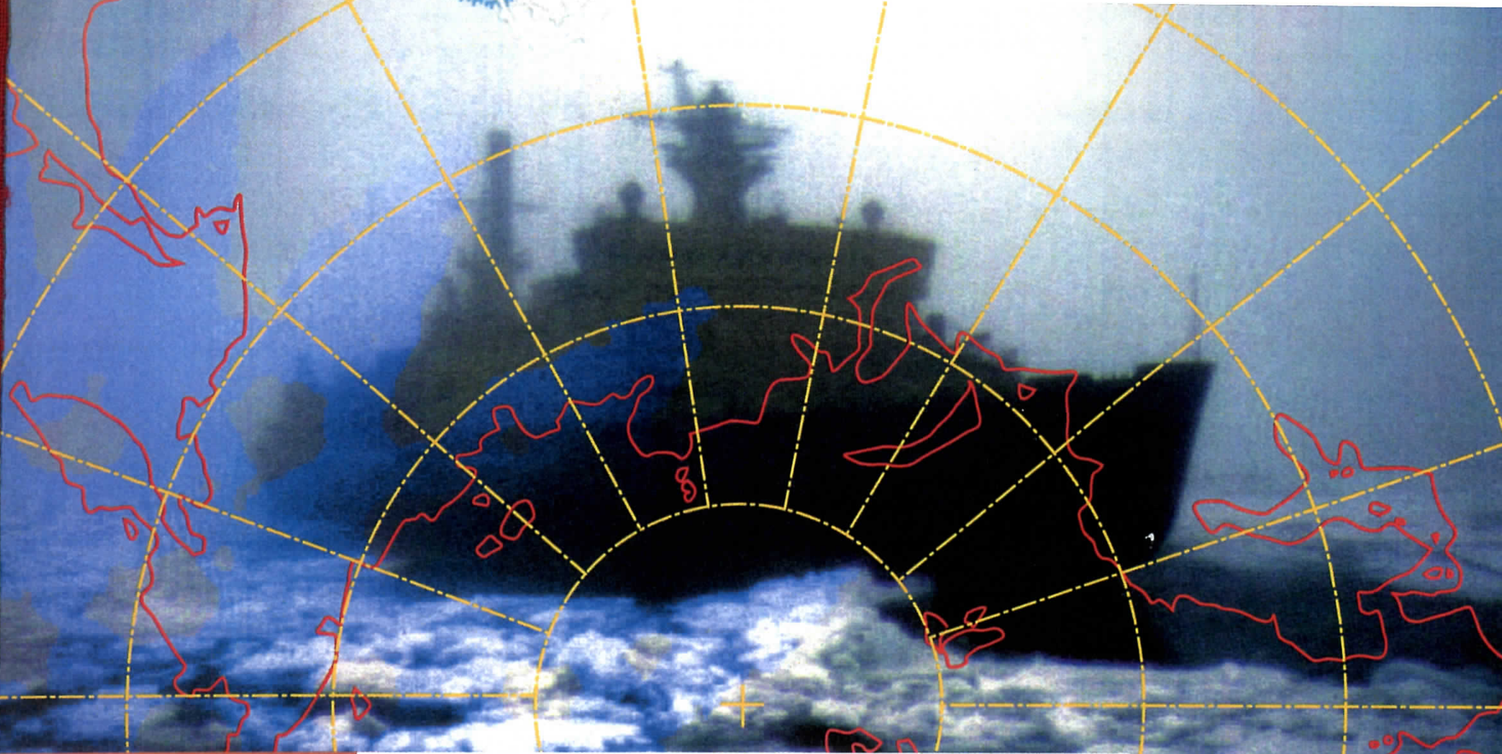
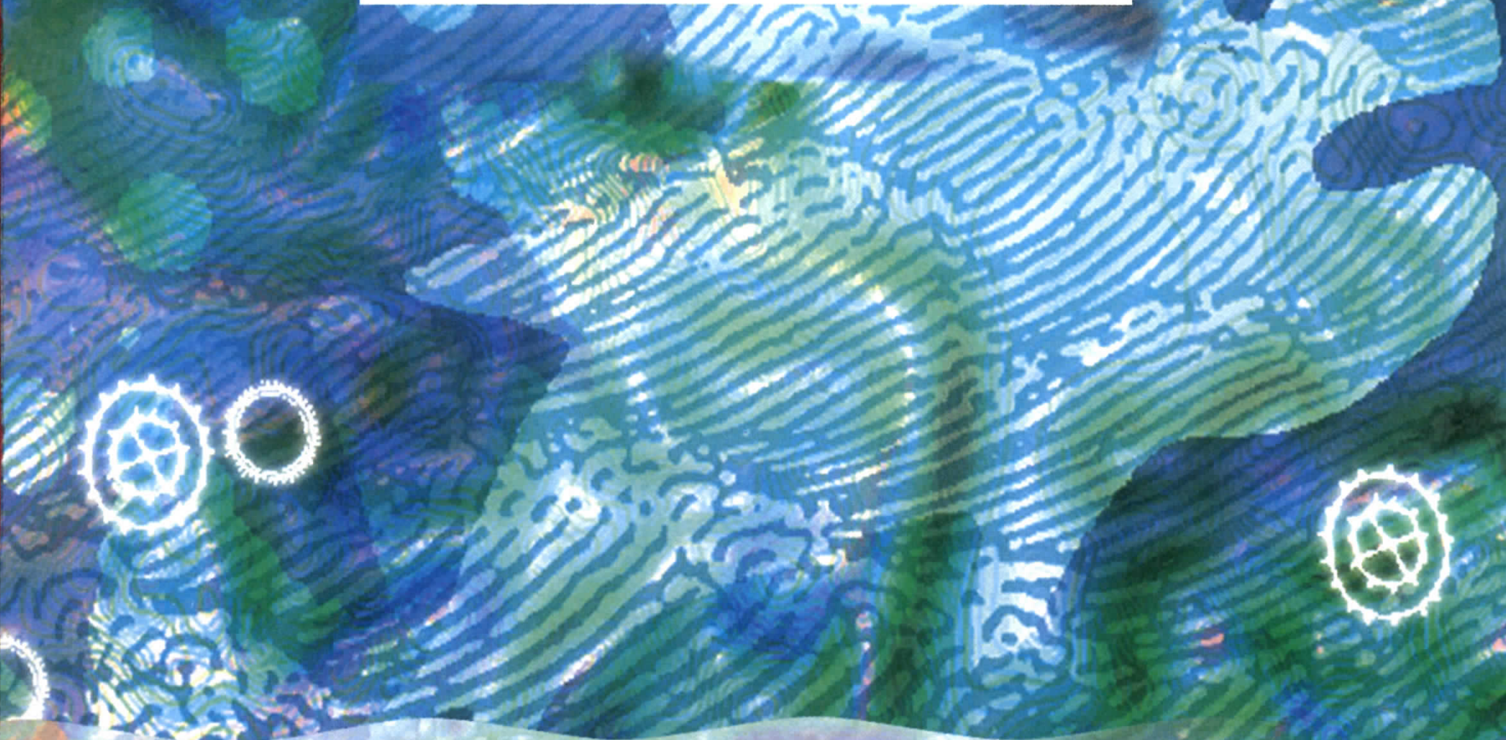


INSROP WORKING PAPER
NO. 62 - 1996, III.11.1

New Concepts of Removing Ice.

