 500 million US dollars in variant of the example data (table 5.1), and with the account of the generalized variables, which are determined in the mathematical model, that is the dependent characteristics and particulars of the ship.

It should be mentioned that considered variation of investment constraint of provided budgetary subsidies associated with the ship construction does not indicate the reduction of the ship construction costs. Costs for construction, dependent on the ship size, design and structure, are not change when varying of provided subsidies in case when they are not enough for the ship creation (it designing, construction and equipping), but it is required the extra funding of corporate finances (the extra budgetary). Considered circumstance influences on composition of invested capital, so as on the penalty amendment (or premium) for compliance of the ship under design with investment constraint of funded subsidies in costs associated with construction of the ship.

Optimal size of multifunctional ice–navigating ship and, it is understood that, the design particulars dependent on size of ship change little for indicated variation of data, that is characterized by the sustainability, and it is visible if to compare the graphs (Fig. 6.5 c and d, Fig. 7.6) of the objective function surface in the case of investments reduction to 250 million US dollars provided in multifunctional ice–navigating ship creation (it designing, construction and equipping), compared with the investment constraint of 500 million US dollars in the example data (table 5.1).

Since investments associated with the costs for the ship construction under the international contracts usually are provided in conditions of participants cooperation from other states, then monetary indexes are used in the US dollars, which could be converted in any currency by the exchange rate of US dollar sets by the national bank of this country for the considered day.

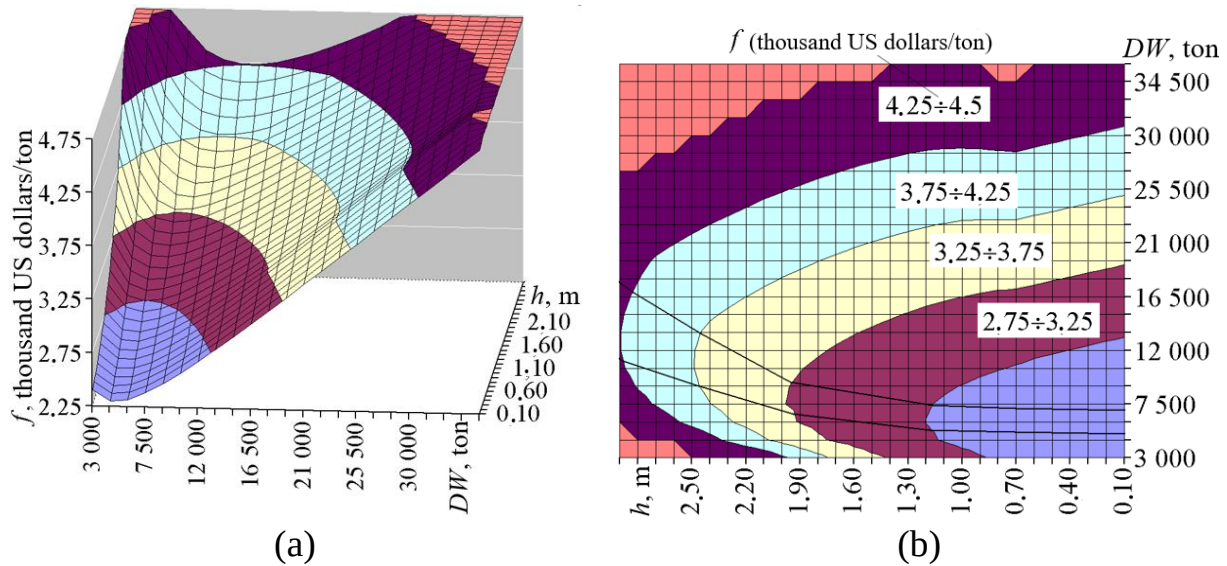


Fig. 7.6. Dependence of objective function f (the generalized criterion of specific present worth) on assigned design constraint of maximal thickness h of solid ice affordable to overcome and on sought variable characteristic of multifunctional ice–navigating ship design deadweight DW with reduction of provided budgetary subsidies associated with ship construction to 250 million US dollars, compared with the investment the constraint of 500 million US dollars in the example data (table 5.1)

Dependence of objective function f in the form of the generalized criterion of specific present worth (PW/DW) is presented on functional graphic surface and on its projection on the base plan (Fig. 7.7 a and b) with the account of penalty (or premium) amendment for compliance with investment constraint of subsidies, associated with construction costs of multifunctional ice–navigating ship under design, on assigned constraint of maximal thickness h of solid ice affordable to overcome and on variable sought, represented by characteristic of design deadweight DW , in case of discount rate increase (the index of merchant risks total) to 10 % compared with rate index of 5 % in the variant of example data (table 5.1), with the account of the generalized variables, which are determined by the mathematical model, that is of the dependent characteristics and particulars of the ship.

On the basis of graphic surfaces of objective function comparison (Fig. 6.5 c and d, Fig. 7.7) with the indicated assumption of data index of the discount rate variation it is visible that the optimal size of multifunctional ice–navigating ship and, it is understood that, the dependent on the size the design particulars change little for the indicated variation of data, that is the ship characteristics and design particulars are sustainable for considered variation of data.

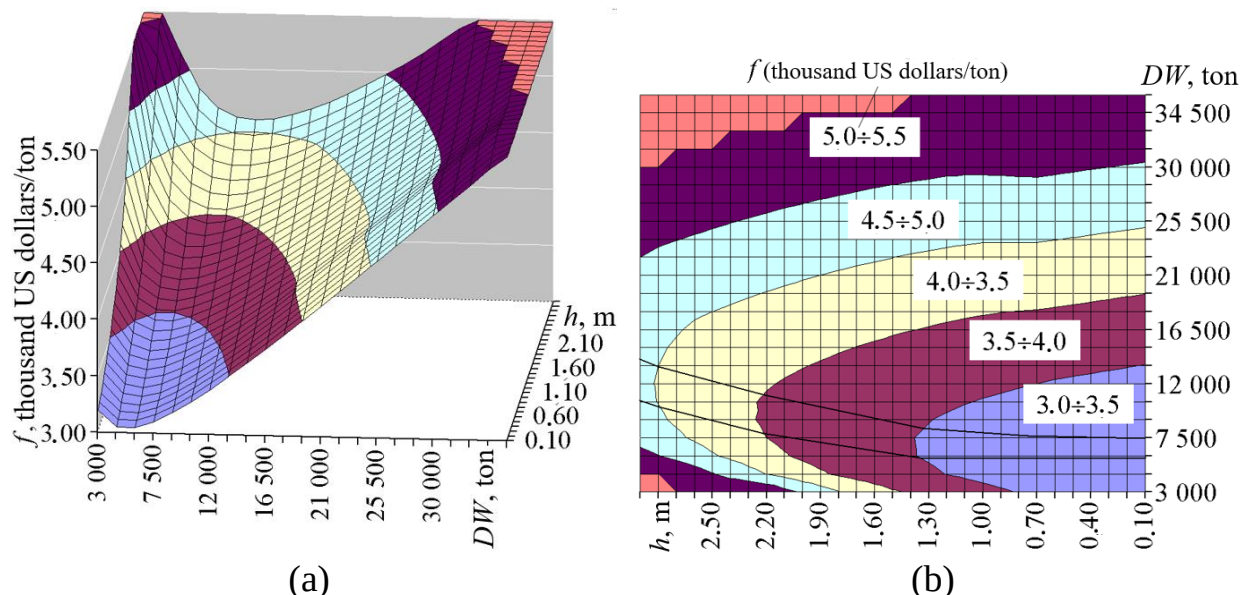


Fig. 7.7. Dependence of objective function f (the generalized criterion of specific present worth) on assigned design constraint of maximal thickness h of solid ice affordable to overcome and on sought variable characteristic of ship design deadweight DW with index of merchant risks total (the discount rate) increase to 10 %, compared with the initial index of the discount rate 5 % in the example data (table 5.1)

On functional graphic surface and on its projection on the base plan (Fig. 7.8 a and b) the objective function f in form of generalized criterion of specific present worth (PW/DW) with account of penalty (or premium) amendment for compliance of multifunctional ice–navigating ship under design with the investment constraint is in dependence on design constraint of the maximal thickness h of solid ice affordable to overcome and on variable sought by optimization, represented the ship characteristic of design deadweight DW , with the assumption of reduction of the transport tariff per unit of cargo i_{CG} to 0.15 thousand US dollars/ton for extra budgetary cargoes sender on the line of definite extent, compared with the transport tariff index of 0.25 thousand US dollars/ton in the variant of example data (table 5.1), with

the account of the generalized variables, which are determined by the mathematical model, that is dependent characteristics and particulars of the ship.

Comparison of the graphic surfaces of objective function (Fig. 6.5 c and d, Fig. 7.8) in case of the reduction of transport tariff per unit of cargo i_{CG} shows that the optimal size of multifunctional ice-navigating ship and, it is understood that, the dependent on the ship size it design particulars change little for indicated variation of data, that characteristics and design particulars of multifunctional ice-navigating ship in case of variation of indicated transport tariff data are characterized by sustainability.

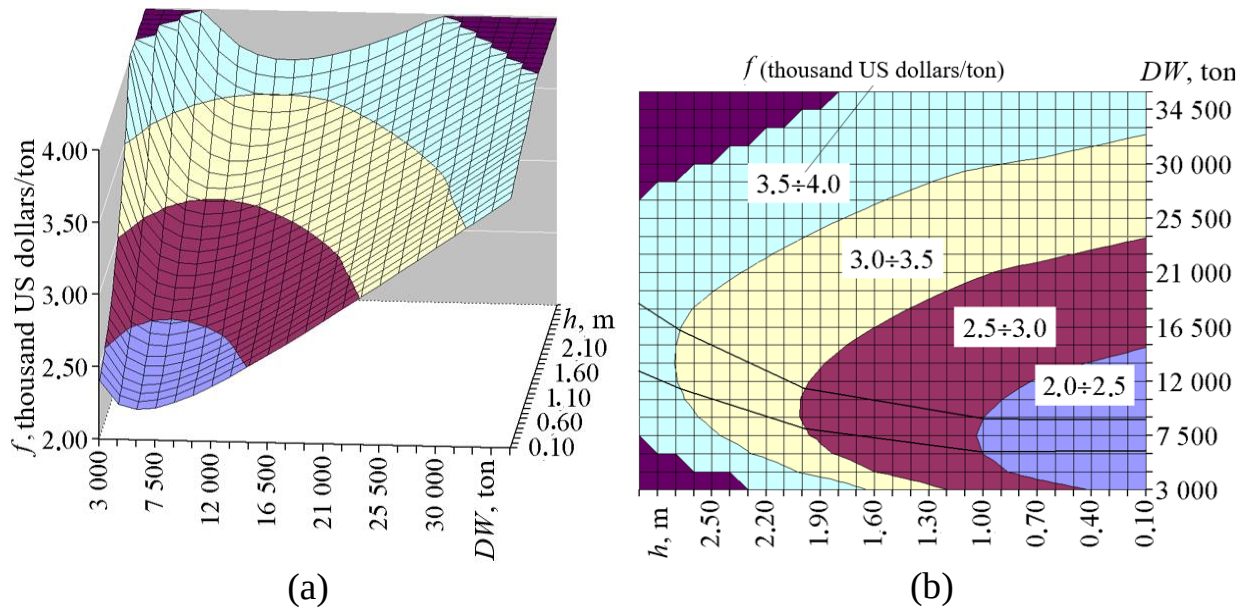


Fig. 7.8. Dependence of objective function f (the generalized criterion of specific present worth) on design constraint of maximal thickness h of solid ice affordable to overcome and on sought variable characteristic of design deadweight DW with definite extent for extra budgetary cargoes transportation tariff i_{CG} on the line per unit of cargo reduction to 0.15 thousand US dollars/ton, compared with the index of 0.25 thousand US dollars/ton in the example data (table 5.1)

7.4. Sustainability of multifunctional ice-navigating ship design particulars

The results of the calculation of multifunctional ice-navigating ship loaded displacement in dependence on the indicated data are specified in the tables 7.1 and 7.2.

It is possible to find approximately the design particulars of multifunctional ice-navigating ship at initial stage of designing with the system of the parametric

formulas (see items: 4.7 and 4.8) in dependence on size characteristic of multifunctional ice–navigating ship of the ship loaded displacement D

$$\begin{cases} L / B = 0.0043 \times L + 3.72, \\ B / T = 0.0161 \times L + 1.083, \\ \delta_w = 0.0007 \times L + 0.541, \\ D = 1.025 \times \delta_w \times L \times B \times T. \end{cases} \quad (7.2)$$

In it turn the ship loaded displacement D in dependence on it design deadweight DW is determined with use of displacement balance equation in the mathematical model with the account of amendments to multifunctional ice–navigating ship loaded displacement depended on design constraint of the maximal thickness h of solid ice affordable to overcome and on assigned in the terms of references characteristic of the ship design deadweight DW when finding the ship particulars.

These results correspond two structural variants of multifunctional ice–navigating ship side overlap at the cargo waterline level of ice impact: the variant with the standard spacing, recommended by the Register, and the variant with the halved spacing when installed the extra frames at the level of ice impact on the side overlaps of the ship. The sustainability of found design particulars depends on this property of optimal characteristics of the ship found impacting on the particulars, one can see this by the data in the tables 7.3 and 7.4.

The effective power, indicated in the table 7.3, is determined for condition of power sufficiency for overcoming of ice field and for keeping the operation velocity in open water no less than the minimal, required from the point of view of ship controllability and got by the mathematical model in dependence on design constraint of assigned maximal thickness h of solid ice affordable to overcome and on the variable characteristic of design deadweight DW .

One can see that the particulars of ship are likely more sustainable, than the characteristics of multifunctional ice–navigating ship size, for example, it loaded displacement D and are varied in relatively narrower ranges accordingly the variation of the ship size characteristic.

Table 7.1

The load line displacement of multipurpose ice-navigating ship in dependence on it design deadweight DW and on the maximal thickness of crossable continuous ice h in the variant with the halved spacing ($a/2$) when installed the extra frames

$h, m \backslash DW, \text{ ton}$	3 000	6 000	9 000	12 000	15 000	18 000	21 000	24 000	27 000	30 000	33 000	36 000
0.10	7 789	15 001	22 213	29 425	36 637	43 849	51 061	58 273	65 485	72 697	79 909	87 121
0.20	7 789	15 001	22 213	29 425	36 637	43 849	51 061	58 273	65 485	72 697	79 909	87 121
0.30	7 795	15 001	22 213	29 425	36 637	43 849	51 061	58 273	65 485	72 697	79 909	87 121
0.40	7 824	15 001	22 213	29 425	36 637	43 849	51 061	58 273	65 485	72 697	79 909	87 121
0.50	7 848	15 035	22 213	29 425	36 637	43 849	51 061	58 273	65 485	72 697	79 909	87 121
1.00	7 924	15 173	22 392	29 592	36 777	43 949	51 111	58 273	65 485	72 697	79 909	87 121
1.50	7 971	15 257	22 514	29 752	36 976	44 187	51 389	58 582	65 767	72 944	80 116	87 281
2.00	8 006	15 319	22 604	29 870	37 121	44 362	51 592	58 815	66 029	73 237	80 439	87 636
2.50	8 033	15 369	22 675	29 963	37 237	44 500	51 754	58 999	66 238	73 470	80 696	87 917

Table 7.2

The load line displacement of multipurpose ice-navigating ship in dependence on it design deadweight DW and on the maximal thickness of crossable continuous ice h in the variant with the standard spacing a , recommended by the Register

$h, m \backslash DW, \text{ ton}$	3 000	6 000	9 000	12 000	15 000	18 000	21 000	24 000	27 000	30 000	33 000	36 000
0.10	7 789	15 001	22 213	29 425	36 637	43 849	51 061	58 273	65 485	72 697	79 909	87 121
0.20	7 817	15 001	22 213	29 425	36 637	43 849	51 061	58 273	65 485	72 697	79 909	87 121
0.30	7 876	15 074	22 243	29 425	36 637	43 849	51 061	58 273	65 485	72 697	79 909	87 121
0.40	7 933	15 174	22 379	29 560	36 721	43 867	51 061	58 273	65 485	72 697	79 909	87 121
0.50	7 981	15 259	22 501	29 717	36 914	44 096	51 264	58 420	65 565	72 701	79 909	87 121
1.00	8 148	15 558	22 928	30 274	37 601	44 913	52 213	59 501	66 779	74 048	81 308	88 562
1.50	8 253	15 747	23 202	30 632	38 045	45 443	52 830	60 207	67 574	74 934	82 286	89 631
2.00	8 330	15 886	23 402	30 895	38 371	45 834	53 286	60 728	68 163	75 590	83 011	90 426
2.50	8 391	15 996	23 561	31 104	38 630	46 144	53 647	61 142	68 630	76 111	83 587	91 057

In other words, the analysis of dependences of design particulars of multifunctional ice–navigating ship on characteristic of it loaded displacement D in the appropriately wide range of the ship size variation in the interval from 7 600 to 91 200 ton, it is possible to find that the ratios of design particulars Y make up in the ranges:

- ratio of ship design length (the waterline length) to it breadth L/B is from 4.06 to 4.76;
- ratio of the ship beam to it draught at cargo waterline B/T is from 2.34 to 4.97;
- ratio of the ship depth up to level of the main deck to draught at cargo waterline H/T is from 1.32 to 1.50;
- coefficient of ship hull overall completeness δ_w is from 0.596 to 0.710.

Design particulars of multifunctional ice–navigating ship by their relative values (L/B , B/T , H/T , L/H , δ_w and etc.) are appropriately sustainable when varying design constraint of maximal thickness h of solid ice affordable to overcome and characteristic of the ship design deadweight DW specified as data when determining the particulars.

On the next steps of multifunctional ice–navigating ship designing the particulars are determined with the use of the optimization approaches, which attributes the gradual nature of designing in the frameworks of systemic approach, or the own methods are adopted for finding of the ship design particulars, or the refining of the particulars values assumed or found previously by the parametrical formulas at the initial designing stages particulars of the ship (L , B , H , T , δ_w , L/B , B/T , H/T , L/H , etc.), almost the same as it is for the ship dependent characteristics (D , PG , GRT , NRT , Ne , N_{ICE} , v_s and etc.) initially found approximately to reduce the ranges of their indexes possible variation, clarifying at the next designing stages, when the optimal values of initially found independent characteristics will be the data (the design constraints).

Table 7.3

The effective power of multipurpose ice-navigating ship N_e , kW

$h, \text{ m} \backslash D W, \text{ ton}$	3 000	6 000	9 000	12 000	15 000	18 000	21 000	24 000	27 000	30 000	33 000	36 000
0.10	6 026	7 669	9 004	10 160	11 196	12 144	13 025	13 852	14 634	15 378	16 090	16 773
0.20	6 026	7 669	9 004	10 160	11 196	12 144	13 025	13 852	14 634	15 378	16 090	16 773
0.30	6 028	7 669	9 004	10 160	11 196	12 144	13 025	13 852	14 634	15 378	16 090	16 773
0.40	6 035	7 669	9 004	10 160	11 196	12 144	13 025	13 852	14 634	15 378	16 090	16 773
0.50	6 041	7 676	9 004	10 160	11 196	12 144	13 025	13 852	14 634	15 378	16 090	16 773
1.00	8 600	10 991	12 897	14 527	15 973	17 285	18 495	19 625	20 695	21 709	22 674	23 597
1.50	15 184	18 344	21 053	23 418	25 537	27 472	29 262	30 936	32 513	34 008	35 432	36 795
2.00	24 537	27 516	30 740	33 697	36 403	38 901	41 228	43 415	45 482	47 446	49 322	51 119
2.50	38 838	39 259	42 421	45 705	48 842	51 800	54 592	57 235	59 749	62 148	64 445	66 653

Table 7.4

The design particulars and the characteristics subject to balance ratios of multipurpose ice-navigating ship

$D, \text{ ton}$	7 600	15 200	22 800	30 400	38 000	45 600	53 200	60 800	68 400	76 000	83 600	91 200
GRT	5 150	11 490	18 671	26 556	35 071	44 162	53 794	63 936	74 567	85 669	97 226	109 224
GRT/D	0.678	0.756	0.819	0.874	0.923	0.968	1.011	1.052	1.090	1.127	1.163	1.198
NRT	1 518	3 387	5 503	7 827	10 337	13 016	15 855	18 844	21 978	25 250	28 656	32 192
$NP, \text{ kW}$	15 597	25 745	34 514	42 494	49 934	56 970	63 686	70 141	76 376	82 421	88 301	94 035
L/B	4.06	4.17	4.26	4.34	4.40	4.46	4.52	4.57	4.62	4.67	4.72	4.76
B/T	2.34	2.78	3.11	3.39	3.64	3.87	4.08	4.28	4.46	4.64	4.81	4.97
H/T	1.32	1.35	1.37	1.39	1.41	1.43	1.44	1.45	1.47	1.48	1.49	1.50
δ_w	0.596	0.615	0.629	0.641	0.652	0.662	0.671	0.680	0.688	0.696	0.703	0.710
$L, \text{ m}$	78.3	105.3	125.9	143.4	158.9	173.0	186.1	198.3	209.9	221.0	231.5	241.7
$B, \text{ m}$	19.3	25.2	29.6	33.1	36.1	38.8	41.2	43.4	45.4	47.3	49.1	50.8
$T, \text{ m}$	8.2	9.1	9.5	9.7	9.9	10.0	10.1	10.1	10.2	10.2	10.2	10.2
$H, \text{ m}$	10.9	12.3	13.0	13.6	14.0	14.3	14.5	14.7	14.9	15.1	15.2	15.3

7.5. Interchangeability of multifunctional ice–navigating ship design characteristics and particulars when finding their optimal values

The other variable characteristics of multifunctional ice–navigating ship size, for example the cargo waterline displacement D , the cargoes capacity of the ship PG , the gross tonnage GRT or the net one NRT and etc., as well, as some the ship characteristics of size, referred usually to it design particulars, that is to characteristics of the ship subsystems, besides of design deadweight DW can be used as the variable characteristics of ship. For example, the waterline length of ship, usually referred to the design particulars, can be used as the variable the characteristic of ship size too. In the same time the use of design deadweight DW as the variable index sought is convenient enough for multifunctional ice–navigating ship, when finding it optimal characteristics at initial stages of designing, since the design deadweight, on one hand, corresponded with the ship cargo waterline displacement by the balance equations and with the other indexes of the ship size, and on the other hand – the design deadweight is the most general payload characteristic of multifunctional ice–navigating ship.

It should be mentioned that the use of each of characteristics of the multifunctional ice–navigating ship size as variable sought at the initial stages of designing indicates usually the reference of rest characteristics to the set of dependent characteristics or design particulars, servicing parameters, that is the constraints, along with the data. The indicated design particulars when determining characteristics of the ship under design are parametrically interdependent and in themselves are subject for determining at the next stages of designing of multifunctional ice–navigating ship.

On the graphics of functional surfaces of objective function f of generalized criterion of specific present worth (PW/DW) on design constraint of maximal thickness of solid ice h affordable to overcome and on other characteristics of multifunctional ice–navigating ship size used in designing as variable sought other than the design deadweight DW at initial stages are represented by the samples: the characteristic of ship design length L (the waterline length, Fig. 7.9a) and the net register tonnage NRT (Fig. 7.9b) for the set of example data (table 5.1) with the account of penalty (or premium) amendment for compliance of the ship under design with the investment constraint of 500 million US dollars of the subsidies provided in multifunctional ice–navigating ship creation (it designing, construction and equipping).

Use of waterline length L or net register tonnage NRT as the examples of multifunctional ice–navigating ship size independent variable characteristics sought indicates the reference of design deadweight DW and the rest characteristics of the ship size to the set dependent on length L or tonnage NRT , or to the set of design

particulars (the parameters in the mathematical model, assumed ad design constraints at initial designing stage, when determining the ship optimal characteristics), dependent on the variable too.

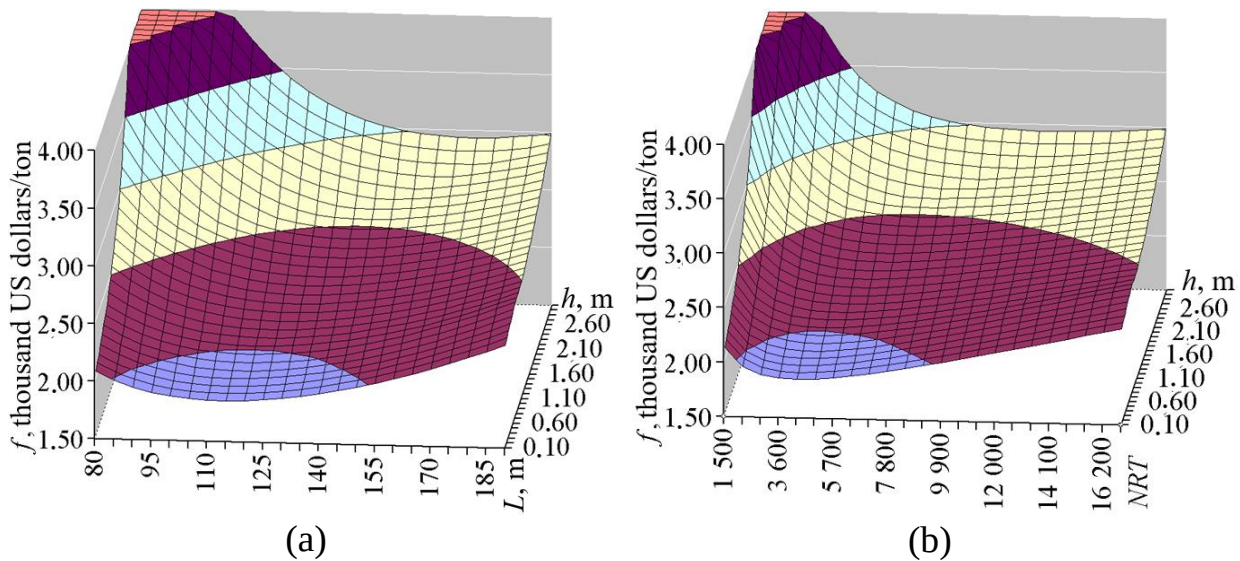


Fig. 7.9. Dependence of objective function f (the generalized criterion of specific present worth) on assigned design constraint of the maximal thickness of solid ice affordable to overcome h and on the index of variable sought in optimization designing: (a) – the characteristic of ship design length L and (b) – the net register tonnage NRT for the example data (table 5.1)

Few exclusions are possible from the considered rule when using other of independent characteristics of the ship, along with the characteristic of it size, not associated with the methodological contradictions. For example this exclusion at the initial stages of ship designing is the use of the second independent variable characterizing the ship performances of the follows indexes set (the couple) could be considered: the characteristic of ship icebreaking patency or the ship other performance when operating in frozen seas, in particular, characterized by index of maximal thickness of the solid ice h , affordable to overcome, that is the index, simultaneously servicing the design characteristic of multifunctional ice-navigating ship and the assigned constraint in the design (the initial data) – the characteristic (the terms of references specification) of the more general system, to which the ship under design belongs as the subsystem, for example, the assigned district of ship operation in frozen sea, and the operating velocity of ship in open water v_s , which determines the effective power Ne , commensurate with the ship propulsive power of N_{ICE} , required to overcome ice field, and the capacity of the power installation (the total power of energy generation sources NP) with the account of the ship size

as well, characterized by one or another size index, on which the rest characteristics of the ship size are depended by the balance equations, and the design particulars depended by the parametric formulas.

In the specified couple of the ship characteristics (h and v_s), independent on ship size within the systemic approach, one can be independent, and the second one is determined in dependence on selected first one and on the ship size, because this size in together with the characteristic of the icebreaking performances or with other defined patency in frozen seas, or in the couple of the ship size with it operation velocity characteristic in open water give in the initial approximation the index of the effective power (the propulsive) and the index of capacity of multifunctional ice–navigating ship power installation.

When finding optimal characteristics of multifunctional ice–navigating ship at the initial stages of it designing in the frameworks of systemic approach it is required to consider the superposition of the ship characteristics and design particulars property associated with their independent determining consistently at different (the consequent) designing stages, or in the methodological sense associated with independent determining of the ship characteristics and increments of these characteristics. And at each individual designing stage these indexes (in each couple of the indexes: the ship characteristics and the particulars or the characteristics and their increments, etc.) could be considered independent due to disparity of the intervals of their variation, or the disparity of the index variation on one hand, and variation of this index increment or the deviation from it previously anticipated or assumed value, on the other hand.

For example, if that or other characteristic of size of multifunctional ice–navigating ship under designing is used as independent variable sought, then, as a rule, the rest characteristics of the ship size (of the set: D , DW , PG , GRT , NRT and etc.) are in the balance ratios with the selected one. In other words, the possible intervals of their deviations from originally anticipated approximal values are substantially narrower, than the range, in which selected independent characteristic of the ship size can vary.

Intervals of deviations from assumed values of other characteristics of multifunctional ice–navigating ship, anticipated by the balance ratios, used in the composition of the constraints at the initial stages of designing of ship, and the intervals of the deviations of design particulars of the ship, that is characteristics of it subsystems, then others attributed to independent ones, are proportionate the errors of original prediction by balance ratios and by parametric equations, by which

the dependent characteristics and design particulars are depended on the selected independent ones at the initial stages of designing of the ship.

In the considered examples the superposition, that is the ability of the independent finding of the ship design characteristic and other characteristics and design particulars anticipated dependent on found, the systemic property arises due to the disparity of the intervals of variations irrespective determined characteristics and design particulars, since the independent design characteristics of the ship when finding they optimal values at the initial stage of designing are varying in the intervals, compared with their actual values, and the other ones (the dependent), as well, as the design particulars, are determined at the next stages of designing in substantially narrow intervals proportional with errors of balance ratios working between the ship characteristics and the errors of parametric dependences between characteristics and design particulars.

It is possible to represent other example of use of the systemic property of the superposition when finding design characteristics, corresponded with the decision of balance equation of multifunctional ice–navigating ship displacement (4.10, item 4.5). The cargo waterline displacement of the ship one can consider dependent on assigned design deadweight $D(DW)$ and on the displacement increment $\Delta D_{P(h)}$ due to implicitly impacting load increment $\Delta P(h)$, depended on assigned design constraint of maximal thickness h of solid ice affordable to overcome, that is in the general case on the ship specified performances and patency in frozen seas, or on specified in the terms of references it ice category (the arctic, or polar, or icebreaking class).

Superposition, that is the methodological ability of the independent approximal determining of indicated components of cargo waterline displacement, corresponded, as well, with the disparity of variation intervals of design deadweight of multifunctional ice–navigating ship and the displacement increment due to implicitly assigned ice load, follows from the way of cargo waterline displacement determining as the total of it components with use of the balance equation of displacement in the direct form or in the differential one (the assessing of mathematical derivatives and increments).

Given that the design particulars of multifunctional ice–navigating ship in finding of it optimal design characteristics are determined in dependence on these characteristics, which are specified at the next designing stages (when the subsystems of ship are the objects under designing), wherein the intervals of design particulars variation for determining of their optimal values are proportionate with the errors of the parametric formulas used at the previous stage for the parameters anticipation, and given that generalized variable characteristics of the ship are determined

by balance ratios in dependence on varied at design optimization independent characteristics. At the next designing stages when finding particulars, servicing the characteristics of ship's subsystems, it generalized characteristics are specified, wherein the intervals of their variation are proportionate with the errors of the balance ratios projected, then for determining of optimal design characteristics of the ship the corresponding stock of the ship size (the non-distributed at initial designing stage part of the ship displacement) is required, or the stock of design deadweight, which can be used for compensating considered refinements of the ship size, which are depended on refined design particulars at the following stages of designing when determining these particulars and the relevant other characteristics of the ship.

It should be mentioned that, despite the variety of design particulars of multifunctional ice-navigating ship subject to determine at the following designing stages as the characteristics of it subsystems, the excessive designing stock of ship size is not required, in particular, the stock of cargo waterline displacement, of design deadweight or of other characteristics of the ship size, used as independent variables sought at the initial designing stages, since the impact on the ship size of each of design particulars subject to refine within the relevant intervals of variation at following designing stages it is possible to characterize probabilistically as factors of bilateral influence of increase or reduce of multifunctional ice-navigating ship size. In this way, the cumulative bilateral impact (as the positive, so negative) of design particulars refined at the following stages on size of multifunctional ice-navigating ship under design by this impact relative value is generally less than impact of those or other individual design particulars determined in order of their clarifying consistently after found of the characteristics. Therefore the designing stock of size of multifunctional ice-navigating ship, for example the stock of the ship loaded displacement sought as independent at initial designing stages, the stock of design deadweight, or the stock of other characteristic of size can be as the maximal relative value of the positive expert amendment to the characteristic of ship size, which is in the linear proportional dependence on this size characteristic, in particular as the component of displacement balance equation, dependent on the ship loaded displacement proportional it in first exponent degree (or on design deadweight).

For finding of optimal design characteristics of the ship of insufficient ice category the design constraint of the maximal thickness h of solid ice affordable to overcome (or the other assigned in the terms of references characteristic of the ship performances in frozen seas), servicing in the same time the designing characteristic of ship, has to be replaced with the variable of the ship operation velocity v_s in the open water in the case of ice category insignificance. In this definite case

the operation velocity has to be second variable (besides of the size) subject of design optimization.

The graphic functional surface (Fig. 7.10a) of objective function f dependence on multifunctional ice-navigating ship loaded displacement D (the mass of the equipped ship with the cargoes) and on the operation velocity of the ship v_s in open water and the functional surface (Fig. 7.10b) of maximal thickness h of solid ice affordable to overcome on the ship loaded displacement D and on operation velocity v_s are shown for the example data (table 5.1).

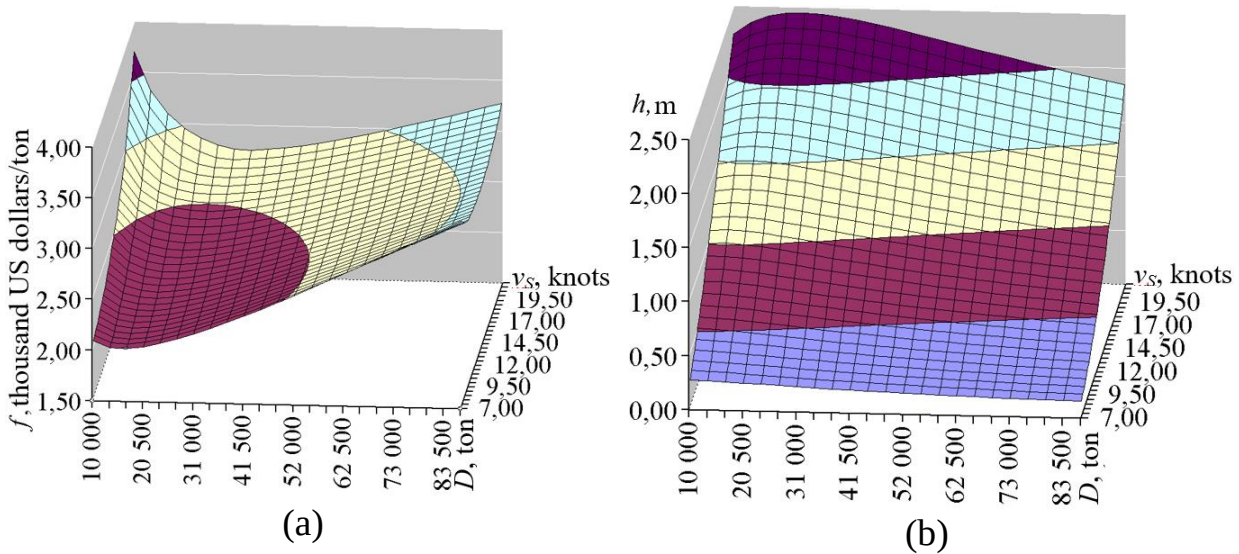


Fig. 7.10. Dependence (a) of objective function f (the generalized criterion of specific present worth) on variable characteristic of ship size – the cargo waterline displacement D and on the operating velocity of ship v_s in open water sought variable characteristics for the example data (table 5.1); the dependence (b) of the index of ship patency in frozen seas – of thickness h of solid ice affordable to overcome on cargo waterline displacement D and on operation velocity v_s for the example data (table 5.1)

The variable characteristic of operation velocity v_s in the couple with the characteristic of the ship size, for example with the ship loaded displacement D , in the general approximation predetermine the effective the power Ne , corresponded with the propulsive power of N_{ICE} , required for overcoming ice, and in the same time predetermine the definite level of ship performances in frozen seas. This means that at insufficient ice categories the level of the ship performances in frozen seas one can define methodologically in dependence on the ship operation velocity v_s in the open water.

The analysis of the indicated functional surfaces shows, that economically logical index of the ship operation velocity v_s in the open water and the constraint of the ship size (probably the ship loaded displacement D , corresponded with the constraint of subsidies in the costs associated with ship construction, provides the penalty or premium amendment to the objective function f , Fig. 7.10a), correspond the insignificant properties of the ship in frozen seas, performed by the index of the maximal thickness h of solid ice affordable to overcome, which is less than 1.0 m and the velocity in open water no less than 12.0 knots for the appropriately wide range of the index of the ship loaded displacement D (Fig. 7.10b).

The more general example of determining by economic criterion of optimal design characteristics of ship (LNG-tanker) at it insufficient ice category planned in the batch construction is considered above (item 5.1) with variation of the ship characteristics: the size – that is design length L (of load-line) of the ship and operating velocity v_s , assuming that other characteristics of the ship (D , DW , PG , GRT , NRT and etc.) in the mathematical model at the initial stage of designing are depended on listed two (L and v_s).

Checklist

379. Importance of multifunctional ice-navigating ship design constraints finding accurate for determining of the ship optimal design characteristics, depended on the constraints.
380. Impossibility at the initial designing stage to have comprehensive data accuracy for the ship created for decades, for example, the ship functional purpose assigned in terms of references, which in particular has to comply with assigned design constraints of specified ice category of the ship, the district of it navigation in this or that distant perspective, the economic environment, etc.
381. Sustainability of optimal design characteristics of multifunctional ice-navigating ship check by the variant calculations changing the data and the parameters and correlating the interval of variation of these indexes with an interval of optimal values of ship design characteristics change.
382. Factors of sustainability of optimal characteristics and design particulars of multifunctional ice-navigating ship: the mathematical properties of objective function and it arguments in the vicinity of optimum point (the optimal extremum) and the balancing ratios between the ship characteristics, as well, as the parametric dependences between the characteristics of the ship and it particulars.

383. Duality of optimal characteristics and design particulars sustainability factors of the ship under design: the property of the optimal values found to remain in the narrow intervals, with the account of possible variability of data, and the ability of this characteristics to remain in the narrow range of their relative values.
384. Sustainability of found design particulars of multifunctional ice–navigating ship is dependence on the optimal characteristics sustainability, which is corresponded with the composition of the objective function, especially with the classification into groups of mathematical indexes from this composition impacting the objective function: the data, the variables and the parameters.
385. Sustainability of property of design characteristics optimality in the vicinity of point (the set, or the vector) of optimal design characteristics of multifunctional ice–navigating ship when varying the design constraints due to equality to zero of partial derivatives of objective function by the variable design characteristics values resulting the insensitivity of the objective function to variation of constraints.
386. Necessary prerequisite of mathematically convex objective function extremum, that is the minimal (or maximal) values of function correspondence zero values of it partial derivatives to varied characteristics of the ship.
387. Sustainability of the property of optimality resulting from continuity and doubly differentiability of convex objective function and corresponding necessary prerequisite of it extremum (the equality zero of objective function partial derivatives respect variable design characteristic).
388. The size of multifunctional ice–navigating ship and, it is understood that, the set of design particulars, dependent on it size, increase with reduce of period of the ship navigation in frozen seas during a year in accordance with increase of the ship transportation function importance in open water for extrabudgetary customers.
389. Steady regular variation of the ship under design characteristics and particulars by variation of assigned design constraints as the kind of optimal design characteristics sustainability.
390. Sustainability of optimal size of multifunctional ice–navigating ship along variation of relative running time during period of navigation in frozen seas and, it is understood that, sustainability of the ship design particulars set, dependent on it size.

391. Sustainability of optimal size of multifunctional ice–navigating ship in case of variation of power load on the ship docked of energy supply on ships, off-shore platforms or onshore and, it is understood that, the set of the ship design particulars sustainability.
392. Costs, associated with multifunctional ice–navigating ship construction, dependence on the ship size, its design and structure, and independence of variation of provided subsidies in case, when they are not enough for the ship creation (its designing, construction and equipping). The needs for extra funding of corporate finances (the extra budgetary).
393. Influence of extra funding of corporate finances (the extra budgetary) on the composition of invested capital and on penalty amendment (or premium) for compliance of the ship under design with the investment constraint of the funded subsidies in costs associated with construction of the ship.
394. Appropriate sustainability of optimal size of multifunctional ice–navigating ship in case of variation of budgetary investments for the ship creation (its designing, construction and equipping).
395. Sustainability of characteristics and design particulars of multifunctional ice–navigating ship in case of variation of data index of the discount rate (the index of merchant risks total).
396. Sustainability of characteristics and design particulars of multifunctional ice–navigating ship in case of variation of data of transport tariff for extra budgetary customers (the corporate).
397. Approximate finding of multifunctional ice–navigating ship design particulars at initial stage of designing with the system of the parametric formulas in dependence on size characteristic of multifunctional ice–navigating ship of the ship loaded displacement.
398. Dependence of multifunctional ice–navigating ship design particulars sustainability when varying the assigned (the constraints) on the sustainability of the ship design characteristics.
399. Ranges of relative values of multifunctional ice–navigating ship design particulars.
400. The practical sequence of multifunctional ice–navigating ship independent design characteristics, dependent ones and its particulars finding, assuming and refining within the methods of systemic approach by design optimization stages.
401. Opportunities of other characteristics, such as use the cargo waterline displacement, the cargoes capacity of the ship, the gross tonnage or the net one and etc.

as independent variables in design optimization of multifunctional ice-navigating ship instead of its design deadweight.