Investigation of the efficiency and advisability to use non-traditional shape of hull lines for icebreakers and icebreaking cargo ships of Arctic navigation

A.V.Ierusalimsky, S.M. Ponomarev
and T.M. Semanova



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Supervisors:	Tor Wergeland and Loly G. Tsoy
Title:	**New Concepts of Removing Ice. Investigation of the efficiency and advisability to use non-traditional shape of hull lines for icebreakers and icebreaking cargo ships of Arctic navigation**
Authors:	Alexander V. Ierusalimsky, S.M. Ponomarev and T.M. Semenova
Address:	Central Marine Research and Design Institute Kavalergardskaya Street 6 193015 St. Petersburg RUSSIAN FEDERATION
Date:	7 October 1996
Reviewed by:	Dr. Devinder Sodhi, US Army Cold Regions Research and Engeneering Laboratory, Hanover, New Hampshire, USA

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FOREWORD - INSROP WORKING PAPER

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INSROP is split into four main projects: 1) Natural Conditions and Ice Navigation; 2) Environmental Factors; 3) Trade and Commercial Shipping Aspects of the NSR; and 4) Political, Legal and Strategic Factors. The aim of INSROP is to build up a knowledge base adequate to provide a foundation for long-term planning and decision-making by state agencies as well as private companies etc., for purposes of promoting rational decisionmaking concerning the use of the Northern Sea Route for transit and regional development.

INSROP is a direct result of the normalization of the international situation and the Murmansk initiatives of the former Soviet Union in 1987, when the readiness of the USSR to open the NSR for international shipping was officially declared. The Murmansk Initiatives enabled the continuation, expansion and intensification of traditional collaboration between the states in the Arctic, including safety and efficiency of shipping. Russia, being the successor state to the USSR, supports the Murmansk Initiatives. The initiatives stimulated contact and cooperation between CNIIMF and FNI in 1988 and resulted in a pilot study of the NSR in 1991. In 1992 SOF entered INSROP as a third partner on an equal basis with CNIIMF and FNI.

The complete series of publications may be obtained from the Fridtjof Nansen Institute.

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PROGRAMME COORDINATORS

- **Yury Ivanov, CNIIMF**
  Kavalergardskaya Str.6
  St. Petersburg 193015, Russia
  Tel: 7 812 271 5633
  Fax: 7 812 274 3864
  Telex: 12 14 58 CNIMF SU
- **Willy Østreng, FNI**
  P.O. Box 326
  N-1324 Lysaker, Norway
  Tel: 47 67 11 19 00
  Fax: 47 67 11 19 10
  E-mail: sentralbord@fni.no
- **Ken-ichi Maruyama, SOF**
  Senpaku Shinko Building
  15-16 Toranomon 1-chome
  Minato-ku, Tokyo 105, Japan
  Tel: 81 3 3502 2371
  Fax: 81 3 3502 2033
  Telex: J 23704

International Northern Sea Route Programme (INSROP)

Central Marine Research & Design Institute, Russia
The Fridtjof Nansen Institute, Norway
Ship & Ocean Foundation, Japan

TRADE AND COMMERCIAL ASPECTS OF SHIPPING

SUB-PROGRAM III

Project III.11.1

New Concepts of Removing Ice

Section of the Project : Investigation of the efficiency and advisability to use non-traditional shape of hull lines for icebreakers and icebreaking cargo ships of arctic navigation

Annual 1994 Final Report

PREPARED FOR
THE JOINT RESEARCH COMMITTEE
AND
THE STEERING COMMITTEE OF SPONSORS

Supervisors :

Prof. Tor Wergeland, NHH/CIES, Norway
Dr. Loly G. Tsoy, CNIIMF, Russia

ST. PETERSBURG
1996

KEY PERSONNEL

Dr. Alexander V. Ierusalimsky,	Responsible executive
S.M.Ponomarev,	Engineer. Translator.
T.M. Semenova,	Support personnel

SUMMARY

Analysis was carried out of the results of full-scale trials of icebreakers "Mudyug" and "Kapitan Sorokin" with barge-like forebody after their conversion by the Thyssen-Nordseewerke as well as of the icebreaker "Kapitan Nikolaev" of the same type as the latter for which the Masa-Yard Company has built a new forebody with conical lines. Comparison was made with the results of similar tests of all three icebreakers prior to the conversion when they had modern icebreaking forebody lines of traditional type having a wedge-like waterline and stem. Analysis was carried out using the results of tests and experimental operation of pushed icebreaking - icecleaning attachments realizing the principle of ice destruction similar to the Thyssen-Waas conception. To estimate the efficiency of non-traditional lines, a comparison is made in this report on the basis of the results of trials and experience of operation of icebreakers of "Kapitan Sorokin" type prior to and after conversion. Preliminary conclusions on the advantages and disadvantages of non-traditional hull lines were formulated.

KEY WORDS: ANALYSIS, RESULTS, FULL-SCALE TESTS, BARGE-LIKE FOREBODY, CONICAL LINES, TRADITIONAL LINES, ATTACHMENT, ICE DESTRUCTION, CONCEPTION, EFFICIENCY, ADVANTAGES, DISADVANTAGES.

CONTENTS

INTRODUCTION

The present work has been performed in the Laboratory of icebreaking technology of CNIIMF and is the second stage of the Project "New concepts of removing ice". At the first stage (see report for 1993) the patent and information search was made, fundamental differences between principal concepts of removing ice analyzed, extent of the practical use of different technical solutions established [1].

As mentioned in the first stage report, the realization of the Project "New Concepts in Removing Ice" should make it possible, in our opinion, to determine the efficiency of various concepts of ice breaking and means to augment ice breaking capability, as well as to elaborate recommendations on their use in icebreakers and commercial ships designed for Arctic navigation depending on their purpose, area and season of navigation. Fulfillment of this main task of the Project is possible by the step-by-step comparison of the efficiency of different new concepts of ice removal with traditional ones by accumulating the results of theoretical and experimental investigations and also of operational experience. At present in Russia the largest body of information on the results of investigations and operational experience is available for the following new concepts of ice removal:

- removal of ice by the ship's hull with the use of non-traditional shapes of lines;
- increase in the efficiency of ice removal and reduction of ice resistance by auxiliary technical means;
- ice removal by air-cushion appliances.

The first two of the above mentioned concepts found widest practical application and were studied for a long time both in laboratory and natural conditions. Investigation of ice removal by air-cushion appliances has been carried out in Russia up to the present time on the basis of theoretical research and also model and full-scale experiments [2-5]. Until now there is no real experience of the operation of air-cushion icebreaking means. The analysis of the efficiency of each of these three concepts represent a separate work. The present report deals with the investigation of the efficiency and advisability to use non-traditional forms of the hull lines for icebreakers and icebreaking cargo ships of arctic navigation. Further on within the framework of Project III.11.1 it is intended to make similar comparative analysis of the efficiency of auxiliary technical means of the increase in the icebreaking capability.

The overwhelming majority of icebreakers constructed have so-called traditional lines characterized by the raked stem and wedge-like waterline. At the same time as far back as in the forties in Russia another concept of icebreaking bow, based on a different principle, was developed and tested in full-scale conditions this bow being notable for a flat section (instead of a pointed stem) excluding the ice cutting. These investigations were completed in 1963 by trials in the Arctic of the nuclear icebreaker "Lenin" with a ski-like flat attachment at the stem [1]. However the experiment was considered as not wholly successful and the authors of this development abstained from patenting and publication (chief designer V.G.Neganov).

The idea to replace the stem by a flat section was patented in other countries (patent of Canada N 1026160, 1974). One modern example of such technical solution is the Swedish icebreaker "Oden". Besides, in the seventies and eighties bow lines of "spoon-like", "cylindrical" and "conical" shape were tested and found application. Unlike traditional design these bow lines also have no wedge-like stem.