402. The possibility and case to use the ship design particular, for example, multifunctional ice-navigating ship length, as its independent variable characteristic in design optimization.
403. The choice of definite characteristic of multifunctional ice-navigating ship as the independent variable in design optimization leading to attribute the corresponded characteristics and particulars to the set of dependent ones to assume their values or to predetermine conventionally to refine at next designing steps.
404. The set of the ship characteristics corresponded the ship seaworthy and patency in ice together with multifunctional ice-navigating ship size, such as: the thickness of the solid ice, affordable to overcome, the operating velocity in open water, the effective power commensurate with the ship propulsive power, required to overcome ice field, the capacity of the power installation, subject to select as other independent variable characteristic of the ship under design.
405. Superposition systemic property of multifunctional ice-navigating ship characteristics and design particulars associated with their independent determining consistently at different (the consequent) designing stages, due to disparity of the intervals of their variation, or the disparity of the index variation on one hand, and variation of this index increment or its deviation from its previously anticipated or assumed value (the error of initial anticipation or assuming), on the other hand.
406. Superposition when determining multifunctional ice-navigating ship design displacement of the independent account of explicitly assigned the ship load (the components of design deadweight) in the terms of references and the implicitly assigned increment of displacement by specification of the ship seaworthy and patency in ice, resulting the increase of the ship structures mass.
407. Assuming stock of multifunctional ice-navigating ship sizes stock (the non-distributed part of the ship displacement), or the stock of design deadweight for compensating of the ship size characteristic errors, when assessing independently the factors of the ship size at initial designing stage.
408. Moderate nature of relative value of the ship size (the displacement) stock follows from generally less bilateral cumulative impact of increase or reduce of size under design of multifunctional ice-navigating ship, when design particulars refined at the following stages and impacted the ship size (as the positively, so negative)

409. Duplicity of mathematical value of maximal thickness of solid ice affordable to overcome servicing as the assigned design constraint in the terms of references and as the design characteristic of ice category of multifunctional ice–navigating ship.
410. Opportunity to substitute the design constraint of the maximal thickness of solid ice affordable to overcome for multifunctional ice–navigating ship of insufficient ice category by its operation velocity in the open water, because of the insignificance of ice category in this case, as the ship with appropriate velocity in open water is able to cross ice of small thickness.

Chapter 8. Characteristics and purpose of the general system, to which the multifunctional ice–navigating ship belongs as subsystem

Characteristics and assignment of the general system, to which the multifunctional ice–navigating ship belongs, impacts the results of ship design optimization.

When creating the approaches of multifunctional ice–navigating ship design optimization in the frameworks of systemic approach it is required to define the concepts of the ship under design and the general object (the general system), to which the ship belongs as subsystem, and the characteristics of this general system serve the initial data for determining of optimal characteristics and design particulars of the ship. Besides it is important the methodological definition of subsystems of the ship under design, which form the ship, given that the subsystem, in core definition is the integral ship, considered from this or that its individual property. In its turn the characteristics of each considered subsystem of the ship (that is the particular property of the integral ship under design) when determining ship characteristics are design particulars (the parameters), used as assumed indexes, that is the other design constraints, besides of the assigned ones in the terms of references.

The indexes of the initial data and the parameters are to be got in the adjacent tasks: the external (the outer) designing – determining of design characteristics of the ship as complex system, consisting of subsystems, and the internal (the inner) designing – finding the design characteristics of the ship subsystems, that is the ship design particulars – the integral ship, considered from behalf its individual property. The seaworthiness properties of the ship, the patency in frozen seas, the strength and durability and etc. are the subsystems when determining optimal design particulars of the ship.

Integrity of internal and external designing issues in the hierarchic composition of multilevel systemic approach is linked with that multifunctional ice–navigating ship as designing object, which is available at both of hierarchic levels, where is represented by the ship characteristics. In the issue of internal designing the optimal values of multifunctional ice–navigating ship, as the complex system, the more general, than studied subsystem, the ship characteristics are the initial data and all combinations of design particulars, that is options of sets of the ship dimensions and their proportions, when finding their optimal values are studied at the similar set of the ship characteristics, which in at the level of internal designing are specified,

and this is the systemic prerequisite of considered options of design particulars comparability, for which the ship characteristics are data – the same characteristics for any compared options of particulars sets.

For general system (any concept of the general system, considered above, see Chapter 2, or other), to which multifunctional ice-navigating ship belongs as subsystem, the ship characteristics are the parameters. For example, it is possible to characterize the navigating company by the ships in composition of the company property complex, the shipbuilding yard – by the constructed ships in accordance with the Shipbuilding Industry Development Strategy, to characterize this or that ocean cargoes traffic, in particular the Northern Sea Route, by the ships it servicing the route, including the multifunctional ice-navigating ships, etc.

The indicated methodological property (the function of the hierarchic levels integration) of determined design characteristics of multifunctional ice-navigating ship, which can be constraints in the adjacent levels of optimization issue, that is the parameters in the issue of more general object designing, which subsystem is the ship, and to be the data in the designing tasks of the ship subsystems (the considered individual property of the integral ship), allows systematically generate the methods and the mathematical models for determining of design characteristics and particulars of the multifunctional ice-navigating ship.

Examples of general system, to which the ship belongs as the subsystem, indicated above (item 2.3), are: the complex of the marine company assets, the fleet of the merchant ships when determining the fleet composition, the ocean freight traffic, the ocean fishery expedition and etc.

Methodological concepts of general system definition for approaches to determine optimal design characteristics of multifunctional ice-navigating ship, include: the innovative function of the ship, specified by the ship purpose, the innovative structural element of the ship or its innovative equipment, that is the complex of the elements, created for the ship and assigned in the terms of references for design, the special shipbuilding technique and the equipment, if, for example, the shipyard could be specifically created for construction of the ships under design, and if the shipyard is assigned in contract, or in the terms of references for the ship construction as the prerequisite.

The question arises of the evaluation of option and methodological definition of general complex system influence on the results of optimal design characteristics of the ship determining, in particular, what is impact of provided subsidies (the investment constraint), funded in the costs associated with the construction of multifunctional ice-navigating ship, corresponding with its functions and with assignment

of these subsidies. Besides, the determining of independent classification attributes is required of general complex system, to which belongs the multifunctional ice–navigating ship as the subsystem. Linkage of these attributes with the ship functional purpose is relevant.

8.1. Impact of the budget investment constraint on optimal size of multifunctional ice–navigating ship

Amendment (penalty or premium) to the objective function for the ship compliance with investment constraint is determined as the cost of missing capital and is estimated as the necessity (or the redundancy) of extrabudgetary (the corporative) extra cash flow value to the specific present worth. Analysis of investment constraint impact on optimal characteristics of multifunctional ice–navigating ship is of the interest, in particular on the ship size.

Objective function f of generalized criterion of specific present worth (PW/DW), covering the amendment (penalty or premium) for compliance of multifunctional ice–navigating ship size (DW) with the investment constraint RC^* by the ship size subsidized index of design deadweight DW^* , is represented by functional graphic surfaces (Fig. 8.1) in dependence on design deadweight DW of the ship and on design constraint of solid ice h affordable to overcome, considering the range of investment constraint of provided subsidies ($RC^* = 250, 500, 750$ and $1\,000$ million US dollars) and the extra funding costs, associated with the ship construction, represented by the ship size subsidized index of design deadweight ($DW^* = 8\,530, 16\,270, 24\,010$ and $31\,750$ ton).

Functional graphic surfaces (Fig. 8.1) indicate that increase of provided subsidies (the investment constraint) is corresponded the extension of the ship interval of optimal values of size. In other words, while the increase of provided subsidies RC^* associated with construction of multifunctional ice–navigating ship not only the optimal size of the ship DW increases, but the differences of criterion in the form of the objective function f reduce of the ship of other sizes of compared options. In this way, at initial designing stages of multifunctional ice–navigating ship one has to consider the constraint of the provided subsidies RC^* for costs of the ship creation (it designing, construction and equipping), which in the terms of the systemic approach corresponds methodologically with the definition of more general system, than the ship, which belongs to this system.

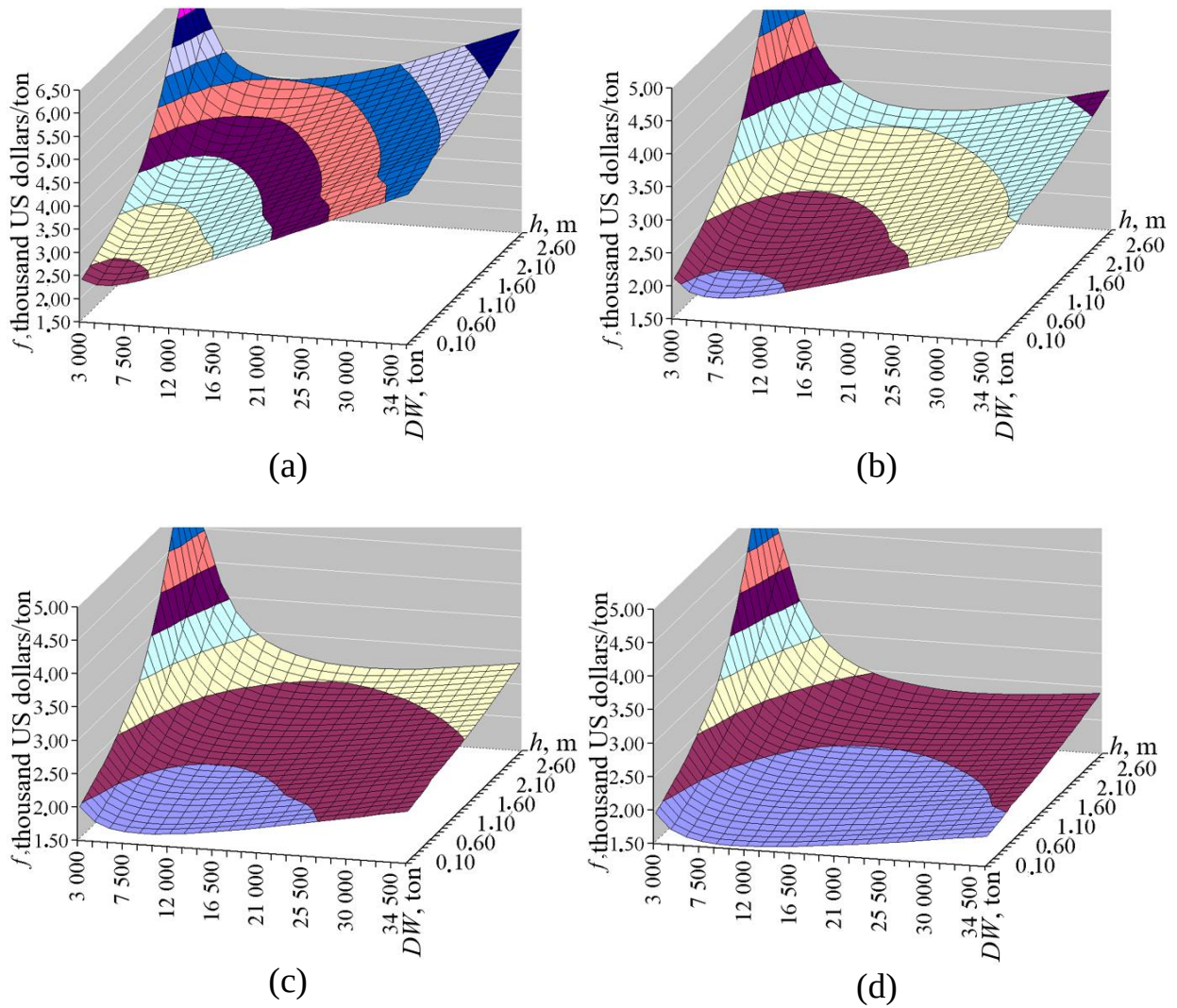


Fig. 8.1. Objective function f of generalized criterion of specific present worth (PW/DW) covering the amendment for compliance with investment constraint RC^* in dependence on design deadweight DW of multifunctional ice-navigating ship and on assigned constraint of solid ice thickness h affordable to overcome with the account of costs of extra capital to the investment constraint of provided subsidies RC^* :

- (a) the ship size subsidized index of design deadweight $DW^* = 8\,530$ ton at the investment constraint of provided subsidies $RC^* = 250$ million US dollars;
- (b) $DW^* = 16\,270$ ton at $RC^* = 500$ million US dollars;
- (c) $DW^* = 24\,010$ ton at $RC^* = 750$ million US dollars;
- (d) $DW^* = 31\,750$ ton at $RC^* = 1\,000$ million US dollars

Besides in the full range of the design constraint values of solid ice thickness h , affordable to overcome the optimal values of design deadweight DW , which correspond the minimum of the objective function f , are less, than the subsidized size of the ship DW^* , although for high ice categories, estimated by the index of solid ice thickness, affordable to overcome, the optimal values design deadweight DW

are close appropriately to the constraints of their the subsidized values DW^* , it is characteristic that the increase of the ship assigned ice category is corresponded with increase of the ship optimal size.

8.2. Innovative marine engineering, as the general system servicing for the determining of the ship design constraints

At initial stages of designing of multifunctional ice–navigating ship the «marine engineering» (the ocean engineering or the marine technology) can be considered as the concept of general system, to which the ship under designing belongs methodologically. The notion of the ship is covered by the concept of marine engineering, but the concept of marine engineering does not contain the ship concept the only and covers other objects as well. Practically the marine engineering usually attributed to the machinery and equipment of ship at the various levels of the generalization of the equipment concept, and the integral ship is probably maximal limiting generalization level.

The standard equipment, selected of batch mastered samples in the designing of the ship is to be determined as the ship subsystem. In the same time the atypical and innovative equipment systemically associated with the functional purpose of multifunctional ice–navigating ship for determining of the ship design characteristics can be considered not as the ship subsystem, but as the more general system, to which the ship belongs methodologically, that is the ship under design is subordinated in the designing sequence to the system of this ship main equipment – the marine engineering, which assignment corresponds with the ship purpose.

For ship of innovative assignment, for example for multifunctional ice–navigating ship under design the general system could be the equipment complex, which is pre–developed up to the ship creation in accordance with the Federal programs, in particular with the State program of Russian Federation «The shipbuilding development for the period of 2013–2030 years» /148/, or according with the Shipbuilding Industry Development Strategy for the period up to 2020 and for the future perspective /142/.

As the examples of the innovative functional equipment, specifically developed in accordance with the assignment of multifunctional ice–navigating ship up to the ship designing, one can designate:

- new types of power installations, in particular, the engines using the fuel of natural gas or the mixture of natural gas with diesel fuel;

- reactor and other parts of machinery under design of the ship with the nuclear power generation;
- energy generation installations of floating power plants, the facilities for sea water industrial desalination or water heating on these floating plants;
- marine industrial facilities for liquefaction of natural gas;
- special systems of multifunctional ice–navigating ships and the ships engineering assigned to overcome ice;
- propulsive devices of multifunctional ice–navigating ships;
- sub–water vehicles of special purpose for operation in freezing seas and etc.

The considered or the similar examples, which are not mastered usually by batch industrial production up to the creation the relevant innovative ships, including multifunctional ice–navigating ships, are covered methodologically by the concept of innovative marine engineering, and at initial stages of designing of the ship the specified innovative functional equipment is planned for the arrangement on the ship of the considered set in accordance with the ship functional assignment.

Considered facilities of the marine engineering are subject to creation up to the ship design, and, despite the fact that physically they are the ship parts, this equipment specifically developing in accordance with the ship functional purpose, nevertheless does not enter in the set of the ship design subject. The characteristics of this the equipment are assigned in the terms of references for the ship designing, in the other words, specified in the set of design constraints. Therefore, the equipment pre–designed in accordance with the assignment of multifunctional ice–navigating ship in the distinction the batch constructed ship can be considered in designing of the ship as the general complex system, in which the ship is created, that is as the set of design constraints.

For the completeness, one can give the examples of typical equipment used for manning of ship and typically considered at the initial stages of designing of ship as the ship subsystem. In the distinction from the functional equipment, specifically developed in accordance with the assignment of the innovative ship, created before the ship design and specifically for this, it is possible to indicate the following engineering as the serial component parts selectable in the process of the ship designing and not included in the set of it design constraints: the internal combusting engines, the diesel–generators, the boilers and fuel equipment of boilers, the pumps, the separators, the compressors, the deck gears of general assignment and their parts, as well, as the structural elements of ship machinery systems and etc.

8.3. Functions of ships linked with the structures of these ships and with the innovative technological facilities in the shipbuilding

Corresponded with design constraints the concept of general system, to which the innovative ship under design, in particular, the multifunctional ice–navigating ship belongs as subsystem, corresponded with the ship structure and with the used technological facilities in shipbuilding.

One can consider the new technical opportunities in shipbuilding and ones under creation as the ship properties, that are the technological opportunities of this ship construction, which are required according the Federal programs or the Shipbuilding Industry Development Strategy. This property is the link with the new technological opportunities of the ship construction. Technological opportunities, which are created previously the ship construction or ones are under creation, allowing to construct the ship or its structural parts, are in the set of data for finding of the ship optimal design characteristics, that are the kind of data, indicating the ship of innovative assignment.

The suitability of multifunctional ice–navigating ship for the construction on those or other assigned shipyards with their self–inherent technological constraints, or with the definite constraints of design characteristics of the ship can be specified as its assigned function. For example, the significant technical characteristics in shipbuilding, which predetermine the opportunities of the ship construction, are the technical processes of modular ship construction provided with the facilities (that are the industrial capacities and the equipment), if the assembling shipyard is acting and the shipbuilding enterprises are in the cooperation with it for production and supply the sections and modules of the assembled ships. The opportunities of modular construction are associated with the ships structures, assembled of modules and sections, and this structural feature could be assigned in the terms of references as design constraint.

One would put the attention on the fact that structural features of the ship under construction or the techniques of its construction are possible to redefine methodologically as the ship functional specifications. This allows to indicate in the terms of systemic approach the innovative technological opportunities in shipbuilding as the form of main system (systemically general) of ship under design, for construction of which these innovative technological opportunities are required, and in the set of the ship functional characteristics at initial stages of its designing the constraint could be specified, that the ship or its parts have to match the assigned construction technique.

Besides of the construction technique assigning the ship that or the other characteristics of structure can be indicated as it functional properties too. In particular, the purpose of the ship as «the membrane gas carrier» indicates not only the structural feature of ship and it functional attribute, and as well the corresponded way of the liquefied natural gas transportation. The similar examples of the structural characteristics of ship determining in the form of it functional properties are quite a few. The ice–navigating ship and the name of this class serves another example and indicates as the structural features of the ship, so it functional assignment.

8.4. Priorities of shipping in the industrial balance with shipbuilding

Given the interrelation of the industries of shipbuilding and shipping acting and developing in the balance, usually the shipping is of economic importance priority, since the characteristics of ships under construction, demanded in shipping, are to be used as data (the design constraints) for shipyards creation, acting and developing. This would mean, that the more general system than shipbuilding yard can be considered the ship. The shipbuilding enterprise has to be created or selected of the set of existing shipyards to place the contract to construct the ship, and this indicates the sequence of the ship creation and the subordination of the shipbuilding industry to the navigation one. Exactly this priority has the place in the Shipbuilding Industry Development Strategy for the period up to 2020 and for the future perspective /142/, which specifies the ships and the classes of ships subjected for construction, initiating the directions of shipbuilding developing, and the created shipbuilding facilities are the expected valuable results along with the ships.

Industrial interdependences between shipbuilding and shipping in the frameworks of methodology of optimal characteristics determining at initial designing stages of multifunctional ice–navigating ship one can determine as the double–sided:

- on one hand, the priority of economic demand in navigating, predetermined fleet composition and replenishment, is obvious for creation of the shipyards;
- on the other hand, it is possible to specify the innovative methods of shipbuilding in the composition of design constraints for the ship, that is to include in the set of the ship purpose it accordance with the assigned methods of construction.

In the case of existed shipbuilding technology, it would be in the composition of general complex system to which the ship studied for determining of it optimal design characteristics belongs as the subsystem. That is the systemic hierarchic priority of navigating over the shipbuilding is characteristic if only the shipbuilding industry is under improving.

In the other words, the subordinated industry of the considered couple is one under developing, using the resources of the other one industry (the dominated one or the prior for the subordinated). The resources are continuously redistributed between the industries by this way, which characterizes the common development of navigation and shipbuilding, and these industries development process can be of the oscillating nature or of growing one, if besides these industries self-sufficiency the funding aside is provided, like the federal subsidies.

Just the bilateral nature of industrial interrelation between shipbuilding and navigating indicates the methodological significance of the ship under design, which is the common object. The industrial interdependence is indicated in the set of design characteristics of the ship and of it functional assignment. These functions and characteristics define the ship as object in shipbuilding and in shipping mutually.

In the economic attitude the investing directions in development of navigation and shipbuilding in the great degree are in the balance considering the interdependence of navigating demand and shipbuilding supply. For example, the increase of demand with for the ships replenishment can serve the criterion of investments redistribution relevance from navigation into the shipbuilding industry. In case of this interdependence the eventual reduction of demand for new ships could cause the appropriate investments transfer from shipbuilding industry into the navigation.

Considering the selection from two alternatives of the investment – in the creation of shipbuilding enterprise or in construction of the innovative ship – for example, when formulating the designing issue, including defining of the subject and the object, for the program of shipbuilding development this selection can give the determining of the object, for which the general complex system would be it purposes in accordance with the Federal programs or the Shipbuilding Industry Development Strategy. And by itself the selected priority object, whether the innovative ship or the planned for creation the shipbuilding yard, would serve as the general complex system for the second of two these objects. Wherein the characteristics of selected one priority object in navigating or in the shipbuilding would be the data (the design constraints) for the creation of the second of these two objects.

In this way, the concept of general complex system is not limited to initially given four examples (1–4, item 2.3), and the following definitions, as well, as the specified, could be considered as the concepts of general system, to which the ship under design belongs, required for formulation of design constraints at the initial stages of multifunctional ice-navigating ship designing:

1) created innovative methods mastered in the shipbuilding, given that the functional characteristics of the ship could be specified in the terms of references as the ship accordance with these methods of shipbuilding;

2) innovative engineering equipment developed for the shipbuilding, meeting the functional purpose of the ship under design and construction, which characteristics and particulars have to meet the developed engineering equipment;

3) complex of the ship under design functions in accordance with the Strategy /142/ or with the Federal programs, which, in these case, are the general complex system, to which the ship under design belongs, and the design constraints are the indexes of the indicated Strategy and the Federal programs.

8.5. Subsidy objectives corresponding characteristics of the general system, to which the ship belongs as subsystem

For the analysis the design constraints one need to consider the options of more general system than multifunctional ice–navigating ship, to which the ship belongs as the subsystem. The generalization of these options or their combining subject to possible interchangeability is of the interest as well. This analysis could give a judgment regarding the completeness of the considered set of options of the system more general, than the ship, to which the ship belongs as the subsystem.

For determining of subsidies in the creation of multifunctional ice–navigating ship (designing, construction and equipping), which impacts the optimal size and dependent characteristics and particulars of the ship, one has to consider, at first, that the total subsidies provided for all objects (in particular, the ships, planned for the construction) are constrained, and, secondly, that the various purposes of the subsidy could be associated with the creation of the ship, that is the concept of the more general system, than the multifunctional ice–navigating ship, to which the ship at the initial designing stages belongs as the subsystem in the options of the general complex system (1–4, item 2.3, and 1–3, item 8.4) listed above, or in the other it options, which can be considered as the independent goal when subsidizing.

Summarizing the specified set of options of the general complex system, to which the ship under design belongs as the subsystem, including possible other options of the general system, the independent purposes of the costs subsidizing, associated with construction of multifunctional ice–navigating ship, one can designate:

1) replenishment of the fleet of marine cargoes carriers (the usual example of the external designing task of the merchant ship design optimization);

2) creation of the marine company property complex (the navigating company), to which the ship belongs as the asset;

3) operation of sea cargo traffic of the specified intensity and extent, serviced by similar ships, the same as one under design, that is the creation of complex of similar ships (the cluster or series);

4) creation of the series of similar ships (the cluster), implementing development of ocean resources in specified ocean district (the extraction of aquatic biological resources, mineral extraction in the sea, etc.), or complex of the ships of various assignments, mutually complementary in the complex (for example, the fishery expedition);

5) creation of new shipbuilding plants and yards practicing the innovative methods of shipbuilding, given that purposes of the ships under construction include as well the compliance with the created methods of shipbuilding;

6) development of the innovative specific marine engineering equipment, which is relevant the functions of the ships under construction and is not selected at completion of the ship design but assigned in the terms of references for design, unlike the batch equipment, produced for completing of any function of ships under construction;

7) creation of the ships (the designing, construction and completing) for the purposes specified in the Shipbuilding Industry Development Strategy or with the Federal programs in shipbuilding and navigation.

As it noted above, besides of indicated options of more general system than the created ship the other purposes general systems are possible, these can mean the independent subsidy goals, suitable methodologically for finding of initial data and the constraints at the initial stages of the ship designing.

By decisions of the administrations, implementing the fulfillment Shipbuilding Industry Development Strategy and the Federal programs in shipbuilding and navigation besides of the corporate investors possible participation the subsidies can be of the federal budget and the territorial budgets of the various administrative of provincial levels, as well the industrial budgets in shipbuilding and navigation. The additional off-budget financing is of great importance, if in the next the goals of privatization of constructed innovative ships and new facilities of the shipbuilding yards are set, and the refund of the subsidized money in the budgets is assumed.

8.6. The classification of independent purposes for which the construction of ships and the development of shipbuilding industry are subsidized

The attributes of classification of independent purposes, for which the shipbuilding industry development and the fleet renewal are funded by subsidies, one can determine in correspondence with functional and structural features of ships under construction and of the innovative technological equipment in shipbuilding, as well, as in correspondence with functional attributes of innovative marine engineering relevant the ships under construction, for which these marine engineering facilities are assigned as the main system (the general).

It is possible to indicate the following general classification of attributes of purposes of the ships under creation: the functional attributes, the structural, the technical attributes and the economic (the property possession) of the new ships, the marine engineering equipment and the ship construction methods assigned to use in the terms of references.

Such purposes, as the replenishment of fleet cargoes carriers (1, item 2.3), are of the functional nature. The replenishment of fleet largely corresponds with the purpose of the service of sea cargo traffics of the definite intensity and extent (3, item 2.3) and by itself does not indicate the creation of new types of the marine engineering or the opportunities of shipbuilding (the innovative facilities etc.; 4, item 2.3).

Assignment of the subsidies in creation of the marine company (2, item 2.3) in the form of property complex, which has separate financial account, to which the ship belongs as the asset, is of the economic nature (of the property possession) associated with the economic payback. The corporative investors, which motivation is the increase of capitalization of the working property complex of assets of the navigation company, among which the ships under creation are, can participate in the off-budgetary establishing and the developing of the property complex of this company, in particular in it creation, besides of probably provided the budgetary funding. Construction of innovative ships, as well, as the production of marine engineering equipment, or creation of new assets and technological facilities in shipbuilding are not required by their-self for creation of this company, and it property complex can be formed on the basis of investing in the available technologies and the assets.

The development of the ocean resources in the specified district and the creation of the series of similar ships to do that, or the creation of different ships functionally mutually complementary in the complex (4, item 2.3), is possible to characterize as the independent functional assignment of funding the costs, associated with

ship construction, and since to ocean resources in the wide economic sense can be attributed not only the mineral deposits on the offshore, or the aquatic biological resources, and any resources of ocean, suitable for their productive use /9/, then one can see the definite similarity of functional nature of following purposes of the considered list: the development of ocean resources and the creation the complex of ships (4, item 2.3) for that, the replenishment of transport fleet (1, item 2.3), as well, as the servicing of ocean cargo traffics of definite intensity and extent (3, item 2.3). Need to clarify that for finding of optimal characteristics of multifunctional ice–navigating ship at the initial designing stages it is possible to attribute to ocean resources not only the offshore resources, the ocean biological ones and etc., but any opportunities of the ocean industrial activity on the economic payback basis, or on otherwise determined concepts of utility using the economic criteria. For example, in the economic sense it is possible to attribute the ocean cargoes traffics, the offshore works, the processing of natural gas (liquefaction, storage and transportation), the power generation, the other industrial issues in the ocean, in particular in frozen seas, to the set of marine resources, subsidized or meeting the solvent demand.

The creation of the innovative technological methods and the facilities in shipbuilding (5, item 8.5), given that the assignments of ships under construction include as well the compliance of these ships with the methods of their construction, corresponding the definite features of functional or technological purpose, to which the ship under construction belongs, as the subsystem to the general system, predetermining the design constraints.

The functional and structural nature of the purpose, as the systemic property of general system, to which the ship under designing belongs methodologically, means the elaboration of the innovative marine engineering equipment (6, item 8.5) functionally relevant the ship, for which these the marine engineering equipment is constructed or predesigned as the main system.

Implementing of the Shipbuilding Industry Development Strategy and the Federal programs in shipbuilding and navigation (7, item 8.5), which largely predetermine the creation of the innovative ice–navigating ships, corresponds the functional nature of purpose of these ships creation, and the initial data by the Strategy and by Federal programs correspond the set of constraints at initial stages of the ship designing.

Functional assignment of the ship subject to construction, which is assigned the Shipbuilding Industry Development Strategy and in the Federal programs is closely corresponded with the general system by defining of functions of new marine engineering equipment, which assignment to complete the ship is corresponded

with the ship subject to construction (6, item 8.5), for which these this marine engineering equipment is intended as the main system.

The main system (the general) in this case could be or physical gear or the mechanism, that is definite complex of the engineering equipment, developed specifically up to the ship construction as it innovative part, which is the main methodologically, matching the ship under design purpose as it is specified for the integral ship in accordance with the Shipbuilding Industry Development Strategy and the Federal programs.

Given the analysis of indicated options of general systems, to which the multifunctional ice-navigating ship belongs as the subsystem in one way or another, it is possible to adhere four attributes of multifunctional ice-navigating ship of any creation purpose, as the characteristics of general complex system for determining of the constraints at the initial stages of the ship designing:

I. The attribute of economic payback (the property attribute) of independent purpose of creation of the ship (it designing, construction and equipping), or the innovative marine engineering, or of conceptually new shipbuilding technique and the shipbuilding companies facilities, aimed at economic results, subject to evaluation in the comparable forms: the concepts of the economic payback and the subsidies refund in the budget, as well, as the payout of the interest for the subsidies use, or the sales of the created ship and the facilities to a corporate investor and the refund in the budget of subsidies and the capital costs. The different forms of the subsidies refund are possible as in the merchant turnover of the property or in the operation use of the created ship with the use of the joint-stock, leasing or credit financial instruments.

II. The technological attribute of the purpose of ship creation indicates the independent value of creation of the innovative opportunities in the shipbuilding, given that these opportunities are closely associated with the structures of the ship under construction, and at the initial stages of designing of the ship these opportunities can be specified as well in the composition of it function as the indication of the ship suitability for the construction with the use of new created technical facilities, being self-valuable within technological attribute.

III. The structural attribute of purpose of provided subsidies for the ship creation indicates the value of creation of the ship main system (the general), that is of innovative engineering equipment, gears, structures, the parts of ship, which are not batch mastered in shipbuilding up to the considered ship creation, in the design of which the innovative engineering equipment is assigned, is developed up to the fulfillment of the ship design and is included in the composition of data and the constraints

in the terms of references for designing. The main system (the general) of multifunctional ice–navigating ship under construction is a new product, and the engineering object on the ship, as well, as methodological concept and is linked, on one hand, with the ship function, that the main system is not the batch engineering equipment of general assignment, which is used on the ships of all types, and on the other hand, with the innovative technologies of the shipbuilding. It should be mentioned that other than creation of innovative ship, including its designing, the elaboration of those or other subsystems of the ship, not produced before, and making up the new shipbuilding technological equipment, which is not available serially produced, but the batch construction of ships would mean the repeatability of the decisions, and this serial construction will not be the subject of optimization designing within the systemic approach, and, perhaps, in this case it is more logical to use conventional designing methods based on prototypes, which can be used as well, as the parts of mathematical model of innovative ship design optimization, in particular, of multifunctional ice–navigating ship.

IV. The functional attribute of the ship creation purpose, characterizing the value of the ship assignment functions, is determined on those or the other available methodological grounds, for example with the Shipbuilding Industry Development Strategy and the Federal programs in shipbuilding and navigation and etc. That is the innovative assignment of multifunctional ice–navigating ship in itself acts the functional attribute of the ship creation purpose, if defined without appeal to other considered above attributes of the purpose.

The sequence of specification of economic, technological, structural or functional attributes of the independent purposes of the ship creation, which is listed above (the items: I, II, III and IV), is conventional and does not indicate their hierarchical subordination. In the general case the indicated attributes can be considered as methodologically equivalent for determining of the constraints at initial stages of designing of multifunctional ice–navigating ship by forming the image of general complex system, which subsystem is the ship under creation, in particular, for use of this methodological general system for evaluation of the subsidies distribution and for finding of the financial constraint of investments in the costs, associated with the ship construction, considering that the total subsidies provided for all objects (in particular, the ships, planned for the construction) are constrained. In the same time the choice as of the priority importance of one of considered attributes would lead to the change of the general complex system form, to which the ship under design belongs. The form of this system, used for determining of constraints (the data) at initial stages of the ship designing, in the definite case can have the kind

of the ship creation purpose, represented in designing as the main system (the general) associated with the set of other purposes.

Need to pay attention on the fact that functional, structural, technological and economic attributes of construction purpose of the ship, marine engineering equipment and of the innovative technology facilities in shipbuilding are compatible and not mutually exclusive, and it is visible the definite interdependence of these four attributes, which can give the ability of appropriate re-definition of one's purpose attributes of the indicated set by the others three of the considered set: I, II, III and IV – nevertheless in many cases one can consider practically independent by the following reasons:

- the selection of the structural attribute or the technological as the priority one depends on the purposes hierarchy in the industrial system of shipbuilding and shipping, when the shipping can be the priority industry in this couple, and the characteristics of the ships, assigned for construction, are used in the data for creation of the shipyards, or the shipbuilding could be of the priority importance, if the ship suitability for the construction on the definite shipyards with inherent technological features and constraints can be the function of the ship;

- despite the fact that it is possible to formulate the attribute of ship function occasionally as the structural, corresponded with the ship function, or as the purpose attribute in the field of the shipbuilding technique, corresponded as well with the ship structure or its function, nevertheless it is logical to consider the value of purpose of the ship under construction as attribute of the independent purpose, because the planning in shipbuilding and navigation in accordance with the Shipbuilding Industry Development Strategy and with the Federal programs, in particular with the State program of Russian Federation «The shipbuilding development for the period of 2013–2030 years» /148/ is usually represented by the assignments and the characteristics of ships, which structural features and construction technique and facilities are independent industrial issues and correspond with the subject of the decision in shipbuilding and navigation industries.

8.7. Finding of investment constraint of subsidies in the costs, associated with ships construction, considering the subsidies distribution for the assigned purposes

Considering of the listed examples (1–4, item 2.3 and 1–3, item 8.4) the other separate options of methodological concept of the general system, to which the mul-

tifunctional ice–navigating ship under design belongs as the subsystem, for determining investment constraint of the subsidies in ship construction it is possible to characterize the general system as the complex of the independent purposes, for which the ship is created (designed, constructed and equipped). Distribution of investments in the ship construction is carried out considering investment risks and balance of the constrained total of provided investments in independent purposes, methodologically characterizing the general complex system.

The assumption of total balance of the investments in the creation of the innovative ships, the marine engineering equipment and the innovative facilities of shipbuilding enterprises, and in replenishing of existing shipbuilding yards technology, on one hand, and the total amount of the provided subsidies for achieving of the self–valuable purposes (I, II, III and IV, item 8.6): economic payback (the self–sufficiency), technological, structural and the functional ones – on other hand, can be used for relevant distribution of the subsidies into these purposes, for which the ship is created.

The constrained investments total indicates the full amount of funding (the total subsidies) RC_{Σ} provided for financing of purposes in accordance with the Shipbuilding Industry Development Strategy and with the Federal programs, and the approach of the subsidies distribution into their parts is the issue and, ultimately, the distribution into the objects of investing – the ships under creation, as well, as the other objects, for which the indicated subsidies are provided.

For each considered object of the investment, in particular for multifunctional ice–navigating ship, the subsidy RC_{FMQK} is provided corresponding the investment constraint RC^* , used when finding the design characteristics, depended on of the constrained investments total RC_{Σ} and on the way of the subsidies distribution into the invested objects. In this way, the subsidy RC_{FMQK} is characteristic of the general complex system, to which the ship under design belongs. This index RC_{FMQK} indicates provided subsidies into the object (the ship under creation) of $FMQK$ and the way of their distribution into the object.

Balance assumption of constrained investments total RC_{Σ} and provided subsidies into the object RC_{FMQK} , in particular, in the creation of multifunctional ice–navigating ship, or the other object of the set of innovative marine engineering equipment, as well, as in the creation of the facilities of shipbuilding enterprises looks like

$$RC_{\Sigma} = \sum_F \sum_{M_F} \sum_{Q_{FM}} \sum_{K_{FMQ}} (RC_{FMQK}), \quad (8.1)$$

where RC_{Σ} – constraint of the investments total indicating the full subsidies, provided for funding of purposes in accordance with the Shipbuilding Industry Development Strategy and with the Federal programs of the innovative ships creation, of marine engineering equipment and the technological facilities of shipbuilding enterprises; RC_{FMQK} (or RC_K) – provided subsidies into the object (the ship under creation) of $FMQK$, corresponded the investment constraint RC^* , used when finding design characteristics, provided the total investments of the costs associated with the creation (designing, construction and equipping) of the definite object of investing, in particular the ship, are equal the investments in all purposes with the attributes: K -th function of ship under construction purpose K_{FMQ} , characterizing the value of this function assigned in the accordance with the Shipbuilding Industry Development Strategy or with the Federal programs of the innovative ships creation, Q -th structural attribute of the purpose Q_{FM} indicated the value of the main system of ship creation: the innovative engineering equipment, the gears, the structures, the mechanisms and etc., which are not the batch mastered up to the ship creation, in which design they are assigned, the main system item of ship developed before the fulfillment of the ship design and included in the set of the data (the design constraints of the terms of references), M -th the technological attribute M_F , corresponded the creation of innovative technological facilities of the shipbuilding yard, given that these facilities are closely associated with the structure of the ships under construction and are to be assigned at the initial stages of designing within the set of design constraints in the terms of references, with regard the required suitability of ship under design for its creation with the use of the indicated innovative technological facilities, F -th the attribute of economic payback and self-sufficiency (attribute of the property possession nature), aimed at the economic result and at subsidies and extrabudgetary capital cost refund.

Simplification of symbols can be used for investments balance equation (8.1)

$$RC_{\Sigma} = \sum_F \sum_M \sum_Q \sum_K (RC_{FMQK}), \text{ or } RC_{\Sigma} = \sum_{FMQK} (RC_{FMQK}), \quad (8.2)$$

as well, as the symbolic entry of subsidies balance assumption: $RC_{\Sigma} = \Sigma RC$.

The grouping of summation indices in the record $FMQK$ or the indices omission is not canceling of the summation sequence in the equations (8.1 and 8.2). Each of the indices of summation: K , Q , M and F – is used within the assigned more general indices of their offered consistency, which corresponds the list of attributes of the self-valuable purposes of the subsidies funding: I, II, III and IV (item 8.6). List of the subsidies purposes attributes does not indicate the priority of those

or other sequence is appropriately conventional, despite the fact that, the indicated consistency: K , Q , M and F is obeyed in the considered study for correct use of the investments balance assumption and for the uniformity.

Need to pay attention, that probable introduction of the additional attributes of subsidies purposes besides of offered ones (I, II, III and IV, item 8.6) does not change the constrained investments total RC_{Σ} , associated with construction of the innovative ships, the marine engineering equipment and the innovative facilities of shipbuilding enterprises, and this amount RC_{Σ} is the restrictive assumption, that is the initial data for the investments balance equations (8.1 and 8.2).

When using the specific index of investments rc_{FMQK} per unit of ship size (in brief abbreviation rc_K) the equation of the investments balance (8.1 and 8.2) looks like

$$RC_{\Sigma} = \sum_{FMQK} (rc_K \times DW_K), \quad (8.3)$$

where DW_K (that is DW_{FMQK}) – K –th size, in particular, the design deadweight of K –th created ship (that is $FMQK$ –th) for K –th attribute of the intrinsic value of functional assignment of the ship under construction K_{FMQ} , Q –th attribute of the intrinsic value of the ship of innovative structural type Q_{FM} , M –th attribute of the intrinsic value of the innovative shipbuilding technology creation, assigned for construction of this ship M_F for F –th attribute of the economic self–sufficient (the self–sufficiency) purpose of the subsidizing.

Prerequisite (the assumption) of the investments balance (8.1, 8.2 and 8.3) in creation of innovative ships (multifunctional ice–navigating ones) and facilities of shipbuilding enterprises using the specific index of investments is provided in the functional dependence on the characteristics of size (the design deadweight) of the ship under creation. This is relevant because the ship size linked with the need in the costs associated with the ship creation, including the designing and the commissioning in operation (in the working assets replenishment), and because the size characterizes not only the ship, but the shipbuilding yard, implementing the construction of the ships not bigger than of assigned size and, as well, as limits of the ship size characterizes of the marine engineering equipment for the ship completion, the devices, structures, parts of equipment of the ships under construction.

It should be mentioned that index of the supply characteristic for determining of the ship design particulars according to the Register rules: the deck gears, machinery and other equipment, which the ship completed with under the Register regulation, is decided in dependence on the ship size.

Besides of design deadweight DW the other characteristics of ship size in the assumption of investments balance would be used, which says not only about assigned function of cargoes transportation, but indicates the ship suitability for fulfillment of the service–auxiliary functions in frozen seas, for the navigation servicing and the escort of other ships in these conditions, the ship suitability to carry onboard the special equipment, assigned for fulfillment of those or the other functions in frozen seas.

The characteristic of multifunctional ice–navigating ship size can be used in equation of the investments balance (8.3) of the set: cargo waterline displacement D , cargoes capacity of the ship PG , tonnage (the great GRT or the net NRT) and etc., as well, as this or the other characteristic of the ship power generation capacities or the mechanisms: effective power Ne , required power in ice N_{ICE} , total capacity of the ship power installation NP and etc.

The determining of the investment constant rc , that is the characteristic of provided specific investment per unit of the ship size, corresponded with the design deadweight DW (or with other characteristic of the ship size), and of the product of investment constant by the index of total risk $[rc(DW) \times i]$, in the assumption of balance with the constrained investments total RC_{Σ} , the investments in the creation of multifunctional ice–navigating ship RC_{FMQK} it is possible to find by the system of equations

$$RC_{\Sigma} = rc(DW) \times \sum_{FMQK} ((rc_K/rc(DW)) \times DW_K), \text{ or } rc(DW) = \frac{RC_{\Sigma}}{\sum_{FMQK} DW_K},$$

and

$$RC_{\Sigma} = [rc(DW) \times i] \times \sum_{FMQK} (DW_K/i_K), \text{ or } [rc(DW) \times i] = \frac{RC_{\Sigma}}{\sum_{FMQK} (DW_K/i_K)}. \quad (8.4)$$

The use of specific index of investments per unit of size of the ship under creation at the initial stages of designing it is possible to determine in proportion to various characteristics of ship size or the power, that is not only per unit of design deadweight DW , although this index is convenient to use. In particular, in the of shipbuilding industry it is widely used the investments index per unit of the construction mass, that is per unit of the ship empty displacement DP , which, as known, is the difference between the ship loaded displacement D and it design deadweight DW : $DP = D - DW$.

The determining of indexes: the specific index rc (the investment constant), used in the equation of investments balance, and it product on the interest

rate $[rc \times i]$ by the system of equations (8.4) for finding the investment constraint or the ship size subsidized index of design deadweight DW^* in dependence of the ship purposes, assigned in the terms of references, on the basis of generalization of independent purposes of the ship creation (I, II, III and IV, item 8.6): the economic payback (the self-sufficiency), the technological, the structural and the functional ones according to the considered model of balance of the investments associated with construction of the innovative ships and facilities of the shipbuilding enterprises should be performed practically in the spreadsheet of the Microsoft Excel.

From the economic side the specific index of provided subsidies associated with the ship construction correlates in the inverse proportion with the risks of investment. For independent purposes of the ship creation (I, II, III and IV, item 8.6) the ratio of considered indexes is characteristic ($rc_F, i_F, rc_M, i_M, rc_Q, i_Q, rc_K, i_K, rc$ and i), which follows from the applied method (8.4) of the specific indexes of investments distribution in the inverse proportion to the investment risks independent in each intrinsic valuable purpose, linked with the innovative ship creation

$$[rc \times i] = rc_M \times i_M = rc_F \times i_F = rc_Q \times i_Q = rc_K \times i_K, \quad (8.5)$$

where rc_F and i_F – specific index of the subsidies per unit of the ship size and index of the risks of investing in the economic purposes (the self-sufficiency), aimed at economic result, evaluated by the concepts of economic payback and refund of subsidies in the budget and payment of the capital cost, or selling to another corporate investor with same self-sufficient purpose; rc_M and i_M – specific index of the subsidies per unit of the ship size and index of the risks of investing in creation of the innovative technological opportunities and facilities in the shipbuilding, which can be assigned at initial designing stages as the constraint with regard to required suitability of ship construction with use of created innovative technological facilities; rc_Q and i_Q – specific index of the subsidies per unit of the ship size and index of the risks of investing in creation of the main system of the ship, which characteristics are the design data of innovative engineering equipment, gears, structures, the part of the ship equipment and structures, etc., not serially mastered up to the ship creation; rc_K and i_K – specific index of the subsidies per unit of the ship size and the index of risks of investing for the functional attribute of investing in the ship creation, characterizing the intrinsic value of this function, determining according with the Shipbuilding Industry Development Strategy and with the Federal programs in the form of the ships under construction assignments.

At initial stages of designing, considering the analysis of composition of the general complex system, which part is the ship under creation, represented the variants of this complex system (1–4, item 2.3 and 1–3, item 8.4 or others), as well, as the independent purposes (self-sufficient) of ship creation (I, II, III and IV, item 8.6): the economic payback (the self-sufficiency), technological, structural and the functional ones, provided constraint of the subsidies RC^* in the ship creation (it designing, construction and equipping), distributed of constrained investments total RC_{Σ} , one would find on the basis of the risks analysis upon reaching each of the purposes (i_F , i_M , i_Q and i_K), specified in the terms of references, according the Shipbuilding Industry Development Strategy and with the Federal programs, and dependent on the specific index of investments $rc(DW)$ per unit of ship size and it product on the interest rate $[rc \times i]$ by the system of equations (8.4), as

$$RC^* = [rc(DW) \times i] \times DW^* / i. \quad (8.6)$$

8.8. Determining of the ship size subsidized index of design deadweight with account of investments risks in independent purposes

Using approximal formula (6.3) for transforming to the ship size subsidized index of design deadweight DW^* of the investment constraint RC^* of provided subsidies in costs associated with the construction of multifunctional ice-navigating ship, when combining with the formula (8.6) of distributed subsidies RC^* in the ship construction considering the specific indexes of investment constant rc and it product $[rc \times i]$ on risks index i , one can determine the ship size subsidized index of design deadweight DW^* , used for finding of amendment (penalty or premium) to objective function in optimization designing, as

$$\begin{aligned} DW^* &\approx 789.5 / (1 - 0.0301 \times rc(DW)), \text{ or} \\ DW^* &\approx 789.5 / (1 - 0.0301 \times [rc(DW) \times i] / 1), \text{ ton,} \end{aligned} \quad (8.7)$$

where index the investment constant $rc(DW)$ applies in thousand US dollars / ton.

The dependences on the specific index of provided subsidies: $rc(DW)$ or $rc(DP)$ of multifunctional ice-navigating ship subsidized indexes of sizes: DW^* and DP^* in the form of the investment constants, in their turn dependent on investments total RC_{Σ} in the costs associated with construction of innovative ships and on risks upon achievement of each of the purposes of innovative ship creation (i_F , i_M , i_Q and i_K): the functional, structural, technological and the economic (the self-sufficiency, the payback), as well, as on total risk i are presented on graphs (Fig. 8.2).

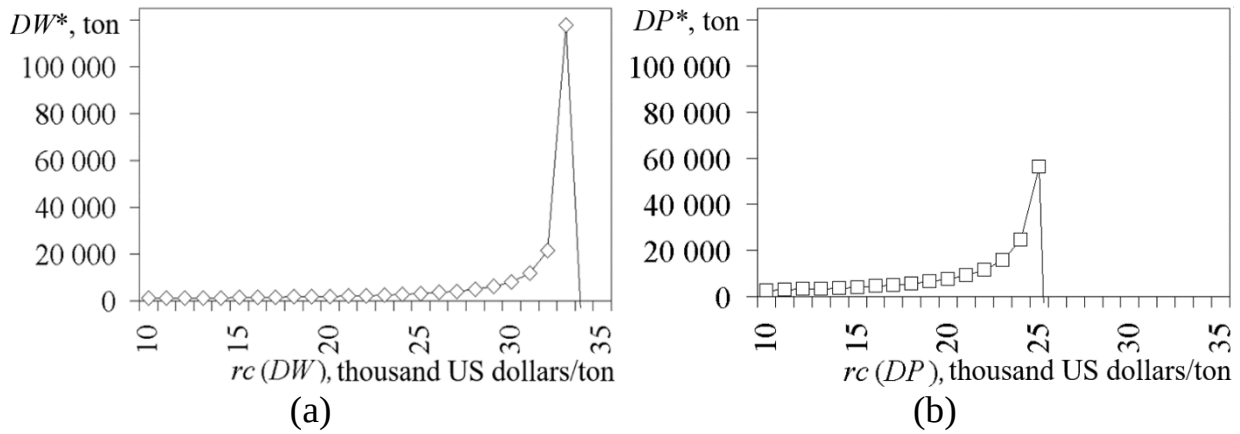


Fig. 8.2. Evaluation of the subsidies constraints provided in the costs associated with construction of multifunctional ice-navigating ship, transformed to dependences on the ship size characteristics of: (a) the ship size subsidized index of design deadweight DW^* on the investment constant $rc(DW)$; (b) the ship size subsidized index of the ship displacement empty DP^* on $rc(DP)$

The investment constraint RC^* of subsidies associated with construction of multifunctional ice-navigating ship is possible to assess in dependence on the investment constant $rc(DW)$, accordingly

$$RC^* \approx 789.5/(i/[rc(DW) \times i] - 30.96), \text{ or} \quad (8.8)$$

$$RC^* \approx 789.5/(1000/rc(DW) - 30.96), \text{ million US dollars.}$$

The constraint of provided investments RC^* in the creation of multifunctional ice-navigating ship and the index of investment constant rc , that is the characteristic of the specific investment per unit of the ship size, corresponded with the design deadweight DW (or with other characteristic of the ship size), depends on assigned investments total RC_Σ in the creation of the innovative ships, the marine engineering equipment and in the development of shipbuilding companies and characterize the distribution of investments total in the conformity with the independent risks of investments (i_F , i_M , i_Q and i_K), accordingly with composition of general complex system, which subsystem is the multifunctional ice-navigating ship, meaning the value of the ship purpose determined in accordance with the Shipbuilding Industry Development Strategy and with the Federal programs in shipbuilding industry and in the navigation.

When using the parametric equation (5.8) of dependence of the required investments RC on size of multifunctional ice-navigating ship, considering the specific indexes of investment constant $rc(DP)$ and it product on the risks index

$[rc(DW) \times i]$ dependent on the risks, one can determine the ship size subsidized index of displacement empty DP^* , as

$$\begin{aligned} DP^* &\approx 1687/(1 - 0.0388 \times rc(DP)), \text{ or} \\ DP^* &\approx 1687/(1 - 0.0388 \times [rc(DP) \times i]/1), \text{ ton,} \end{aligned} \quad (8.9)$$

and the investment constraint RC^* of subsidies associated with construction of multifunctional ice–navigating ship is possible to assess in dependence on the investment constant, accordingly

$$\begin{aligned} RC^* &\approx 1687/(i/[rc(DP) \times i] - 43.5), \text{ or} \\ RC^* &\approx 1687/(11000/rc(DP) - 43.5), \text{ million US dollars,} \end{aligned} \quad (8.10)$$

where the indexes of investment constant $rc(DP)$ and its product on the risks index $[rc(DW) \times i]$ are determined with the system of two equations, similar to those which are considered above (8.4) with the change of the ship size variable characteristic of design deadweight DW to its displacement empty DP

$$rc(DP) = \frac{RC_{\Sigma}}{\Sigma_{FMQK} DP_K}, \text{ and } [rc(DP) \times i] = \frac{RC_{\Sigma}}{\Sigma_{FMQK}(DP_K/i_K)}. \quad (8.11)$$

8.9. Impact of budget investment constraint on objective function and on the optimal size of multifunctional ice–navigating ship

Dependence of objective function f is shown on functional graphic surface and on its projection on the base plan (Fig. 8.3) of specific present worth (PW/DW) of multifunctional ice–navigating ship with amendment (the penalty or premium) for variable size of the ship (of its design deadweight DW) compliance with subsidized index DW^* on design deadweight DW and on the design constraint of assigned solid ice thickness h affordable to overcome and on provided amount of subsidized investments in the form of the investment constant $rc(DW)$, characterizing the distribution of the subsidies for independent intrinsically valuable purposes of investing in the creation of the ship: the economic payback (the self–sufficiency), technological (the innovative technological facilities of shipyard), structural (the innovative marine engineering equipment production) and the functional.

The interval of possibly optimal values of ship size (the design deadweight DW) corresponding to the minimal values of objective function is indicated by the graphic surface in the dependence on the provided subsidies of costs, associated with the construction of multifunctional ice–navigating ship, by the specific index

of the investment constant $rc(DW)$. For the specified design constraint of solid ice thickness h affordable to overcome of 1.0 m the possibly maximal values of the ship optimal size increase as one increase the provided subsidies associated with ship construction by the value of the investment constant $rc(DW)$.

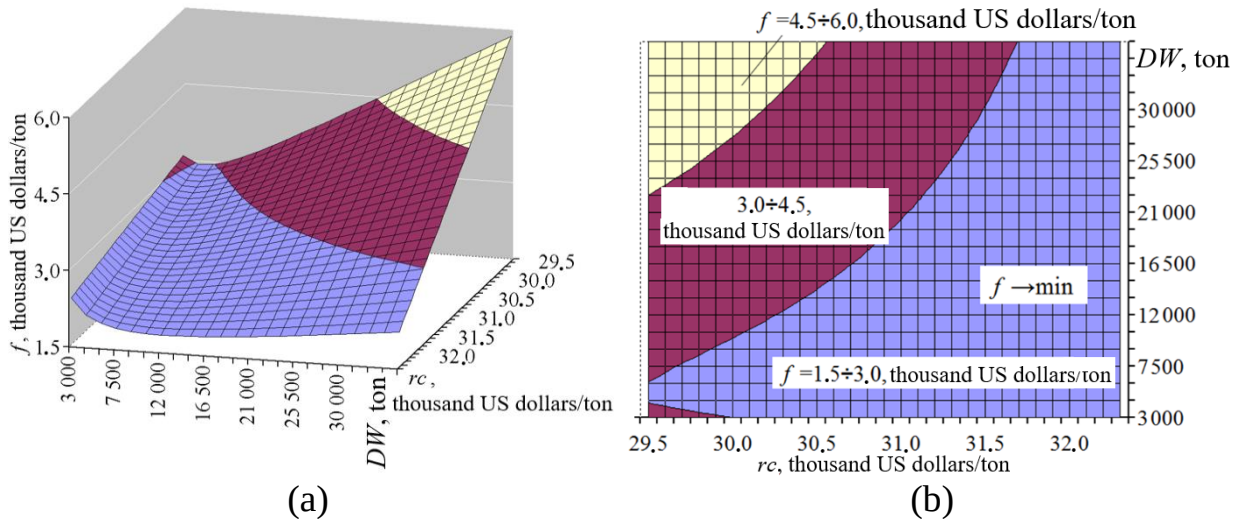


Fig. 8.3. Dependence of objective function f of specific present worth per unit of multifunctional ice-navigating ship p size (PW/DW) with account of financial constraint of subsidies in the costs of multifunctional ice-navigating ship creation (it designing, construction and equipping) on design deadweight DW and on investment constant $rc(DW)$ characterizing the distribution of subsidies for assigned design constraint of thickness of the solid ice h of 1.0 m, affordable to overcome

Objective function f is characterized by increase of it value as the reduce of provided subsidies, associated with the construction of multifunctional ice-navigating ship ($rc(DW)$ or RC^*), given that missing subsidies are raised in financial markets at the definite capital cost, which impacts the cost increases.

Constraint of total provided investments in the costs, associated with construction of multifunctional ice-navigating ship, along with the other design constraints characterizes the link of ship with the general system, to which the ship under design belongs as subsystem. General system could be methodologically identified by complex of self-valuable purposes of the subsidies in the ship creation, including the economic payback purpose (the self-sufficiency), technological, structural and the functional ones. The evaluation of the design constraint of provided investments in the creation of multifunctional ice-navigating ship can be performed with the account of balance assumption (the prerequisite) of constrained investments total RC_{Σ} , and the risks of investment, relevant the independent purposes attributes,

as well, as of total risk of investing in the creation of multifunctional ice–navigating ship. Amount of the provided investments and the other constraints at the initial stages of designing impact the optimal size of multifunctional ice–navigating ship: with the increase of provided subsidies, associated with the ship construction, the ship optimal size increases.

Checklist

411. Definition of general system, to which multifunctional ice–navigating ship belongs as the subsystem, while this general system characteristics serve data (the design constraints) for determining of the ship characteristics and design particulars.
412. Core definition of multifunctional ice–navigating is integral ship, considered from this or that it individual property.
413. Integrity of internal and external designing issues in the hierarchic composition of multilevel systemic approach, linked by the concept of multifunctional ice–navigating ship as designing object, which is available at both of hierarchic levels, where is represented by it characteristics.
414. Representation of multifunctional ice–navigating ship in the adjacent systems by the ship characteristics, which are: the particulars in the more general system, to which the ship under design belongs as the subsystem, and the data – when the ship is the general system and the characteristics of the ship subsystems (the ship particulars) are determined.
415. Examples of general system, to which the ship belongs as the subsystem (the complex of the marine company assets, the fleet of merchant ships when determining the fleet composition, the ocean freight traffic or fishery expedition, etc.).
416. Methodological concepts of general system definition for approaches to determine optimal design characteristics of multifunctional ice–navigating ship (the innovative function of the ship, the innovative structural element, the special shipbuilding technique and the equipment, if the shipyard is assigned in contract, or in the terms of references for the ship construction as the prerequisite.
417. Increase of provided subsidies associated with construction of multifunctional ice–navigating ship resulting in the extension of interval of size of the ship optimal values and in the increase of the ship optimal size although below the ship size subsidized index of design deadweight.
418. Growing of optimal size of multifunctional ice–navigating ship with increase of assigned constraint of solid ice thickness affordable to overcome.

419. The opportunity to consider the marine engineering concept (the ocean engineering or the marine technology) as the general system, to which the ship under designing belongs methodologically.
420. Physical attribute of the marine engineering object to the set of the ship structural parts, machinery and equipment, for which the integral ship is probably maximal limiting generalization level.
421. Opportunity to consider the shipyard facilities as the marine engineering, because the facilities correspond the ship under construction.
422. Standard equipment, selected of batch mastered samples set in accordance with design, in the designing of the ship is to be considered as the ship subsystem.
423. The equipment complex, assigned for multifunctional ice–navigating ship, which is pre–developed up to the ship creation in accordance with the Ship–building Industry Development Strategy and with the Federal programs, as the general system for the ship designing (the set of data, or design constraints).
424. Examples of the innovative functional equipment, specifically developed in accordance with the assignment of multifunctional ice–navigating ship: new types of power installations, reactor of the ship with the nuclear power generation; energy generation installations of floating power plants, the facilities for sea water industrial desalination, marine industrial facilities for liquefaction of natural gas, special systems assigned to overcome ice, propulsive devices for frozen seas, etc.
425. Marine engineering facilities subject to creation up to the ship design and specifically developing in accordance with the ship functional purpose does not enter in set of the ship design subject.
426. Samples of marine engineering parts selectable in the process of the ship designing and not included in the set of it design constraints: the internal combusting engines, the diesel–generators, the boilers and fuel equipment of boilers, the pumps, the separators, the compressors, the deck gears of general assignment, as well, as the structural elements of ship machinery systems, etc.
427. Technological opportunities, which are created previously the ship construction in the set of data for finding of multifunctional ice–navigating ship optimal design characteristics.
428. Function of multifunctional ice–navigating ship suitability those or other assigned shipyards with their self–inherent technological constraints, or with the definite constraints of design characteristics of the ship.
429. Opportunities of methodological redefining of multifunctional ice–navigating ship structural features as it functional specifications.

430. The examples of redefining of the ship structural features as it functional specifications: «the membrane gas carrier» as the specification of the ship structural feature and the functional assignment of the way of the liquefied natural gas transportation, or the ice–navigating ship notion corresponds with the structural features of the ship and with it functional assignment, etc.
431. Hierarchic subordination of the shipbuilding industry to the navigation one, as the demand for new constructed ships motivates the creation of the shipbuilding enterprises or improving of acting ones.
432. The double–sided nature of industrial interdependences between shipbuilding and shipping: the priority of economic demand in navigating predetermined fleet composition and replenishment is obvious for creation of the shipyards and the specification of the innovative methods of shipbuilding in the composition of design constraints for the ship designing.
433. Systemic hierarchic priority of one industry over the other one in the couple of navigating and shipbuilding in dependence of which one is under improving using he resources of the other.
434. Redistribution of economic resources for navigation and shipbuilding industries development and the development oscillating nature or growing one, if besides these industries self–sufficiency the funding aside is provided, like federal subsidies.
435. Methodological significance of the ship under design, which is the common object in shipbuilding industry and in navigation, and the set of design characteristics of the ship and of it functional assignment as the data, which linked the industries of shipbuilding and navigation.
436. Defining of concepts of national programs of shipbuilding development due to the selection of the directions: of creation of shipbuilding enterprise or construction of the ship, resulting the ship designing issue formulating with defining of the ship assignment and it design constraints.
437. Selection of the priority object as the general system of the couple: the innovative ship or the planned for creation the shipbuilding yard, resulting in the definition of the second one as object under design optimization.
438. Extra examples of general complex system for determining of design constraints of multifunctional ice–navigating ship, corresponded with the innovative facilities and the technique in the shipbuilding, including the specified in national strategies of the shipbuilding development: the created innovative methods mastered in the shipbuilding, the innovative engineering equipment developed for the shipbuilding, etc.

439. The subsidies determining in the creation of multifunctional ice–navigating ship (designing, construction and equipping), impacting on the ship optimal size and on dependent characteristics, considering that the total amount of subsidies is usually constrained (the total provided for definite strategy, which is composition of nationally demanded independent assignments of new ships) and that the ship creation purposes (the assignments of the general system) can be independent within the strategy.
440. The main system (the general), corresponded with independent purposes, for which the shipbuilding industry development and the fleet renewal are funded by the subsidies, definition by attributes of functional and structural features of the ships under construction, of innovative technological equipment in shipbuilding and of innovative marine engineering relevant the ships under construction.
441. Classification of attributes, assigned to use in the terms of references, of purposes of the ships under creation: functional attributes, structural, technical attributes and the economic (the new ships and facilities possession), set of marine engineering equipment and the construction methods.
442. The functional nature examples of investing in the replenishment of fleet cargoes carriers, considering sea cargo traffics of the definite intensity and extent as the general system, to which the ship under designing belongs as subsystem, or in the replenishment in fleet for ocean resources development and in creation of the series of similar ships to develop the resources, or in creation of different ships, mutually functionally complementary in the complex.
443. The economic nature (the property possession) of marine company (the navigation, the shipbuilding) complex of assets creation, as the general system, to which the ship under designing belongs as subsystem (the asset).
444. Examples of developed ocean resources as any kind of the economic activities in frozen seas, including not only the aquatic biological or the mineral resources, but the ocean cargoes traffic, the economic potential of coasts and the opportunity of it servicing, etc.
445. Created innovative technological methods and the facilities in shipbuilding, indicated in the terms of references for the ship under creation compliance with these methods and facilities, as the example of general system, to which the ship under designing methodologically belongs as subsystem.
446. Functional and structural nature of the purpose of elaboration of the innovative marine engineering equipment relevant the ship, for which these the marine engineering equipment is constructed or predesigned as the main system

- (the general), to which the ship under designing methodologically belongs as subsystem.
447. The functional nature of purpose, as the characteristic of general system, to which the ship under creation belongs as subsystem, implementing national strategy of shipbuilding development, if the strategy specifies the set of the ships, required for the federal demand, or the structural nature of general system characteristic, if the strategy specifies the creation of shipbuilding enterprises.
 448. Example of functional nature of the general system of the ship under creation, to which the ship belongs as subsystem, if the general system (the main) is definite complex of the engineering equipment, developed specifically up to the ship construction as it innovative part.
 449. Comparable alternatives of economic payback attribute (the property attribute) of subsidies provided in the construction of multifunctional ice–navigating ship or the shipbuilding facilities: economic payback and subsidies refund in the budget and payout of interest for the subsidies use, or the sales of created ship and the facilities to a corporate investor and the refund in the budget of subsidies and the capital costs.
 450. Use of joint–stock, leasing or credit financial instruments to do the subsidies refund when the possession of created ship and the facilities are transited to corporate investors from the federal property.
 451. Opportunity to indicate the technological attribute of the ship purpose of subsidies provided in construction, that is suitability of the ship construction at assigned shipbuilding enterprise, as the ship structural or functional assignments to be constructed at indicated shipbuilding enterprise, characterizing purpose of subsidies.
 452. Self–valuable creation of the ship main system (the general), included in the composition of data and the constraints in the terms of references, that is it innovative engineering equipment, gears, structures, parts of the ship, which are not batch mastered in shipbuilding up to the considered ship creation, definition as the structural attribute of provided subsidies for the ship creation purpose.
 453. The main system of multifunctional ice–navigating ship as physical form of the general system, to which the ship under construction methodologically belongs as the subsystem, considered as the engineering object or the innovative facilities and techniques of the shipbuilding, not only as the concept and not the batch engineering equipment of general assignment, which is used on the ships of all types.

454. Relevance of conventional methods, based on prototypes use, for the batch constructed ships designing, not for the innovative ships—prototypes, and to use these methods as the parts of mathematical model of the ship design optimization (for determining of generalized variables and the ship particulars).
455. The ship assignment functional attribute of provided subsidies for the ship creation purpose, on those or the other available methodological grounds, in particular, with the national shipbuilding development strategy and etc., if defined without appeal to other available attributes of the purpose.
456. Systemic equivalence of other attributes of the purpose of provided subsidies for multifunctional ice—navigating ship creation, corresponded with the optional abilities to interchange some of the attributes of purpose, used for defining of subsidized funds, that is the assigned constraint in the terms of references for the ship creation, if the general amount of the subsidies for all purposes (the ships under construction with the national shipbuilding development strategy) is constrained.
457. Defining the main system (the general) of the ship under designing, to which the ship systemically belongs as the subsystem and which is used for determining of the ship design constraints (the initial data), by the choice of priority important attributes of the purpose of provided subsidies for innovative ship creation, associated with the set of the other purposes, ordered in definite case by their relation to selected priority important attributes or the selected main system.
458. Compatibility of practically independent and interchangeable attributes of functional, structural, technological and economic purposes of subsidies funding in multifunctional ice—navigating ship creation.
459. Influence of priority in the couple of shipbuilding and navigating industries on the functional or technological purposes of subsidies hierarchy, if navigating would be the priority industry, then the characteristics of the ships, assigned for construction, are used in the data for creation of the shipyards, or if shipbuilding could be of hierarchic priority, then the ship suitability for construction on specified shipyard with it inherent technological features and constraints will be in the function of the ship.
460. Indication in the national shipbuilding development strategies and in the federal programs of assignments of the ships intended for construction, although the characteristics of the ships, their design particulars and the construction technique and facilities are independent industrial issues and correspond with the subject of the decision in shipbuilding and navigation industries.

461. Distribution of investments in the ship construction considering investments risks and balance of independent purposes, methodologically characterizing the general complex system.
462. Balance assumption (the prerequisite) of constrained investments total and the total subsidies into the object, in particular, in the creation of multifunctional ice–navigating ship, or the other object of the set of innovative marine engineering equipment or in the creation of the shipbuilding facilities
463. Equation of the investments balance of the subsidies in multifunctional ice–navigating ship creation (it designing, construction and equipping) using the specific index of investments.
464. Relevance of equation of the investments balance of the subsidies in multifunctional ice–navigating ship creation in the functional dependence on characteristics of size of the ship under creation, in particular, on the ship design deadweight.
465. Examples of multifunctional ice–navigating ship size and power characteristics to use in equation of the investments balance: cargo waterline displacement, cargoes capacity, tonnage, as well, as this or the other characteristic of the ship power generation capacities: effective power, required power in ice, total capacity of the ship power installation and etc.
466. Specific indexes of investments in creation of multifunctional ice–navigating ship distribution in the inverse proportion to the investment risks independent in each of intrinsically valuable purposes: the economic payback (the self–sufficiency), technological, structural and the functional of innovative ship creation.
467. Investment constant, as the characteristic of provided specific investment per unit of the ship size, corresponded with the design deadweight or with other characteristic of the ship size (or power, etc.), determined considering the constrained investments total, provided for national shipbuilding development strategy, distributed considering risks of investments in the ship creation for intrinsically valuable purposes: the economic payback (the self–sufficiency), technological, structural and functional.
468. Increase of possibly maximal values of multifunctional ice–navigating ship optimal size by the growth of provided subsidies associated with ship construction by the value of the investment constant.

Chapter 9. Concepts of serial modular shipbuilding yard evaluation in the system of industries links

While creating a new shipbuilding enterprise or improving existing one, as well, as establishing a system of their partnership, the support of the federal administration is necessary from the economic side, as well, as the output of shipbuilding production, provided that demand exceeds the supply that arises when constructing the ships of innovative projects. At the initial stage, the construction of ships for the needs of the government is carried out at new enterprises, while the profit is spent for creation of the industrial facilities of shipbuilding yards or plants, and then there is a return of federal subsidies in one form or another and in this case the conversion of the shipyard from the federal orders to the construction of ships meeting the market demand. The development of serial modular shipbuilding is carried out gradually and includes the creation of the industrial facilities, which is done at the initial stage. The size of ships under construction is general technological constraint in the mass shipbuilding. Opportunities for cooperating of existing shipbuilding plants would open up by the modular assembling shipyard will be available, which unites the plants. When the issues of pilot orders development and fulfillment of duties to investors, the creation of professional teams, the organization of a personnel training system and etc. are to be carried out the shipyard acts with the economic self-sufficiency at the next stage.

The navigating companies or other participants working in the interests of these companies are usually the customers for the serial construction of merchant ships. Certain funds or financial institutions, federal departments can act in the interests of the navigating companies funding the shipbuilding enterprises. The various forms of participation of indicated participants are possible: both the investment in fixed assets and partnership with founders, equity holders or shareholders, and the contracts for the ships construction, the production of structural parts and modules of serial ships, or the output of ship equipment. A certain variety of forms of participation in the development of shipbuilding enterprises does not essentially change the fact that in a systemic respect the merchant navigating (shipping) company acts as a partner in the development of the shipbuilding yard or plant directly or with other organizations, and this partnership on the part of navigating companies serves factor of shipbuilding growth.

Initial processes of new shipyard work, its departments and production facilities are taking place in the conditions under which they can be influenced by intra-industry competition, which is of international nature.

9.1. Cooperation in the innovative shipbuilding based on creation of specialized ship assembling yards for modular construction

Construction of conceptually new ships, including the multifunctional ice-navigating ones on reconstructed and renewed existing shipbuilding plants, repurposed for production of modules and sections for their modular assembling and united technologically by the way of ship assembling yards creation. The construction of these ships by this way can be the driving motive for the indicated re-profiling of enterprises for release of the ship structural modules, for creating of the shipyards and for combining the indicated enterprises in the shipbuilding complexes (the holdings). In the considered variant the creation of new shipbuilding companies and the improving of the existing ones could serve the additional purpose of budget subsidies in the construction of the innovative ships on such a basis.

Availability of storage spaces for modules of hull structures ready for assembly is provided in the complexes of specialized ship assembling yards besides of the assembling sites, the dry docks, the slipways, as well, as large wheeled vehicles or the floating ones for delivery of modules by land or by water and large-capacity lifting equipment for loading and unloading of ships hulls modules. For the delivery of hull modules on the assembling shipyards in the order of technological association with the plants constructing the modules, the ships can be used assigned to transport of oversized cargoes or the floating docks – self-propelled or tugged. Of course, the ships or the floating docks for transportation of the ships structural modules are required, if the assembling yard is located remotely with the other participated enterprises on which the structural modules are produced, which is characteristic for the Russian Federation and for some other states (the USA and Canada, or the Japan–China–Republic of Korea –etc., or technologically associated shipyards of European states), in which the existing shipyards were created and are acted in the associations or independently, being the subject for association on the technological basis in the transition from the usual technique of ships construction to batch modular one.

Considered shipbuilding enterprises, as the assembling shipyards, so the plants, on which the production of structural modules is carried out, administratively could be the independent legal entities acting jointly under general contracts.

Joint work of the specialized shipyards for the modular assembling of ships and the work of the reconstructed plants for production of the structural modules can be based not only on the basis of industrial cooperation but of the international one. For example, for the assembling shipyard emerging on the Pacific coast of the Russian Federation the modules for ships mass assembling could be produced in the Russian Federation, and as well at the shipyards in China, Republic of Korea, Japan, Taiwan, Indonesia, Vietnam, Singapore and others.

International cooperation of the shipbuilding plants by production of structural modules and the specialized assembling shipyards could be considered as the combining of second and third of general directions of practical fulfillment of national shipbuilding strategies and programs, considered below (item 10.2), particularly, in the frameworks of the Shipbuilding Industry Development Strategy fulfillment and covers the mass production of the modules of serial ships in the Russian Federation or in the overseas, which corresponds with the investing by the second direction, and the assembling of the batch constructed ships at the specialized shipyard in the Russian Federation (the third specified direction).

For the shipbuilding enterprises existing at the industrial centers in the European territories of Russian Federation the cooperation is possible with the shipbuilding yards and plants in other European states, on which the structural modules of the ships could be made for assembling at the shipyards in Russian Federation. As the example of the joint work it is possible to consider the cooperation of shipbuilding plants in St. Petersburg and the enterprise Arctech Helsinki Shipyard, Inc.

Cooperation of shipbuilding plants and yards at the European territories of the Russian Federation and at the Russian Far East, as well, as in the overseas is desirable for successful fulfillment of the Shipbuilding Industry Development Strategy and the Federal programs, since this partnership in shipbuilding and in the navigation accessing the technologies and the components markets, as well, as the geographic location advantages and etc. one can consider as an additional factor of international partnership potential in this industrial sector, which improves the shipbuilding development.

By the Decree # 394 of March 21, 2007 President of the Russian Federation established JSC «United Shipbuilding Corporation» (JSC USC), this corporation establishment was completed on April 2009. Tasks were set ahead the JSC USC: the inventory and the reconstruction of existing shipyards, the development of the effective shipbuilding, ships maintenance and the repairing.

During the period from 2007 to 2008 in complex of the JSC USC the four shipbuilding and repairing centers were established with 100 % of the federal property: JSC «Western Center of Shipbuilding», JSC «Northern Shipbuilding and Ship Repair Center», JSC «Far Eastern Shipbuilding and Ship Repair Center» (JSC FESRC) and JSC «South Center for Shipbuilding and Ship Repair».

Need to pay attention on definite similarity of the shipbuilding location using the national geographic advantages in the Russian Federation and in Canada, in which two shipbuilding development centers are practically developed for the National Shipbuilding Strategy on the bases of Seaspan ULC in British Columbia and Irving Shipbuilding Inc in Nova Scotia.

On the Pacific coast of the Russian Federation the four independent shipbuilding zones were established on September 2009 by the Board of Directors of JSC USC in the complex of JSC «Far Eastern Shipbuilding and Ship Repair Center», located at Pacific coast: the zone of shipbuilding «Vostok» (East) and zone of shipbuilding «Zvezda» (Star) in the Primorye Region (Fig. 9.1 a–c, www.sskzvezda.ru), LLC «Zvezda» Shipbuilding Complex (LLC «Zvezda» SC), assigned originally for construction of large ships for transportation of liquefied natural gas; the zone of shipbuilding «Amur» in the Khabarovsk Region on the basis JSC «Amur Shipbuilding Plant» was done for construction of ships and the submarines; the zone of small tonnage shipbuilding on the basis of the shipyards in Khabarovsk (on the Amur river).

In the complex of JSC FESRC includes assets of shipyards and other companies of the shipbuilding industry: JSC «179 Ship Repair Plant» (Khabarovsk), JSC «North–Eastern Repair Center» (Vilyuchinsk), JSC «Far East plant «Zvezda», JSC «92 Ship Repair Plant» (Vladivostok), JSC «Dalzavod Ship Repair Center», JSC «30 Ship Repair Plant», LLC Far Eastern Project Institute «Vostokproektverf», LLC «Service-Vostok». The shipyards are available on the Pacific coast of the Russian Federation, which are not included in the complex of JSC FESRC. In total, 25 companies in the Far Eastern Federal District of the Russian Federation are working in shipbuilding and the repair, which make up about 6% of Russian shipbuilding production, have more than 700 hectares of the land and about 3 million of sq. m total of industrial facilities.

PJSC «Rosneft Oil Company», concluded an exclusive agreement with JSC «Far Eastern Shipbuilding and Ship Repair Center» (JSC FESRC) on the placement of all orders for the construction of new marine equipment and ships at JSC FESRC's facilities, as well, as contracts for the designing, construction and supply of multifunctional supply ships of ice class, tankers of the type

«Aframax» (big sized, the Green Ships), arctic shuttle tankers of ice class Arc7, Arctic shuttle tanker of deadweight 69,000 ton and a drilling ship, providing pilot occupation of facilities of LLC «Zvezda» SC. This shipyard has the extra orders from Federal State Unitary Enterprise (FSUE) «Rosmorport», PJSC «Sovcomflot» (lit. «Modern Commercial Fleet») and PJSC «Gazprom».

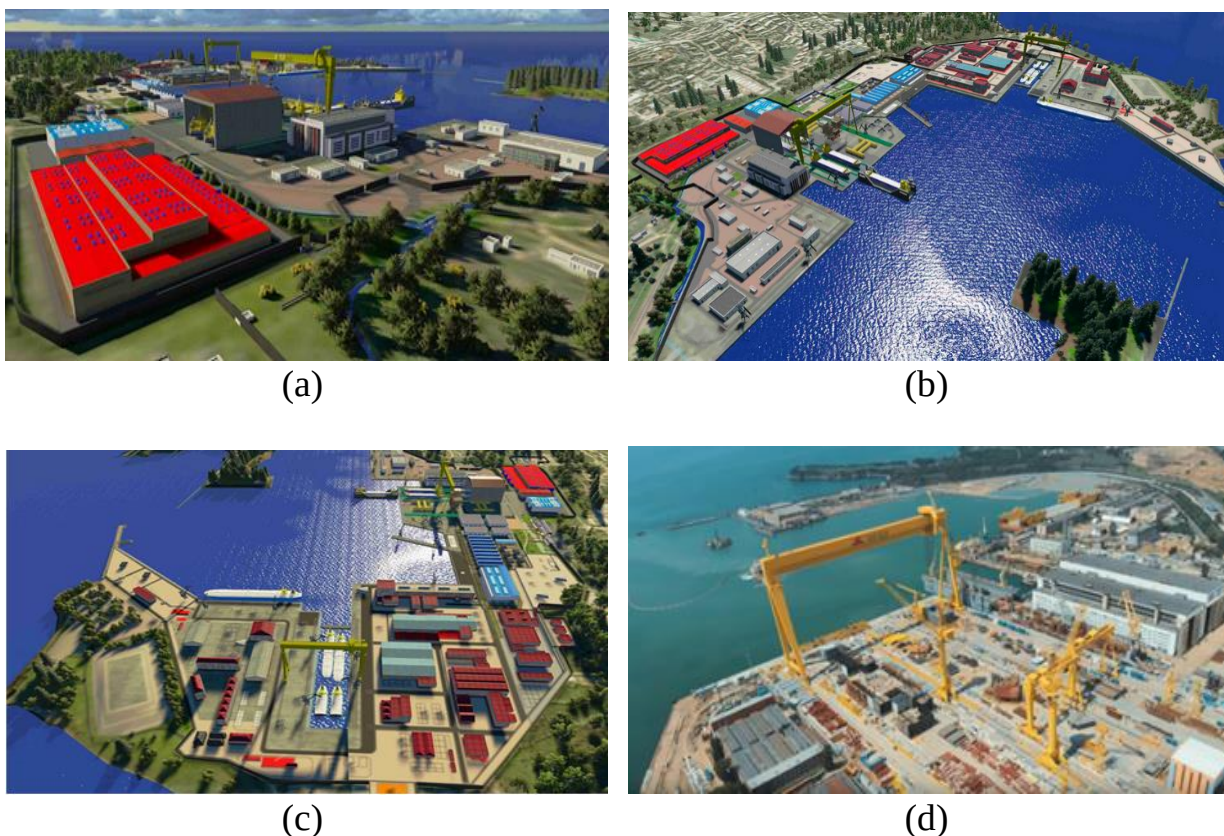


Fig. 9.1. Layout of the shipyards of LLC «Zvezda» SC of large-tonnage ships mass construction and ones for navigation in freezing seas (www.sskzvezda.ru)

Over 30 ships to build, and project of the construction program until 2035 is about 180 units of ships and marine equipment are in order book of LLC «Zvezda» SC.

The orders in progress and the projected ones of LLC «Zvezda» SC include:

- multifunctional supply ships of ice class (4 units);
- arctic tankers with deadweight of 42 000 ton (10 units);
- arctic tanker with deadweight 69 000 ton (1 unit);
- shallow draft icebreaker (1 unit);
- the «Aframax» class tankers (10 units);
- icebreakers of project 10510 LK-120 (2 units).

For organizing of mass modular shipbuilding in the Russian Federation the availability of specialized assembling shipyards or the creation ones are required, which could help to promote the market demand to existing shipbuilding yards and plants, which ones need to convert output to the production of the ships hulls modules for purposes of technological participation in modular shipbuilding in co-operation with specialized assembling shipyards, which then can act together for the common orders fulfillment of the ships modular construction.

The creation at the Far East of the Russian Federation of the shipbuilding enterprise of LLC «Zvezda» SC for construction of the ice–navigating ships, including the ships of large size, was done when consulting by the company IMG Ingenieurtechnik und Maschinenbau GmbH (Germany). The planning period of the Shipbuilding Complex development – from 2012 to 2024. During that time 7.5 thousand of jobs will be opened. The development of this shipbuilding enterprise includes the creation of the industrial facilities: the shops of ship modules production, the construction of the shops structures and spray booths for the produced modules, the building of open slipway and the floating dock for the construction of medium–sized vessels, the dry dock and the industrial shops for construction of the large ships. The creation of the enterprise for the floating platforms and the offshore stationary rigs construction in the zone of shipbuilding «Vostok» is projected.