In the fifties and sixties a concept of regulated ice breaking was also put forward. It consisted in the ice cutting with lateral structures (knives) ice plates being subsequently broken by a bow inclined plane and broken ice driven under the channel edge by means of an ice dispersing wedge. Examples of such proposals are "River icebreaker" of G.M.Tekuchev (inventor's certificate of the USSR N 125735, 1959) and a pushed Supplementary icebreaking gear" of G.Ja.Serbul (inventor's certificate of the USSR N 310837, 1969) [1]. Fig.Int.1. shows the above technical solutions.

It should be noted that pushed attachments similar to those proposed by G.Ja.Serbul have been successfully used in Russia on rivers since the middle seventies and in 1983-1986 were tested in sea conditions. As similar principle has formed the basis of a proposal of Ch.Waas (patent of FRG N 2530103, 1977) the development of which are bow lines

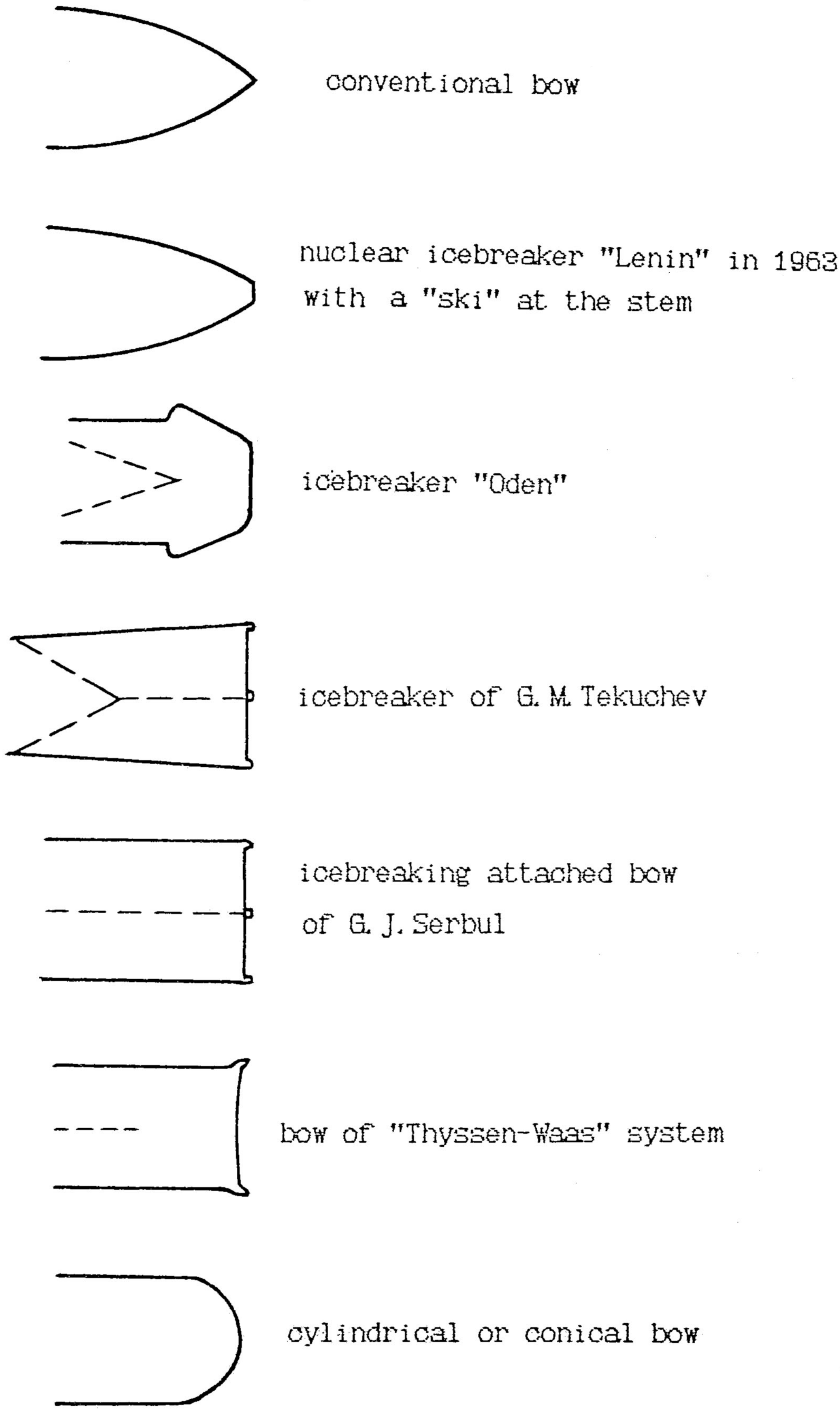


Fig. Int.1. Waterline shapes of non-conventional forebodies of the icebreaker "Max Waldeck" as well as icebreakers "Mudyug" and "Kapitan Sorokin" (further on "Kapitan Sorokin 91") converted by "Thyssen Nordseewerke". As is known, the first tests of the icebreaker "Mudyug" proved the high efficiency of the lines of the "Thyssen-Waas" system in the breaking of compact level ice [6,7]. At the same time, shortcomings of the new bow were detected during operation in other ice conditions. Therefore in 1991 while converting the icebreaker "Kapitan Sorokin" the company tried to take into account these disadvantages and used modified lines.

In 1990, as an alternative, the Finnish shipyard "Masa Yards" refitted the icebreaker "Kapitan Nikolaev" (further on "Kapitan Nikolaev 90") for which a new forebody with conical lines was manufactured.

The present report contains comparison of the results of full-scale ice tests which were conducted with the following ships: the icebreaker "Mudyug" prior to and after conversion, icebreaker "Dikson" and other icebreakers with icebreaking ice-removing attachment LLP-20, the "Kapitan Sorokin" type icebreakers prior to and after conversion [5-13]. On the basis of these results, icebreaking capabilities of the icebreaker with different hull forms were compared. Besides, on the basis of three-year operation of the converted icebreakers "Kapitan Sorokin 91" and "Kapitan Nikolaev 90" an attempt was also made to compare their economical efficiency and operational advantages and disadvantages.

1. HULL FORM VERSIONS COMPARED

As stated above, the following three concepts of ice removing by the ship's hull of the most widespread application are compared:

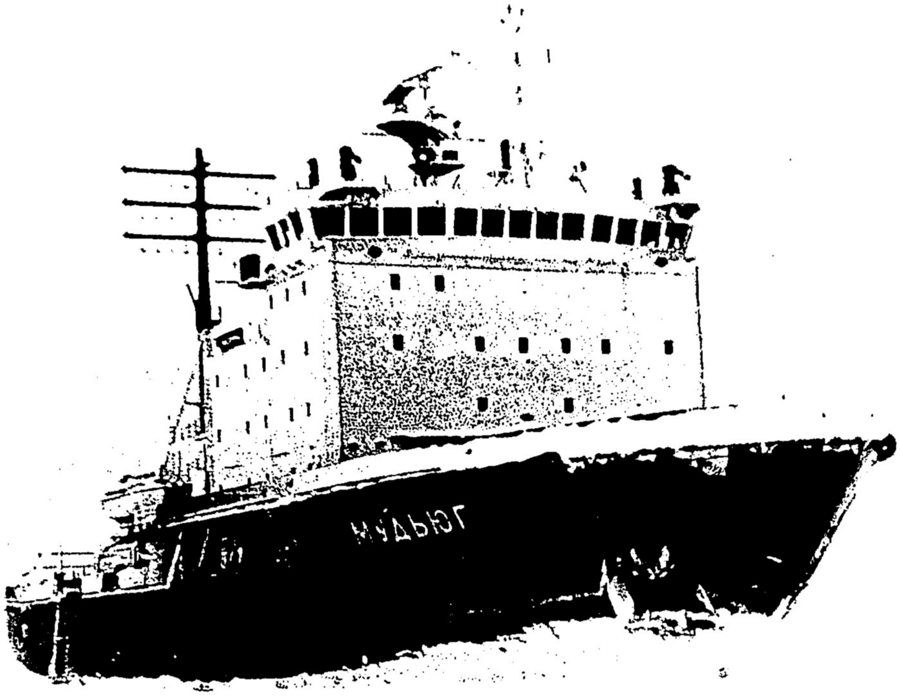
- traditional forebody
- "conical" bow shape
- "barge-like" form with cutting structures