9.2. Technological and investments constraints

When projecting investments in creation of shipyard for modular serial construction of the ships, it is necessary to take into account existing technological and investment assumptions (the prerequisites) [34 and 143], among which the follows are:

1. Constraint of size of the ship under construction corresponded with possibilities of the ship assembly and launching.

The concern of ecology and the protection of ocean environment in many cases is associated with an increase of size of the ships under construction, while per unit of the ship size, the best indicators can be defined not only economically, but also ecologically, which serves as one of prerequisites for so called Green Ships construction.

Creation of the slipway for assembly of large–tonnage ships or the dry dock requires large initial investments, which not every shipbuilding enterprise can afford, especially at the initial stages of operation, when the total need for investment in all created facilities is high.

Since the market demand for shipbuilding production in the great degree covers the indicated segment of large-tonnage ships, the other shipbuilding enterprises, which do not have the appropriate capabilities for these ships assembling and launching are separated from the demand, and this affects these enterprises prospects.

In this case, the way out for small shipbuilding plants could be the partnership with large assembling shipyard and fulfillment of certain re-profiling of the output for the construction of modules of assembled large-tonnage ships, matching with those ships construction standards, which are typical for the assembly yard, as well, as finding of the organizational principles of the partnership with this shipyard.

2. Limitation, which is associated with serial production due to the fact that intra-industry competition in shipbuilding is typical for the construction of series of the ships in accordance with the market demand.

When creating a shipyard and at the initial stage of its operation, the support and additional resources for development can be available, for example, the national demand for the ships creation of single or small series for needs of government, which thereby assist the development of the shipyard, or for public corporations' demand, in particular, the ships for the frozen seas washing the coast of the Russian Federation.

On the other hand, the use as the resource for development of the shipyard of the available demand for construction of single ships or small series by orders of administrations or corporations will in the future be associated with the re-profiling of the shipyard after the creation of its production capacities and the accumulation of sufficient industrial assets (the facilities), that is, the industrial re-orientation to production of the ships series, demanded by the market, as the industry competitiveness of the shipyard improves, and subject to matching the demand of these administrations and corporations of the ships construction for their needs, i.e. when fulfilling the duties of the shipyard to the partners (the investors).

The operation of shipyard could consider consisting two general stages in the construction of the ships, the first of which is associated with the creation and accumulation of the shipyard technological facilities with support of the investors (the partners in the process of shipyard creation). Investors can participate in the creation of shipyard in one form or another. For example, they can participate in the form of orders of the ships construction for own needs of the investors, and in the next of the shipyard conversion to modular serial shipbuilding, aimed to meet market demand for the ships, including large-scale ones, at which the greatest efficiency of this technology is achieved, by that the technological processes are based on widespread use of automated tools and on modern technologies of structural modules construction of these ships.

The study of the principles of serial modular shipbuilding organizing at the shipyard is based on comparative evaluation of options. At the final stage of shipyard creation, it is necessary to adhere to the methodological prerequisite of refund of the subsidies invested by partners. The refund of the subsidies, interests and capital cost for the use of investors' funds is among the systemic assumptions for evaluating of the effectiveness, according to economic criteria of options compare and selection when creating the shipyard: establishing, constructing, equipping and operating.

Assumption of shipyard sale after its creation to another owner as well serves the systemic prerequisite for the definite technique of economic indexes finding, does not mean an absolute fact, but is an object of economic expediency for partners who have originally invested in the creation of the shipyard.

9.3. Technological facilities of the shipyard workshops

Creation of the LLC «Zvezda» SC facilities can be considered as the characteristic example (www.sskzvezda.ru). Construction of LLC «Zvezda» SC began in 2009. The LLC «Zvezda» SC was established on December 17, 2015. The founders of the shipyard were: Russian Holding Company (RHC) «Rosneftegaz», PJSC «Rosneft Oil Company» and JSC «Gazprombank» (JSC GPB).

Main industrial facilities LLC «Zvezda» SC are created in two stages.

At first stage the facilities were created:

- the slip assembly (Fig. 9.2);
- the workshops block of structures and modules of ships production (Fig. 9.3);
- the spray booths (Fig. 9.4b).



(a)



(b)

Fig. 9.2. Shipyard facilities: (a) heavy outfitting berth for modular assembly of the ships and the «Goliath» crane with lifting capacity of 1200 ton for installation of the assembled ships modulus on the assembly slip; (b) transport–transfer floating dock with loading capacity of 40 000 ton for launching of the ships and their floating parts



(a)



(b)



(c)



(d)

Fig. 9.3. Spaces in the buildings of workshops of the production of the ships modules and the structures



(a)



(b)

Fig. 9.4. Multi-wheeled cargo platform (a) for delivery of hull modules to assembling slipway; the spray booths for the ship structures and hull modules (b)

Following production units are in the process of construction and retrofiting:

- dry dock (is in the construction, $485 \times 114 \times 14$ m);
- full-cycle production workshops the hull-processing for production of the structures and structural modules of the large-tonnage ships);
- workshops for the construction of the offshore structures.

Phased commissioning of the entire production complex of the shipyard will be completed by the end of 2024 of 7.5 thousand new jobs should be opened.

Maximal volume of annual output of LLC «Zvezda» SC in the future will be 330 thousand tons. This volume of shipbuilding production is consistent with the planned production capacity at the assembling shipyard (that is on the existing slipway and in the dry dock, which is under construction). LLC «Zvezda» SC will be the largest shipbuilding enterprise in the Russian Federation after commissioning of all facilities in terms of the total tonnage of constructed ships.

9.4. Equipment and processes used in the construction workshops

In the workshops of LLC «Zvezda» SC the high-precision and efficient automated equipment operates (Fig. 9.5), which allows performing technological operations with profiled and sheet metal and producing large-sized sections and modules of the ships, which are transferred to the slipway for assembly using heavy-duty cranes.



Fig. 9.5. Installation for automated plasma cutting of steel sheets up to 300 mm thick for construction of ships' hulls parts

The ship hull modules in workshops are made of panels and sections.

In construction of the elements the automated welding portal is used.

Production of curved sheets is carried out using an automated press with a force of up to 1,000 ton (Fig. 9.6b) by the 3D templates of curvilinear structures of ships.

Large T-profile structures for the ships' hulls are produced from flat-rolled sheets in the hull production shop, using an automated installation for non-contact induction welding (Fig. 9.7). The technology used makes it possible to minimize residual stresses and thermal deformations and achieve the best mechanical properties of produced T-structures, which is of fundamental importance in the construction of large tonnage ships, as well, as ones of ice classes.



(a)



(b)

Fig. 9.6. Lots for construction of panels and sections of the ships' hulls



(a)



(b)

Fig. 9.7. The plant for non-contact welding at the LLC «Zvezda» SC of T-profile structures by the induction heating

Prior to being sent to the assembly berth, the pipelines of ships' systems and equipment elements are installed in modular sections of the double bottom and sides (Fig. 9.8) and inside other ships' hulls compartments during their producing, which makes it possible to reduce the labor intensity of installation work at assembling sites, as well, as to improve the quality of specified structural elements and to reduce the costs, associated with their transportation and storage at the shipyard.



(a)



(b)

Fig. 9.8. Installation of equipment and pipelines in double bottom spaces and in hull compartments of multifunctional ice-navigating ship of the project IBSV 10022 AH

9.5. Construction of series of multifunctional supply vessels of ice class of project IBSV 10022 AH at the LLC «Zvezda» SC

At LLC «Zvezda» SC the multifunctional ice–navigating vessels of project of IBSV 10022 AH (Fig. 9.9) are under construction. It is projected to build four ships of this project. Ships of the IBSV 10022 AH project are assigned for following purposes:

- transportation of goods to/from offshore drilling rigs and production platforms;
- anchors routing;
- icebreaking operations;
- ice control;
- rescue in ice of crews of ships in distress;
- escorting of ships in ice, which do not have a sufficient ice category;
- elimination of oil spills;
- fighting external fires;
- towing jack-up platforms and other large floating objects;
- transportation of standard ISO containers on the main deck.



(a)



(b)

Fig. 9.9. Multifunctional ice–navigating supply ship of IBSV 10022 AH project under construction at the LLC «Zvezda» SC: (a) the ship model; (b) construction of bulk module

Hulls framing and assembling of sectional volumetric modules for multifunctional ice–navigating ship of IBSV 10022 AH project are constructed in the hull production shops at the LLC «Zvezda» SC (Fig. 9.10).

In the production of parts, automated installations for cutting steel sheets, bending and welding and other technical equipment are used.

Multi-wheeled cargo platforms are used for delivery of completed modular sections of up to 240 ton across the territory of the LLC «Zvezda» SC on the assembly slip the (Fig. 9.4c and 9.11).



(a)



(b)

Fig. 9.10. Construction of volumetric modules (the stern and bow sections) of multifunctional ice-navigating ship of IBSV 10022 AH project



(a)



(b)

Fig. 9.11. Delivery to the assembling slip of the LLC «Zvezda» SC of completed modular section weighing up to 240 ton

Assembly of the ships' hulls modulus on the slipway of the LLC «Zvezda» SC and installation of equipment is carried out using heavy-duty cranes, including the «Goliath» of lifting capacity up to 1200 ton (Fig. 9.12). Also, for the modular assembly of the ship hull, the cranes with a lifting capacity of 300 and 100 ton are used.



(a)



(b)



(c)



(d)

Fig. 9.12. Using the crane «Goliath» for the assembly of large hull modules of multifunctional ice-navigating ship of IBSV 10022 AH project on the slipway (a, b); the docking on the slipway of modular hull sections (c, d)

9.6. Construction at the LLC «Zvezda» SC of large-tonnage oil tanker

On the slipway of the LLC «Zvezda» SC in the process of construction is oil tanker of «Aframax» class of project 114K with a deadweight of 114 thousand ton (Fig. 9.13 and 9.14) designed to transport crude oil and oil products. Taking into account the high standards of environment safety, the ship of project 114K is equipped with combined fuel power plant, both the main engine and auxiliary ones, which operate both on diesel fuel and on natural gas.



(a)



(b)

Fig. 9.13. Oil tanker of 114K project (a) of the deadweight of 114 thousand ton; the use of transport-transfer dock (b) to move the modulus of aft part when assembling the hull of oil tanker

For launching of the ships and their large modular parts, assembled on the slipway of the LLC «Zvezda» SC, the transport-transfer dock with lifting capacity of 40 000 ton is used.

The use of this dock for moving in the water area of the LLC «Zvezda» SC of modular part of oil tanker of project 114K, including the middle part of the ship

with cargo compartments and its stern part with superstructure, engine room and installed tanks for gas fuel, is shown in the photo (Fig. 9.14b).



Fig. 9.14. Modular parts of oil tanker of project 114K on the slipway of shipyard

In the construction of hull modules of oil tanker of 114K project in the hull construction workshops of the LLC «Zvezda» SC the original dimensions of large-sized sheet metal can be up to 20×4 m, the specialized tilter is used for production of the ships' hulls parts of this size without deforming the sheets.

9.7. Assumptions and the used effectiveness criteria of investments in the shipyard and in ships construction evaluation

In addition to the demand for construction of the ships for federal needs and for corporate investors by the contracts concluded to construct single or small series of innovative ships, not mastered by batch construction, to which the demand, although not big, exceeds the supply, an important motivating factor for continuous development of the shipbuilding enterprises at subsequent stages is the market demand for serially built ships of various types, as well, as other shipbuilding products done in series.

Economic criteria for work evaluation of the created shipyard are as follows /25/:

- payback period and/or interrelated indicator of internal rate of return (*IRR*), corresponding the index of profitability, adjusted for the inflation index (the characteristic of rate of the consumer price index growth);

- net present value (*NPV*), as the difference between market capitalization of the shipyard and the total investments in its creation, respectively, both initial indicators have to be determined present on same time, in particular, on the date of the shipyard establishing or on the other one (the day of sale\purchase, the shares emission, etc.).

When doing comparative evaluation of options for planning of the shipyard work, the factors of differences between compared options may be the following specifications:

- characteristics of the facilities and of the shipyard integral property complex;
- list of shipbuilding products and their characteristics, including, in addition to the ships under construction, such products, as constructed equipment of ships: the devices and gears, the engines suitable for use in the sea conditions, the electro-mechanical equipment, the automation, etc.;
- characteristics of financing amount and its schedule (the periodicity), including both the initial investment and the other increase of initial capital, as well, as the use of borrowed funds, of income from core activities and the profit invested in fixed assets (the facilities) of the shipyard;
- the set of stages of the shipyard creation and operation and their specifications.

Methodologically, for the purposes of economic assessment, the creation of shipbuilding enterprise could be considered done if the following results assumed achieved:

- completion of the construction and equipping of hull production shops and the shipyard sites for modular assembly of the ships;
- mastering the construction of innovative ships for the needs of investors, financing pilot issues of the shipyard, including the construction of multifunctional ice-navigating ships;
- implementing of serial ships construction in accordance with market demand;
- redemption of industrial facilities, created for budget subsidies, and refund of these subsidies to budget in amount got, including the interest (the cost of capital use);
- opening of new jobs created at built and reconstructed shipyards, the decision of social issues for shipyard employees;
- creation of system of education and training of shipbuilding programs and in related professional areas, etc.

Organization of a vocational training system for these programs to train a sufficient number of workers of various qualification levels is a critical issue that predetermines the total duration of the creation of the operating shipyard.

At development of shipbuilding enterprises, especially at initial stages, the participation of federal departments providing budget subsidies is usually required, or participation of investors acting on behalf of these departments, for the following reasons:

1. The initial stage includes the implementation of such issues, as establishment of intersectoral and the international cooperation in the field of shipbuilding, the organizing of training system and forming the professional community, etc.,

which can be decided only at the highest level of management with the federal participation.

2. Economic advantages that serve as factors in the development of the shipbuilding enterprise, constructed the ships of innovative types, are characterized, on one hand, by the excess of demand for the innovative ships over the supply, on other one, by the lag of this stimulating factor in relation to the emerging needs for subsidies.

9.8. General task of the shipyard efficiency evaluation

In the standard formulation the economic criteria of internal rate of return and net present value (*IRR* and *NPV*) are found based on determination of following accounting indicators and on market valuation of assets (the facilities) of the shipbuilding enterprise:

- equity and invested capital;
- short-term and long-term liabilities;
- fixed and the current assets;
- working capital and long-term liabilities;
- accounts receivable and payable;
- income and cost of sales.

Besides, to determine criteria, for purposes of planning and comparative evaluation of the development options of the shipbuilding enterprise the external economic characteristics and indicators of the industrial activity are assessed, among which:

- forecasts of inflation (the characteristic of rate of the consumer price index growth), the currency exchange rate, the investments risks and the discount rate (*i*);
- projected costs, revenues and profits consistent with concluded contracts for construction of the ships and characteristics of production capacity of the enterprise.

Creation of operating shipbuilding enterprise systematically encompasses two successive stages, which separate parts can be carried out jointly or simultaneously:

Stage 1. Creation of the shipbuilding enterprise, i.e. it major technological facilities for construction of structural modules and for the ships assembly, in particular, constructed for the needs of government or the other investor, who may act on behalf of the interests of the administrations: the subsidized investments RC_3 generate the shipyard income I_3 .

Stage 2. As the pilot program of orders is being carried out at first stage, the shipbuilding enterprise becomes self-sufficient in fulfilling of serial orders of the ships construction, meeting market demand. Considering the projected

income I_3 of shipbuilding enterprise and operating costs C_3 this corresponds it capitalization $((I_3 - C_3)/i)$.

As a result of implementation of the ships construction, meeting market demand (the second stage), systemically, that is not as the absolute fact, but as the methodological presumption for efficiency evaluation, it is projected to transfer (to sell) the created technological facilities of the shipbuilding enterprise to corporate investors, as they buy out these facilities and refund the investments subsidized in the creation of the shipyard (RC_3) to the budget or to other initial investors. The given sequence serves the model of closed economic cycle. It is assumed that in particular cases the stages could be the other, but the equivalent methodologically to refund of subsidies and the fulfillment of obligations.

Designations used for main indicators, taking into account the characteristic relationships between them, in the system of hierarchical industrial links of the shipbuilding enterprise with other participants (the levels 1 to 4) are indicated in the Table 9.

Table 9

Interdependence of economic indicators of the shipbuilding enterprise with it partners (the investors) and subcontractors

Investments	Costs	Income	Criteria
1. The economic environment			
...	...	...	i
2. The navigating companies and subsidies funders			
$RC_2 = I_3 / IRR_2$	C_2	I_2	NPV_2 and IRR_2
3. The shipbuilding enterprise			
RC_3	$C_3 \sim I_4$	$I_3 = RC_2 \times IRR_2$	NPV_3 and IRR_3
4. The subcontractors of the shipbuilding enterprise			
...	...	$I_4 \sim C_3$	...

Partners for shipbuilding enterprise, acting directly or with the representatives, including with the administrations, financial institutions, etc., or the partners in form of participants (the limited liability holders, the founders or the shares holders) in systemic attitude are navigating companies, and this partnership for shipbuilding enterprise is factor of development. This indicates the tendency of navigating companies to participate in the possession of shipbuilding ones.

Criterion in the form of the net present value NPV_3 , defined in this setting as the difference between the market capitalization of shipbuilding enterprise

and the total of the investments, for assessing of the investment options in shipbuilding enterprise creation, taking into account a certain set of assumptions, has the form

$$NPV_3 = (I_3 - C_3)/i - RC_3, \quad (9.1)$$

where I_3 and C_3 – total annual income of shipbuilding enterprise and the annual operation costs corresponding this total income of counterparties I_4 (payments to counterparties from shipbuilding enterprise under subcontracting contracts) and the shipbuilding enterprise own operating costs, i – the discount rate, that is the macroeconomic index of total risks, RC_3 – the total investments in the creation of shipyard facilities, defined by the present value for the same time, as the present value of operation costs C_3 , one year ahead of the time of the determining of the present value of the total income I_3 .

Considering the ratio of internal rate of return IRR_3 of the shipbuilding yard and the market value of all costs: $RC_3 = (I_3 - C_3)/IRR_3$, the criterion of the net present value NPV_3 of the shipbuilding enterprise can be converted to the form

$$NPV_3 = (I_3/i) \times (1 - C_3/I_3) \times (1 - i/IRR_3), \quad (9.2)$$

or, given that the incoming (or assumed) income of shipbuilding enterprise is consistent with navigating companies investments: $I_3 = RC_2 \times IRR_2$, the criterion of the net present value NPV_3 of the shipbuilding enterprise is determined as

$$NPV_3 = RC_2 \times (IRR_2/i) \times (1 - C_3/(RC_2 \times IRR_2)) \times (1 - i/IRR_3), \quad (9.3)$$

where RC_2 – the planned and the implemented in the navigating companies total investments in fixed assets (the ships under construction) associated with shipbuilding enterprise income; $RC_2 \times (IRR_2/i)$ – the cash flow, corresponding the macroeconomic evaluation of investments in navigating companies, the third factor in formula (9.3) means the return on sales R_{I3} of shipbuilding enterprise, that is the profit (or the net operation income: $I_3 - C_3$) corresponded with total income of shipbuilding enterprise ($I_3 = RC_2 \times IRR_2$):

$$1 - C_3/(RC_2 \times IRR_2) = 1 - C_3/I_3 = (I_3 - C_3)/I_3 = R_{I3}$$

the fourth factor in formula (9.3) shows the ratio of internal economic risks index i_{R3} , that is the own non-systematic risk of shipbuilding enterprise, to its internal rate of return: $i_{R3}/IRR_3 = 1 - i/IRR_3 = i_{R3}/(i + i_{R3})$, at the same time, it is taken into

account that the internal rate of return IRR_3 exceeds the discount rate i by the size of the index of industrial economic risks i_{R3} , denoting the risk premium for investing in the shipbuilding enterprise: $IRR_3 = i + i_{R3}$.

Considering specified explaining for the formula (9.3) the index of net present value NPV_3 for the shipbuilding enterprise is determined as

$$NPV_3 = RC_2 \times (IRR_2/IRR_3) \times (i_{R3}/i) \times R_{I3}, \quad (9.4)$$

and the capitalization of the shipbuilding enterprise is

$$RC_3 + NPV_3 = RC_2 \times (IRR_2/i) \times R_{I3}, \quad (9.5)$$

where R_{I3} – is the index of sales profitability of the shipbuilding enterprise, that is the ratio of this enterprise profit, to be more accurate, its net income ($I_3 - C_3$), to its sales (the annual income I_3).

Under the assumption of an established investment balance in the related industries of shipbuilding and navigating, in which the internal rate of return in shipbuilding has the tendency of the equality to this indicator in navigating: $IRR_2 = IRR_3$, the dependences (9.4 and 9.5) of the net present value and the capitalization of the shipbuilding enterprise on the investments amount RC_2 on occupation programs of the shipbuilding enterprise, in particular, on the pilot ships building programs for founders and partners and on financial indexes used in these formulas, look like

$$\begin{aligned} NPV_3 &= RC_2 \times (i_{R3}/i) \times R_{I3}, \\ \text{or } NPV_3 &= RC_2 \times (IRR_3/i - 1) \times R_{I3} \\ \text{and } RC_3 + NPV_3 &= RC_2 \times ((i + i_{R2})/i) \times R_{I3}, \\ \text{or } RC_3 + NPV_3 &= RC_2 \times (IRR_3/i) \times R_{I3}, \\ \text{at } i_{R2} &= i_{R3}, \text{ when } IRR_2 = IRR_3 \end{aligned} \quad (9.6)$$

As well, to use these dependences and to analyze the results it is assumed, that the profitability of sales R_{I3} is smaller than the internal rate of return ($IRR_2 = IRR_3$) and can be about of $\frac{2}{3}$ on the internal rate of return, which in general approximation corresponds to the characteristic ratio of these indicators in shipbuilding and navigating: $R_{I3} \approx \frac{2}{3} \times IRR_3$.

Macroeconomic index of the discount rate i can practically be determined by taking into account the risk-free part of this rate with the amendment for systematic risk. To do this the investment valuation methods can be used.

The discount rate i , when investing in US dollars could be about 5 % (any way it is usually no more than 10 %). By the indicated assumption the internal rate

of return for a shipbuilding enterprise when finding its capitalization or its net present value, taking into account the indicator of risks i_{R3} in the shipbuilding industry can approximately be assumed as: $IRR_3 = 0.05 + i_{R3}$.

An overview of concluded and projected contracts in the future for practical assessment makes it possible to outline data intervals for determining graphical functional surfaces of the shipbuilding enterprise capitalization indicator and its net present value, similar to those that, considering the definite assumptions, are determined and shown as functional surfaces (Fig. 9.15).

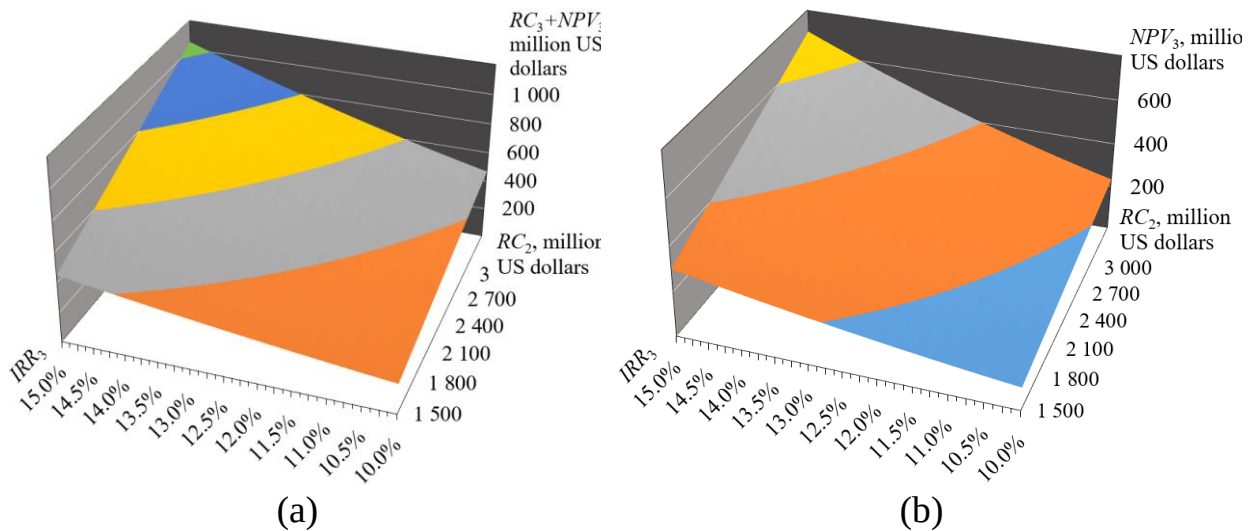


Fig. 9.15. Dependences of the shipbuilding enterprise indexes:
(a) of market capitalization ($RC_3 + NPV_3$) and (b) of its net present value (NPV_3)
on the enterprise orders monetary amount ($RC_2 = I_3 / IRR_2$)
and on its internal rate of return index ($IRR_3 = i + i_{R3}$)

Considering the assumptions used, it is necessary to clarify that the formulas (9.1–9.6), used to determine the performance indicators and to calculate the functional graphic surfaces, as well as the characteristic ratios of the main indexes of the shipbuilding enterprise in the system of industrial links with other participants, which are shown in the Table 9, have the methodological approximations, which most closely correspond to the specified indicators under the assumption that the subcontractors of the shipbuilding enterprise are the tenants of its production facilities and bear the operation costs, i.e. ratios and formulas characterize most accurately the efficiency of the shipbuilding enterprise facilities, which are working and its final financial result are based on use of these facilities.

The results of determining target indicators: the capitalization of shipbuilding enterprise ($RC_3 + NPV_3$) and the net present value (NPV_3), shown in the diagrams (Fig. 9.15), help to analyze the dependence of the achieved and expected results

of the creation of the shipbuilding enterprise for serial modular shipbuilding, taking into account the characteristic industrial links with navigating companies, which create demand for shipbuilding products directly or with partners.

The considered example illustrates the technique of the systemic approach to evaluate economic efficiency of the shipbuilding enterprise, considering it links with partners (the investors or customers) and subcontractors.

9.9. Investment directions in the organization of shipbuilding

Needs arise to use the contracts for construction of the innovative ships and, in particular, the multifunctional ice-navigating ships, to use the subsidies and the profit of these contracts for creation of the modular assembling shipyards to reduce the duration of shipbuilding and the construction costs by the technological cooperation, in which several hull production workshops or the individual shipbuilding plants could work together in cooperation for the common orders.

Additional benefits of modular shipbuilding technology are associated with a reduction in the amount of «frozen» funds in the works in progress and with the possibility of participation of individual shipyards, which manufacture parts in case of construction of large-tonnage ships, in partnership with assembling shipyards capable to launch of big-sized ships. Large-tonnage assembling shipyards can serve the basis for the formation of serial shipbuilding production associations, created, for example, in the form of technologically integrated holdings, which construct the structural modules and deliver them to the assembling shipyards.

In the Pacific Rim (the Pacific coast of Asia continent) the modules supplied to the shipyard for assembly of the serial ships could be produced not only in the Russian Federation, but also at shipyards of states: China, Republic of Korea, Japan, Taiwan, Indonesia, Vietnam, Singapore and others. That is, it is possible both the location of the hull production units in the adjacent territories with the shipbuilding yard, and in the other points, having into account the transport accessibility.

Innovative shipbuilding, in particular, the construction of multifunctional ice-navigating ship is usually aimed at creating ones that have not been sufficiently mastered by mass production, therefore, local demand for them, for example, the national demand exceeds supply, which impacts the investment attractiveness.

Construction of ships in accordance with the pilot program of orders coming in, for example, by the investors creating the shipyard, can serve the original purpose beyond competing with existing shipyards, which are characterized by advanced mass shipbuilding. As shipyard experience is gained, the technological facilities

are renewed and replenished, and pilot orders for the investors and founders are completed, it is likely that the approach and order line will change in accordance with market demand, as well, as the assembling shipyard engaged in serial shipbuilding for this purpose will cooperate with the shipbuilding plants.

Shipbuilding and navigating companies are in the system of industrial links, while the demand for new merchant ships is of international nature and formed in the maritime navigating, which serves the source of investment for the shipbuilding, both directly, when the ship is built by order of navigating company, and indirectly, if investments come from partners, which can be departments or organizations of various profiles, including the financial institutions, the funds and leasing companies ultimately acting in the economic interests of the shipping industry, and pre-subsidizing the construction of ships.

Investments in the fixed assets of the shipbuilding complex and the mass modular assembling shipyard (in the industrial facilities and the real estate: the shops, slip-ways, dry-docks, berth and piers, the technological equipment, the warehouses, the appliances and other, machines, devices, etc.) are made corresponding the applied technology of ships construction when performing it engineering development, the technological processes implementing and methods of works management at the stages of the ships construction, assembly, testing, as well, as the repair and maintenance, the inventories and products storage, i.e. the investments in the fixed assets (the facilities) are done for the fulfillment of follows works specific for construction of the ships:

- engineering preparation of the ship construction;
- works on general construction technology planned at the stage of the ship design, including use of the digital technologies;
- modeling of the ship shape surfaces and the formation of mathematical models of the ship geometry using digital CAD / ASTPP systems;
- other works related to digital technologies in the shipbuilding production;
- completing the technological processes with tooling and equipment, including the automated one;
- manufacturing of parts of the ships hulls and systems, assemblies and parts of the hulls on the construction lines and at the specialized areas;
- construction of ship structures by welding methods, using welding equipment operating on the basis of various thermophysical principles, which ensure the proper physical and mechanical properties of the structures joints;

- technological operations to reduce or improve welding deformations of the ship structures, to prevent or eliminate them using specialized equipment and rigging, as well, as to check the water tightness of welded joints;
- forming of hulls of the ships, including on the basis of modular principles, using devices, equipment and accessories that ensure the quality and accuracy of the hulls assembly;
- installation of machines, mechanisms and pipelines on the ships under construction, the assembly of equipment units and their installation, including the main power plants, shaft lines, the centered and non-centered mechanisms;
- manufacturing and assembling of the ship systems, pipeline tracing;
- finishing of the ships premises;
- testing the ships, their modules, sections and the individual structures, machinery, mechanisms and systems and devices;
- investments in the facilities for the performance of other works, corresponding the applied technology of shipbuilding.

Checklist

469. Funding for creating a new shipbuilding enterprise or improving existing one by support of the federal administration and by the excess of demand over supply for the ships of innovative projects.
470. Gradual developing of the shipbuilding enterprise constructing initially the ship for the government needs and in the next transforming the production for the construction of merchant ships meeting market demand, and the refund of obtained subsidies with the interest for the capital use for the enterprise privatization.
471. Technological constraint of size of the ship under construction to access the market demand for ships of specified and big size is decided by shipbuilding plants cooperation with the assembling shipyard.
472. Customers for shipbuilding enterprises and entities acting on behalf of these customers are merchant navigating companies, the financial institutions and federal or industrial administrations acting in the interests of the navigating companies funding the shipbuilding enterprises.
473. International nature of economic intra-industry competition in merchant batch shipbuilding and the international nature of the partnership of assembling shipyards and shipbuilding plants constructing the structural modules for the shipyards.

474. Industrial holdings (the joint stocks holding companies) as the relevant way of partnership of the existed shipbuilding plants, subject to renew and re-profiled for output of the structural modules and parts of the batch constructed ships, and the ship – assembling yard (which usually is to be suitable to assemble large tonnage ships).
475. Staff of the assembling shipyards facilities includes the assembling sites, the dry docks, the slipways, as well, as large wheeled vehicles or the floating ones for delivery of modules by land or by water and large-capacity lifting equipment for loading and unloading of ships hulls modules, as well, as the storage spaces for modules of hull structures ready for assembly.
476. National geographic locations of definite states, providing the advantages of partnership in shipbuilding and access to markets of the ships, their components and construction technologies, in particular, location of the Russian Federation, uniting East and West regions, as well, as the geographic location of North American states, washing by Pacific and Atlantic oceans, which give the industrial partnership opportunities in shipbuilding and navigating with Europe and the Pacific Rim states.
477. Partnership with large assembling shipyard as the way out for small shipbuilding plants to access the demand for construction of large-sized ships, including the Green Ships, assuming that these small shipbuilding plants have to do the re-profiling of the output for the construction of modules of assembled large-tonnage ships, matching the standards, which are typical for the assembly yard.
478. Assistance and support for new shipyard development at its creation stage and the initial stage of operation provided by the administrations as contracts for the ships construction for the needs of national government and by the private corporations for single or in small series innovative ships construction, for the demand is not provided by the supply and profit interest is guaranteed, other than the scale of the demand.
479. Systemic assumption (the prerequisite) when finding the economic indexes of refund of the subsidies, interests and capital cost for the use of investors' funds (budget or private) spent for construction of the ships or the shipbuilding enterprises.
480. Assumption for definite technique use of economic indexes finding of shipyard sale after its creation to another owner, which does not mean an absolute fact, but is in the concept of economic expediency for partners, who have originally invested in creation of the shipyard, and the assumption is part of efficiency evaluation technique.

481. Market demand for serially built ships of various types, as well, as for other shipbuilding products done in series, required at subsequent stages of the shipbuilding enterprises in addition to the demand for construction of the ships for federal needs and for corporate investors by the contracts concluded to construct single or small series of innovative ships, not mastered by batch construction.
482. Interrelated economic efficiency criteria of payback period and the internal rate of return use for evaluation of the shipyard creation and operation.
483. The net present value economic efficiency criterion of the shipyard, as the difference between its capitalization and the total investments in its creation, determined present on same date, in particular, on the day of the shipyard establishing, or the day of sale\purchase, the shares emission, etc.
484. Factors of the difference of compared options of evaluated shipyard by economic efficiency criteria, considering follows specifications: the facilities and integral set of the property complex, the shipbuilding products list (the ships, the machinery and equipment, etc.), the financing schedule, including both the initial investment and the other increase of initial capital, as well, as the use of borrowed funds, the stages of the shipyard creation and operation.
485. Criteria of the fulfillment of the shipbuilding enterprise creation or improving: the construction and equipping done of hull production shops and assembling units, mastering of the innovative ships construction, implementing of serial ships construction, redemption of industrial facilities, created for budget subsidies, and refund of these subsidies to the budget, including the interest (the cost of capital use), opening of new jobs, creation of system of education and training.
486. Need for participation of federal departments providing budget subsidies in the shipbuilding enterprise creation or improving due to the factors of intersectoral and the international cooperation in the field of shipbuilding and due to the financial lag between economic stimulating factor of excess of demand for the innovative ships over the supply and the emerging needs for indicated subsidies.
487. Accounting indicators use and market values of the facilities of the shipbuilding enterprise to find the economic criteria of internal rate of return and net present value of the follows: equity and invested capital, short-term and long-term liabilities, fixed and the current assets, working capital and long-term liabilities, accounts receivable and payable, the income and cost of sales.
488. External economic characteristics and indicators assessed of industrial activity of the shipbuilding enterprise, evaluated to determine criteria, for purposes of planning: the characteristic of rate of the consumer price index growth

(the inflation), the currency exchange rate, the investments risks and the discount rate, projected costs, revenues and profits.

489. Navigating companies in systemic attitude are the factor of development of shipbuilding enterprise, acting directly or with representatives, including with the administrations, financial institutions, etc., or with partners in form of participants (the limited liability holders, the founders or shares holders), indicating the tendency of navigating companies to participate in the possession of shipbuilding enterprises.
490. Determining of macroeconomic index of the discount rate, consisting of risk-free part and the amendment for systematic risk, characteristic for considered industry of shipbuilding or navigation, to use this index in the evaluation of economic efficiency of investments in creation or improving of the shipbuilding enterprise.
491. Approximal values (the ranges of values) of macroeconomic index of the discount rate and the index of internal rate of return, characteristic for shipbuilding industry, and these indexes correlation.
492. Use of contracts and the initial subsidies (the budget or corporate) for construction of the innovative ships to develop modular batch construction of ships, reducing the production costs and «frozen» capital funds in the works in progress, by the shipbuilding plants partnership with assembling large-tonnage shipyard.
493. Sea transport accessibility the only one characteristic of national or the geographic location of assembling shipyard and the shipbuilding plant influencing the opportunity of their partnership in the batch construction of merchant ships of modules.
494. Participation of investors, creating, in particular, the assembling shipyard, in the form of the pilot program of orders for this enterprise to construct the innovative ships out of the competition with mass shipbuilding companies.
495. Order line change of shipbuilding enterprise in accordance with market demand as the experience is gained, the technological facilities are renewed and replenished, and pilot orders for the investors and founders are completed.
496. Parties, such as departments or organizations of various profiles, including financial institutions, the funds and leasing companies, contracting with the shipbuilding enterprises, are working ultimately in economic interests of the navigating companies fleet replenishment.
497. Shipbuilding enterprise facilities subject to investing usually: the general construction facilities, including use of the digital technologies; equipment of shops to process the ship geometry, including one using digital CAD / ASTPP

systems; the automated equipment and tooling for technological processes; equipment of the construction lines for production of the ship modules and parts; the welding equipment, on the basis of various thermophysical principles; the equipment to check welding deformations, their prevent, reduce or improve; the equipment to check the water tightness of welded joints; devices, equipment and accessories that ensure the quality and accuracy of the hulls assembly; the equipment for installation of machines, mechanisms and pipelines on the ships, including the main power plants, shaft lines, the centered and non-centered mechanisms; facilities for manufacturing and assembly of ship systems, pipeline tracing; equipment of the spray booths and one for finishing of ships premises; equipment and instruments for testing the ships, their modules, sections and the individual structures, mechanisms and systems.

Chapter 10. Organization of shipbuilding industry, including for construction of multifunctional ice–navigating ships, and the development of training system for the industry

The shipbuilding in the past and in the present has great impact on the society development in different ways. Modern shipbuilding refers to the number of high-tech industries, is environmentally friendly production and is characterized by significant level of value added in the composition of the constructed ships prices. The innovative shipbuilding aimed at construction of conceptually new ships, which are not mastered in large series construction at existing shipyards, therefore the economic demand with regard for the conceptually new ships and for the other innovative output of shipbuilding industry exceeds the supply.

It is possible to implement construction of the innovative ships, including the multifunctional ice–navigating ones, the only in condition of shipbuilding industry renewal organizationally and technologically, which is the issue of the intrinsic value as well. On the general level the technology of the conceptually new ships construction, which are demanded accordingly with the Shipbuilding Industry Development Strategy and with the Federal programs /148/ of Russian Federation «The shipbuilding development for the period of 2013–2030 years» and with the other decisions, it is possible to characterize systemically by the existing shipbuilding yards and plants and planned for the creation and by the concepts of their operation.

Essential factors of the modern technique development of innovative ships construction, corresponded with these ships purposes, are the follows:

- partnership of federal authorities and other administrations with corporate investors in development of the shipbuilding companies, in creation of the new shipyards and plants, besides of construction of the innovative ships, as they are;
- industrial and international cooperation in renewal of the shipbuilding companies, as well, as in the ships creation at all stages, including the designing of the ship, its construction, equipping, operation and technical maintenance, the ship withdrawal and its utilization for scrap;
- ways of the specific issues decision of joint property, considering the necessary cooperation, of industrial nature and international one, the partnership of federal and corporate investors;

- joint participation of existing shipbuilding companies and the new created ones in the Strategy and the Federal programs of shipbuilding development;
- planning of the budgetary subsidies refund as fulfillment of purposes and the issues assigned by the Strategy and the Federal programs of shipbuilding development, attracting the corporate (extrabudgetary) investments;
- sequences of the Strategy and the Federal programs fulfillment stages, including the ships construction of new classes for needs of the Government, the use of this activity to renew the shipbuilding plants and shipyards, the extension of ships batch construction sector matching the international market demand;
- complex nature of the purpose, covering as fleet renewal in accordance with needs of the Government, so the development of the shipbuilding companies and etc.

Besides the federal demand of the ships construction in accordance with the Shipbuilding Industry Development Strategy the second important motive is matching the market demand with regard the various types of the batch constructed ships, primarily the cargo and the fishery, as well, as the other series of the shipbuilding output, such as the various equipment for the ships and the marine machinery, the gears, the devices, the internal combustion engines for they use onboard, the electromechanical equipment, the mechanisms of automation control, etc.

The economic issues of shipbuilding industry in the Russian Federation development are characterized by the necessity of shipbuilding productivity increase and extension of the constructed ships' types, including as mass constructed ones of the various types, demanded by the market, so the innovative ships, which creation is conducted with the Shipbuilding Industry Development Strategy without the competitiveness of indicated issue to construct innovative ships in shipbuilding industry of the Russian Federation, compared with serial merchant shipbuilding in definite states of the Pacific Rim and in some others places.

Most important feature of economically effective mass shipbuilding is the modern technology of construction, in which the ship is not completely constructed at the building site, and the assembling from the pre-constructed sections and the modules is implemented. Wherein the maximal level of standardization at the stage of modules and the ships' parts construction and assembly is characteristic, which opens the additional opportunities of mechanization and automation techniques. Besides, the considered shipbuilding enterprises can be of integrated holdings organizational form.

It is required the assembling shipyards, capable to assemble the modules and launch the large-tonnage ships, for the service of which the network of partners is formed with the shipbuilding plants implementing the structural modules production

and they delivery to the assembly yard. Capability of modular assembling of the ships at the shipyards in distinction from the supporting shipbuilding plants, producing the ships' structural modules, are the analogy of an assembly lines in other industries.

The additional benefits of modern modular shipbuilding technique include as the reduction the technological construction cycle extent, which is sufficient problem in shipbuilding (finding the way of construction term reduce), given that the shipbuilding plants and the assembling shipyards work simultaneously for common orders, and the appropriate reduction of funds amount «frozen» in the work in progress, so as the conceptually new opportunities of construction of the ships of large displacement (more 100 thousand ton of the empty ship), in which small shipbuilding plants, constructed the ships' modules and parts, can participate besides of the assembling shipyards.

Opportunities of modular series construction of the ships and creation of the shipbuilding enterprises, adopted for construction of the ships of maximal possible size, corresponded with the general focus on the environmentally friendly navigation fleet replenishment, since the ships of big size are characterized by lower fuel and other resources specific consumption per unite of cargo transportation or per the unit of the size, for which the technological constraint is the only the shipyard opportunity to assemble the large-tonnage ship and to launch it, and not the other constraints are relevant for all cooperated shipbuilding plants, constructing modules and the ships' parts for same orders, besides only of the satisfaction of all these plants to the standards of the assembling shipyard.

For development of innovative shipbuilding it is necessary the enhancement of ship construction technique: the introduction of automation in construction of the ships structural modules, the specialization of shipbuilding enterprises in the directions of it structural modules construction and assembling and the partnership of shipbuilding plants cooperated with assembling shipyards.

The factor determining the competitiveness of the regional shipbuilding, due to a number of obvious reasons can be the cross-sectoral and the international cooperation and specialization in the production of structural modules of ships under construction and the modules assembling. On the Far East (the Pacific shore) of the Russian Federation prospects of shipbuilding are associated with the possibilities of the cooperation as inside the region, so with the oversea shipbuilding yards of Republic of Korea, China, Japan and the set of the other states.

One would consider that the Republic of Korea, Japan and China dominate in the batch ship construction, directed on the mass market demand of batch mastered ships of the prevailing types.

Besides the of the mass shipbuilding demand the local one is available for the new constructed ships of various types, which are not constructed in large series. To their set the ships of various assignment for navigation in frozen seas are assigned in particular, which is required for the development of the Northern and Southern Oceans. The demand for single or small series construction of the ships of innovative types, in particular, the multifunctional ice–navigating ships is characteristic in the Russian Federation, the USA, Canada, Norway, Finland, Denmark, Sweden, the other EU states, Australia, Chile, etc.

Besides of that in the numerous of states the local demand is available for the ships of other classes in dependence on the states industrial compositions, on geography and the ocean coasts locations, on the ocean resources available and on the national needs. In this way, the innovative shipbuilding is aimed not only at the satisfaction of national demand, but of the other states' demand too, and the consolidation of the local markets demand makes sense for the ships construction.

Since the innovative shipbuilding is generally aimed at construction of the ships, which types are not mastered enough in the batch shipbuilding, then the demand for these ships construction exceeds the supply (the offer). This predetermines the economic efficiency and the attractiveness for investments in innovative shipbuilding. Need to pay attention on the fact that these additional investment benefits, arising for innovative shipbuilding development due to predominance of the demand over the supply for construction of conceptually new ships, are largely associated with an effective system of the professional personnel training, and this issue is of paramount importance for construction of the innovative ships, which are required in accordance with the Shipbuilding Industry Development Strategy and with the Federal programs.

Creation of innovative ships, which are not mastered by mass construction at large shipbuilding enterprises, is of great importance for the development of national shipbuilding not only in the Russian Federation, but in other states, for which the serial merchant shipbuilding was not before the typical national industry. The construction of ships of these classes can be the original purpose for the national shipbuilding industry development out of frames of competing with the shipyards in the Republic of Korea, Japan, China and in some other states of the Pacific Rim.

The approach changes, and the cooperation with the shipbuilding companies of indicated states comes to the forefront when changing the «product line», that is by the experience accumulation of the innovative ships construction, by renewal and replenishment of facilities of new created shipbuilding yards and the plants with

partial replacement of the ships construction for the budgetary subsidies in accordance with the Strategy and the Federal programs in to the serial shipbuilding, in co-operating with indicated assembling shipyards at the next step.

It is relevant to combine the benefits of technological cooperation with the Asia-Pacific region countries of mass shipbuilding and the minimization of economic competition with them, given that the batch construction is aimed at the mass demand, and the innovative ship construction at the local demand or at consolidated demand, consisting of it segments identified by national, geographic, industrial and other attributes.

10.1. Forms of common participation of administrations and corporate investors in the development of innovative shipbuilding

Development of the innovative shipbuilding is the systemic process and includes the multisided issues fulfillment of the international and the inter-industrial partnership, of the professional training, of the management and financing and etc., which could be decided together at the highest hierarchical level the only. It should be borne in mind that the additional opportunities for investing arise by reason of demand exceed over supply for construction of conceptually new ships are characterized by lagging behind the subsidy needs emerging. Thus, the participation is required of federal authorities and other administrations for decision of shipbuilding enterprises development issues and for creation of the innovative ships, in particular, the multifunctional ice-navigating ones.

The participation of Government and the administrations of other levels is required for subsidies funding in the costs associated with the ships construction, for the reasons: the subsidizing of long-term investments and the funding of costs for the investment use (the interest or the capital cost), the equalization of economic environment for the shipbuilding enterprises and the companies in other industries, for the shipbuilding development promotion, for decision of the issues of created facilities possession between the administrations and the corporate investors, for establishing and developing of the professional training system and etc.

Participation of local or the federal authorities is required, as well, for compensation of the subsidies lag at emerging of the investment subsidizing needs and the attraction (the obtaining) of private investments in the shipbuilding.

Besides of administrations (the industrial, territorial, the Governments of states, others) the other participants in developing of innovative shipbuilding can be:

- acting shipbuilding companies of various organizational forms, for which there are motives of joint activity with the administrations;
- marine navigating companies, interested in the investing in shipbuilding by the reason of profit redistribution between shipbuilding and shipping in the conditions of market demand predominance over the supply for the investing in construction of the conceptually new ships;
- financial institutions: the commercial banks, the investment funds, the leasing companies and etc., which when choosing the investment directions are interested in the cost of capital increase and the commercial risks reduce in joint activity with the administrations of various levels;
- universities and the colleges, which are interested in the creation of the relevant departments on their own basis and in the implementation of new curricula with the account of the expected in future return of funds for training in this professional area as many students as possible on an off-budget basis, these establishments are interested too in the successful employment of graduates, etc.

For the effective development of innovative shipbuilding the budgetary subsidies have to facilitate extrabudgetary investment (the corporate). Budgetary subsidies in the development of shipbuilding can be «the economic leverage» to attract the corporate investors.

It is possible to characterize general issues of budget subsidies in the development of innovative shipbuilding, by corresponding «economic leverage» as follows:

- creation of specialized assembling yards for construction of ships of the previously constructed modules and for association of other shipbuilding enterprises in the cooperation with the indicated shipyards;
- tax subsidies for corporate investors, as well, as subsidizing interest on loans used for funding of innovative shipbuilding;
- creation of municipal infrastructures in the districts of new shipbuilding yards, the subsidizing (partially or completely) of the interest on loans for residential real estate and for the professional training of employees for new shipbuilding enterprises;
- other possible assignments of budget subsidies in the development of shipbuilding, which can be considered as economically equivalent to the listed ones.

Budgetary subsidies or the corporate investors participation could take the forms of direct financing in the development of shipbuilding plants and yards, as well, as the economic guarantees, benefits, tax and loans subsidies, etc. The listed other forms of participation of the administrations of various levels are preferable economically, rather than direct financing of the ships construction at the existing shipyards.

Participation of the administrations, as well, as the attraction of corporate investments should be based on a realistic assessment of the prospects of predominance the demand over the supply (the offer) of conceptually new ships construction, which gives shipbuilding companies the benefits in perspective.

Expected opportunities subsidized by administrations or by the corporate investors would be available to citizens or organizations in form of loans, and emerging obligations to repay these loans are to be fulfilled by borrowers with their participation in creation of shipbuilding enterprises or the ships. This planning of the investing by involving of other participants in shipbuilding development at the insufficient participation of a wide range of the partners (persons and legal entities) in these processes would be the more effective than direct subsidies in the ships construction at the existing shipyards and plants or the subsidies in the creation of assembling shipyards and in renewal of the existing ones.

In the prospective, the transfer to corporate investors of property rights for the facilities created in shipbuilding is economically preferable in the form of their buyout of these facilities, which were originally created with federal subsidies, when funding conceptually new ships construction. Wherein the burden on the budget for shipbuilding costs is reduced, and the budget is better filled with taxes. Further participation of administrations could be in the form of contracts for the ships creation, and, in the condition of assets (the facilities of the shipbuilding enterprise) redemption by corporate investors, the federal contracts placed in the enterprises, created jointly by the administrations and the corporate investors, could be subsidized by the profit of these enterprises in order of the redemption.

It should be taken into account as well that the direct budget funding in construction of conceptually new ships at the existing shipyards and the plants in definite cases the mistakes could be done, having negative social and economic consequences for local communities. Since the existing shipyard and the infrastructure of the local community do not receive the development from direct subsidies for the ships construction, then negative socioeconomic side effects could be manifested, that is locally the level of consumer prices may rise, because the direct federal financing of contracts in the definite industrial sectors is usually not balanced by the development of local commodity markets and of the infrastructure. On the contrary, when funding the shipbuilding enterprises development, transferring they when redeemed in the corporate investors property, the indicated negative consequences for the local community and consumer goods markets do not arise. Preferably the budget subsidy goes in shipyards and plants development for their next

gradual transit by the redemption in the private possession of investors and in financing of development of the professional environment and training of the specialists for shipbuilding, that is the subsidies funding is desirable in the indirect promotion of shipbuilding industry development.

For private investors participated in shipbuilding the support for one or another guarantee is required on behalf of the administrations and the Governments of states, which would help to reduce the commercial risks for investors.

The simultaneous construction of several ships, the redistribution of resources and the facilities use contribute the alignment of the workload of the shipbuilding plants and shipyards. In the other words, the federal contracts in shipbuilding can be carried out simultaneously with construction of the ships under commercial contracts, thus the budgetary subsidies can have stabilizing impact on the workload of the shipbuilding yards, which is usually characterized by fluctuations in dependence on technical cycles and stages of the ships construction.

10.2. The directions of shipbuilding industry development, given the world general experience

Generally, it is possible to indicate three interrelated but not identical directions of the Shipbuilding Industry Development Strategy and the Federal programs practical fulfillment, which are:

1. Construction at the shipyards in the Russian Federation of the ships of definite types and designs in accordance with the federal demand for the purposes, indicated in the Shipbuilding Industry Development Strategy, that is the tankers for transportation of liquid cargoes in freezing seas, including the liquefied natural gas (LNG-tankers), the icebreakers, the container cargo ships for frozen seas, the platforms and the equipment for operation on the offshores of frozen seas, the scientific-research ships for operation in frozen seas; the equipment for power generation in the offshore districts, including the power generation with use of the renewable sources (tides, currents and winds), the floating equipment for processing of natural gas in frozen seas.

2. Construction for the federal needs of the ships of indicated types and projects at the shipyards in the overseas, for example in China, Republic of Korea, Japan, Taiwan, Indonesia, Vietnam, Singapore and others and in definite other countries, considering the choice of construction berth in order of the budgetary subsidies economy.

3. The investing not directly in construction of the ships, but in the enhancement of shipbuilding companies in the Russian Federation, in creation of the assembling shipyards, in the development of modern shipbuilding and the mass technique of ships construction, which in the next could be used for collateral construction of the conceptually new ships single or small series on the created facilities in accordance with the federal needs.

The first and the second of the considered ways of implementing of the Shipbuilding Industry Development Strategy and the Federal programs do not mean by themselves the development of shipbuilding, although in the first option the profit can be used for improvement of the shipyards and plants.

The construction of conceptually new ships in accordance with the Shipbuilding Industry Development Strategy by itself does not indicate a refund of the subsidies in the budget, and the ships under construction indicated in the Strategy for the most part are not intended for operation in order of income and profit achievement. Therefore, further budgetary subsidies for maintenance of constructed ships will be needed to keep the ships in fit condition and operation. In particular for the needs of national Government it may turn out that it would be more economical to build the ships at enterprises in overseas, since at the enterprises in the definite states the mass ship construction is well developed. This corresponds with the second of considered directions of federal subsidies funding in fleet replenishment in accordance with the Shipbuilding Industry Development Strategy, although with not the development of national shipbuilding industry. For example, the opportunities of the orders for construction of ships for federal demand placing are in the Republic of Korea and in China, and from the economic point of view these would be considered as the preferred on the contrary with the option of these ships construction in the Russian Federation, if in Russia the modernization of the shipyards will not be fulfilled before the ships construction to allow the costs on the ships construction rationalize.

To clarify the advantages and disadvantages of the third of the considered versions of investing not directly in the ships construction, and in the industrial facilities improvement and in the equipment completion of shipbuilding enterprises in the Russian Federation, in the creation of new jobs and in the development of modern technologies of mass shipbuilding one would take note of the features of mass shipbuilding in the leading states of the Republic of Korea, Japan and China. In the media, the opinion was repeatedly expressed that for shipbuilding industry in the Russian Federation one has to use the efficiency experience of holdings,

vertically integrated in the technological and administrative attitude, which is characteristic in the considered industry of leading states. The technology of mass shipbuilding in the indicated states is modular. The third of the considered optional version of federal investment could mean the development of a serial modular shipbuilding in the Russian Federation, and it is required to create the specialized ship assembling yards for the construction of ships from modules, delivered from existed shipbuilding plants in the Russian Federation and in the overseas, which are technologically cooperated with assembling shipyards.

Shipbuilding yards and plants in the Russian Federation are capable to construct ships within the size technological constraint – up to 100 thousand ton of displacement empty. The most of the existing shipyards in the Russian Federation are located in the European territories. For the ships construction in the Russian Federation usually the completing import is used. It is possible to estimate the indicated features of shipbuilding as the shortcomings and subject of the required works.

It is of the interest the comparison of national ways of shipbuilding industry development in Russian Federation and in the other states. It makes sense to consider Canada among the states in some measure similar to the Russian Federation in terms of the ocean navigation, of the industrial development and of the merchant shipbuilding level. The comparable to the Shipbuilding Industry Development Strategy the Canada has National Shipbuilding Strategy (NSS) budgetary funding is provided for the investing in the ship construction of the amount 33 billion Canadian dollars during the period of 20÷30 years, opening of 15 thousand of new jobs in the shipbuilding.

In the considered example with a qualitative similarity of strategies of shipbuilding industries development in the Russian Federation and in Canada (the NSS), focused on construction of the ships for frozen seas, the definite differences between the types of ships planned for construction are available. The list of the ships intended for the construction by the Strategy NSS in Canada in the distinction with the Shipbuilding Industry Development Strategy in the Russian Federation does not cover the construction of ships of the follows types for frozen seas: cargo ships (oil–tankers, the LNG–tankers and the containers carriers), offshore stationary rigs and platforms, floating power generation plants and ones for natural gas process in the ocean – the liquefaction.

It is of the interest, that the compositions of innovative ships, planned for construction with budget subsidies as according to the Shipbuilding Industry Development Strategy in the Russian Federation, so to the Strategy NSS in Canada include the ships for frozen seas and icebreakers. In accordance with the shipbuilding plans

by the Strategy NSS it is decided the creation of patrol ships for coastal navigation in frozen seas, the combat vessels, the polar icebreakers, the support ships (the servicing), the scientific ships for coastal navigation and fishery exploration, as well, as for oceanographic research.

Essentially, in the both strategies the methodic similarity is available that the purposes of fleet renewal of ships for the freezing seas are designated, although this is development of navigation in frozen seas and the fleet replenishment, but itself it is not development of shipbuilding industry. The navigating in frozen seas is funded usually with the budget subsidizing, and the market demand has not the essential influence. That is in both strategies the funding principles are largely the same.

As well it is possible to indicate the similarity of approaches to the choice of national shipbuilding supplier companies, which are the Seaspan ULC, uniting three shipbuilding enterprises in British Columbia and the Irving Shipbuilding Inc in Nova Scotia. In the Russian Federation the main suppliers are created shipbuilding centers.

Strategies of shipbuilding development in the Russian Federation and in Canada corresponds with the similarity that each of them differs with the ways of aimed at the satisfaction of market demand mass shipbuilding operation in the Republic of Korea, Japan, China and in the other industrially developed countries in the Pacific Rim and in others regions. The ships for needs of Governments of these Asian states can be built at reasonable prices at the same shipyards collateral with the mass constructed ships for market demand.

Shipbuilding industry in the world entered the recovery cycle after 2003. In this period, the shipyards of China entered the leading positions, which were previously occupied by shipbuilding enterprises of the Republic of Korea and Japan. Key factors of shipbuilding development industry in China are as follows: access to the resources in the shipbuilding industry and in the production of the ships equipment; the large-scale internal demand in China; the integration of China into the world economy; the industrial partnership opportunities with companies in Hong Kong, Macau and etc.

10.3. Investors in the Shipbuilding Industry Development Strategy

With proper planning the joint participation of the administrations and the corporate investors from the Russian Federation and from the overseas in the development of shipbuilding is possible by the aggregate of budgetary subsidies and the private investments. The joint participation is more effective, if the complex issues are decided, including the creation of the assembling shipyards and renewal

of the existing ones, the construction of the innovative ships for needs of the administrations and the Governments of states, including development of mass modular shipbuilding facilities, aimed at the satisfaction the international market demand of constructed merchant ships of general classes. Total consolidated budget for shipbuilding industry development, including the budgetary subsidies and the private investments, may, in a certain multiplicity, exceed the planned federal subsidies, assuming the relevant planning.

For successful fulfillment of the Shipbuilding Industry Development Strategy and the Federal programs the configuration of investors and the composition property by the results got of the Strategy and the Federal programs fulfillment are of great importance, and moreover the property composition also acts the characteristic the Strategy and the Federal programs fulfillment as well, as the results of the facilities creation themselves: the shipyards built and reconstructed (improved), the innovative ships constructed, the processes mastered of modular mass shipbuilding and etc.

Results of the Strategy and the Federal programs fulfillment can be considered successful in the terms of economy, if the created property for the industrial facilities and the ships constructed would pass to the investors possession by their ransom, and further development of shipbuilding yards and plants will be carried out on the basis of economic self-sufficiency and the payback without the necessity of further budgetary subsidizing, directed originally for the support of the innovative ships construction and the assembling shipyards and shipbuilding plants improving.

In the interest of economy improving the investors have to have the ability of redemption of the ships and the shipyards, created with the use of budgetary subsidies with the participation of administrations and the Government of state, or purchase of ships and created facilities in the other form: by the lease with the redemption, or by loan and etc. For foreclosure of the constructed ships and created or improved shipbuilding enterprises the investors would have to reimburse the primary budgetary subsidies and a reasonable interest for these subsidies use.

For the companies of investors it has to be the ability of receipt in use of the industrial facilities of assembling shipyards and shipbuilding plants, created or reconstructed with the budgetary subsidies, subject to their redemption, as well, as the ability of the refund of the subsidized costs by using the industrial facilities, while constructing at these facilities the ships for the needs of the Government of state and their communication to this customer, in particular the delivery of constructed innovative ships and marine engineering equipment, subject to construction by the Strategy and the Federal programs. Moreover, the investors for this have

to have the ability to construct by the federal orders these ships, at the expense of the profit received of the modular mass construction of ships, demanded by international market, although the construction of ships series for market demand is not indicated directly in the Strategy, but in the prospective this serves important economic factor.

After completion of the facilities redemption by corporate investors of the property share for new created assembling shipyards and the improved shipbuilding plants the following ways of the facilities operation can be carried out:

- new assembling shipyards and the improved shipbuilding plants, implementing construction of the ships structural modules, can do the shipbuilding in co-operation and to participate together in the economic competition with the existing shipbuilding yards of mass shipbuilding, meeting the market demand, if no more required the participation of administrations and the Government in the funding;

- creation of shipbuilding enterprises, implementing the construction of structural modules and assembling of serial ships, and these enterprises developing could be continued, if the budget subsidies for the indicated issues and legislative support of shipbuilding development will continue.

10.4. Relevance of combining of innovative ships construction and the serial ones meeting the market demand

For the industrialized states in the North America and in Europe, the shipbuilding for needs of the Governments is characteristic and, in the lesser degree, the large series construction of the ships demanded by the market economy, if to compare this with the Asian shipyards. This linked with the features of shipbuilding technique in the listed states. The workload of the shipbuilding enterprise on the stage of the ship keel laying usually is not so big in the proportional value and has pulsating nature, since the works intensity is the higher than the closer the completion of the ship construction, launching, it finishing and it delivery to the customer.

Parallel shipbuilding in the both ways: the batch construction of ships demanded by the market and the ships of innovated types constructed single and small series for federal needs can be implemented to equalize the fluctuations of workload of periodic intensity on shipbuilding enterprises, considering, for example, the constructed with budget subsidizing, or by fulfillment of obligations to refund previously granted budgetary subsidies, spent for construction of new assembling shipyards or for improving the existing plants, reimbursable by profits of simultaneous batch construction of the ships.

In prospective, after the redemption by corporate investors of their obligations participating in the Shipbuilding Industry Development Strategy, the relevant can be the other priority of the shipyards work by indicators of the production output: the construction of ships for the needs of Government simultaneously with the main work of mass construction of the ships, demanded by market, refunding the subsidies doing works for the Government. In this regard it has to be considered, that the federal subsidies funding in the development of shipbuilding industry opens the prospective opportunities for more effective shipbuilding, including for the needs of the Governments of states, besides of the mass shipbuilding for the international market demand.

10.5. Sources of subsidies for shipbuilding industry development

From the financial point of view the difference is appropriately formal of the considered directions (1, 2 and 3, item 10.2) of practical fulfillment of the Shipbuilding Industry Development Strategy and the Federal programs with the budget subsidies and with corporate (the extra budgetary) investments in replenishment of fleet (the directions: 1 and 2), in the development of shipbuilding yards (the direction 3), in the combined directions to create the specialized assembling shipyards (corresponds to the direction 3) when completing the constructed ships by the details, aggregates and the structural modules of ships from the foreign shipbuilding plants (the direction 2), in the construction of structural modules at the national shipbuilding plants without of their reconstruction and with mass assembling of the ships at the built specialized assembling yards, which indicates the combining of considered directions: 1 and 3, and etc.

The indicated similarity of the directions (1, 2 and 3, item 9.2) of the Shipbuilding Industry Development Strategy and the Federal programs fulfillment and of combining of the directions, differ by the sequence of investing in the shipbuilding or in the creation of innovative ships, means that evaluations of the financial indexes: the investments (subsidies), the operating costs, the incomes, the profit index dependent on the listed ones, etc. by their present value – formally leads to similarity of each of these indexes final values for any of the considered general ways or the combined directions in the frameworks of systemic approach at the conformities of the data used in each case. The directions (1, 2 and 3) and their combinations characterize the sequence of investments in construction of the ships or the assembling yards, as well, as in the reconstruction of existing shipbuilding plants, have, in this way, the industrial and technological differences, which indicate not so much

the distinction of economic indexes, how much the alternative: will or not be the innovative shipbuilding industry and how much successful it will be.

Despite the fact that national strategies of shipbuilding development usually do not specify explicitly the shipbuilding improvement as the priority task, nevertheless for specified in the strategies construction of innovative ships, in particular, in the Russian Federation or in Canada, the any ways (1, 2 and 3, or of their combinations) of these strategies fulfillment are possible to meet the participants' interests. Using the available economic tools (the legal economic relations) each of the participants can find the additional sources of shipbuilding industry development projects financing, since in the next prospective the guarantee is available of orders of national Governments for construction of the ships of the specified types, according to the decided strategies, and the profit would be used for the initial investments pay off.

Besides of subsidies for construction of the innovative ships assigned by the Shipbuilding Industry Development Strategy, the sources of starting investments associated with creation of the assembling yards of the ships mass construction and with the improving of existing shipbuilding plants could be of the follows:

- the funds when sold to the corporate investors of property shares or the stocks of created assembling shipyards and improved shipbuilding plants, given that these shares are characterized by high capitalization due to the incomes expected in prospective by the construction of ships in accordance with the Shipbuilding Industry Development Strategy and with the Federal programs;

- loans and borrowings for creation and reconstruction of the shipbuilding enterprises with account the guarantees of return in the future of finances upon admission the budgetary subsidies for construction of the ships in accordance with the Strategy.

Both of the examples of extra sources of original investments for creation of assembling shipyards and improving of shipbuilding plants, considering the expected budgetary subsidies for construction of the ships in accordance with the Strategy, are based on guarantees of national Government for the ships construction subsidizing.

Redemption of property shares or the stocks of shipyards or plants could be done for the profit, generated by mass construction of the ships meeting the market demand, spent for the ships build at the created or improved shipbuilding enterprises, subsidized in accordance with the Shipbuilding Industry Development Strategy. This form of gradual repayment by the corporate investors of the created industrial facilities in shipbuilding corresponds economically other options: of borrowed funds use and the option of the created facilities lease with redemption.

Other options of financing of created specialized assembling yards and reconstructed shipbuilding plants purchase, which are closely similar by their economic estimation, are considered below.

The lease option (A). The financing of the subsidies for construction of the innovative ships with the Shipbuilding Industry Development Strategy and the improving of the shipbuilding enterprises can be provided in the form of the lease with redemption. In this option the initial budgetary subsidies used for construction of ships and the shipbuilding enterprises improvement, are redeemed by own profit of the corporate investors, leased the created shipyards and plants, when built of the ships for the needs of Government provided budgetary subsidies, as well, as by mass construction of the ships meeting market demand.

In particular, in the Russian Federation the leasing opportunities for obtaining funds at 3÷5 % per annum with a repayment period of up to 10 years are available for financing of the ships construction (not the shipyards). Investor's down-payment in the amount no less than 20 % is usually needed to accept this financing and to secure obligations to return subsidies in construction of the ship by the indicated assumptions.

The credit option (B). Investing in creation of the shipbuilding enterprises creation or improvement can be carried out by the investors by use of borrowed funds, in particular, with the commercial banks function of lending real industrial sector. Loan and credit commitments are paid by the corporate investors at the expense of own profit by the ships mass construction, meeting the market demand, at the created shipbuilding enterprises for borrowed funds, or when building the ships for needs of the Government by budgetary subsidies.

If financing of the shipbuilding enterprises creation or improvement is provided combined by considered options A and B, that is if original budgetary subsidies for improving of existing shipbuilding plants and for creation of assembling shipyards are used, so the commercial loans, then their refund at the redemption of created industrial facilities by the investors could be made or in the financial form by the own profit generated by mass construction of ships at these shipbuilding enterprise, or in the form of innovative ships construction for budgetary subsidies with the Shipbuilding Industry Development Strategy.

The joint stock option (C). Investing in construction of the ships and in the shipbuilding enterprises creation or improvement is fulfilled by own funds of the investors (the stockholders, the shareholders or the other participants). Starting budgetary subsidies in the joint stock option could be reimbursed by emission of shares of the shipbuilding enterprises under creation or improving. The guarantee of these

shares value and the created enterprises capitalization is by provided federal subsidies for construction of the ships with the Shipbuilding Industry Development Strategy.

As an example, of joint stock option of initial investing and the organization of common activity of participants in implementation of the Shipbuilding Industry Development Strategy and the Federal programs it is possible to consider the creation and improvement of the LLC «Zvezda» SC.

The comparative in the economic terms other options of the original budgetary subsidies reimbursement, or the combined forms, in particular, combined on the basis of the considered options: the lease option (A), the credit option (B) and the joint stock one (C) are possible for fulfillment of the Shipbuilding Industry Development Strategy and the Federal programs.

The joint stock option (C) of investments financing is relevant as well for creation of the assembling shipyard, for improving of existing plants, when the possession rights for the created industrial facilities and assets are transferred to corporate investors by these properties redemption, as well, as for federal subsidies use account, the stocks issues and the shares of the holders. The preferred form is the establishment of the legal entity, in particular, the joint stock company for joining the efforts of corporate participants and the joint account of their investments and budgetary subsidies.

10.6. Priority of budgetary funding in development of shipbuilding companies

Despite the fact that various forms of initial investments (of the options: A, B and C, item 10.5) are possible in development of the shipbuilding industry and in creation of the innovative ships, it is possible to recommend the following sequence of investing: at first, the creation of assembling shipyards and improving of existing plants with budget subsidies and, secondly, the gradual redemption by the corporate investors of the created industrial facilities and the assets, the use of lease option (A) for redemption. Without denying consistency and the ability of credit option of the investing and the joint stock one (B and C) for fulfillment of the Shipbuilding Industry Development Strategy, that is for reimbursement of initial budgetary subsidies in order to redeem by the corporate investors of created industrial facilities.

The other possible options of the investing are dealing actually with the use of those or other derivatives: the shares, the credit or other equivalent agreements,

associated with the budgetary commitments in the future, or with the orders guarantees for the ships construction with the Shipbuilding Industry Development Strategy, but not in the implementing of investments directly, in the creation ship assembling yards or in the reconstruction of existing shipbuilding plants.

In the credit option (B, item 10.5) or the joint stock one (C), associated indirectly with the creation of new ship assembling yards or with the reconstruction of existed ones, the original investing in the creation of new industrial facilities in shipbuilding and the assets is carried out not with the budget subsidies of investments (the lease option A), and with the involvement of other participants, for example the creditors. In the credit or the joint stock options the investing in the development of shipbuilding (the options B and C) the administrations and the Government commit the subsidizing funds in the future, in particular in construction of the innovative ships with the Shipbuilding Industry Development Strategy, and these commitments at the initial investing stage in creation of new industrial facilities are the budget subsidy substitute and financial derivatives of definite kind, which may have negative macroeconomic consequence, like the veiled monetary emission.

For considered reasons the budget subsidy in development of the shipbuilding companies, associated with the lease option (A) of participation of corporate investors, at which the assembling shipyards are created and existing shipbuilding plants improved by budgetary subsidies, is more logical, and participating investors receive (lease) the created industrial facilities in the operation and the assets, and obtain the commitments to build the ships at these shipyards for needs of the Government, as well, as the investors are carrying out a systematic buyout of the industrial facilities, delivering the innovative ships constructed for the profit of mass construction of other ships meeting the market demand (by the corporate orders) with the use of leased shipbuilding enterprises created by budgetary subsidies with the Shipbuilding Industry Development Strategy.

10.7. General characteristics of object of the investing in implementing of the Shipbuilding Industry Development Strategy

For developing of the shipbuilding industry, one need to determine criteria of choice and the complete set of comparable options of investing object, for which necessary to specify the characteristics among the subsidies directions (item 10.2) and the forms of financing (item 10.5), that is to assign the characteristics of investing object:

- subsidizing of construction of the ships for needs of the Government (1, item 10.2) at the national shipyards, the subsidizing in construction of these ships at the foreign shipyards (2, item 10.2) or the subsidizing in creation of national assembling shipyards and in the improving of existing shipbuilding plants (3, item 10.2);

- funding in creation of industrial facilities and assets of the shipyards, including, along with the budget subsidy on the basis the lease option (A, item 10.5), the attraction of the corporate investors for financing and their subsequent redemption by shares of the created enterprises, while the corporate investors lease the created assembling shipyards and reconstructed (the improved) shipbuilding plants and redeem the shares of created facilities with the budgetary subsidies by constructing of the ships for needs of national Government and delivering these, as well, as the use of the credit or joint stock options of investing (B and C, item 10.5), at which the industrial facilities and assets of the shipyards are created by borrowed funds or by the equity capital (the joint stock option), and the guarantee of borrowed funds refund or guarantee of the required capitalization of the shipbuilding enterprise in the considered case are the obligations of the Government to order the ships construction for the federal needs at the created shipbuilding enterprises.

Complex of indicated directions of the subsidies: 1, 2 and 3 (item 10.2), as well, as their combinations, for example the directions: 1 and 3; 2 and 3; 1, 2 and 3, and the set of forms of the sources of investments financing (the options: A, B and C, item 10.5) and their combinations indicate general set of options of which one would find the set of the relevant ones for the fulfillment of the Shipbuilding Industry Development Strategy. These sets of options can be compared in order to select the best direction of the Strategy fulfillment and the best option of investing in the development of the shipbuilding companies and in the construction of the innovative ships. For this selection the criterion of the follow set can be used: the internal rate of return, the net present value, the investments payback period, the present worth and etc.

10.8. Expected results of national shipbuilding development strategy

Implementing of the Shipbuilding Industry Development Strategy could be considered completed upon achievement of following results:

- creation of the innovative ships, including the multifunctional ice-navigating ships in accordance with the Strategy and with the Federal programs;
- completion of the improving (the reconstruction and conversion) of existing shipbuilding plants and creation of the assembling shipyards;

- development of cooperation of the assembling shipyards to promote market demand of the ships assembled of structural modules mass construction with the automatic technique at the existed improved shipbuilding plants;
- buyout and transfer of the property shares of created industrial facilities and the assets of the shipbuilding enterprises to investors, which subsidized the corporate funds, the fulfillment of financial obligations by the participants;
- refund of budgetary subsidies, invested initially in the fulfillment of the Shipbuilding Industry Development Strategy, by participants, who received ownership for the created facilities of shipbuilding companies and for constructed ships, and the pay off the percentage for the use of subsidies (the cost of capital);
- completion of planned set of jobs creation at the shipbuilding enterprises, the purchase of comfortable housing by the families of employees, the creation of social infrastructure, of system of employees professional training, of the system of lending to support the employees;
- development of scientific study and education system of the training of ships construction programs, naval architecture, marine engineering and the associated ones, having in mind, that the education system and scientific study in considered area of the expertise are independently valuable too.

10.9. Directions of personnel training for innovative shipbuilding

Approaches of the optimization designing of multifunctional ice–navigating ship, for which the design according to the analogues is not of the first importance, due to the fact that mass construction of such innovative ships is not mastered enough, put forward special requirements for the level of qualifications of specialists, which participate in the designing and construction of the innovative ships, and the requirements for the organizing of professional training of personnel. This determines the structure of required curriculum and the content of the multilevel training programs in shipbuilding and in the associated professional directions, linked with shipbuilding.

For the innovative shipbuilding, that is for creation in accordance with the Shipbuilding Industry Development Strategy of conceptually new ships, which were not constructed before, including the multifunctional ships for ice navigation, the high qualifications of shipbuilding specialists and the development of multilevel system of their training are required. More than that, just the additional investing opportunities for shipbuilding development, emerging due to predominance of the demand for innovative ships over the supply, are predetermined by an effective system

of professional training of the personnel in shipbuilding and in the other professional directions linked with shipbuilding, these who will participate in construction of innovative ships, in the creation of new ship assembling yards and in the reconstruction of existing plants. In this way, the investing opportunities for the innovative shipbuilding are interdependent systemic with funding of the effective professional training of the personnel of all levels of skill.

Availability of professional training system is important to continue mass construction of the ships, but probably not so much in the states, having experience in creation of the merchant ships series, for example, in Republic of Korea, Japan and China, since the technology of mass construction is based on repeatability of typical works. If the ships series are mastered and it is not required the creation of ships of new projects, then the professional training should be focused primarily on the skills improvement of qualified technical workers, capable to use the design documents, to maintain the equipment and to comply with specifications and instructions.

Enhancement of system of the professional training of shipbuilding and of the directions, associated with shipbuilding, including the programs of teaching of ships and the marine engineering designing approaches; the navigation and the technical maintenance of the ships, as well, as the introduction of new educational programs and curricula in these areas, refer the purposes of the innovative ships building along with the development of collectives of the created enterprises, including the creation of the social infrastructure etc.

The progress of university campuses and the laboratories is required and the organizing of new programs teaching, as well, as funding, for example, the cost for borrowed capital, lend by the students for learning of the professional programs, which are linked with the shipbuilding.

Issues of the professional training system improving, considering the required duration and the multistage nature of these issues, should be addressed as a priority in relation to industrial issues on the creation of assembling shipyards and the reconstruction of existing plants.

Since modern shipbuilding works in the system of industrial and the international cooperation, then for qualification compatibility it is required to obey the concepts of the Bologna Protocol in the professional training.

The training programs of the shipbuilding and the associated professional directions, linked with the shipbuilding, provided in the universities, as well, as retraining and advanced training in the indicated universities, in training centers of industrial enterprises, in vocational educational institutions and in the professional societies are coordinated on the basis of specified universities.

10.10. Organizing of professional training of shipbuilding programs, naval architecture, marine engineering and the associated ones

System of professional training of shipbuilding programs, naval architecture, marine engineering and the associated ones, covering training of the technical skills and the theoretical knowledge in accordance with this or that graduation degree, is a the heart of modern shipbuilding industry, implementing the construction of innovative ships with the Shipbuilding Industry Development Strategy and with the Federal programs, including the multifunctional ice–navigating ships.

Systematic process of the programs training is required for the purposes:

- of shipbuilding programs training and of associated professional directions combining with the developing the methodology for training process;
- forming of the multilevel training system, including the following qualification levels: the additional education in shipbuilding for mechanical engineers and for the other professions (not the shipbuilding ones), as well, as the retraining of mechanical engineers and qualified seafarers for those cases when it is the demand for the retraining; the training of bachelors and masters of the shipbuilding profession; the organization of work and the professional training of highly qualified personnel – the doctors of sciences (of the ship theory, the ship structural mechanics, the ship designing approaches, naval architecture and marine engineering, the ship machinery, theory and construction technology of the machinery and equipment, the technology of construction of ships, etc.).

On the basis the experience analysis of the training process organizing in shipbuilding professional domain, given the standards and the curriculums of the education of bachelors and masters, in the Russian Federation for shipbuilding professions and in the other states, in particular, in the North America, including the ship study, design, construction and maintenance in the navigation, to the number of the basic (undergraduate) programs the follows can be attributed:

1. Introduction in the ships classification, structure, structural mechanics and the seaworthiness, machinery and equipment classification /3, 14, 38, 149, 151, 152/.
2. Technology of shipbuilding and the organizing of ships construction /34, 143/.
3. Power installations with internal combustion engines, ships machinery /74/.
4. Structure of ship hull /13, 169, 178/.
5. Core of ship structural mechanics /134, 144, 178/.
6. Core of theory of ship seaworthiness /2, 41, 49, 50, 134, 139, 167, 168, 172/.
7. Few elective programs, corresponded with basic ones /4, 16, 27, 82, 156, 158, 177, 179, 180/.

When planning the composition and volume of professional training of bachelors for shipbuilding graduate programs and for associated professional directions it is possible to recommend the follows additionally to the basic ones:

8. Ship design theory /9, 22, 28, 42, 51, 152, 167/.
9. Determining of design particulars of ship devices and machinery /25, 74, 151/.
10. Determining of particulars of ship systems /61, 74/.
11. Unsinkability of ship and structural ensure of unsinkability /49, 50, 134, 139, 168/.
12. Evaluation of investments in construction of the ship, indexes of the costs, the value of ship and it economic efficiency criteria /20, 21, 64, 65, 146, 145, 174, 176/.
13. Some elective programs corresponded with course of the bachelor training /16, 27, 177, 180, 181/.

It should be mentioned that demarcation of the indicated lists of the basic programs for shipbuilding and the associated directions and of the additional programs when studying for bachelor's degree to certain extent is conventional and corresponded with the planning of the training process in each individual profile university, in particular, when implementing along with the training of the bachelors as well the teaching of skilled technical workers, who are not the gradulators with a bachelor's degree, or the skills improving of specialists in other professions associated with the navigation or the technical maintenance of the fleet, but not directly with the shipbuilding.

For training of masters by shipbuilding programs and the associated directions (if one has already the bachelor's degree) it is possible to recommend the follows graduate programs additionally to the basic and the bachelor's ones:

14. Hydromechanics, the water resistance, the propulsive performances of ship, the characteristics and performances of propellers, the hydromechanics of ship hull shape /8, 27, 41, 49, 50, 172/.
15. Ship controllability of and maneuverability /4, 43, 158, 172/.
16. Seaworthiness, pitching and the stability of ship in waves /2, 17, 69, 158/.
17. Vibration, the fatigue durability and the wear of ship structures /179/.
18. Ships designing approaches (by classes of ships with account of their theoretical and technical features), including multifunctional ice–navigating ship /29, 161/.
19. Some elective programs corresponded with course of the master training /16, 60, 82, 131, 156/.

Specified general set and the list of programs of the shipbuilding, naval architecture, marine engineering and in the associated areas corresponds approximately with the follows expert estimates of the learning workload and it extent:

- training for bachelor degree during the period from 4 to 4.5 years includes the study of the programs of the indicated list subject to simultaneous study from 4 to 5 programs, as well, as the general engineering and the general scientific programs not indicated in the specified list by the relative volume is about 50 % of the considered basic programs (from 1 to 7 items) and the general scientific programs, not included in the lists (mathematics, physics, computer science, etc., from 8 to 13 items);
- training for master degree with the indicated programs takes in average two academic years, if one has the bachelor's degree, and the general engineering and the general scientific programs wherein make up by 25 % in relation to the specified programs (listed from 14 to 19).

Original implementing of the specified volume of training programs for degrees of bachelor and master of the shipbuilding, naval architecture, marine engineering and in the associated areas can be implemented during few years, and the teaching of the main part of these the programs could begin after about two years after admission of students, right after completion of the general engineering and the general scientific programs teaching, educated during this period, which usually almost do not require the preparing for the teaching, because these programs are of the universal nature for all engineering professions. By this time, the staffing and the methodological base of professional training for special programs (listed from 14 to 19) should be completed.

Basis for training of the shipbuilding programs and in the associated areas in the university is: the highly qualified teachers, the educational and methodological literature, mostly electronic textbooks, manuals and methodological guidelines available in the networks, the lecture halls and laboratory rooms.