At present, icebreakers of "Mudyug" series with traditional and barge-like bow shape of the "Thyssen-Waas" system are in operation. Detailed descriptions of the technical solutions adopted in conversion and the conversion projects proper are to be found in literature and are not included in this report [6,7]. For clarity and the possibility to compare the forms of lines, figs.1.1 - 1.3 represent general view lines form and main view of lines body plan of the icebreaker prior to and after conversion. Principal characteristics of icebreakers "Mudyug" and "Mudyug 86" are given in table 1.1.

Besides, the icebreaker "Dikson" (of the same type as "Mudyug") was tested in 1985 and 1986 with an icebreaking - ice removing attachment LLP-20 having a barge-like form. The prototype of the LLP-20 attachment was developed at the Leningrad Central Design Office (part of CNIIMF) and in 1981 fabricated at the Riga Ship Repair Works. The attachment was tested in 1982-1984 in the Gulf of Vyborg of the Baltic Sea with port icebreakers. General arrangement plan of the attachment is shown in fig.1.4. After that the attachment was somewhat updated (intermediate side knives were removed) and tested in 1984 on the Yenisei river with the icebreaker "Kapitan Voronin". In 1985 and 1986 on the Yenisei river the experimental operation of the LLP-20 with the icebreaker "Dikson" was carried out. Fig.1.5 shows general view of the LLP-20 after updating and table 1.1 - its principal characteristics.

Thus tests of icebreakers of "Mudyug" type allow not only to assess the efficiency of the concept of ice removal by the barge-like bow, but also to compare advantages and disadvantages of two specific technical solutions realizing this principle. It should be emphasized that the results and observations during the first trials of the attachment of G.Ya.Serbul were also taken into account in the analysis. For instance, attachment LLP-14

a)



b)

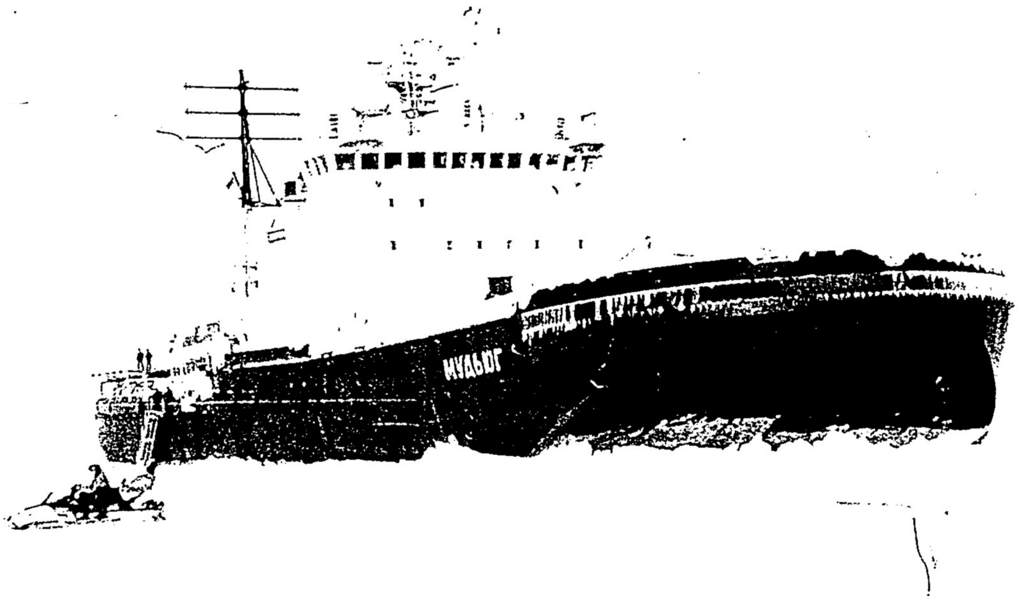
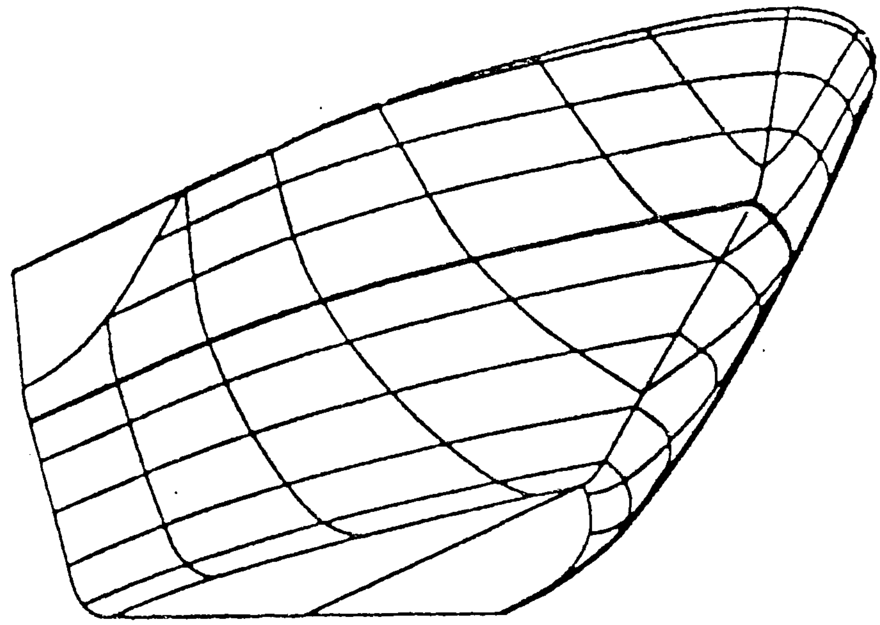


Fig. 1.1. Icebreaker "MUDYUG"
a) -prior to conversion; b)- after conversion

a)



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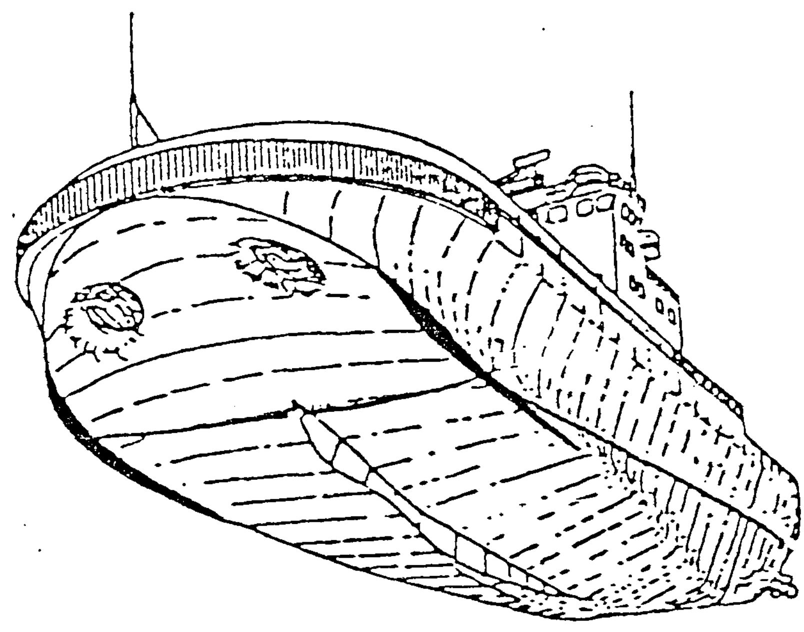