For training of the shipbuilding programs and in the associated areas, the specialized laboratories have to be used, including the hydrodynamic one (the multifunctional towing tank) and the technical laboratories for study of the ship devices, systems and the processes: assembling and welding in the shipbuilding, strength and the vibration of the ship structures, processes of heat and mass transfer in the internal combustion engines, dynamics and the strength of the ship machinery, the automation of control, the hydraulics and hydraulic systems, the electromechanical devices, the hydro-acoustics and etc. These laboratories, as well, as technological shops and classrooms in the universities can be merged in the shipbuilding technological parks, the marine engineering and the ship machinery ones for combining of scientific study with the training programs of the shipbuilding.

On the basis of e-book libraries appropriate for shipbuilding programs and for other professional directions, linked with the shipbuilding, it is relevant to do

the distance learning system for bachelors and masters, as well, as distance learning system of the continuous and the additional training of personnel, having the degrees of bachelor or master of the engineering directions. Wherein subject to create the system of remote control of students' knowledge and automated results collecting. Makes sense the combining of single network of the distance learning system with students automated workplaces by the system of their authorized entry, the access to portals of professional organizations, which establish the professional standards, the options of survey and technique, the quality control, the advanced training rules and etc.

Follow standard software: CAD, CAM, CAE and PDM for engineers is used for basic training of design documentation process automation, for it automatic storage and digital processing. For experts in the shipbuilding and in the associated areas the follow software is relevant: AutoCAD, ANSYS, CATIA, COSMOS, NASTRAN, Unigraphics and etc. This software with the professional e-book libraries of the shipbuilding, with the databases and the remote access opportunities is the automated workstation. The indicated digital processing facilities and the other software are necessary for implementing of the innovative shipbuilding, and it corresponds the technological level for training of the specialists in the shipbuilding and in the associated areas. It has to be clarified for students, that these software is the convenience, but not the substitute of training programs of ships construction, naval architecture and the marine engineering, and the associated ones and the qualification requirements.

Besides of the programs learning of shipbuilding and ones linked with the shipbuilding the applicants for bachelor's or master's degrees develop qualification projects or research studies, according to individual programs.

Set of programs of professional training (listed from 14 to 19) of shipbuilding and other professional directions, linked with the shipbuilding, gives opportunities:

- coordination of the teaching approaches and the scientific-researches of the indicated directions in the specialized universities;
- accelerating the professional training programs implementing and works organizing with the curriculum of several specialists at the same time;
- formation (the collection) of educational and methodic libraries of e-books for set of programs, allowing to create a distance training system;
- organizing of the multilevel training and the professional retraining by the considered programs;
- organizing the scientific study of applicants for academic degrees given that from formal point of view the scientific work in the profile university predominantly aims at the enhancement of used training programs;

- developing of cooperation of the specialists from the various institutions on the basis of common assignments and issues of the professional training programs continuous improving;

- relevant spending of provided subsidies, since the programs of professional training in the most general form define the subsidizing tasks, and etc.

In training programs of the shipbuilding, naval architecture, marine engineering and the associated ones the probable methodological obstacles should be avoided, in particular, the follows:

- violation of systemic logical consistency, fragmentation of programs according to individual professional preferences and probable insufficient integrity of the training curriculum;

- probable inappropriate transformation of the training process, merging it to the technological level (almost only the use of software, the drafts plotting, etc.), this would be not enough for training for the bachelor's or master's degrees.

10.11. Specializations of the training programs of shipbuilding and of other professional directions, linked with shipbuilding

Training of the shipbuilding programs and of the directions associated with shipbuilding from general point of view is possible to identify of two specializations: the shipbuilding and the marine engineering (ocean engineering), wherein it should be borne in mind, that marine engineering could be considered as more general definition covering concept of the ship, which belongs methodologically to the marine engineering too along with the other objects included in this concept, and the shipbuilding indicates as well the technological process of the ship construction.

By educational specialization «The designing of ship» (Ship design theory) the training of the basic programs prevails: «Structure of ship hull» (4, item 10.10), «Technology of shipbuilding and the organizing of ship construction» (2), as well, as of some programs of the considered set (from 8 to 19), which has definite similarity with the programs of the mechanical engineering.

Since shipbuilding industry has the differences from the general engineering primarily by the object concept, by the ship design processes and the technology of construction when the assembling at the shipyards (the construction plant equipped with assembly facilities for the ship or its part and the launching slipways or the dry docks), then the specializations of shipbuilding programs and of other professional directions, linked with the shipbuilding, could be indicated as follows:

the Naval Architecture (the development not only the combat designs, but the merchant ships), the technology of shipbuilding and the marine engineering. Marine Engineering, by the analogy with the Mechanical Engineering, can mean the industrial technology of the machines and vehicles constructing, that is the definition of process, as well, as the shipbuilding can mean the industry, on one hand, and the process of ship construction, on the other one.

By the other way the shipbuilding and ocean engineering could be considered consisting of two specializations: «The designing of ship» (the Naval Architecture) and «The Marine Engineering», as well covering the training programs (from 1 to 19, item 10.10), attributing to marine engineering the construction of ship gears and systems, as well, as of the equipment and the structural elements of these devices, systems, etc., and the technological processes in the shipbuilding industry, besides of considering the mechanisms, as the designing objects, or as the processes being the part of ship designing, when it completing by machinery and equipment. Strictly speaking, the considered definitions (like the Marine Engineering, or the close ones) can mean not only the name of object under design, but the technological process of it construction. This is to be taken into account when working out of the teaching curriculums and programs.

The set of the training programs of shipbuilding and other professional directions, linked with the shipbuilding, is of the systemic nature, and the methodological demand of each of programs and for each of level of the professional training is the characteristic of upper methodological levels. The professional training is generally crowned by such programs as: «Ship design theory» (8, item 10.10), «Theory of ship seaworthiness» (the Core see 6, item 10.10), «Ship structural mechanics» (5), «Structure of ship hull» (4) and «Technology of shipbuilding and the organizing of ship construction» (2), given that they are methodologically more general, than the rest listed programs, linked with shipbuilding, and in the process of ship designing, when using these programs, the main adopted decisions are sufficiently impacting on the resulting efficiencies in shipbuilding and navigation.

It should be mentioned that of the general set of recommended programs of shipbuilding and other professional directions, linked with the shipbuilding, the minimal initial effort to organize the training process and the minimal requirements to level of the initial student knowledge are required for learning of the programs of general technological nature, such as: «Introduction in the ships classification, ship structure, ship structural mechanics and the seaworthiness, the ship machinery and equipment classification» (1, item 10.10), «Technology of shipbuilding

and the organizing of ship construction» (2), «Power installations with internal combustion engines, ships machinery» (3) and «Structure of ship hull» (4). In the same time the programs of technological nature (from 1 to 4) by themselves have practical importance not only for further training of the general programs, like the «Ships designing approaches», but also for training of workers of high qualifications. In this way, these general technological programs can be a connecting link to cooperate training in the universities and in the colleges. This corresponds with the concept of the continuous multilevel training.

Set of programs of the multilevel professional training of shipbuilding and other professional directions, linked with the shipbuilding, is to be considered as subject of continuous improving. Ship under designing in the frameworks of the systemic approach, that is when finding of it optimal designing characteristics and particulars, is the complex system consisting of subsystems. Most important performances for ship under design, absent in the individual subsystems, emerge when combine these subsystems in the integral ship. Each of considered shipbuilding programs and of other professional directions, linked with the shipbuilding, discovers this or that individual property the complex ship, and the continuous developing of methodological concept of «the ship» is the general motive for scientific study and the improving of each considered program and their total set in the training curriculum.

10.12. Professional environment in the shipbuilding industry

Creation professional environment, consisted of skilled and educated personnel, of the researchers, experts, designers and the students, trained the shipbuilding programs, naval architecture and the marine engineering and the associated ones, that is forming the training system of the enough number of the professional people of various qualification levels, is critically important stage, predetermined the general duration of fulfillment of the Shipbuilding Industry Development Strategy and the Federal programs. This is necessary for improvement of the shipbuilding technology and facilities at the national shipyards, for creation of the specialized assembling shipyards of mass construction of the ships and their structural modules, produced at the existing shipbuilding plants after their renewal and improvement.

It is possible to acquire and to install the equipment of new shipyards and plants facilities in the appropriately short period of time, but professional training of specialists for high-tech innovative shipbuilding and organization of professional collectives require longer time. Besides, for organizing of bachelors and masters training, the definite time and the resources are required for improvement of training

processes in the universities, including the personnel qualification improving and re-training of teachers, as well, as the creation of modern methodological support of the training process.

Training of the shipbuilding programs and of other professional directions, associated with shipbuilding, is the most time-consuming process along with the solution to other issues of innovative shipbuilding development and the construction of ships for needs of the Government of state with the national strategy. Wherein to keep the required number of the personnel of all qualification levels in the shipbuilding the annual graduation required of the number of about 4÷7 % of the occupied personnel. Given that the professional training of the bachelors and masters for the shipbuilding and for other professional directions, associated with shipbuilding, takes from 4 to 6 years for each person, for the annual graduation of the required number of professionals it is required the number of simultaneously trained students be equal from 25 to 45 % from the number of permanently employed people in the shipbuilding, corresponding the degrees of bachelor and master, and considering the usual dropout of students in the first years of study.

About one third of the general number of the bachelors, masters and the doctors of the shipbuilding, naval architecture, marine engineering and associated professions, and the applicants of the indicated qualifications have to be occupied and trained as students in the specialized universities, compared with the total people permanently working in the shipbuilding and training.

Accordingly, in the of shipbuilding industry, including the shipyards, the plants, the designing bureaus and in other industrial institutions, are employed about of two thirds of specialists, having the degree from the university of the shipbuilding, naval architecture, marine engineering and associated ones. Approximately such a qualification set of the personnel assessed needed for construction of the innovative ships with the national strategy of the shipbuilding development and with the Federal programs, including for construction of multifunctional ice-navigating ship, for creation of the assembling shipyards and for renewal and improving of existing shipbuilding plants.

Checklist

- 498. Intrinsic value of renewed organizationally and technologically shipbuilding industry capable to implement the creation of the innovative ships.
- 499. Existing shipbuilding yards and plants, and ones planned for creation as general characteristic of national shipbuilding development strategies.

500. Essential factors of the modern technique of innovative ships construction: partnership of federal authorities with corporate investors; industrial and international cooperation; the specific issues of joint property; joint participation of existing shipbuilding companies and the new created ones in the Strategy of shipbuilding development; planning of the budgetary subsidies refund, attracting the corporate (extra budgetary) investments; sequences of national strategy fulfillment stages; complex nature of the purpose, covering as fleet renewal in accordance with federal needs, so the development of the shipbuilding companies and etc.
501. Specialization of shipbuilding plants constructing the ships' modules and structural parts and assembling shipyards, capable to assemble the modules and launch the large-tonnage ships, is important feature of economically effective mass shipbuilding, requires the maximal level of standardization and opens the opportunities of mechanization and automation techniques.
502. Analogy of shipyards capability of modular assembling of ships with an assembly lines in other industries.
503. Simultaneous work of assembling shipyards and shipbuilding plants, which reduces the funds amount «frozen» in the work in progress
504. Partnership of large-tonnage assembling yards and shipbuilding plants promotes the existing plants, renewed and changed the production lines from construction small-sized ships to the output of modules and parts of large-tonnage ones, to international market of merchant large-tonnage ships.
505. Technological constraints of the cooperated shipyards, capable to assemble and to launch the large-sized mass constructed ships, and the shipbuilding plants of any capacity constructing the modules and parts of the ships meeting the standards of the assembling shipyard.
506. Shipbuilding enterprises activity in the Republic of Korea, Japan and China aimed at the demand for mass construction of ships of the prevailing types.
507. Demand for single or small series construction of the ships of innovative types, in particular, the multifunctional ice-navigating ships is characteristic in the Russian Federation, the USA, Canada, Norway, Finland, Denmark, Sweden, the other EU states, Australia, Chile, etc.
508. Relevance for local demands consolidation for construction of the ships of innovative types, in particular, the multifunctional ice-navigating ones.
509. Paramount importance of the issue of professional personnel training to master the designing and construction of innovative ships, in particular the multifunctional ice-navigating ones, to access these ships local markets, as the stereotype

nature of mass production of merchant ships of prevailing types less requires the employees' professional degree and skills in the ships construction technique.

510. Purposes of Government participation in subsidizing of costs associated with the ships construction: the subsidizing of long-term investments and the cost of capital, the equalization of economic environment for the shipbuilding and other industries, the promotion of shipbuilding development, decision of issues of created facilities possession, the establishing and developing of the professional training system and etc.
511. Need of the administrations participation for compensation of the subsidies lag at emerging of the investment subsidizing needs and the attraction (the obtaining) of private investments in the shipbuilding.
512. Participants likely interested in developing of innovative shipbuilding besides of authorities are: acting shipbuilding companies, marine shipping companies, financial institutions, universities and the colleges.
513. General issues of budget subsidies in the development of innovative shipbuilding: creation of specialized assembling yards, tax subsidies for corporate investors, as well, as subsidizing interest on loans, creation of municipal infrastructures in the districts of new shipbuilding yards, other possible assignments of budget subsidies, considered as economically equivalent to the listed ones.
514. Preference of other forms of participation of administrations of various levels or the corporate investors in shipbuilding plants and yards development, like the economic guarantees, benefits, tax and loans subsidies, etc., rather than direct financing of the ships construction at the existing shipyards.
515. Opportunities open to citizens or organizations in form of loans repay by the borrowers by their participation in creation of shipbuilding enterprises or the ships.
516. Next participation of administrations in form of contracts for the ships creation when the transfer to corporate investors of property rights for the facilities created in shipbuilding is done, when funding conceptually new ships construction in form of their buyout of these facilities, which were originally created with federal subsidies.
517. Obstacle subject to avoid of direct funding in shipbuilding enterprises or the ships creation probable negative impact, when locally the level of consumer prices due to this direct funding may rise, because the amount of money may increase not balanced by the development of local commodity markets and of the infrastructure, and if the transfer of created assets (the facilities or ships) to the private possession is not done by these assets redemption.

518. Risks reduce or private investing in improving of shipbuilding industry and the ships construction by the one or another guarantee on behalf of the administrations, in particular the guarantee of orders to construct the ships.
519. Simultaneous construction of several ships, in particular, the ships for federal needs by the budget subsidies simultaneously with construction of the ships under commercial contracts, and redistribution of resources and the facilities use contribute the alignment of the workload of the shipbuilding plants and shipyards and the stabilize the facilities use.
520. General ways of the shipbuilding development strategy by implementing the options: construction of the ships of assigned types and marine engineering at national shipyards and plants, using the profit got for developing of the shipbuilding enterprises; construction of these ships in the overseas, selecting the ship-construction berth in order of the budgetary subsidies economy; investing not in construction of the ships, but in the facilities enhancement of national shipbuilding companies to use them in the next for construction of the ships of assigned types for government needs too.
521. Construction for needs of government of conceptually new ships single of in small series does not indicate by itself the refund of subsidies in the budget, and the operation costs are required for maintenance and to keep the ships in fit condition.
522. Expected economic preference to build the ships for federal needs at enterprises in the overseas, since at these enterprises in definite states the mass ship construction is well developed, although this not improves national shipbuilding industry.
523. Probable preference of construction of ships for federal needs at the national shipbuilding enterprises if they modernization will be fulfilled before the ships construction to allow the costs on the ships construction rationalize.
524. Expediency of investing in creation of assembling shipyards cooperation with the shipbuilding plants constructing modules and parts for assembling the ships on the form of shipbuilding holdings (the joint-stocks companies), vertically integrated in the technological and administrative attitude, which is characteristic in the shipbuilding industry of leading states.
525. Main indicators of national Shipbuilding Strategy of Canada, generally comparable with Shipbuilding Industry Development Strategy of the Russian Federation, of provided budgetary funding amount and period, the set of new opened jobs.
526. Key factors of shipbuilding development industry in China, including the access to the resources in the shipbuilding industry (the good quality labor for the rea-

sonable cost) and in the production of the ships equipment, the large-scale internal demand in China and the industrial partnership opportunities with the companies in Hong Kong, Macau and etc.

527. Importance of joint participation of administrations and corporate investors national and from the overseas to fundraise the investments over the budget subsidies.
528. Configuration of investors and possession composition within the results of fulfillment of the Shipbuilding Industry Development Strategy and the Federal programs besides of the created facilities themselves.
529. Economic criterion of the successful fulfillment of the Shipbuilding Industry Development Strategy and the Federal programs – if the industrial facilities and the ships constructed would pass to the investors possession by their ransom, and further development will be carried out on the basis of self-sufficiency and the payback.
530. Use of the created shipbuilding industrial facilities to construct the ships for the needs of the Government, to refund the subsidized costs using created industrial facilities and to redeem these facilities.
531. Use of the profit received of the modular mass construction of ships, demanded by international market, to refund the subsidized costs using created industrial facilities and to redeem these facilities, although the construction of ships series for market demand is not indicated directly in the Strategy.
532. Capability of created assembling shipyards and improved shipbuilding plants cooperation in construction of the ships and their structural modules and economic competition with the existing shipbuilding yards of mass shipbuilding, meeting market demand, if no more required federal participation and budgeted subsidizing.
533. Capability to continue creation of shipbuilding enterprises, implementing the construction of modules and assembling of serial ships, if the budget subsidies for the indicated issues and legislative support of shipbuilding development will continue.
534. Pulsating nature of shipbuilding enterprise workload on the stages of ship keel laying to the constructed ship launching, it finishing and delivery to the customer, that is the workload increasing closer the completion of the ship construction.
535. Equalizing the fluctuations of workload of periodic intensity on shipbuilding enterprises by the workload redistribution and parallel shipbuilding in the both ways: the batch construction of ships demanded by the market and the ships of innovated types constructed single and small series for federal needs.

536. Options to combine the ways of fulfillment of national strategies of shipbuilding development: the creation of new national assembling shipyards and completing the constructed ships by the details, aggregates and the structural modules of ships from the foreign shipbuilding plants, and construction of the ships modules at the national shipbuilding plants without reconstruction of the plants and with mass assembling of the ships at the built assembling yards.
537. Formal economic equivalence of the general ways and the combined options of the shipbuilding development strategy implementing (the equality of the ratios of economic results to the investments, adjusted for risks) and the technological results differences of these ways – the issue, will be created and improved the shipbuilding facilities if the ships are constructed at national or overseas shipyards without the national shipbuilding improvement.
538. Use of resources, provided by national strategies of shipbuilding development for construction of the ships, and the available economic tools (the legal economic relations), as well as the resources of other participants (acting shipbuilding companies, marine shipping companies, financial institutions, etc.) for improving of the shipbuilding enterprises, if it is not explicitly indicated in the strategies.
539. Extra sources of financing of the assembling shipyards creation and improving of shipbuilding plants: the funds when sold the property shares of created and improved shipbuilding enterprises and the loans and borrowings to develop the shipbuilding, considering the guarantees of budgetary subsidies for construction of the ships in accordance with national strategy of shipbuilding development.
540. Property shares or the stocks of shipyards or plants redemption by the profit, generated by mass construction of the ships meeting the market demand, spent for the ships build at the created or improved shipbuilding enterprises, subsidized in accordance with the Strategy.
541. Conformity of economic forms: of gradual repayment by the corporate investors of the created industrial facilities in shipbuilding, of borrowed funds use and the option of the created facilities lease with redemption.
542. Lease option of initial budgetary subsidies refund by own profit of the corporate investors, leased the created shipyards and plants, when built the ships for needs of the Government provided budgetary subsidies, as well, as by mass construction of the ships meeting market demand.
543. Credit option of borrowed funding use for the shipbuilding enterprises creation or improvement paid off by the corporate investors at the expense of own profit

by the ships mass construction, meeting the market demand, at the created shipbuilding enterprises for borrowed funds, or when building the ships for needs of the Government by budgetary subsidies.

544. Financing of the shipbuilding enterprises creation or their improvement combining the credit and the lease options, in particular, if original budgetary subsidies are used together with the commercial loans, then their refund at the redemption of created industrial facilities by the investors is carried out at the expense of own profit by the ships mass construction, meeting the market demand, or when building the ships with budgetary subsidies for needs of the Government.
545. Joint stock option of initial subsidies funding corresponding the construction of the ships and creation or improvement of the shipbuilding enterprises by own funds of the investors (the stockholders, the shareholders or the other participants) with the guarantee of these shares value and the created enterprises capitalization by provided federal subsidies for construction of the ships for federal needs.
546. Financial derivatives emission (the shares, the credit or other equivalent agreements, associated with the budgetary commitments in the future, or with the orders guarantees for the ships construction with the national strategy) is characteristic for the credit option of borrowed funding use and for the joint stock option of initial subsidies funding and their combining options, and not characteristic for the lease option of initial budgetary subsidies refund.
547. Obstacle of risks of negative macroeconomic consequence of emission of the derivatives (the shares, the credit or other equivalent in the credit option of borrowed funding use and the joint stock option of initial subsidies funding), which can be considered as substitute of budget subsidy at the initial investing stage in the creation of new shipbuilding facilities or in the ships construction.
548. Classified by two attributes: the budget subsidies directions and the forms of financing the considered options of investing object can be: construction of the ships for needs of the Government or creation of national shipbuilding enterprise, on one hand, the leasing and redemption of shipbuilding facilities created for the budget subsidies, including by constructing of the ships for needs of national Government, or the use of borrowed funds or joint stock options of investing, considering the Government guarantee of orders to construct the ships, on the other hand.
549. Expected results of national strategy of the shipbuilding development: creation of the innovative ships, including the multifunctional ice-navigating ones, completion of shipbuilding enterprises, development of assembling shipyards

cooperation with shipbuilding plants; buyout of possession rights to the corporate investors by redemption of facilities created by budget subsidies, opening new jobs at the shipbuilding enterprises, development of scientific work and the education system.

550. Needs for the curriculum of training programs of ships construction, naval architecture and the marine engineering, and the associated ones and the qualification requirements for creation of innovative ships, in particular, the multifunctional ice-navigating ones, usually not mastered batch and having insufficient analogs for to use the simplified design approaches by analogs, considering, as well, that construction of these ships performs the first step to develop mass ships construction in the next.
551. Needs of multilevel system of training and of high qualifications of specialists for creation of conceptually new ships in accordance with the national strategies of shipbuilding development, which are not constructed batch and were not before, including the multifunctional ships for ice navigation, because the economic driver of these ships construction, that is the systemic predominance of the demand over supply, is inextricably linked with required qualification of specialists involved, which is the factor of specified predominance of the demand for innovative ships over supply.
552. Needs of the technological skills for mass construction of the ships: to use the design documents, to maintain the equipment and to comply with specifications and instructions.
553. Qualification levels of specialists in the shipbuilding, naval architecture, marine engineering and in the associated areas: the extra education in shipbuilding for mechanical engineers and for the other professions (not the shipbuilding ones), the retraining of mechanical engineers and qualified seafarers; the bachelors and masters of the shipbuilding; the doctors of sciences – highly qualified experts.
554. General directions of scientific study in the shipbuilding, naval architecture, marine engineering and in the associated areas: the ship theory, the ship structural mechanics, the ship designing approaches, naval architecture and marine engineering, the ship machinery, theory and construction technology of the machinery and equipment, the technology of construction of ships, etc.
555. Basic programs aimed at skills improvement (undergraduate).
556. Graduate programs to train bachelors in the shipbuilding, naval architecture, marine engineering and in the associated areas.
557. Graduate programs to train masters in the shipbuilding, naval architecture, marine engineering and in the associated areas.

558. Technical laboratories used for study of the ship devices, systems and processes: assembling and welding in the shipbuilding, strength and vibration of the ship structures, processes of heat and mass transfer in the internal combustion engines, dynamics and the strength of the ship machinery, the automation of control, the hydraulics and hydraulic systems, the electromechanical devices, the hydro–acoustics and etc.
559. Programs curriculum (the set of professional training programs) of shipbuilding and other professional directions, linked with the shipbuilding, allows to decide the issues: coordination of training and scientific study, organizing common work of several specialists, collection of libraries of e–books, allowing to create a distance training system, organizing of the multilevel training, organizing the scientific study of applicants for academic degrees, developing of cooperation of the specialists from the various institutions, relevant spending of provided subsidies.
560. Probable obstacles of implementing of programs of the shipbuilding, naval architecture, marine engineering and the associated ones, subject to avoid: violation of systemic logical consistency, fragmentation of programs according to individual preferences and insufficient integrity of the training curriculum; probable inappropriate transformation of the training process, merging it to the technological level (almost only the use of software, the drafts plotting, etc.).
561. Semantic analogy of concepts of Shipbuilding, the Marine Engineering with the Mechanical Engineering, which can be the designation of the industries, or the processes of construction of definite object (the ship, the machine).
562. Hierarchic subordination of programs in the curriculum of the shipbuilding, naval architecture, marine engineering and the associated ones, considering, that the general programs (like the «Ships designing approaches», or «Technology of shipbuilding and the organizing of ships construction») predetermine the methodological demand for the subordinated programs, the general scientific, the general engineering ones, and the special programs of ship hydromechanics, of structural mechanics, etc.
563. Concept of the continuous multilevel training developing, using the practical importance of general technological programs of «Technology of shipbuilding and the organizing of ship construction», of «Structure of ship hull», etc., which are of the minimal requirements to level of the initial student knowledge, and are appropriate before the academic level programs learning.
564. Within the systemic approach the ship, when determining it optimal design characteristics and particulars, considered as integral system, consisted

of the subsystems, that is of individual properties of the integral ship, and of the new property emerged, when combining the subsystems together in the integral ship, and each program of the curriculum considers this or that individual property of the integral ship, the physical, technological, structural, functional, economic, etc.

565. Assessed proportion of occupied people of the shipbuilding, naval architecture, marine engineering and of associated professional areas of the various qualification levels of workers, bachelors, masters and the doctors, required to implement the national shipbuilding development strategy, are in the universities for one third of the total people, considering the training from 4 to 6 years for each person and usual dropout of students in the first years of study, and about of two thirds of specialists are to be employed in the of shipbuilding industry, including the shipyards, the plants, the designing bureaus and other industrial institutions.

Conclusions

Creation of multifunctional ice–navigating ships (it designing, construction and equipping) is carried out for the needs of national Government with the Shipbuilding Industry Development Strategy, with the Federal programs and with other relevant decisions. Demand of corporate investors is available as well for the innovative ships construction for frozen seas, besides of the federal needs. Creation of the innovative ships, in particular, the multifunctional ice–navigating ones is not only the supply for the federal demand (of for local demand) for the ships of this class, but the first step of national shipbuilding industry improving out of the competition with highly developed batch construction of the ships of general classes for international market.

Object in the process of finding of design characteristics and particulars is the multifunctional ice–navigating ship, suitable for autonomous navigation and for servicing of other ships and escort in frozen seas, that is the multifunctional icebreaking ship if with an icebreaker category. The icebreaking support vessels (IBSV) belong to the multifunctional ice–navigating ones. The multifunctional ships for ice navigation, which are constructed in accordance with the Shipbuilding Industry Development Strategy and with the Federal projects, assigned for autonomous navigation in the ice, usually combine two or number of purposes and besides of the overcoming of ice can also transport cargoes: the liquid cargo (or liquified), in particular, the natural gas, the dry cargoes, including the aggregated unified cargoes – ISO containers, tank containers, the modular equipment in the dimensions of the standard containers, – they would be used for delivery of the supply and it unloading, including with use of the helicopter, for servicing of offshore stationary platforms, to fulfill rescue, patrol or the other works in frozen seas, the supporting and the servicing of the submarine equipment or for using in the other purposes. Functional flexibility and suitability for modernizations, as for the variations in the ships designs, so for practical modernization of existing multifunctional ships for ice navigation are characteristic attribute of the ship of this class. Some of multifunctional ice–navigating ships of the new projects are intended to install the double fuel power installations, operating as on diesel fuel, so as on natural gas.

In the same time the merchant ships, which meets the market demand, which assignment can be classified generally or multifunctional and specialized or universal ones, considering the last specified as specialized in the transport of the general

cargoes. But many of these ships batch constructed are the specialized for one function. The functional specialization is possible to attribute to the other types of cargo ships, as transported the liquid cargoes (or the liquefied), including the oil and the regime ones, so the dry cargoes: the general, the aggregated unified cargo (the containers, etc.), the bulk cargo, the rolling cargo (roll on – roll off), the timber cargo, the refrigerated or frozen cargo (fish or meat food cargo) and etc., – in case if the ship, in particular, is not assigned for navigation in frozen seas and for the overcoming of ices. As well, the specialization is usually characteristic the mass constructed ships of fishery assignment, the support vessels (the auxiliary for others navigation servicing), the ships of technical purpose and etc.

Ships specialization corresponded with preferences when choosing the methodological approaches for finding of design characteristics of these ships. Determining of design characteristics and particulars is logically based on the use the data of analogues with sufficient number of mass analogs of the specialized ships. In the same time at initial designing stages to determine characteristics and particulars of the innovative ships, created single or in small series in accordance with the national strategy of shipbuilding improving, in particular, of multifunctional ships for ice navigation it makes sense to use design optimization methods, based on the systemic approach, on the criteria optimality and objective functions, as well, as on the design constraints, that is to use the designing approaches less dependent on the availability of required prototypes.

When finding optimal design characteristics of multifunctional ice–navigating ship in accordance with the systemic approach it is required to determine the concept of the general system, which is the more general object in methodological sense, than the ship under design, and the ship belongs to this general system as it subsystem. Besides, it is required to define methodologically the subsystems of multifunctional ice–navigating ship itself.

The objects of two kinds can be considered as the ship subsystems – or the integral ship, studying from the point of view of this or that it individual property, or the structural part of the ship under design, attributing to the set of these parts the ship hull or it parts, the devices, the gears, the systems, the machinery, the electric mechanisms, etc. In the first considered option the subsystem of the ship is methodological concept, in the second option – the subsystem is the physical one and the methodological concept, correspondingly.

In the issue of optimal design characteristics finding of multifunctional ice–navigating ship the hierarchy of the levels emerges, which includes the general system, to which the ship belongs as the subsystem, as well, as the levels of the ship

subsystems, for which the ship is the general object, that is the ship under design includes methodologically all its subsystems (the physical parts of ship, or the individual performances of the integral ship), and the new performance of the ship, absent in its individual subsystems, emerges, when combining these subsystems together.

Methodological approach, at which the multifunctional ice-navigating ship under design is considered as the complex probabilistic system, consisting of subsystems, allows to decide important methodological issues at the designing. These issues include the question, corresponded with the classification of the mathematical values describing the ship under design, included in the mathematical models, and issued, corresponded with the attributing of these values, considering their properties, to the sets: the independent variables, which values are studied subject to finding of the optimal design characteristics of the ship, the set of input data, which serve the design constraints, when finding of optimal characteristics of ship, in the other words, the data characterizing the general system, to which the ship under design belongs as the subsystem, and the parameters, that is the characteristics of the ship subsystems, that is the ship design particulars.

The systemic approach, at which the design constraints are determined, allows to decide the issue of the ship options comparability for determining of its design characteristics subject to find their optimal values, when comparing the options of the ship under design, and the comparable options of the ship are the sets of the values of variable characteristics, which correspond with the similar indexes of the design constraints (the data). In the other words, the general designing constraints (the initial data) accordance of multifunctional ice-navigating ship is the comparability rule of considered options (the compared sets of the ship design characteristics), when carrying out the optimization designing.

When finding the design particulars of multifunctional ice-navigating ship, that is the characteristics of its subsystems, for example, when determining the ship dimensions or their proportions, which is the subject of internal designing, the ship is considered from the points of view of its seaworthy performances, patency in frozen seas, the mechanics of the ship structures, the processes and mechanics of the engines and mechanisms, etc., the assessments of the ship properties for determining of appropriate particulars are performed on the bases of the ship theory, its structural mechanics and the other appropriate approaches and criteria.

Design characteristics of ship of this type, such as its cargo waterline displacement, deadweight, cargo capacity, tonnage, effective power of machines or the installation power and others, among which the independent variable characteristics are too, at the initial stages of designing have to be determined by the optimization

methods and could not be found only by the methods of the ship theory, its structural mechanics, etc.

To determine the characteristics of size of multifunctional ice-navigating ship, which is possible to characterize by its loaded displacement, or design deadweight, by the tonnage or the other appropriate interdependent indexes, among which the independent variable characteristics are too, the independent one or the set of them, got with use of economic criteria, objective function and concepts of systemic approach, have to be specified.

Physically the ship can be of any size, and the dependences between the found independent optimal characteristic of the ship size and its particulars is of the physical nature, defined by the ship theory, its structural mechanics, etc., and between this independent optimal characteristic and others characteristics of the ship size (the dependent, or, the generalized) are in the balance ratios of the probabilistic nature.

Besides of physical patterns used in the ship theory and in structural mechanics for determining of multifunctional ice-navigating ship design particulars, which to do the characteristics of the ship are previously got, which are the data when finding the ship particulars, the probabilistic features of the ship as object under design are used as well, which besides of physical regularities help to establish links between the ship characteristics and to reduce the dimension of designing task, because by these links the dependent variables are excluded from set of independent characteristics, varied for searching of their optimal values at the initial stages of designing.

In particular, the equation of balance of multifunctional ice-navigating ship loaded displacement, establishes the dependence between two of size characteristics of the ship, that is between the ship loaded displacement and the independent part of the loaded displacement – the design deadweight, and, accordingly, allows to reduce the dimension of the issue of determining of optimal characteristics of the ship size.

Equation of balance of the ship loaded displacement shows the probabilistic impact of great number of factors on the ratio between covered characteristics of the ship size, although it is not one this or that factor or the ship physical feature, which would establish the ratio between the ship loaded displacement and its cargoes capacity when designing the ship.

Ships for ice navigation have essential structural differences of the hull external overlaps (the sides), the stem and sternpost, and the protruding parts from ships, not having ice or arctic categories or the icebreaking class. Besides, for the ships of arctic categories and icebreaking classes the specific features the particulars of the ship hull shape, of power installation set, of the movers' structures and of the ship control equipment. At the level of the ice-strake of shell in the spacings

between frames of hull of multifunctional ice–navigating ship the additional frames can be installed, as well. By evaluation of design pressure, the sides shell thickness is determined increased.

Great experience is available accumulated by Russian experts in determining of the ships strength in ice, of hydrodynamic resistance, propulsion and patency of the ships in frozen seas and other performances. At the initial designing stages, the systemic recommendations are required for use the mathematical models, intended for finding of multifunctional ice–navigating ships design characteristics.

For example, the known experimental formula, indicating the dependence of solid ice thickness affordable to overcome by the continuous motion on the ship loaded displacement and on the effective power, given the available data of analogs – the indexes of new ice–navigating ships and their designs, given that difference emerges between the assumptions of the experimental study, by which the formula is got, and the real phenomena of ice overcoming by the «acceleration» with use of the trim system, the propellers and other special systems of ship. Therefore, for use of the formula in the mathematical model when finding characteristics and particulars at initial stages of designing of multifunctional ice–navigating ship the appropriate amendments are required. Besides, for determining of the effective power (the propulsive, when overcoming ice) and installation power of the ship machinery the variety of the constraints is considered, associated as with ice thickness affordable to overcome, so as with the minimal safe velocity in the open water – for the insufficient ice categories of the ship.

Despite the convention of various indexes of the ship patency in ice, when finding optimal characteristics at initial designing stages, it is required the evaluation of multifunctional ice–navigating ship patency in ice considering those or other criteria, for example: the capability to overcome solid ice of definite thickness, the enough propulsive power for the ship motion in cohesive broken ice and for proper controllability of the ship in these environment, the enough strength of shell and sides overlaps of hull to overcome solid ice and the hull extremities strength, as well, as enough strength of the hull at the level of the ice–strake compression, and the other criteria of the ship strength, seaworthy and patency in ice, which is difficult to define together by the unite one index.

In the frameworks of systemic approach it is possible to establish the hierarchy of indexes of the indicated set or other, and it is possible to adhere the most important criterion of the ship performances in ice with this hierarchy as the constraint, when finding design characteristics of multifunctional ice–navigating ship, considering

that the other indexes are in dependence on selected one, assumed the most important, and are methodologically subordinated to it and will be subject for evaluation of at the next stages when finding the design particulars of multifunctional ice–navigating ship.

Assumptions of multifunctional ice–navigating ship characteristics balance, established by interdependences between these characteristics or between this or that characteristic of the ship and the independent part of this characteristic, for example, between the ship loaded displacement and its design deadweight, are specific own regularities between the ship under design characteristics in their couples and are not of physical nature and not considered by ship theory and its structural mechanics.

In the mathematical models at the initial stages of designing to determine multifunctional ice–navigating ship characteristics the balance equations are used, considered in direct form or in the differential one, for finding of the ship characteristic or its increment (the increase or reduce), in particular, the characteristic of the ship size, like its loaded displacement increment, depended on the increment of payload, assigned explicitly or implicitly, that is specified as component of design deadweight, or as function of the ship, in other words, as design constraint specified in the terms of references, for example, the maximal thickness of solid ice, affordable to overcome, given that this constraint corresponded with the other indexes of the ship patency in ice.

Design deadweight can be considered as variable characteristic of multifunctional ice–navigating ship size, on which other characteristics of size depend, as well, as its particulars at initial designing stages. In the mathematical models, developed and used for scientific studies the ship characteristic of design deadweight is understood as the biggest amount of variable items of the load, including the mass of cargo, fuel, ballast, the crew with luggage, ship stocks and the other variable components of payload, which in designing of the ship are not depended on its displacement, that is depended on the displacement formally – in zero exponent degree, in the total with the assigned constant components of the design payload, for example, the mass of main equipment, in particular, the modular one, created up to designing of multifunctional ice–navigating ship in accordance with the ship functional purpose, and the other components of the ship mass, which in designing of the ship do not depend on the ship loaded displacement.

Since in the process of multifunctional ice–navigating ship characteristics finding the parameters, in other words, the design particulars of the ship, which are the characteristics of the ship subsystems, are design constraints along with data, that is with assigned constraint characteristics of the general system, to which

the ship under design refers as subsystem. The relevant form of the constraints account is the parametric dependences of the ship particulars on its characteristics including in the mathematical models. In the internal optimization designing tasks, when the design particulars of the ship are determined, and the characteristics of the ship found previously are the design constraints in the form of input data, the values of design particulars are found on the basis of the use of optimization approaches or by the other own methods of ship particulars finding, and intervals of design particulars variation wherein are rather narrow and are depended on the particulars, determined approximately at the determining of multifunctional ice-navigating ship characteristics. Approximal values of the particulars got previously with the parametric dependences are used when optimizing the ship design characteristics.

Finding of optimal design characteristics of multifunctional ice-navigating ship is carried out with the use of the economic criteria. It is known, that the variety of these criteria could be consolidated in two groups: the criteria, which are indexes of costs, including as the one-time investment, so as the annual costs (the cash flows of costs), which is possible to generalize by their present worth, and the criteria, based on the accounting of the income and profit, along with the costs, including the criteria of profitability and the payback period, or the methodologically comparable indexes with these two groups. It is indicated in the example, considered in the study, that by these criteria use it is possible to determine optimal design characteristics of cargo ship, assigned for batch construction.

When finding optimal design characteristics of multifunctional ice-navigating ships, which primarily are created with the budgetary subsidies, the use of the minimized criteria of efficiency, based on the evaluation of costs, is likely relevant. In the same time the opportunities have to be considered of the ship use for corporate (extra budgetary) income reception and the amendment to the costs efficiency criterion of multifunctional ice-navigating ship. That is the reference to one of the indicated groups, defined by the attribute of the costs, include in the criterion or of the incomes and profit, besides of costs, because the opportunities of multifunctional ice-navigating ship use for reception of corporate (extra budgetary) income are to be considered, and the amendment to the costs in efficiency criterion is applied in this case.

For determining of optimal design characteristics of multifunctional ice-navigating ship the efficiency criterion is used in the form of objective function in mathematical model, that is the form of its dependence on the values of: the independent variables, in other words, the ship characteristics sought, varied for finding of their optimal values, and the design constraints (the input data, specified in the terms of references), containing the characteristics of general system, to which

the ship under design methodologically belongs as subsystem, and the constrained parameters, that are adopted particulars – the characteristics of subsystems of the ship under design.

Dependence of efficiency criterion on characteristics of multifunctional ice–navigating ship, varied along optimization, on initial data and on parameters, is provided in developing of objective function, which is the generalization of indexes of one–time (the initial) investments in ship construction and the annual costs, deducting the amendment of expected extra budgetary income, and these indicated three economic indexes (the investments, costs and the amendment of costs for extra budgetary income) are generalized in the composition of criterion and objective function. These three economic indexes are themselves the functional dependences on listed variables, data and parameters, on which the utility function depends, as well, that is the index of effect, included in composition of economic criterion of the present worth, which is determined per unit of effect.

Annual cargoes carrying capacity is usually the utility function of merchant cargo ship, assigned in the batch construction. The effect index in the composition of efficiency criterion of multifunctional ice–navigating ship at initial designing stages characterizes as the ship utility for servicing in ice of ships, not having the ice category or having the insignificant one, so as the own autonomous operation in frozen seas of the ship under design, it's work of cargoes transportation and etc. Size characteristic of multifunctional ice–navigating ship can be used as the effect index in the composition of economic criterion, when finding the ship optimal design characteristics, since the ship size can characterize its utility performances in the ice: on one hand, the volume of works provided by the ship navigational servicing of the others in solid ice of assigned thickness, in particular, to characterize the size of the channel to be laid in ice field, on the other hand, the ship size can characterize the space onboard available for arrangement of not only the cargoes, but the ship functional parts, indicated in the terms of references of the ship under design, assigned for the fulfillment of the rescue tasks, the patrol or the other ones, of the arrangement of assigned in the terms of references the off–board equipment: the submarine vehicles, the helicopters and etc.