Fig. 1.2. Forebody Lines of the MUDYUG-type Icebreaker
a) -prior to conversion; b)- after conversion

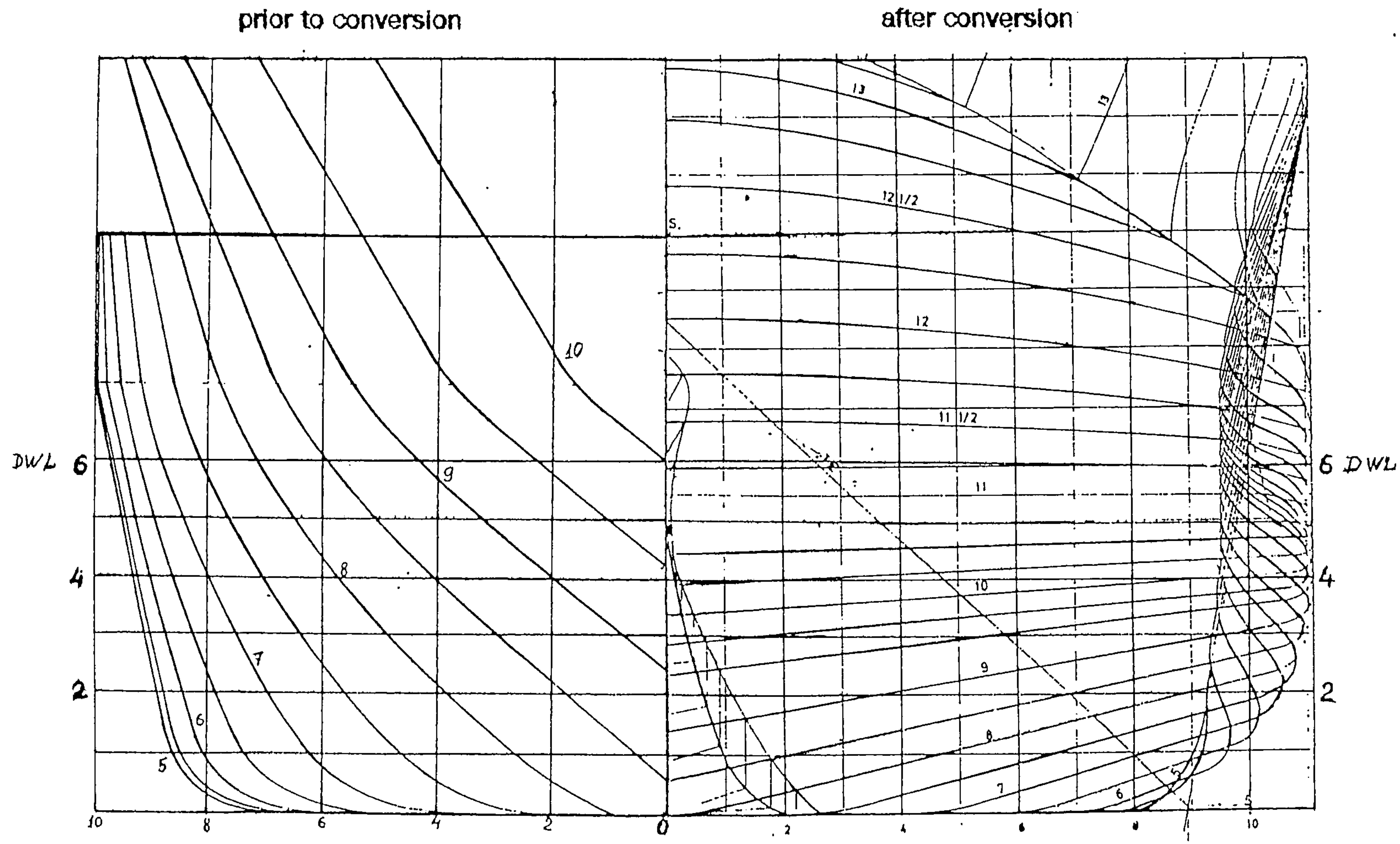


Fig. 1.3. Forebody plan of the MUDYUG-type Icebreaker Prior to and After conversion