When using the characteristic of size as the utility function of multifunctional ice–navigating ship and index of the effect it is of interest, that this index could be as well the independent variable design characteristic of the ship when finding its optimal size at initial stages of the ship designing. Variant study shows, that the size of multifunctional ice–navigating ship is in close proportional interdependence with the cargoes carrying capacity. When using one of these two characteristics

(that is the ship size or its annual cargoes carrying capacity) as the utility function in composition of optimality criterion it is possible to consider they are interchangeable in the broad intervals of the variation, that is the location of the optimal extremum of objective function and the corresponding values of sought optimal characteristics of multifunctional ice-navigating ship practically does not depend on the choice of one of these alternatives as the effect index: or the cargoes carrying capacity of the ship, or its size.

Besides of versatile performances of multifunctional ice-navigating ship size characteristic, which indicates as the sought design characteristic, renowned versatility as well can be referred to the ship performances in ice, in particular to the design constraint of limiting thickness of solid ice, affordable to overcome, which corresponded with ice category of the ship, or with the ship icebreaking class, and as well, with the other dependent performances of the ship in frozen seas. In other words, the design constraint of the thickness of solid ice, attributed to initial data set, in the same time indicates the characteristic of multifunctional ice-navigating ship.

Factor of investment constraint of the budgetary subsidies is taken into account by the penalty (or premium) amendment to the objective function. For the creation of multifunctional ice-navigating ship (the designing, construction and equipping, etc.) the investment constraint of provided budgetary subsidies is conventional in definite degree, since in addition to budgetary subsidies it is possible to raise funds from the extra-budgetary sources by the corresponding market cost of the capital under reasonable commercial interest of the investors. Considering the symmetry of approach, the premium amendment is applied as well besides of penalty one to the optimality criterion while saving the budgetary subsidies, when the compact multifunctional ice-navigating ship could be created, which would nevertheless meet all relevant design constraints, including the investment constraint, and in such a compact size will be the optimal according to the criterion used.

In finding of optimal design characteristics of multifunctional ice-navigating ship the evaluation of input data is of the great importance, which are the design constraints, that is the characteristics of general system, to which the ship belongs as the subsystem, and the parameters, in other words, the assumed design particulars of the ship. It is possible to attribute the ship to number of objects, for which the determining of data for designing is of difficulty, and the data errors can emerge.

On the stage of the ship designing, constructed for decades, in this or that distant prospective one cannot know in the details the required functional purpose of the ship in future and the other design constraints, which would be relevant, for example the ice category assigned for designing of ship, the districts of navigation,

the economic conditions and other data, which will be characteristic in the future. For this reason, the optimal characteristics of multifunctional ice–navigating ship, got at initial designing stages, must be of the enough sustainability, and expected changes of the data, relevant in the future, would not negate the choice of optimal characteristics of the ship under designing. Variant calculations confirm sustainability of optimal design characteristics of multifunctional ice–navigating ship, determined in accordance with concepts of the systemic approach and with use of appropriate objective function and design constraints.

Optimal design characteristics of multifunctional ice–navigating ship depend on the investment constraint of subsidies in ship construction. For smaller budget subsidies the optimal ship is of more compact design. Although the additional extra budgetary subsidies can be used, the amount of which is not the design constraint. Since the federal budget subsidizes are provided for creation of the ships and the development of shipbuilding yards and plants, then the budgetary subsidies is distributed systemically by the purposes of investing and by the individual objects, considering the risks inherent in the objectives of subsidizing. This is taken into account when finding the investment constraint, impacting the optimal design characteristics of the ship, in particular on the ship size.

Values of the initial data and the parameters are determined in the adjacent tasks: in external designing task, when determining the characteristics of general complex system, to which the multifunctional ice–navigating ship belongs as subsystem, and in the internal designing task, when finding characteristics of each individual subsystem of complex ship, that is the ship design particulars. The integrity of the system of external and internal designing tasks in the composition of the multilevel approach is linked with that the ship under design methodologically represents the object at both specified hierarchical levels, at which the ship is indicated by its design characteristics and particulars.

In the set of examples of the general system, to which the ship of definite type, in particular, the mass constructed cargo ship, belongs as subsystem, one can designate: the complex of the marine company assets, which part is the ship under design, the fleet of the merchant ships when determining the fleet composition, the ocean freight traffic, the ocean fishery expedition and etc.

Besides, with regard to ships of innovative assignment, including multifunctional ice–navigating ship, which creation is provided according with the Shipbuilding Industry Development Strategy and with the Federal programs, it is possible to extend the list of examples of the general objects, to which the ship belongs methodologically as subsystem, and to indicate follows: innovative function, specified

by the ship purpose, the innovative functional element of the ship or innovative equipment, that is the complex of the elements, created for the ship and assigned in the terms of references for the ship design, the special shipbuilding technique and facilities, which is assigned in the terms of references and in the contract for ship construction, if the shipyard is specified as the constraint for the ship designing, etc.

In each designing task for finding of constraints (the design data) no one and the number of indicated and other possible samples of general system can be usually combined in this or that degree. That is the general system, to which the multifunctional ice–navigating ship belongs as subsystem, is not so much this or that particular example, which in the most degree would correspond the assigned general purpose, as much the methodological concept, which is characterized by the set of attributes, relevant various options of general system, considered in the examples and others.

It is possible to indicate the attributes of general system among the follows: property attribute of the independent purpose of created ship and of it creation process, aimed at economic result; industrial technique attribute of the ship construction purpose, indicating the independent value of the creation of new opportunities in shipbuilding; attribute of the structural purpose, indicating the value of creation of main system of the ship in the case, if this or that it equipment, which is not batch produced, is worked out specifically for this ship creation; attribute functional purpose of the ship creation, characterizing the value of ship functional assignment, defined in particular by the Shipbuilding Industry Development Strategy and the Federal programs in shipbuilding industry and in shipping. These and other possible attributes of methodological concept of general complex system, to which the created innovative ship, in particular, multifunctional ice–navigating ship belongs as the subsystem, can characterize this or that own goal of the budget subsidizing in shipbuilding.

For construction of multifunctional ships for ice navigation, which are needed by the Shipbuilding Industry Development Strategy and the Federal programs, it is required the renewal of shipbuilding industry in the organizational and in the technological respects. Besides of the various levels of industrial and territorial administrations, subsidizing the development of fleet and the shipbuilding industry, the other participants in the developing of the innovative shipbuilding can be the existing shipbuilding enterprises, the navigation companies, the financial institutions, the universities and colleges, which are interested in establishing of relevant departments on own bases and in the introduction of new curriculums.

Need to create specialized shipyards, assigned for assembling of the ships of modular blocks and structural parts, arises to reduce the duration of construction and the costs since technological cooperation, in which several hull production workshops or plants could work together in cooperation for common orders. Additional benefits of modular shipbuilding technology are associated with a reduction of amount of the «frozen» funds in the work in progress and with possibility of participation of individual shipyards producing modules and parts of large-tonnage ships in partnership with shipyards, capable to assemble and launch the ships of this size.

Large-tonnage assembling shipyards can serve the basis for formation of shipbuilding associations of serial ships construction, created, for example, in the form of technologically integrated holdings of the shipbuilding plants, which construct the structural modules and deliver them to the assembling shipyard. Possibilities of increasing of size of the ships under assembling, is technological limitation and general characteristic of the shipyard, corresponding the concept of environmentally friendly shipping, since larger Green Ships are characterized by lower consumption of fuel per unit of cargo transportation, or per unit of another utility index.

Innovative shipbuilding, in particular, the construction of multifunctional ice-navigating ships are usually aimed at creating ones that have not been sufficiently mastered by mass production, therefore, local demand for them, for example, the national one, exceeds supply, which is the reason for the investment attractiveness. The construction of ships in accordance with the pilot program of orders coming in, for example, by the investors creating the shipyard, can serve the original purpose beyond competing with existing shipyards, which are characterized by advanced mass shipbuilding. As shipyard experience is gained, the technological facilities are renewed and replenished, and pilot orders from the investors and founders are completed, it is likely that the approach and order line will change in accordance with market demand, as well, as the assembling shipyard engaged in serial shipbuilding for this purpose will cooperate with the shipbuilding plants.

Shipbuilding and navigating companies are in the system of industries links, while the demand for new merchant ships is of international nature, is formed in the maritime shipping, which serves the source of investments for the shipbuilding, both directly, when ship are built by order of navigating companies, and indirectly, if investments come from partners, which can be departments or organizations of various profiles, including the financial institutions, the funds and leasing companies ultimately acting in the economic interests of the navigation companies, and pre-subsidizing the construction of the ships.

Decision of issues, specified in the Shipbuilding Industry Development Strategy and in the Federal programs, can generally be implemented in three directions: construction of at the national shipyards of assigned ships in accordance with the federal needs, construction for the federal demand of specified ships at the shipyards in the overseas, or the investing not directly in the construction of ships, and in the enhancement of national shipbuilding companies, which in the next will work for construction of conceptually new ships in accordance for the federal needs. The indicated directions of the decision of strategic issues in shipbuilding can in the this or that degree be combined with the international cooperation in shipbuilding industry.

With proper planning it is possible the joint participation as the administrations of shipbuilding industry development, so the corporate investors national and foreign. The construction of ships of the innovative types, including the multifunctional ice-navigating ships, at the renewed and reconstructed shipbuilding plants, repurposed for production of the ships modules and parts, and united by the assembling yards, could be driving motive for the indicated repurposing of the plants for production of structural modules, for creation of the assembling shipyards and for uniting of the indicated enterprises in the shipbuilding joint stock complexes (the holdings).

Implementing of the national strategy of shipbuilding development aimed at the following general results: creation of the innovative ships, including the multifunctional ice-navigating ones, completion of the reconstruction and the repurposing of existing shipbuilding plants and creation of the assembling shipyards, cooperation of the assembling shipyards and the shipbuilding plants for mass assembling of structural modules of ships, redemption of the created assembling shipyards in the investors' property, which are funded by federal subsidies and by the corporate money from the private markets, and the refund of the federal subsidies to the budget by the participants, that is by the owners, having the property in shipbuilding enterprises, completion of planned number of jobs at new assembling shipyards and at renewed plants, development of scientific studies, of training system, etc.

Checklist

566. Multifunctionality of ice-navigating ships in the most general approach, considering it relevance for two industries: shipbuilding and the navigation, like for satisfaction the federal demand to replenish fleet of the ships of this class

and as first step object of national shipbuilding industry improving out of competition with highly developed batch construction of the ships of general classes for international market.

567. Multifunctionality of ice–navigating ship in the process of finding of it design characteristics and particulars, that is two functions at least, the first – overcoming of ice, the second – two functions likely – the autonomous navigation for other functions: transportation, delivery, accommodation and support, navigation and rescue works, etc., and the servicing in ice of other ships, which do not have ice category or have the insignificant category.
568. Specialization of purpose of mass constructed merchant ships, not assigned to navigate in frozen seas, in particular, the specialization of cargoes transported ships, of the mass constructed fishery ships, the support ships (the auxiliary), the ships of technical purpose and etc.
569. Relevance to use design methods for determining of characteristics and particulars of multifunctional ice–navigating ship, based on the systemic approach, on criteria optimality and objective functions, as well, as on the design constraints, that is to use the designing approaches less dependent on the availability of required prototypes, as the multifunctional ice–navigating ship is of innovative nature.
570. Concept of multifunctional ice–navigating ship general system, to which the ship belongs as subsystem, and concepts of the ship subsystems, that is in each case the integral ship, studying from the point of view of this or that it individual property, or the structural part of the ship under design, attributing to the set of these parts the ship hull or it parts, the devices, the gears, the systems, the machinery, the electric mechanisms, etc., considering subsystem as the physical object (the integral ship under design or it part) and the methodological concept, correspondingly.
571. Dialectic feature of systemic approach, combining the subsystems in the integral ship the new property of the ship emerges, which is absent in it individual subsystems, and emerged property is of first importance in determining of the ship optimal design characteristic within the systemic approach, for example, combining of the ship hull with it cargoes capacity and the propulsion complex, characterized by power, the ship property to carry cargoes emerges, which is absent in assumed individual hull and propulsion complex.
572. Systemic hierarchic levels, which includes the general system, to which the ship belongs as the subsystem, as well, as the level of all subsystems the ship (the physical parts of ship, or the individual performances of the integral ship),

for which the ship is the general object, and the new performance of the ship, absent in it individual subsystems, emerges, when combining these subsystems together.

573. Issue of classification of the mathematic values describing the ship under design, included in the mathematical models within the systemic approach: the independent variable characteristic of the ship, studied subject to their optimal values, the data (the design constraints) – assigned in terms of references characteristics of general system, to which the ship belongs as subsystem, the parameters, assumed the constraints when determining optimal characteristics, that is the characteristics of the ship subsystems (the particulars of the ship).
574. Comparability systemic concept of design options of multifunctional ice–navigating ship, when these options comparing to find the optimal one, defined as the similarity of design constraints for all compared options, that is the equivalence of the input data, assigned in the terms of references, this means that for each option comparable it is similar the general system, to which the ship belongs as the subsystem.
575. Analogy of systemic comparability concepts of design options of the ship, when it optimal design characteristics are determined and the hydromechanics similarity criteria (Froude, Reynolds and Strouhal, others), necessary for comparability of the models with different characteristics, when their hydrodynamic resistances are tested.
576. Assessments of multifunctional ice–navigating ship properties for determining of it particulars are performed on the bases of the ship theory, it structural mechanics and the other appropriate approaches and criteria, the systemic approach and design optimization by objective function and the economic criteria for finding of the ship particulars are of minor importance, compared with determining of design characteristics of the ship.
577. Insufficiency of physical properties (the seaworthy, patency in ice, strength, etc.) of multifunctional ice–navigating ship to determine the set of it independent optimal design characteristics, got with use of economic criteria, objective function and concepts of systemic approach, considering dependence of the ship particulars on this set of optimal design characteristics and on indicated physical properties of the ship.
578. Assigning the set of optimal independent design characteristics of multifunctional ice–navigating ship, got with use of economic criteria, objective function and concepts of systemic approach, to determine of the rest design characteris-

- tics (the dependent) with use of balance ratios of the probabilistic nature, in particular, to determine the ship loaded displacement, or design deadweight, or the tonnage, or the other appropriate indexes, which are not in the set of independent variable characteristics.
579. Exclusion of the dependent variables from set of independent characteristics of multifunctional ice–navigating ship and reduce of the designing task dimension, using the links of the probabilistic nature between the ship characteristics (the balance assumptions).
 580. The probabilistic interdependence of multifunctional ice–navigating ship loaded displacement and its independent part – the design deadweight, established by these indexes balance assumption and allow to reduce the dimension of the issue of determining of optimal characteristics of the ship size.
 581. Ratio between multifunctional ice–navigating ship loaded displacement and its cargo capacity when designing the ship is not this or that one factor or the ship physical feature but is the probabilistic impact of great number of factors.
 582. Structural features, hull shape, propulsion and the control equipment of ice–navigating ships and these characteristics differences from ones of the ships, not having ice category.
 583. In the experimental formulas, which are available to determine the ship motion resistance in ice, the required amendments with use of the analogues data (of their propulsion power, size and observed patency in ice) means adjustment of assumptions from the experimental ones, when the ship moves continuously and overcomes solid ice by motion the only, to practical approaches of ice of maximal thickness overcome by motion accelerations, using trim system, if available, and the fore propellers control of water pressure under ice layer, etc., and so final recommendations to determine resistance in ice at initial designing stages are superposition of the assumptions.
 584. Diversity of multifunctional ice–navigating ship patency in ice criteria: capability to overcome solid ice, enough propulsive power motion in cohesive broken ice and for proper controllability, enough strength of shell and sides overlaps and the hull extremities strength, enough strength of the hull at the level ice–strake in the compression and the other criteria of the ship strength, seaworthy and patency in ice.
 585. Systemic hierarchy of indexes of multifunctional ice–navigating ship patency in ice at its initial designing stage, when determining the ship characteristics, assuming the most important index of the ship patency in ice and subordinating

the others to the selected one, studying these others at the next stages, when determining the design particulars of multifunctional ice–navigating ship.

586. Probabilistic interdependences establishing the ratios between characteristics of multifunctional ice–navigating ship or between characteristic of the ship and the independent part of this characteristic for example between the ship loaded displacement and its design deadweight, are not of physical nature and not considered by ship theory and its structural mechanics.
587. The direct or differential forms of balance equations, used at initial stages of multifunctional ice–navigating ship designing for finding of the ship characteristic or its increment, in particular, the characteristic of the ship size, like its loaded displacement increment, depended on increment of payload, assigned explicitly or implicitly, as component of design deadweight, or as function of the ship, specified in the terms of references, for example, the maximal thickness of solid ice, affordable to overcome.
588. Concept of design deadweight of multifunctional ice–navigating ship, containing of the biggest amount of variable items of the load, including the mass of cargo, fuel, ballast, the crew with luggage, ship stocks and the other variable components of payload, which in designing are not depended on the ship loaded displacement, and assigned constant components of the design payload, for example, the mass of main equipment, in particular, the modular one, created up to designing of multifunctional ice–navigating ship in accordance with its functional purpose.
589. Use of the design deadweight as variable characteristic of multifunctional ice–navigating ship size, on which other characteristics of size depend, as well, as the ship particulars.
590. Relevance of account of constrained particulars of multifunctional ice–navigating ship by their parametric dependences on the variable characteristics, when determining optimal design values of these characteristics.
591. Narrowing the range of values of design particulars variation around approximal values adopted by their parametric dependences on the variable characteristics, when determining optimal design values of multifunctional ice–navigating ship characteristics.
592. Adopting got optimal design values of multifunctional ice–navigating ship characteristics as the input data (the constraint), when the design particulars of the ship are determined on the basis of optimization approaches use or by the other own methods of the ship particulars finding.

593. Two groups of economic criteria, used for determining of the ship optimal design characteristics: the criteria, which are indexes of costs, including as the one-time investment, so as the annual costs (the cash flows of costs), and the criteria, based on the accounting of the income and profit, along with the costs, including the criteria of profitability and the payback period.
594. Relevance of minimized criteria of efficiency, based on the evaluation of costs, for finding optimal design characteristics of multifunctional ice-navigating ships, which primarily are created with the budgetary subsidies.
595. Definite conventionality of criteria reference to the group of ones, associated with costs, and to the group of criteria, corresponded with the income and profit consideration, besides of costs, because the opportunities of multifunctional ice-navigating ship use for reception of corporate (extrabudgetary) income are to be considered, and the amendment to the costs in efficiency criterion is applied in this case.
596. Objective function used for design optimization of multifunctional ice-navigating ship in the form of efficiency criterion dependence on independent variables – the ship characteristics sought, and on assumed design constraints, consisting of input data, specified in the terms of references as characteristics of general system, to which the ship belongs as subsystem, and of constrained parameters, that are adopted particulars of the ship – the characteristics of it subsystems.
597. Objective function, that is the dependence of efficiency criterion on multifunctional ice-navigating ship varied characteristics, on the ship particulars and on input data, emerges when combining the indexes of the investments, costs and the amendment of costs for extrabudgetary income into unit criterion, because each of the specified indexes is the dependence on varied characteristics, on the ship particulars and on input data.
598. Use of multifunctional ice-navigating ship size characteristic as utility function (index of effect) in the composition of efficiency criterion characterizes as the ship utility for servicing in ice of ships, not having the ice category, so as the own autonomous operation in frozen seas.
599. Size of multifunctional ice-navigating ship characterizes it utility performances in the ice: on one hand, the volume of works provided by the ship navigational servicing of the others in solid, in particular, the size of the channel laid in ice field, on the other hand, the space onboard for arrangement of not only the cargoes, but the ship functional parts for the fulfillment of the rescue tasks,

the patrol or the others, of the arrangement of offboard equipment: the submarine vehicles, the helicopters and etc.

600. Combining of multifunctional ice–navigating ship properties of its size characteristic, which can be used as independent variable and is the option of the ship utility function in ice.
601. Close proportional interdependence of multifunctional ice–navigating ship size characteristic and its carrying capacity of cargoes in the broad intervals of these indexes variation, allowing to ensure, that the ship optimal size found by use of this characteristic (in particular, the design deadweight) as utility function in optimality criterion satisfies the ship optimal size in the option of carrying capacity of cargoes use as the ship utility function.
602. Versatility of multifunctional ice–navigating ship performance in ice, in particular, the solid ice thickness, affordable to overcome, which corresponds simultaneously with design constraint, assigned in the terms of references, and in the same time indicates the ship ice or arctic category, or its icebreaking class, which are the ship design characteristics and not the assigned data only, and the versatility corresponding systemic hierarchic subordination of the ship dependent performances in frozen seas, which indicates definite interchangeability of considered indexes.
603. Conventional nature of provided budgetary subsidies in creation of multifunctional ice–navigating ship (the designing, the construction and equipping, etc.), considering the ability of funding from the extra–budgetary sources by the corresponding market cost of the capital.
604. Symmetry of approach when determining the penalty (or premium) amendment to objective function, assuming premium amendment, while saving budgetary subsidies, if the compact multifunctional ice–navigating ship could be created meeting all specified design constraints, including the investment one, and if in such a compact size is optimal according to the used criterion.
605. Importance and methodological difficulty to ensure the input data for determining of optimal design characteristics of multifunctional ice–navigating ship, assuming that the ship is created for coming decades, and in this or that distant prospective one cannot know in the details the required functional purpose of the ship in future and the other design constraints, which would be relevant, for example the ice category, the districts of navigation, the economic conditions and other data.
606. Need for the property of got set of optimal characteristics sustainability of multifunctional ice–navigating ship under creation (its designing, construction

- and equipping) in case of expected changes of the data, relevant in the future, which would not negate the choice of optimal characteristics of the ship.
607. Integrity of the system of external and internal designing tasks in the composition of the multilevel approach, linked with that the multifunctional ice–navigating ship under design methodologically represents the object at both specified hierarchical levels, at which the ship is indicated by its design characteristics and particulars.
 608. Examples of the general system, to which the ship belongs as subsystem: complex of the marine company assets, which part is the ship under design; fleet of merchant ships when determining the fleet composition; ocean freight traffic; ocean fishery expedition, etc.
 609. Examples of the general objects, to which ships of innovative assignment, including multifunctional ice–navigating ship, belong methodologically as subsystems: innovative function, specified by the ship purpose; innovative functional element of the ship, assigned in the terms of references for the ship design; special shipbuilding technique and facilities, which is assigned in the terms of references and in the contract for ship construction, if the shipyard is specified as the constraint, etc.
 610. Abstract concept of general system, to which multifunctional ice–navigating ship belongs as subsystem, is not so much as particular example, which in the most degree corresponds the assigned purpose of multifunctional ice–navigating ship, as much the methodological concept, which is characterized by the set of attributes, relevant various options of general system, considered in the examples and others.
 611. Indication of general system by the attributes: the property attribute of the independent purpose, aimed at economic result; the industrial technique attribute of the independent value of new opportunities in shipbuilding; the attribute of structural purpose, indicating the value of main system of the ship, specifically created for this ship; the attribute of the ship functional purpose, defined in particular by the national strategy of shipbuilding development.
 612. Other participants, besides the administrations, subsidizing the development of fleet and the shipbuilding industry, are: the existing shipbuilding enterprises, navigation companies, financial institutions, universities and colleges, which are interested in establishing of relevant departments on own bases.
 613. Technological cooperation of assembling shipyards and the shipbuilding plants reduces the duration of construction and the costs, as well as the «frozen» funds in the work in progress.

614. Recommended form of technologically integrated holdings of the shipbuilding enterprises association, founded on the bases of large-tonnage assembling shipyard, associated with the shipbuilding plants, which construct the structural modules and deliver them to the assembling shipyard, promotes the market demand for construction of the ships of any tonnage to the plants.
615. Innovative shipbuilding aimed at local demand, for example, the national one, which exceeds supply for construction of multifunctional ice-navigating ships is usually aimed at creating ones that have not been sufficiently mastered by mass production, as the experience is gained, the technological facilities are renewed and replenished, and pilot orders from the investors and founders are completed, it is likely that the approach and order line will change in accordance with market demand.
616. Maritime shipping is source of investments for the shipbuilding, both directly, when ships are built by order of navigating companies, and indirectly, if investments come from partners, which can be departments or organizations of various profiles, including the financial institutions, the funds and leasing companies ultimately acting in the economic interests of the navigation companies.
617. General directions of national shipbuilding development strategy implementing: construction of at the national shipyards of the ships of assigned types for the federal needs, construction of these ships for federal demand at the shipyards in the overseas and investing in the enhancement of national shipbuilding companies, which in the next will work for the federal needs too.
618. Expected results of national shipbuilding development strategy implementing: creation of the innovative ships, including the multifunctional ice-navigating ones, reconstruction and the repurposing of existing shipbuilding plants and creation of the assembling shipyards, cooperation of the assembling shipyards and the shipbuilding plants for mass assembling of ships, redemption of the created assembling shipyards by the investors and the refund of the federal subsidies to the budget, completion of planned number of jobs, development of scientific studies, of training system, etc.

Legend, the definitions, dimensions and abbreviations

D – loaded displacement of multifunctional ice–navigating ship (the cargo waterline displacement, the ship loaded displacement, mass of the loaded ship at the load–line), the mass of full loaded and equipped ship with all assigned cargoes, the mass of displaced water at the cargo waterline draught, ton.

DW – design deadweight (the deadweight at the load–line draught), ton; terminological clarification: in the mathematical models of optimization the design deadweight DW contains the maximal total of variable loads: cargoes, fuel, supply, ballast, the residual bilge water or the water on the deck, the crew with luggage, ship stocks and other maximal of variable summands, which is usual for determining of deadweight in operation of the ship, and besides of listed items the design deadweight consists the constant summands of payload, assigned in the terms of references for designing, that is the mass of main equipment, for example, the modular equipment created before designing of the ship in accordance with the ship assignment, and the another items of ship mass, which in the designing of multifunctional ice–navigating ship do not depend on it loaded waterline displacement D , in other words, the items of the ship mass, depended on displacement with zero exponent index (D^0).

PG – cargoes capacity of the ship, the greatest onboard amount of cargoes (the mass), assigned in the terms of references (the design cargoes capacity), ton.

$[PG/DW]$ – coefficient of utilization of multifunctional ice–navigating ship design deadweight by cargoes capacity.

$P(D^{A_n}, Z)$ – component of ship displacement empty (ton), dependent on the ship loaded displacement D of multifunctional ice–navigating ship and on assigned data Z .

DP – the displacement empty of multifunctional ice–navigating ship, ton; the total of the components: $P(D^{A_n}, Z)$, dependent on ship displacement and on assigned data Z .

n – ordinal number of the balance equation of summand (of the summand of displacement empty), dependent on cargo waterline displacement D .

A_n – index of exponent degree of the ship loaded displacement for n –th summand in the equation of balance.

D_{MIN} – minimal displacement, at which the ship can overcome solid ice of the specified thickness h by continuous motion without cyclicity and without

the use of special systems for ice overcoming (the trim system, the ballast, the propellers in the bow and etc.), the minimal constraint of the ship loaded displacement in designing of multifunctional ice-navigating ship, ton.

GRT and *NRT* – gross and net register tonnages.

PFL – design stock of bunker fuel onboard (the maximal mass of fuel, the specification stock of fuel), ton.

PBL – water ballast mass (the maximal assumed water ballast), ton.

Ne – effective power when ship moving in open water (the propulsive power in open water) corresponding the total shaft power on the flanges of propulsion motors, kW or MW.

v_s – operating velocity of the ship (the index of design velocity), knots.

v_0 – relative velocity of the ship to wave profile (the index used when determining the wave pressure on the ship sides), m/s.

v – velocity index for determining of pressure when hitting the edge of ice, m/s.

v_D – allowed safe velocity of the loaded ship at the draft of cargo waterline in the autonomous navigation in broken ice, knots.

N_{ICE} – propulsive power in ice, required when overcoming by continuous motion of the ship of solid ice, which thickness is assigned in the terms of references directly or as the ship ice category, kW or MW.

CA – Admiralty coefficient for determining of effective power, when moving with operation velocity v_s in open water, $\text{ton}^{2/3} \times \text{knot}^{2,5} / \text{kW}$.

NP – total power of generation sources of ice-navigating ship, kW or MW; the capacity of the ship power installation.

X – set of the independent variables (the vector, number); combination of sought design characteristics of multifunctional ice-navigating ship, varied for determining of their optimal values, for example, the design characteristics of the ship include the following set: *D*, *DW*, *PG*, *GRT*, *NRT*, *Ne*, N_{ICE} , v_s and etc., in the case of the internal designing issue the other examples of variables are: *L*, *B*, *H*, *T*, δ_w , *L/B*, *B/T*, *H/T*, *L/H*, etc., and the mathematic values listed above (*D*, *DW*, *PG*, *GRT*, *NRT*, *Ne*, N_{ICE} , v_s , etc.) for the internal issue are the data set.

x – variable of set of variables (the ship design characteristic sought).

L – design length, the length of multifunctional ice-navigating ship cargo waterline (m), the length between bow and the stern perpendiculars according to theoretical drawing of the ship, or the length of theoretical cargo waterline considering the close similarity of these indexes and they probable difference within 3 %.

B – breadth of multifunctional ice-navigating ship, m.

H – the hull depth – the height from the main plane (the bottom plane) up to the deck of watertight transverse bulkheads, m.

T – cargo waterline draught at the middle ship (the design draught), m.

δ_w – coefficient of overall completeness of the ship hull shape.

LOA – overall length of the ship (the length over all), m.

L/B , B/T , H/T , L/H and etc. – ratios of multifunctional ice–navigating ship design particulars, the relative values of the ship particulars.

Y – set of parameters (the vector, number); the combination of design particulars of multifunctional ice–navigating ship; the characteristics of the ship structural elements; the characteristics of considered individual performances of the integral ship; the design particulars are specified for determining of the ship optimal design characteristics in composition of the constraints, to which the parameters are referred along with the data; the examples of the ship design particulars: L , B , H , T , δ_w , L/B , B/T , H/T , L/H and etc. for considered examples of the characteristics (D , DW , PG , GRT , NRT , Ne , N_{ICE} , v_S and etc.).

y – parameter of the set of parameters Y (the characteristic of the ship subsystem), the constraint of multifunctional ice–navigating ship design particular, specified when finding the ship optimal characteristics of the variables set X .

Z – set of initial data (the vector, number); the constraints and data, assigned in the terms of references for designing of multifunctional ice–navigating ship; the vector or data set, which are characteristics of general system, to which the ship belongs as the subsystem; the initial data are the design constraints for determining of the ship design characteristics, the same as the parameters are; the examples of assigned initial data are: the investment constraint of provided subsidies RC^* , the thickness of solid ice h , affordable to overcome; in the case of internal designing task, when finding the ship design particulars, considered as variables (L , B , H , T , δ_w , L/B , B/T , H/T , L/H , etc.), the mathematic values listed above: D , DW , PG , GRT , NRT , Ne , N_{ICE} , v_S and etc., when finding the ship design particulars, are not variables and belong to data set as well.

z – data (the initial data, the input data); the index of the set of data Z ; the design constraint, specified when finding the optimal design characteristics X ; the data index characterizing the general complex system, to which the ship belongs as the subsystem.

ΔD – given increment of the displacement, ton.

dD – resulting increment (the full) of the displacement, $dD = \eta_N \times \Delta D$, ton.

$\sum_n d(P(D^{A_n}))$ – given increment of the displacement, ton.

$\sum_n \Delta(P(\Delta Z))$ – implicitly assigned ship load increment, ton.

$\Delta P(h)$ – mass increment of hull (ΔP), corresponded with extra thickness of side shell ($\delta - \delta_{MIN}$), dependent on assigned design constraint of maximal thickness of solid ice h affordable to overcome, ton.

ΔD_P – given increment of multifunctional ice–navigating ship displacement, given the increment of hull weight $\Delta D_{P(h)}$, considering increment of assigned design constraint of solid ice thickness h , affordable to overcome, ton.

dD_P – resulting (full) increment of the ship displacement considering the change of assigned design constraint of thickness h of continuous ice: $dD_P = \eta_N \times \Delta D_{P(h)}$, ton.

ΔDW – increment of design deadweight (the assigned constant part of design deadweight), ton.

ΔZ – increment (the deviation, variation) of data of the set of design constraints, for example, increment of specified thickness of solid ice (Δh) affordable to overcome.

η_N – the Norman factor, the ratio between the caused increment of the ship displacement, determined by differentiation of the ship displacement balance equation, on one hand, and the total of explicitly and implicitly assigned increments of load components in composition of the displacement balance equation, on other hand.

S_O – shell area of the ship hull, including the area of the wetted surface and the freeboard surface, sq. m.

Ω – area of the wetted surface of the ship hull, sq. m.

k_T – factor of wetted surface area.

α – angle of ice–navigating ship cargo waterline entry (the angle of fore sharpening of the ship waterline shape).

β – angle of ice–navigating ship sides slope (the angle of zero theoretical frame inclination to the diametral plane).

φ – angle of ice–navigating ship stem tilt to main plane (or to waterline plane).

F – function of ice–navigating ship bow shape.

f_D – dynamic friction coefficient of the ship hull on ice (the indicator equal of about $f_D \approx \dots 0.10$, dependent on properties of ice).

$IceQ$ – generalized criterion of the ship seaworthy and patency in ice, knots×m.

h – maximal thickness of solid continuous ice, affordable to overcome, specified in the terms of references for designing of the ship of the corresponding ice category, that is the limiting thickness with the assigned requirement of exclusion of the ship running performances and patency in ice lost, m.

h_1 – limiting thickness of the breakable ice, which is critical for loss of the ship running performances, while avoiding the danger of the «ice captivity», m.

h_2 – limiting thickness of ice critical for strength of the ship hull, m.

S – index of broken ice cohesion, point.

a_P, R, F, f_{ICE} – characteristics of ice edges and the ship hull shape in contact area.

p_{ICE} – design pressure of ice; the ice crushing pressure in the contact area, in particular the pressure crushing solid ice, MPa.

p – limiting pressure, which the side shell can withstand in the composition of the floors with transverse framing, MPa.

a – smaller size of the shell plate under the pressure (equal to spacing of transverse framing).

b – bigger size of the ship hull shell plate.

m_a and m_b – indexes of mechanical hinges resistance in the lengthwise and crosswise sections of sides floors, N×m.

a_{ICE} – length of the contact spot under ice pressure, m.

b_{ICE} – height of the contact spot under ice pressure, the height of ice load distribution, m.

σ_0 – yield stress of the structural steel, MPa (N/mm²).

δ – thickness of shell, dependent on solid ice thickness design constraint and on the ship ice category (or arctic one, or on its icebreaking class), required for the ship strength ensuring with the account of the wear margin, mm.

δ_{MIN} – minimal thickness of the ship hull shell (mm), determined in accordance with recommendations of the Register, depended on the ship size.

$\Delta\delta$ – thickness margin for the wear of the shell plate elements, which standard operation term exceeds 12 years, mm.

u – average annual decrease of thickness of the outer shell of multifunctional ice–navigating ship, mm.

a_0 – standard spacing, determined by recommendations of the Register, m.

m – coefficient of side shell bending moment.

k_σ – coefficient of normal stresses, characterizing the ratio of shell plate sizes.

p_W – design pressure without ice load due to the ship motion along the wave profile, considering when finding thickness of shell plating by recommendations of the Register, kPa.

p_{W0} – design pressure, when finding thickness of the shell plating at the level of cargo waterline, that is at the level of the shell ice–strake, kPa.

a_X, c_W and a_V – coefficients in the Register formula 1.3.2.2–1 /137/ for determining of design pressure on the shell plating.

η – coefficient of the mechanical properties of structural steel use.

k_{ICE} – coefficient of ice category, when determining the ice loads on the fore.

u_m – maximal value of the ship bow shape factor.

T_1 – period during a year of navigation servicing in frozen seas and escort of other ships, having lesser performances in frozen seas, day.

T_2 – period during a year of the navigation functions in open water, day.

$[T_{R1}/T_1]$ – relative running time in frozen seas during annual operation period, including the maneuvering, including channels laying in solid ice, in particular, to the docks or to stationary objects, fulfillment of the rescue issues in frozen seas, support works, the training ones, navigation service and the escort in frozen seas of ships, having lesser performances in ice, etc.

ΔT_{R2} – duration of the ship maneuvering during the round trip of cargoes transportation in open water, day.

T_{CT2} – berth time during the round trip, day.

T_{R1} – running time of multifunctional ice–navigating ship in frozen seas, day.

T_{R2} – the running time of the ship in open water, day.

T_{PR2} – berth time of the ship in harbors during the round trip (the sum of time of the ship berth in points of departure and arrival), day.

T_{EXP} – annual navigation period, day.

n_{R2} – number of round trips during period of the ship navigation in open water.

k_G – loading coefficient of the ship in reverse direction of round trip.

x_Q – relative value of energy load (in proportion to the installation power), consumed for own needs of the ship docked.

y_Q – relative value of energy load (in proportion to the installation power) for power supply of serviced ships, offshore platforms or onshore.

k_{C1} and k_{C2} – generalized coefficients of the operating costs.

$q_1(N_{ICE})$ or $q_1(N_e)$ – daily fuel consumption on run in frozen sea and in open water, ton/day.

q_2 – daily fuel consumption of the ship docked with the account of own needs and the power supply of serviced ships, offshore platforms or the onshore customers, ton/day.

c_{FL} – fuel price per ton, consumed by power installation.

LR – distance from departure to destination, nautical miles; the extend of marine cargo line.

i_{CG} – price of transportation of one unit of cargo for extra budgetary customer on the line of specified extent (the sea transport tariff on specified line), thousand US dollars / ton.

i_E – price of the power supply of serviced ships, the offshore platforms or the onshore of extra budgetary consumers per unit of power delivered, thousand US dollars per kW×hour.

f – optimality criterion in the form of objective function $f(X, Y, Z)$, that is the efficiency criterion dependence on the varied combinations (the vector, set) of independent variables (design characteristics of the ship) X , parameters Y and data Z ; economic criterion of efficiency, determined by the mathematic transformations over the main economic indexes (I, C, RC or MV).

RC – reproduction costs of total projected expenses for multifunctional ice–navigating ship construction in the market prices, including the profit and taxes of the shipbuilding enterprise, million US dollars; the investment index used in the composition of the criterion and the constraints for determining of optimal characteristics of the ship, million US dollars.

MV – market value, million US dollars; the variant of investment index in the economic criterion in the case if multifunctional ice–navigating ship is purchased at the second–hand market.

i – macroeconomic index of investment risks total; the discount rate; the index of proportion of investments and cash flows; the index corresponded sum of the internal rate of return and indicator of consumer price index growth (the inflation index).

t – time variable, used for determining of economic indexes and criteria for accounting the present value of distributed cash flows, year.

C – annual operating costs of multifunctional ice–navigating ship, million US dollars / year.

C_{CR} – operating costs of crew salary annual, million US dollars / year.

C_{FCR} – operating costs of crew supply (the food, accommodation, work clothes, appliances and etc.), million US dollars / year.

C_{DCR} – operating costs for crew with luggage delivery, million US dollars / year.

C_{TXCR} – annual payments to the budget and the employees taxes, million US dollars / year.

$(C_{CR} + C_{FCR} + C_{DCR} + C_{TXCR})$ – total of operating costs, associated with crew support, million US dollars / year.

C_{FL} – operating costs for fuel of multifunctional ice–navigating ship with internal combustion engines or gas turbines, million US dollars / year.

C_{FL1} – operating costs for fuel during of period the fulfillment navigation functions in frozen seas, million US dollars / year.

C_{FL2} – operating costs for fuel during period in open water, million US dollars / year.

C_{SP} – operating costs for the ship supply, million US dollars / year.

C_{RM} – operating annual costs for the ship repairs and maintenance, million US dollars / year.

n_{CR} – number of crew, men.

c_{CR} – average annual salary per crew member, thousand US dollars / year.

OC – working assets for the ship operating costs prepay, million US dollars.

I – total annual income of multifunctional ice-navigating ship, million US dollars / year.

E – index of annual effect (the useful effect), ton (unit of ship size), or ton (the amount of cargoes transported) per year; the utility function of multifunctional ice-navigating ship; the characteristic of the ship functional efficiency; the physical (non-cash) characteristic of annual income, which is proportional to the monetary income.

Q_G – annual carrying capacity of the ship, ton/year (container/year, cubic feet/year, etc.); the characteristic of economic effect; the index of utility function of cargo ship.

CD – annual budgetary costs saving (the operating costs discount), million US dollars / year; the extra budgetary funding of income, associated with servicing of the corporate customers.

CD_1 – extra budgetary income, corresponding the fulfillment of marine transportations in open water for the extra budgetary customers, million US dollars / year.

CD_2 – extra budgetary income, corresponding the power supply for the extra budgetary consumers on the serviced ships, the offshore platforms or the onshore, million US dollars / year.

PW – minimized criterion of comparative (the relative) effectiveness of present worth $(C+(RC+OC)\times i)$, used as kind of the objective function at the initial stages of design optimization of the ship, million US dollars / year; the discounted costs, that is the cash flow, equal the annual operating costs C with the accrual of the annual cash flow for one-time investments in the ship creation $(RC+OC)$ by the discount rate i .

PW/E – economic criterion of specific present worth per unit of the effect, US dollars / ton (for the case of size of multifunctional ice-navigating ship, considered the effect index); for the merchant ship, designed for mass construction, the economic criterion of specific present worth per unit of the annual carrying capacity PW/Q_G .

IRR – maximized criterion of overall efficiency (absolute) of the internal rate of return: $(I-C)/RC$.

RC^* – investment constraint of provided budget subsidies in multifunctional ice–navigating ship creation, including it designing, construction and equipping for the operation, million US dollars.

DW^* – constraint of the ship subsidized size (the ship size subsidized index of design deadweight) dependent on provided subsidies, ton.

$\Delta_{PW/DW}$ – absolute value of penalty (or the premium) amendment to the objective function of specific present worth (PW/DW), US dollars / ton.

$\delta_{PW/DW}$ – relative value of penalty (or the premium) amendment to the objective function of specific present worth (PW/DW).

a_F – expert factor for the amendment (penalty or premium) to the criterion of specific present worth with the account of compliance with investment constraint on subsidies in the ship construction.

RC_Σ – constraint of the investments total indicating the full subsidies, provided for funding of purposes in accordance with the Shipbuilding Industry Development Strategy and with the Federal programs.

RC_{FMQK} (or RC_K) – provided subsidies into the object (the ship under creation) of $FMQK$, corresponded the investment constraint RC^* , used when finding design characteristics, provided the total investments of the costs associated with the creation (designing, construction and equipping) of the definite object of investing, in particular the ship, are equal the investments in all purposes with the attributes: K –th function of ship under construction purpose K_{FMQ} , characterizing the value of this function assigned in the accordance with the Shipbuilding Industry Development Strategy or with the Federal programs of the innovative ships creation, Q –th structural attribute of the purpose Q_{FM} indicated the value of the main system of ship creation: the innovative engineering equipment, the gears, the structures, the mechanisms and etc., which are not the batch mastered up to the ship creation, in which design they are assigned, the main system item of ship developed before the fulfillment of the ship design and included in the set of the data (the design constraints of the terms of references), M –th the technological attribute M_F , corresponded the creation of innovative technological facilities of the shipbuilding yard, given that these facilities are closely associated with the structure of the ships under construction and are to be assigned at the initial stages of designing within the set of design constraints in the terms of references, with regard the required suitability of ship under design for it creation with the use of the indicated innovative technological facilities, F –th the attribute of economic payback and self–sufficiency (attribute of the property possession nature), aimed at the economic result and at subsidies and extrabudgetary capital cost refund.

DW_K (that is DW_{FMQK}) – K -th size, in particular, the design deadweight of K -th created ship (that is $FMQK$ -th) for K -th attribute of the intrinsic value of functional assignment of the ship under construction K_{FMQ} , Q -th attribute of the intrinsic value of the ship of innovative structural type Q_{FM} , M -th attribute of the intrinsic value of the innovative shipbuilding technology creation, assigned for construction of this ship M_F for F -th attribute of the economic self-sufficient (the self-sufficiency) purpose of the subsidizing.

rc_{FMQK} – specific index of the subsidies per unit of the ship size (rc_K – the index in symbolic notation) for the functional attribute of purpose of the ship creation, characterizing the intrinsic value of the ship function, determining according with the Shipbuilding Industry Development Strategy and with the Federal programs in the form of ships under construction assignments.

i_K – risks of investments index in the indicated purposes (K -th).

rc_F and i_F – specific index of the subsidies per unit of the ship size and index of the risks of investing in the economic purposes (the self-sufficiency), aimed at economic result, evaluated by the concepts of economic payback and refund of subsidies in the budget and payment of the capital cost, or selling to another corporate investor with same self-sufficient purpose.

rc_M and i_M – specific index of the subsidies per unit of the ship size and index of the risks of investing in creation of the innovative technological opportunities and facilities in the shipbuilding, which can be assigned at initial designing stages as the constraint with regard to required suitability of ship construction with use of created innovative technological facilities.

rc_Q and i_Q – specific index of the subsidies per unit of the ship size and index of the risks of investing in creation of the main system of the ship, which characteristics are the design data of innovative engineering equipment, gears, structures, the part of the ship equipment and structures, etc., not serially mastered up to the ship creation.

rc – specific indicator (the investment constant), that is characteristic of specific investment per unit of the ship size, used in the equation of investments total balance.

Following general rule applies for units, used in the formulas, and for dimensions: if in the used legend the dimension is not indicated, then the any appropriate dimension can be used, obviously with consideration of the conformity of data dimension and the results dimensions.

Bibliography

1. Adamenya A.I. How to revive shipbuilding in the Far East? Domestic shipbuilding should adopt the experience of creating vertically integrated holdings in the industry. Information agency «Prima Media» 19.10.2006, <http://primamedia.ru/>
2. Adrian Biran. Ship hydrostatics and stability, 4 edition. Butterworth–Heinemann, 2003, 344 p., ISBN 0750649887, 9780750649889.
3. Anthony F. Molland Maritime Engineering Reference Book: A Guide to Ship Design, Construction and Operation – Elsevier, 2008, 902 p., ISBN 0750689870, 9780750689878.
4. Anthony F. Molland, Stephen R. Turnock Marine rudders and control surfaces: principles, data, design and applications. Marine engineering series. Butterworth–Heinemann, 2007, 420 p., ISBN 0750669446, 9780750669443.
5. Apalko T.A., Tsarev B.A. Comparison of models of design analysis of icebreakers // Morskoy Vestnik. 2010. # 3. P. 100–104.
6. Apollonov E.M., Nesterov A.B., Timofeev O.Ya. Ensuring ice strength and safe operation of ships in the Russian Arctic and freezing seas on the basis of an integrated system for the formation of fundamental engineering solutions // Proceedings of the Krylov State Research Centre. St. Petersburg, 2008. Issue. 39 (323). P. 69–89.
7. Arikainen A.I., Chubakov K.N. The ABC of ice navigation. M.: Transport, 1987. 224 p.
8. Artyushkov L.S., Achkinadze A.Sh., Rusetsky A.A. Ships propellers: textbook. L.: Shipbuilding, 1988. 296 p.
9. Ashik V.V. Designing ships: a textbook. 2nd ed., Rev. and add. L.: Shipbuilding, 1985. 320 p.
10. Azarova N.M., Rakov A.I. Choice of the objective function in design of ships in a market economy // Proceedings of the XII Far East STC «The impact of the peculiarities of the Far Eastern basin in the design and modernization of ships.» – Vladivostok: Publishing house of the Far Eastern State Technical University, 1995. P. 7–8.
11. Azovtsev A.I., Ogai S.A. Offshore all-terrain vehicles on air-supported tracks to improve the efficiency of the transport system in the Arctic. Polar mechanics: proceedings of the third international conference, September 27–30, 2016, Vladivostok / scientific. ed. A.T. Becker; Engineering School of FEFU. Vladivostok: Far Eastern Federal University, 2016. [1096 p.]. P. 483–495.

12. Azovtsev A.I., Ogai S.A., Moskalenko O.V. The DTNSRDC method in predicting the power of a seaworthy all-terrain vehicle on air-supported caterpillars with a lifting capacity of 100 ton at the initial stages of design // Marine Intellectual Technologies: scientific magazine 2017. # 3 (37), vol. 2. P. 88–92.
13. Barabanov N.V. The structure of the hull of sea-going ships: textbook. 4th ed. revised and augmented: in 2 volumes. Vol. 1: General questions of the design of the ship's hull. 304 p. Vol. 2. Local strength and design of individual hull structures of the ship. 336 p. SPb.: Shipbuilding, 1993.
14. Barrass C.B. Ship design and performance for masters and mates. Marine engineering series. Butterworth–Heinemann, 2004. 252 p. (*) ISBN 0750660007, 9780750660006.
15. Batalov E. Loss-making economy of PJSC FESRC. Business weekly «Concurrent», 02.08.2010, www.konkurent.ru
16. Ben C. Gerwick Construction of Marine and Offshore Structures – CRC Press, 2007, 813 p., ISBN 0849330521, 9780849330520.
17. Borodai I.K., Netsvetaev Yu.A. Seaworthiness of ships. L.: Shipbuilding, 1982. 288 p.
18. Boytsov G.V. Optimization of the safety margins of hull structures taking into account their influence on the indicators of the economic efficiency of the vessel // The questions of shipbuilding. Ser. 1. Design of ships. 1984. Issue. 40. P. 3–11.
19. Brahman T.R. Multicriteria and the choice of alternatives in technology. M.: Radio and communication, 1984.
20. Breslav L.B. Economic the models in the shipbuilding industry. L.: Shipbuilding, 1984.
21. Breslav L.B. Feasibility study of the facilities for the development of the World Ocean. L.: Shipbuilding, 1982. 240 p.
22. Bronnikov A.V. Design of ships: textbook. 2nd ed. revised and augmented. L.: Shipbuilding, 1991. 320 p.
23. Bronnikov A.V. On the formulation of the problem of the theory of ship design // Shipbuilding. 1974. # 11. P. 5–6.
24. Bronnikov A.V. The main components of the science of ship design // Shipbuilding. 1979. # 4. P. 3–6.
25. Bugaenko B.A., Magula V.E. Special ship devices: textbook. L.: Sudostroenie, 1983. 392 p.
26. Bugaev V.G., Voyloshnikov M.V. Concepts and criteria in the methods of optimizing designing of marine engineering complexes // Proceedings of mezh-dunar. conf. «Shipbuilding and Ocean Engineering. Problems and Prospects»

- SOPP–98. Part 1. Vladivostok: Publishing house of the Far Eastern State Technical University, 1998.
27. Carlton John Marine Propellers and Propulsion. 3rd edition – Elsevier Science & Technology, 2012, 576 p., ISBN 0080971237, 9780080971230.
 28. David G.M. Watson Practical Ship Design. Elsevier Ocean Engineering Series – Gulf Professional Publishing, 2002, 558 p., ISBN 0080440541, 9780080440545.
 29. Demeshko G.F. Ship design. Amphibious hovercraft: textbook: in 2 books. SPb.: Shipbuilding, 1992.
 30. Development of shipbuilding in the Far East. Information Agency «Science and Technologies of the Russian Federation», S&T RF, 02.10.2009, www.strf.ru
 31. Development of shipbuilding in the Far East. Website of the Ministry of Industry and Trade, 13.05.2009, www.minpromtorg.gov.ru
 32. Egorov G.V. Design of ships of limited navigation areas based on the theory of risk. SPb.: Sudostroenie, 2007. 383 p.
 33. Egorov G.V., Shtrambrand V.I. Multifunctional icebreakers and icebreakers–rescuers of the new generation / Bulletin of the Odessa National Marine University. 2012. # 34, P. 130–151.
 34. Eyres David J. Ship construction. 6 edition – Butterworth–Heinemann, 2007, 365 p., ISBN 0750680709, 9780750680707.
 35. Federal program «Development of the transport system of Russia (2010–2030)». Approved by Decree of Government of the Russian Federation, dated December 05, 2011 # 848–v.
 36. Filchenok Yu.A. Giant ships will begin to build in Bolshoy Kamen in the south of Primorye. Internet issue «DV–Ross», 19.10.2010, www.trud-ost.ru
 37. Four thousand people. will get a job at two shipyards in Primorye. RIA–Novosti news agency. 05.11.2009, <http://ria.ru/economy/>
 38. Fried E.G. Ship device: textbook. 5-th ed., stereotype – L.: Shipbuilding 1990. 344 p.
 39. Gaikovich A.I. Fundamentals of the design of complex technical systems. SPb.: Publishing house of SRC MORINTECH, 2001. 432 p.
 40. Gaikovich, A.I. Theory of designing displacement ships and vessels: in 2 volumes. Vol. 1: Description of the «Ship» system. Vol. 2: Analysis of the synthesis of the «Ship» system. SPb.: Publishing house of SRC MORINTECH, 2014.
 41. Ghose J.P., Gokarn R.P. Basic ship propulsion – Allied Publishers, 2004, 557 p., ISBN 8177646060, 9788177646061.
 42. Gillmer Thomas, Johnson Bruce Introduction to naval architecture – Naval Institute Press, 1982, 324 p., ISBN 0870213180, 9780870213182.

43. Gofman A.D. The propulsion and steering the complex and maneuvering of ship: help. L.: Shipbuilding, 1988. 360 p.
44. Gotsky M.V. Ice navigation experience. 1st ed. M.: Sea transport, 1957. 360 p.; 2nd ed. M.: Sea transport, 1961. 368 p.
45. Government has approved draft law «On support of shipbuilding and shipping» // Rosbusinessconsulting, newspaper «Kommersant». 20.05.2011, www.rbc.ru
46. Gramuzov E.M., Kalinina N.V. Investigation of the parameters of the movement of icebreakers by raids // Theory, strength and design of ships in ice: the interuniversity proceedings / NSTU. N. Novgorod, 1995. P. 43–51.
47. Gramuzov E.M., Kurnev P.A. Semi-empirical model of ice resistance of a river icebreaker // Issues of designing ships floating in ice: interuniversity proceedings / Gorky polytechnic institute. Gorky, 1988. P. 36–42.
48. Gramuzov E.M., Tikhonova N.E. Justification of the design characteristics of river icebreakers // The proceedings of Nizhegorod. state techn. University named R.E. Alekseev. # 3 (100). Nizhny Novgorod, 2016, P. 195–199.
49. Handbook on the theory of the ship: in 3 volumes / ed. Ya.I. Voitkunsky. L.: Shipbuilding, 1985. 440 p.
50. Handbook on the theory of the ship / V.F. Droblenkov, A.I. Ermolaev, N.P. Muru et al. M.: Voenizdat, 1984. 589 p.
51. Herbert Schneekluth, Volker Bertram Ship design for efficiency and economy. 2nd edition. Referex Engineering – Butterworth–Heinemann, 1998, 220 p., ISBN 0750641339, 9780750641333.
52. Class Regulations 2008 (Finnish–Swedish Ice Class Rules), Finnish Maritime Administration, Bulletin, 10/10.12.2008.
53. Intriligator M. Mathematical Optimization and Economic Theory. M.: Iris–Press. 2002. 553 p.
54. Ionov B.P., Gramuzov E.M. Ice performance of ships. SPb.: Shipbuilding, 2001. 512 p.
55. Ionov B.P., Gramuzov E.M., Tikhonova N.E. Optimization of the main design characteristics of icebreakers // Marine Bulletin. 2003. # 2. P. 33–40.
56. Ionov B.P., Gramuzov E.M., Zuev V.A. Icebreaker designing. SPb.: Shipbuilding, 2014. 512 p.
57. Kantorovich L.M. Economic calculation of the best use of resources. M.: Publishing house of the Academy of Sciences of the USSR, 1959.
58. Kashtelyan V.I., Ryvlin A.Ya., Faddeev O.V., Yagodkin V.Ya. Icebreakers. L.: Shipbuilding, 1972. 288 p.

59. Keel-laying ceremony took place at the Amur Shipyard of the second serial supply vessel for work with semi-submersible floating drilling rigs (SSDR) of project 22420 for LLC «Gazflot». Amur Shipyard, 16.02.2011, www.dv-reclama.ru
60. Khac Duc Do, Jie Pan Control of Ships and Underwater Vehicles: Design for Underactuated and Nonlinear Marine Systems – Springer, 2009, 400 p., ISBN 1848827296, 9781848827295.
61. Khordas G.S. Calculations of general ship systems: reference book. L.: Sudostroenie, 1983. 440 p.
62. Khudyakov L.Yu. Research ship design (introduction to theory). L.: Shipbuilding, 1980.
63. Klimashevsky S.N. Calculation of the patency in ice of icebreakers and ice navigation ships, the analysis of the parameters of the hull shape of these vessels // Sudostroenie. 2012. # 3. P. 11–16.
64. Kraev V.I. Economic feasibility studies in the design of sea-going ships. 2nd ed. revised and add. L.: Shipbuilding, 1981.
65. Kraev V.I., Pantin A.A. Economics of maritime transport: a textbook for cadets of navigation specialties of higher engineering maritime schools. Moscow: Transport, 1990.
66. Kulesh V.A., Ogai S.A., Pec N.G. Project of ice reinforcement of a dry-cargo vessel // Marine intellectual technologies: scientific magazine 2017. # 3 (37), vol. 2. S. 64–70.
67. Kulesh V., Vinogradova N. Standardization of Corrosion Wear of Shell Plating for Ice Ships Operations // Proceedings of the International Northern Sea Route Symposium. Tokyo. Japan. 1995. P. 425–430.
68. Law on the Northern Sea Route. July 28, 2012 # 132-FZ. The Russian Federation. Federal Law on Amendments to Certain Legislative Acts of the Russian Federation Regarding State Regulation of Merchant Shipping in the Water Area of the Northern Sea Route. Adopted by the State Duma on July 3, 2012. Approved by the Federation Council on July 18, 2012.
69. Lewandowski Edward M. The dynamics of marine craft: maneuvering and sea-keeping – World Scientific, 2004, 411 p., ISBN 9810247567, 9789810247560.
70. Lobanov V.A. Estimation ice performance of the ship by numerical methods. Differential equations and control processes. 2011. # 1, electronic journal, reg. El # Φ C77–39410 of 15.04.10.
71. Long-awaited multiplier. Far Eastern capital. 2010. # 7. 15.07.2010, www.zrpress.ru

72. Lyubushin N.P. Regularities of changes in the economic efficiency of ships // Sudostroenie. 1987. # 11. P. 12–14.
73. Materials of the meeting in Komsomolsk-on-Amur on May 12, 2009 with the participation of Prime Minister V.V. Putin on the development of shipbuilding in the Far East, www.fefish.ru
74. McGeorge H.D. Marine Auxiliary Machinery. 7th edition. Referex Engineering – Butterworth–Heinemann, 1999, 528 p., ISBN 0750643986, 9780750643986.
75. Merchant Shipping Code of the Russian Federation 04/30/1999. # 81–FZ.
76. Nesterov O.L., Ronnov E.P. Probabilistic approach to the substantiation of the main characteristics of dry cargo vessels of mixed river–sea navigation // Materials of international. scientific and technical conf. «Shipbuilding and ocean engineering. Problems and perspectives», SOPP'01. Vladivostok: FESTU, 2001, P. 76–78.
77. Nogid L.M. Design of marine vessels. The choice of shape indicators and determination of capacity of the power plant of the projected vessel. L.: Shipbuilding, 1976. 208 p.
78. Nogid L.M. The theory of ship design. L.: Sudpromgiz, 1955.
79. Novoseltsev E.M., Kholosha M.V. On the prospects of commercial shipbuilding in the Russian Far East. Shipbuilding. 2009. # 5. P. 44–48, www.dniimf.ru
80. Novoseltsev E.M., Voyloshnikov M.V. Assessment of the needs and features of approaches to the design of passenger ships for the Far East region // Materials of the international. conf. «Shipbuilding and Ocean Engineering. Problems and Prospects» SOPP – 98. Part 1. Vladivostok: FESTU, 1998.
81. Novoseltsev E.M., Voyloshnikov M.V. Efficiency criteria for prototypes of marine technology // Proceedings of the International scientific and technical conference, dedicated the 300th Anniversary of the Russian fleet. SPb.: SPbGMU, 1996.
82. Ochi Michel K. Ocean Waves: The Stochastic Approach. Cambridge Ocean Technology Series – Cambridge University Press, 2005, 332 p., ISBN 052101767X, 9780521017671.
83. Ogai S.A. Assessment of strength in the ice field of the hull taking into account the installation of additional frames to determine the characteristics of the vessel at the initial stages of design // Marine Intellectual Technologies: scientific magazine. 2016. # 3 (33), vol. 1. P. 81–85.
84. Ogai S.A., Azovtsev A.I., Moskalenko O.V. Development of a standard–size range of seagoing all–terrain vehicles on air–supported tracks for the integrated

- development of the coast and the freezing shelf // Marine Intellectual Technologies: scientific magazine. 2013. Special. # 1. P. 34–37.
85. Ogai S.A. Development of shipbuilding in the Far Eastern Federal District // Marine Intellectual Technologies: scientific magazine. 2011. Issue. 4. P. 7–15.
86. Ogai S.A. Features of determining the characteristics at the initial stages of designing a multifunctional ice navigation vessel // Marine Intellectual Technologies: scientific magazine. 2015. # 3 (29), vol. 1. P. 63–70.
87. Ogai S.A. Finding of utility function as part of the optimality criterion in determining the design characteristics of a multifunctional ice navigation vessel // Marine intellectual technologies: scientific magazine. 2017. # 3 (37), vol. 2. P. 35–45.
88. Ogai S.A. Improvement of multilevel training programs of Naval Architecture and Marine Engineering // The 26th Asian–Pacific Technical Exchange and Advisory Meeting on Marine Structures, TEAM–2012, Fukuoka. P. 59–64.
89. Ogai S.A. Improvement of the system of multilevel professional training in the direction of Shipbuilding and ocean engineering, taking into account foreign experience // Marine Intellectual Technologies: scientific magazine. 2013. Special issue. 1. P. 4–10.
90. Ogai S.A. Influence of the productivity of ocean resources on the value of the complex of assets of marine enterprise taking into account the risks of the investor's innovative strategy // Property relations in the Russian Federation. All–Russian information–analytical and scientific–practical magazine. 2012. # 5 (128).
91. Ogai S.A. International cooperation in shipbuilding and shipping taking into account the trends of economic globalization // Region: Economics and Sociology: All–Russian scientific magazine. 2012. # 4.
92. Ogai S.A. Investing in serial marine shipbuilding // Region: economics and sociology: All–Russian scientific magazine. 2011. # 4. Novosibirsk: Institute of Economics and Organization of Industrial Production SB RAS, <http://region.socionet.ru/>
93. Ogai S.A., Kulesh V.A., Voyloshnikov M.V. Classification and monitoring of the reliability of ice–strake of marine objects // Marine intellectual technologies: scientific magazine. 2015. # 3 (29), vol. 1. P. 55–62.
94. Ogai S.A., Kulesh V.A., Voyloshnikov M.V. Monitoring of the processes of accumulation of defects of steel structures over time of ships operation // Proceedings of the Twenty–fourth (2014) International Ocean and Polar Engineering Conference / Busan, Korea, June 15–20, 2014 / International Society of Offshore

and Polar Engineers (ISOPE), ISBN 978–1 880653 91–3 (Set), ISSN 1098–6189 (Set). P. 529–536.

95. Ogai S.A., Kulesh V.A., Voyloshnikov M.V. Safety and efficiency of operation of ships in ice // Marine intelligent technologies: scientific magazine. 2013. Special issue. 1. P. 11–20.
96. Ogai S.A., Kulesh V.A., Voyloshnikov M.V. The comprehensive analysis of ice-going properties of fishery vessels for the sea of Okhotsk conditions // The 27–th Asian–Pacific Technical Exchange and Advisory Meeting on Marine Structures, TEAM–2013, Keelung. National Taiwan Ocean University. P. 299–305, ISBN 978–986–03–7810–8.
97. Ogai S.A. Objective function for optimizing the design characteristics of a multifunctional ice navigation vessel // Marine Intellectual Technologies: scientific magazine. 2016. # 3 (33), vol. 1. P. 15–24.
98. Ogai S.A. Optimal design characteristics of the vessel in the complex of shipping company assets // The 25th Asian–Pacific Technical Exchange and Advisory Meeting on Marine Structures, TEAM–2011, Incheon.
99. Ogai S.A. The concept of a multifunctional ice navigation vessel and the peculiarities of the application of the systemic approach in determining the characteristics at the initial stage of designing a vessel of this type // Marine Intellectual Technologies: scientific magazine. 2015. # 3 (29), vol. 1. P. 45–54.
100. Ogai S.A., Voyloshnikov M.V. Alternatives in the implementation of the strategy for the development of the shipbuilding industry // «Transport business in Russia» scientific magazine. 2016. # 1. P. 30–34.
101. Ogai S.A., Voyloshnikov M.V. A multilevel systemic approach in determining the optimal design characteristics of ice navigation vessel // Marine intellectual technologies: scientific magazine. 2017. # 3 (37), vol. 2. 205 p. S. 318–326.
102. Ogai S.A., Voyloshnikov M.V. Defining of the utility function and its use as the part of the optimality criterion in determining of design characteristics of multifunctional ice navigation ship // The 31–th Asian–Pacific Technical Exchange and Advisory Meeting on Marine Structures. TEAM–2017. Osaka, 25–28 September 2017, Osaka, Japan: Program and Proceedings. Mokpo, 2017. P. 119.
103. Ogai S.A., Voyloshnikov M.V. Dependence of displacement on the functions in ice field of multifunctional ship // The 29–th Asian–Pacific Technical Exchange and Advisory Meeting on Marine Structures. TEAM–2015. Vladivostok, Russia. P. 95–104, ISBN 978–5–8343–0960–4

104. Ogai S.A., Voyloshnikov M.V. Design load and displacement of a multifunctional ice navigation vessel // *Marine intellectual technologies: scientific magazine*. 2015. # 3 (29), vol. 1. P. 12–27.
105. Ogai S.A., Voyloshnikov M.V. Determination of project characteristics of merchant ship using economic criteria, objective functions and concepts of systematic approach // *BIT's 4th Annual World Congress of Ocean (WCO). Symposium 7: Traditional Ocean Industry*. Qingdao, China, 2015, November 6–8. P. 76–77.
106. Ogai S.A., Voyloshnikov M.V. Economic indexes of multifunctional ice-navigating ship for determining the objective functions at the initial stages of design // *Marine intellectual technologies: scientific magazine*. 2016. # 3 (33), vol. 1. P. 57–64.
107. Ogai S.A., Voyloshnikov M.V. Estimation of the power plant capacity to determine the characteristics at the initial stages of designing a multifunctional ice navigation vessel // *Marine intellectual technologies: scientific magazine*. 2016. # 3 (33), vol. 1. P. 91–99.
108. Ogai S.A., Voyloshnikov M.V. Factors of sustainability of optimal values of design characteristics and particulars of multifunctional ship for ice navigation // *Marine intellectual technologies: scientific magazine*. 2016. # 3 (33), vol. 1. P. 39–51.
109. Ogai S.A., Voyloshnikov M.V. Factors of sustainability of the structure of marine enterprise complex assets // *Property relations in the Russian Federation. All-Russian information-analytical and scientific-practical magazine*. 2012. # 6 (129). www.iovrf.ru
110. Ogai S.A., Voyloshnikov M.V., Khromchenko E.B. A systematic approach in determining the characteristics of ships planned for construction in accordance with the programs for the development of shipbuilding // *Marine intellectual technologies: scientific magazine*. 2013. Special issue. 1. P. 42–48.
111. Ogai S.A., Voyloshnikov M.V., Khromchenko E.B. Determination of load and displacement in the design of multifunctional ice navigation ship // *The 29th Asian-Pacific Technical Exchange and Advisory Meeting on Marine Structures. TEAM-2015*. Vladivostok: Russia. P. 80–86.
112. Ogai S.A., Voyloshnikov M.V., Khromchenko E.B. Prospects of shipbuilding development at Russia's Pacific East // *The 25th Asian-Pacific Technical Exchange and Advisory Meeting on Marine Structures, TEAM-2011*. Incheon, 2011.

113. Ogai S.A., Voyloshnikov M.V., Kulesh V.A. Safety of ships navigation in ice and operational effectiveness // Proceedings of the Twenty-third (2013) International Offshore and Polar Engineering. International Society of Offshore and Polar Engineers (ISOPE). Anchorage, Alaska, USA, June 30–July 5, 201. P. 1227–1234.
114. Ogai S.A., Voyloshnikov M.V., Khromchenko E.B. Systematic approach for determining the characteristics of vessels to be built compliant with the shipbuilding development programs // The 26–th Asian–Pacific Technical Exchange and Advisory Meeting on Marine Structures. TEAM–2012, Fukuoka, 2012. P. 35–40.
115. Ogai S.A., Voyloshnikov M.V., Khromchenko E.B. The balance equation of displacement of ice–going ship and the joint determination of particulars of the ship with the account of hierarchy of the characteristics // The 28–th Asian–Pacific Technical Exchange and Advisory Meeting on Marine Structures. TEAM–2014. Istanbul, Turkey, 2014. P. 363–370.
116. Ogai S.A., Voyloshnikov M.V., Khromchenko E.B. The objective function for determining of design characteristics of multifunctional ship for navigation in icy sea, the methodological constraints, the optimality criterion // The 30th Asian–Pacific Technical Exchange and Advisory Meeting on Marine Structures. TEAM–2016. Mokpo, Republic of Korea: 10–13 October 2016. Mokpo: Publishing house of Mokpo National University, 2016. P. 561–573.
117. Ogai S.A., Voyloshnikov M.V., Khromchenko E.B. The study of stability of optimal characteristics and particulars of multifunctional ship for navigation in icy sea, taking into account the factors of data uncertainty // The 30th Asian–Pacific Technical Exchange and Advisory Meeting on Marine Structures. TEAM–2016. Mokpo, Republic of Korea: 10–13 October 2016. Mokpo: Publishing house of Mokpo National University, 2016. P. 383–394.
118. Ogai S.A., Voyloshnikov M.V. Multilevel systemic approach in the determining of the optimal design characteristics of ice navigation ship // The 31–th Asian–Pacific Technical Exchange and Advisory Meeting on Marine Structures. TEAM–2017. Osaka, 25–28 September 2017. Osaka: Publishing of Osaka University and Osaka Prefecture University, 2017. P. 118.
119. Ogai S.A., Voyloshnikov M.V. Optimization of the design characteristics of the vessel as part of the complex of the shipping company // Marine intellectual technologies: scientific magazine. 2011. # 4 (14), www.morintex.ru

120. Ogai S.A., Voyloshnikov M.V. Systematic approach when choosing directions for the development of shipbuilding in the Far East // Transport business of Russia: scientific magazine. 2016. # 1. P. 119–122.
121. Ogai S.A., Voyloshnikov M.V. The choice of directions for the development of shipbuilding for the freezing seas based on the analysis of alternatives. Polar Mechanics: Materials of the Third Intern. conf. September 27–30, 2016, Vladivostok / scientific edition A.T. Becker; Engineering School of FEFU. Vladivostok: Far East Federal University, 2016. [1096 p.]. P. 527–536.
122. Ogai S.A., Voyloshnikov M.V. The concept of multi-functional training vessel // The 27-th Asian-Pacific Technical Exchange and Advisory Meeting on Marine Structures. TEAM–2013. Keelung, 2013. National Taiwan Ocean. P. 387–392.
123. Ogai S.A., Voyloshnikov M.V. The concept of the multifunctional ice-going ship for the optimization of project characteristics // The 28-th Asian-Pacific Technical Exchange and Advisory Meeting on Marine Structures. TEAM–2014. Istanbul, Turkey, 2014. P. 388–396.
124. Ogai S.A., Voyloshnikov M.V. The dependences of displacement on icebreaking characteristics in designing of ship for navigation in freezing seas // The Twelfth (2016) Pacific-Asia Offshore Mechanics Symposium. PACOMS–2016. International Society of Offshore and Polar Engineers (ISOPE). Gold Coast, Australia, October 4–7, 2016. P. 570–577.
125. Ogai S.A., Voyloshnikov M.V. The innovative ships for navigation in Arctic seas // Northern Maritime Forum 2017. Qingdao, China: 2017. P. 463–474.
126. Ogai S.A., Voyloshnikov M.V. The Sequences of the Characteristics and Particulars Determination in Designing of Multifunctional Ship for Icy Sea // The Twelfth (2016) Pacific-Asia Offshore Mechanics Symposium. PACOMS–2016. International Society of Offshore and Polar Engineers (ISOPE). Gold Coast, Australia, October 4–7, 2016. P. 582–586.
127. Pashin V.M. Optimization of ships. L.: Shipbuilding, 1983.
128. Peresypkin V.I., Tsoy L.G. Arctic icebreakers of Russia. State and development prospects // ICE–TECH'2000, Proceedings of international scientific conference. SPb.: Society of naval architects and marine engineers; Krylov State Research Centre; Central Research and Design Institute of Marine Fleet, 2000. P. 141–146.
129. PJSC «Far Eastern Shipbuilding and Ship Repair Center» (PJSC FESSRC) has radically changed its plans. Internet edition Gorod-Artem.ru, 31.01.11.
130. PJSC USC is planning to raise \$ 1 billion for the construction of shipyards in the Far East. 11/30/2010, www.shenmei.ru

131. Pozdyunin V.L. The theory of ship design. L.: Publishing house of LKI, 1938. Part I. 1939. Part II.
132. Rakov A.I. Optimization of the main characteristics and particulars of fishery vessels. L.: Shipbuilding, 1978. 232 p.
133. Ratovskiy I. Shipbuilding in the Far East will be raised by «nanomaster». The shortage of personnel in shipbuilding is still acutely felt // «Daily News of Vladivostok». 22.07.2009., <http://novostivl.ru/>
134. Rawson K.J., Tupper E.C. Basic ship theory. 5th edition – Butterworth–Heinemann, 2001, 727 p., ISBN 0750653981, 9780750653985.
135. Rosneft will spend \$ 2.6 billion on the construction of drilling platforms. Information agency RIA–Novosti. 28.12.2009, <http://ria.ru/economy/>
136. Ryvlin A.Ya., Kheisin D.E. Tests of the ships in ice. L.: Shipbuilding, 1980. 208 p.
137. Rules for the classification and construction of sea–going vessels: in 3 volumes. Russian Maritime Register of Shipping. SPb.: 2015.
138. Sazonov K.E. The development of marine ice technology in Russia: history and modernity. Arctic: ecology and economics. 2013. # 2 (10). SPb. S. 92–103.
139. Semenov–Tyanshansky V.V. Statics and Dynamics of the Ship. L.: Shipbuilding, 1973.
140. Shipbuilders on Far East will build equipment for \$ 5 billion. RIA Novosti news agency, 28.12.2009, <http://ria.ru/economy/>
141. Shipbuilding in China. Dalsudpromservice website, www.dalsu.ru
142. Shipbuilding Industry Development Strategy for the period up to 2020 and for the future perspective. Approved by order of the Ministry of Industry and Energy of Russia dated September 6, 2007 # 354.
143. Shipbuilding technology: textbook. for universities / V.L. Alexandrov, A.R. Aryu, E.V. Ganov, A.V. Dogadin, V.Yu. Leizerman, A.S. Roganov, I.A. Sokolov, P.I. Shcherbinin; general edition A.D. Garmashev. SPb.: Professiya, 2003. 342 p.
144. Structural mechanics of a ship and the theory of elasticity: textbook for universities: in 2 volumes. L.: Shipbuilding, 1987. vol. 1: Postnov V.A., Suslov V.P. The theory of elasticity and numerical methods for solving problems of structural mechanics of a ship. 288 p.; vol. 2: Postnov V.A., Rostovtsev D.M., Suslov V.P., Kochanov Yu.P. Bending and stability of rods, rod systems, plates and shells. 416 p.
145. Sokolov V.P., Ermilkin A.P. Conceptual model of ships with domination of requirements for speed and seaworthiness // Materials of the conf. Morintech–97. SPb.: TOO, 1997.S. 211–213.

146. Sokolov V.P. Statement of tasks for the economic feasibility of ships. L.: Shipbuilding, 1987.
147. State program of the Russian Federation «Development of the transport system». Approved by Decree of the Government of the Russian Federation # 319 of April 15, 2014.
148. State program of the Russian Federation «The shipbuilding development for the period of 2013–2030 years». Approved by the Decree of the Government of the Russian Federation of December 24, 2012 # 2514–r.
149. Stokoe E.A. Ship Construction. Reeds Marine Engineering Series. 5th edition – A & C Black Publishers Ltd., 2003. 192 p. (*), ISBN 0900335955, 9780900335952.
150. Strategy of Innovative Development of the Russian Federation for the period up to 2020. Approved by the order of the Government of the Russian Federation dated December 8, 2011 # 2227–r.
151. Taylor D.A. Introduction to marine engineering. 2 edition. Referex Engineering – Butterworth–Heinemann, 1996. 372 p., ISBN 0750625309, 9780750625302.
152. Taylor D.A., Tang Alan, Shungtse Alan Merchant ship naval architecture – Institute of Marine Engineers, 2006. 216 p. (*), ISBN 1902536568, 9781902536569.
153. Technical and economic characteristics of ships of the sea fleet. Ref. in 2 volumes. Vol. 1. St. Petersburg: The Central Scientific Research and Design Institute of Marine Fleet, 1997.
154. The decision is made to create four shipbuilding zones at Russian Far East. Primorskoe television and radio branch of All–Russian State Television and Radio Broadcasting Company «STRBC Vladivostok», October 29, 2009, www.ptr-vlad.ru
155. The economic justification of design solutions: a guide for the designer–shipbuilder: ref. / N.I. Teretnikov, N.P. Lyubushin, V.A. Birulya, A.F. Ikonnikov; under total. ed. N.P. Lyubushin. L.: Shipbuilding, 1990. – 216 p.
156. Thor I. Fossen Handbook of Marine Craft Hydrodynamics and Motion Control – John Wiley & Sons, 2011. 596 p., ISBN 1119994128, 9781119994121.
157. Tikhonova N.E. Finding of optimal basic particulars and of ship hull shape the icebreaker in dependence on freezing sea // Proceedings of Nizhegorod State Technical University named R.E. Alekseev. Nizhny Novgorod, 2014. # 5 (107). P. 302–308.
158. Tristan Perez Ship Motion Control: Course Keeping and Roll Stabilization Using Rudder and Fins – Springer, 2010. 322 p., ISBN 1849969787, 9781849969789.

159. Tryaskin V.N., Lazarev V.N., Smirnov Yu.A., Kurdyumov V.A. Designing of hull structures of sea vessels: textbook. allowance. L.: Publishing house of LKI, 1987. 85 p.
160. Tsarev B.A., Konovalova L.V. The interdependence between the evolution of ships and their energy equipment // Materials of the international. scientific and technical conf. «Shipbuilding and ocean engineering. Problems and perspectives», SOPP'01. Vladivostok: FESTU, 2001. P. 115–117.
161. Tsarev B.A. Optimization design of high-speed vessels: textbook. L.: Publishing house of LKI, 1988. 102 p.
162. Tsoy L.G. Determination of the required capacity of icebreakers and icebreaker – transport vessels for a given icebreaking capacity: method. guide. SPb.: SPbGMTU, 2003. 27 p.
163. Tsoy L.G. Formula for determining ice-breaking capacity and recommendations for choosing the shape of the hull lines for icebreakers and ice-navigation transport vessels // Perspective types of sea transport vessels, their seaworthiness and ice qualities // Proceedings TsNIIMF. M.: Transport, 1990. P. 141–144.
164. Tsoy L.G. On the rational field of application of nuclear power plants on icebreakers // Proceedings: Architectural and structural type, seaworthy and ice qualities of transport vessels. SPb.: TsNIIMF, 1992. P. 96–102.
165. Tsoy L.G. Sea icebreakers. Design features. SPb.: SPbGMTU, 2003.
166. Tsoy L.G. Selection of the hull shape for universal icebreakers // Sudostroenie. 1996. # 5/6. Pp. 10–14.
167. Tupper E.C. Introduction to naval architecture. Marine engineering series. 4 edition – Butterworth–Heinemann, 2004. 446 p. (*), ISBN 0750665548, 9780750665544.
168. Turbal V.K., Shpakov V.S., Stumpf V.M. Design of contours and propellers of sea transport vessels. L.: Sudostroenie, 1983. 304 p.
169. Vasiliev A.L. Issues of design of ship hull structures. Systems for ship hull overlaps framing. Choice of space: textbook. SPb.: Publishing SPbGMTU, 2000. 64 p.
170. Vashedchenko A.N. Computer-aided design of ships. L.: Shipbuilding, 1985. 164 p.
171. Vladivostok will become the center of shipbuilding in the Far East. Newspaper «Vladivostok». # 2363. 2008.03.07.
172. Volker Bertram Practical Ship Hydrodynamics. 2nd edition – Elsevier, 2011, 390 p., ISBN 0080971520, 9780080971520.

173. Von Bertalanffy Ludwig General System theory: Foundations, Development, Applications – NY: George Braziller, revised edition 1976, ISBN 0–8076–0453–4.
174. Voyloshnikov M.V. Marine resources and engineering: efficiency estimation, evaluation and optimization. Vladivostok: Publishing house of the Far Eastern State Technical University, 2002. 586 p.
175. Voyloshnikov M.V., Ogai S.A., Ogai A.S. The systematic approach in determining of the project characteristics of the vessel in the complex of the shipping company and the software models of the different levels // The 25th Asian–Pacific Technical Exchange and Advisory Meeting on Marine Structures. TEAM–2011, Incheon.
176. Voyloshnikov M.V. The evaluation of commercial vessels, marine company's assets and ocean resources: textbook. M.: All–Russian Professional Organization «Russian Society of Appraisers», 2010. 361 p.
177. Wilson James Franklin, Muga Bruce Jennings, Reese Lymon C. Dynamics of offshore structures. 2nd edition – John Wiley and Sons, 2003, 325 p., ISBN 0471264679, 9780471264675.
178. Yasuhisa Okumoto, Masaki Mano, Yu Takeda, Tetsuo Okada Design of Ship Hull Structures: A Practical Guide for Engineers – Springer, 2009, 578 p., ISBN 3540884440, 9783540884446.
179. Yong Bai Marine structural design. Referex Engineering – Elsevier, 2003, 606 p., ISBN 0080439217, 9780080439211.
180. Yong Bai, Qiang Bai Subsea Engineering Handbook – Gulf Professional Publishing, 2012, 960 p., ISBN 0123978041, 9780123978042.
181. Zakharov I.G. The theory of compromise decisions in the design of a ship. L.: Shipbuilding, 1987.
182. Zuev V.A., Gramuzov Ye.M., Ionov B.P. Power Approach to Investigation of Ice–Ship Interaction // International Conference POAC–91, vol. 1, St–Johns, Canada, 1991. P. 728–746.
183. Zuev V.A., Gramuzov Ye.M., Ionov B.P. Theoretical Modelling of Ice Resistance of Ships // Proceedings of Ice Symposium JAHR–94, Trondheim, Norway, 1994. P. 905–928.
184. Zuev V.A., Gramuzov E.M., Semenov D.A. New possibilities of model studies of the speed of icebreakers // News of VolgGTU. Nizhny Novgorod, 2013. P. 23–26.
185. Zuev V.A., Knyazkov V.V. Assessment of the effectiveness of icebreaking facilities. // River transport. 1997. # 4. P. 32–33.

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Editor Oksana G. Sikorskaya

Accounting sheets – 27 Format 60×84 1/16

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