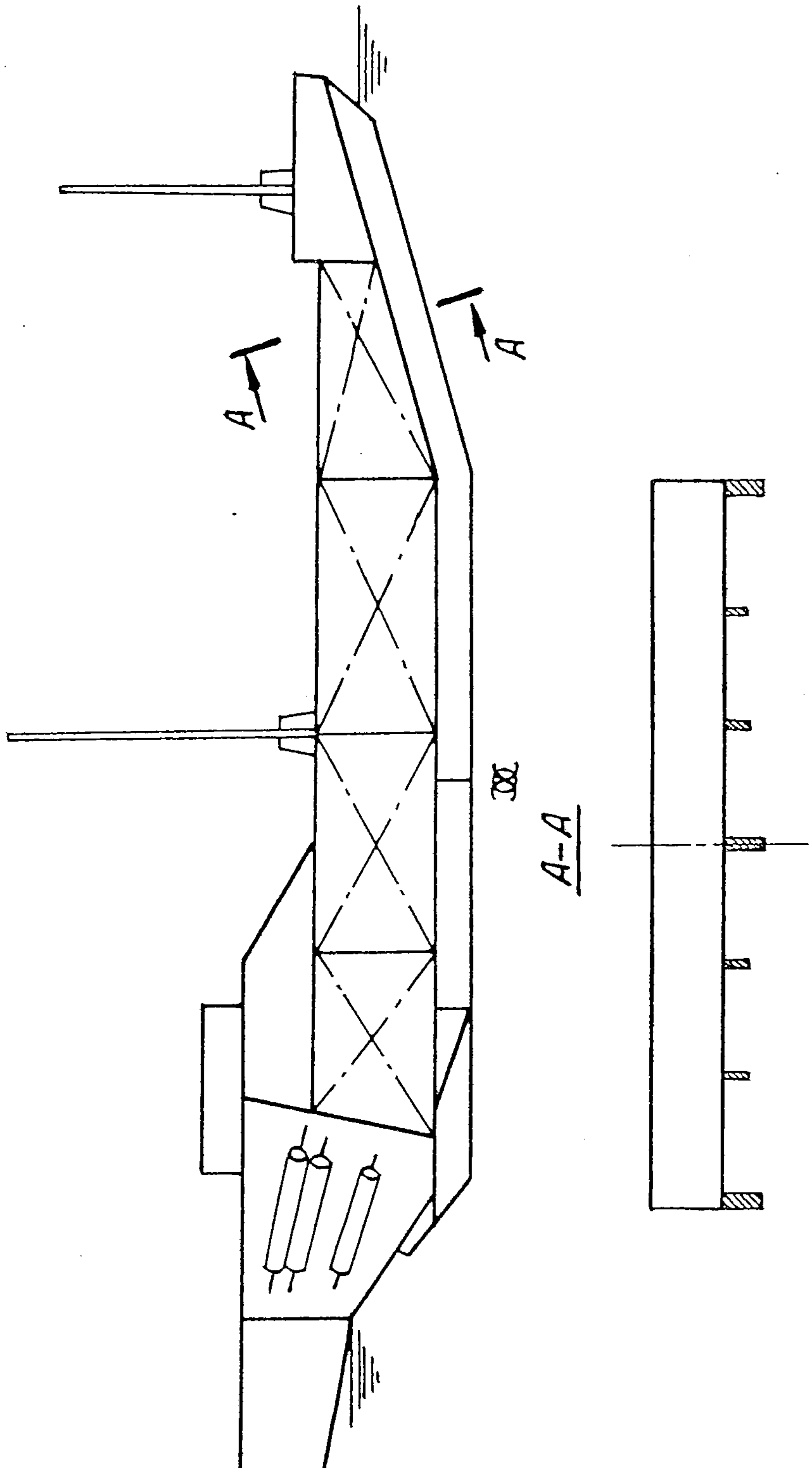


Fig.1.4. Scheme of LLP-20

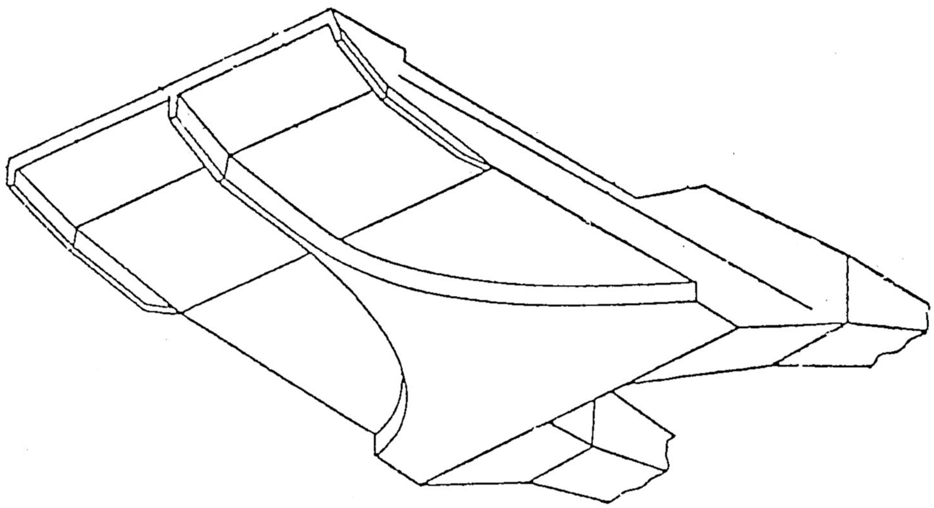


Fig.1.5. Icebreaking and Iceremoving Attached Bow LLP-20
(after modification)

which had smaller breadth than that of LLP-20, tested in 1975 - 1976 on the Volga river with tugboat of "Dunaisky-35" type having a horse power of 1300 (see table 1.1).

All the three concepts mentioned above have been realized on icebreakers of the "Kapitan Sorokin" series. It allows to perform the most reliable comparison of ice properties as well as of operational possibilities provided by different concepts as applied to the same icebreaker.

The icebreakers "Kapitan Sorokin" and "Kapitan Nikolaev"(the second ship of the series), were built in Finland at the shipyard "Wartsila" in 1977 and 1978 and have the **LL3** class of the Maritime Register of Shipping. Conception of such shallow-draft icebreaker and its main technical and operational requirements were developed in CNIIMF in the mid-seventies. The principal purpose of the icebreaker is the escorting of ships and other icebreaking works in the shallow water areas of the Arctic and most of all in the estuary part of the Yenisei river on the route between Murmansk and Dudinka Figure 1.6 shows a sketch of the original shape of ship of "Kapitan Sorokin" and "Kapitan Nikolaev".

With the introduction of this type of icebreakers, navigation in the western part of the Russian Arctic became practicable all the year round though with the winter conditions regarded as "heavy" ones, the icebreaking capability of these icebreakers proved insufficient for the secure escorting of ships on the Dikson - Dudinka run, especially in March and April. This was the reason for the construction at the end of the eighties of new, more powerful nuclear icebreakers of the "Taimyr" type of similar purpose with a minimum draft of 8.0 m.

With the object of increasing the icebreaking capability and investigating the efficiency of non-traditional hull lines "Kapitan Sorokin" and "Kapitan Nikolaev" icebreakers of the Murmansk Shipping Company were converted in the beginning of the nineties. In March 1990 at "Masa-Yards" in Helsinki the icebreaker "Kapitan Nikolaev" was provided with a new forebody having so called conical lines (see Fig.1.7 -1.8). In January 1991, the icebreaker "Kapitan Sorokin" was provided with a new forebody of the Thyssen-Waas system and with partially changed stern lines (see figs.1.8 and 1.9) at the "Thyssen-Nordseewerke". Main characteristics of the icebreaker prior to and after conversion are shown in Table 1.1.

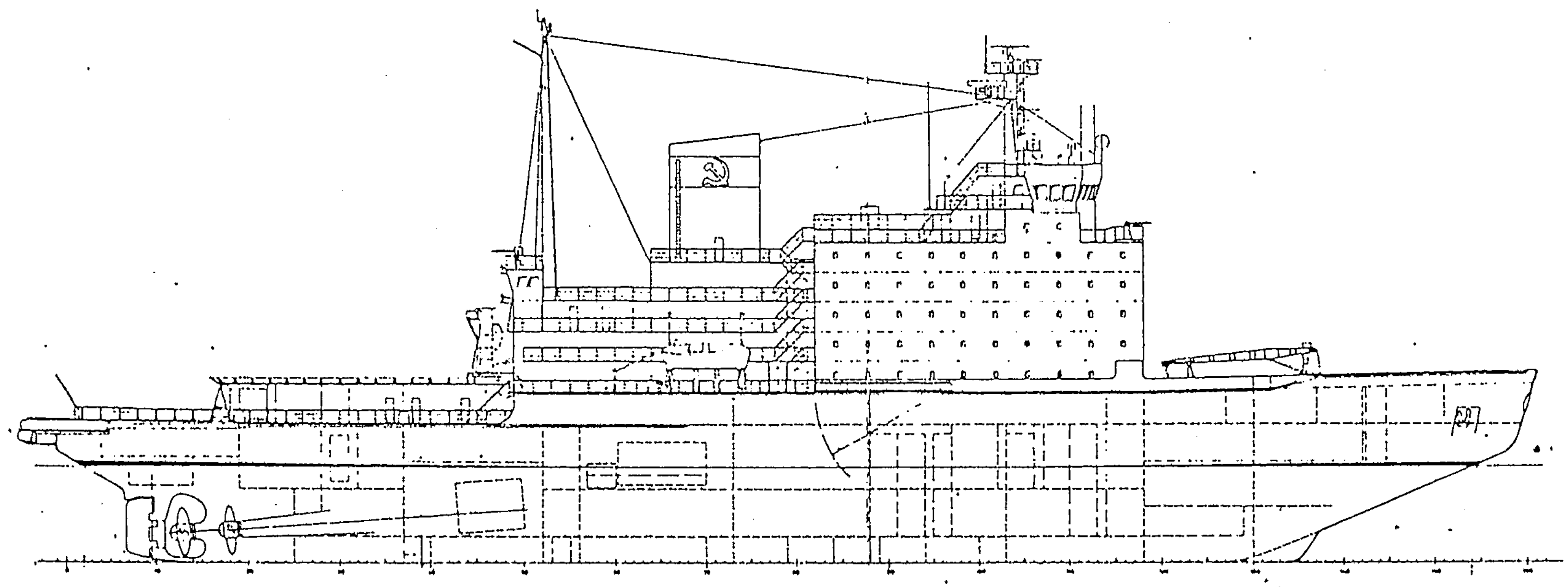


Fig. 1.6. KAPITAN SOROKIN - Type Icebreaker

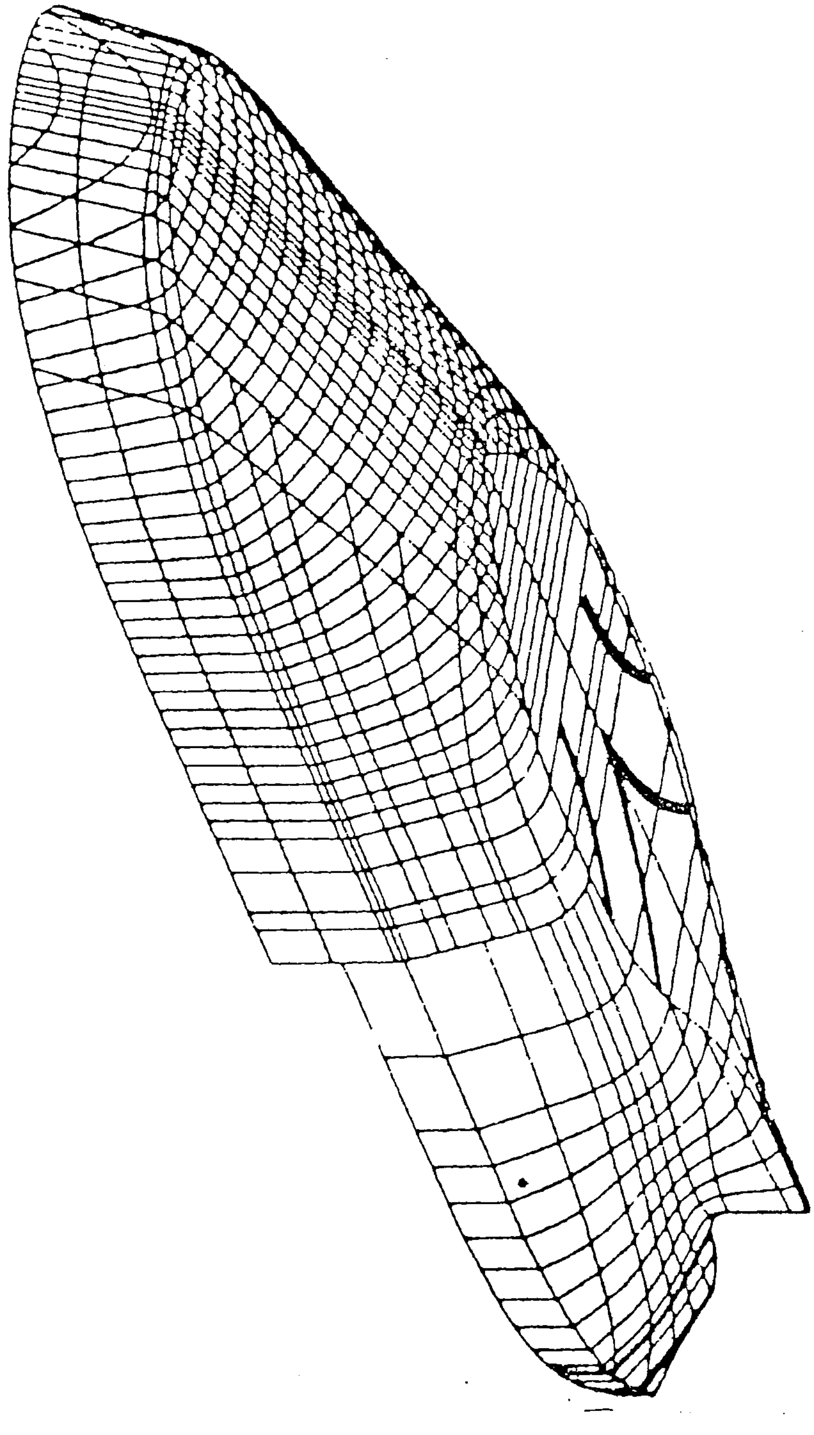
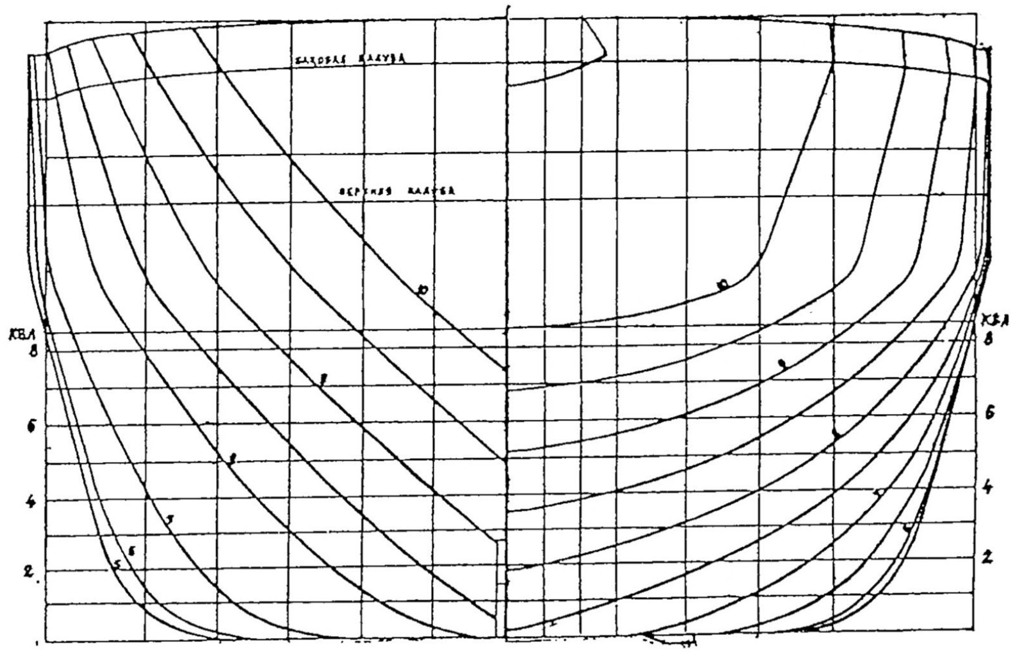


Fig. 1.7. Forebody Lines of the Icebreaker KAPITAN NIKOLAEV
After Conversion

ORIGINAL BOW CONICAL BOW



ORIGINAL BOW TYSSEN-WAAS BOW

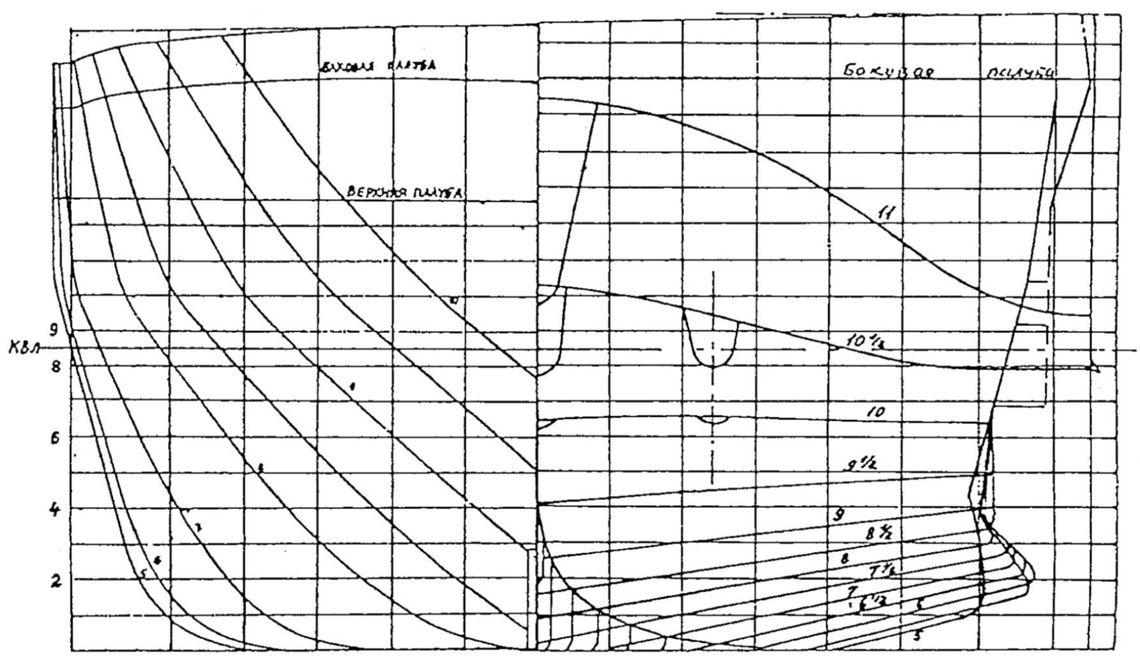


FIG. 1.8. FOREBODY LINES OF ICEBREAKERS OF "KAPITAN SOROKIN" TYPE PRIOR TO AND AFTER CONVERSION

a)

b)

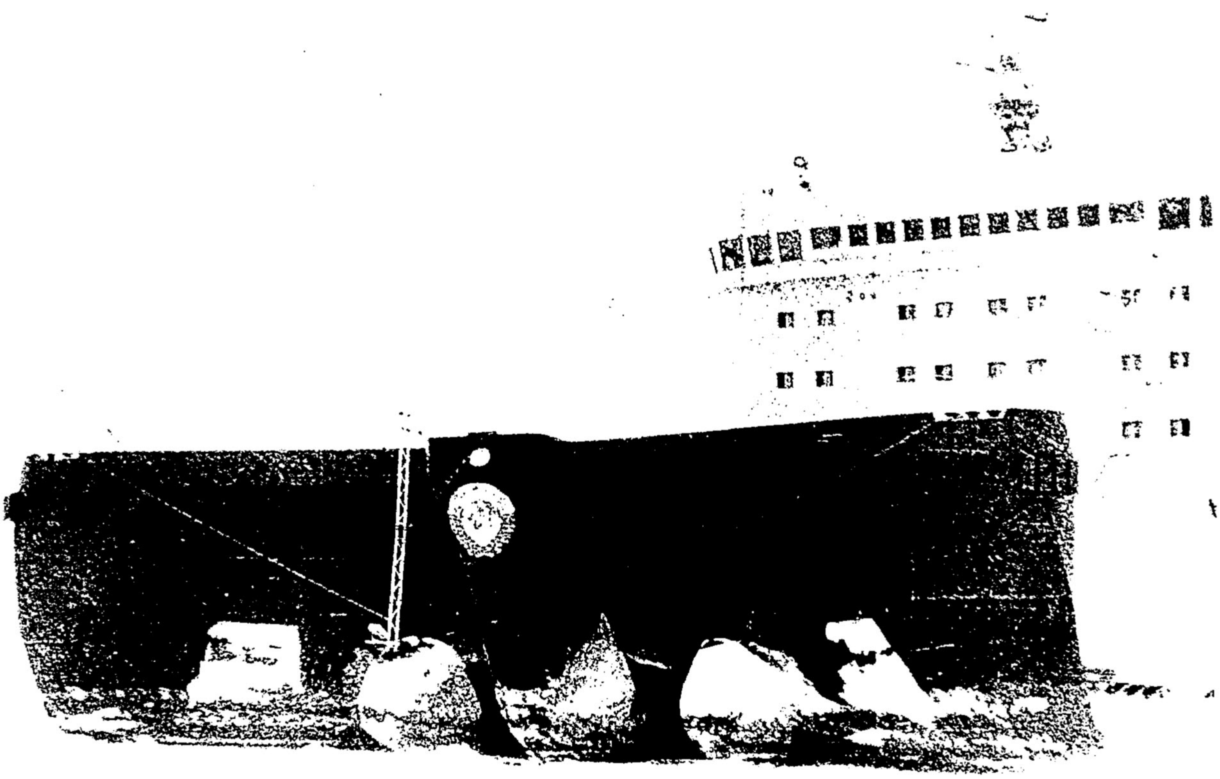


Fig. 1.9. Forebody of the Icebreaker KAPITAN SOROKIN
a)- prior to conversion; b)-after conversion

Table 1.1

Main characteristics of the icebreakers and attached bows reviewed

Characteristics	Kapitan Sorokin series			Mudyug series		Attached bows	
	Prior to conversion	Kapitan Nikolaev 90	Kapitan Sorokin 91	Prior to conversion	Mudyug 86	LLP - 20	LLP - 14
Length overall, m	129.4	135.5	141.4	88.5	111.4	43.0	18.0
Length on design water line, m	121.2	125.8	130.4	78.5	89.8	28.0	16.3
Breadth overall, m	26.6	26.5	31.1	20.9	22.4	21.4	14.0
Design water line breadth, m	25.6	25.7	30.2	20.0	22.2	20.0	14.0
Design draught	8.5	8.7*	8.5	6.0	6.0	3.12	1.3
Depth up to the main deck	12.3	12.3	12.9	10.5	10.5	4.0	1.25
Displacement, t	14920	16017	17150	5530	6880	1170	160
Block coefficient	0.547	0.569	0.590	0.572	0.621	0.67	0.54
Shaft power, kW	16200	16200	16200	7000	7000	-	-
Open water speed, kn	19,4	19,2	18.0	16.5	16.1	-	-
Bow stem angle, degrees	23	15	12	25	13	15	16
Angle of waterline entrance	28	90	90	31	90	90	90
Bow flare angle, degrees	53	89	90	52	90	90	90

* - taking into account ice-pushing battens

2. RESULTS OF ICE TRIALS

2.1. Ice conditions during the tests

Majority of tests for all concepts to be compared was made in the fast level ice as well as in the channels broken through in this ice (see table 2.1). Along with the tests in level ice systematic observations were carried out over the work in drifting hummocking ice of the Kara, Barents and White seas and also under conditions of old constantly operating channels in the Yenisei, Northern Dvina and Volga rivers.

2.2. Equivalent ice thickness

While carrying out tests in different years, different methods of taking account of snow cover thickness were used. The Yenisei river area where the tests were mainly made is characterized by significant snow thickness, especially in April - May. Therefore during the conversion of the icebreaker "Kapitan Sorokin" the presence of snow cover 25 cm thick on ice was allowed for in contract obligations. When actual values of snow thickness during the tests deviated from this figure an equivalent ice thickness was determined by formula:

$$h_{eq} = h_{ice} + \Delta h_{ice} ,$$

where $\Delta h_{ice} = 0.5\,(h_{snow} - 0.25)$ at $h_{snow} > 0.25$ m

$$\Delta h_{ice} = 0.33\,(h_{snow} - 0.25) \text{ at } h_{snow} < 0.25 \text{ m}$$

In this paper the results of all tests were recalculated by this formula in order to make the comparisons possible.

2.3. Test in compact level ice

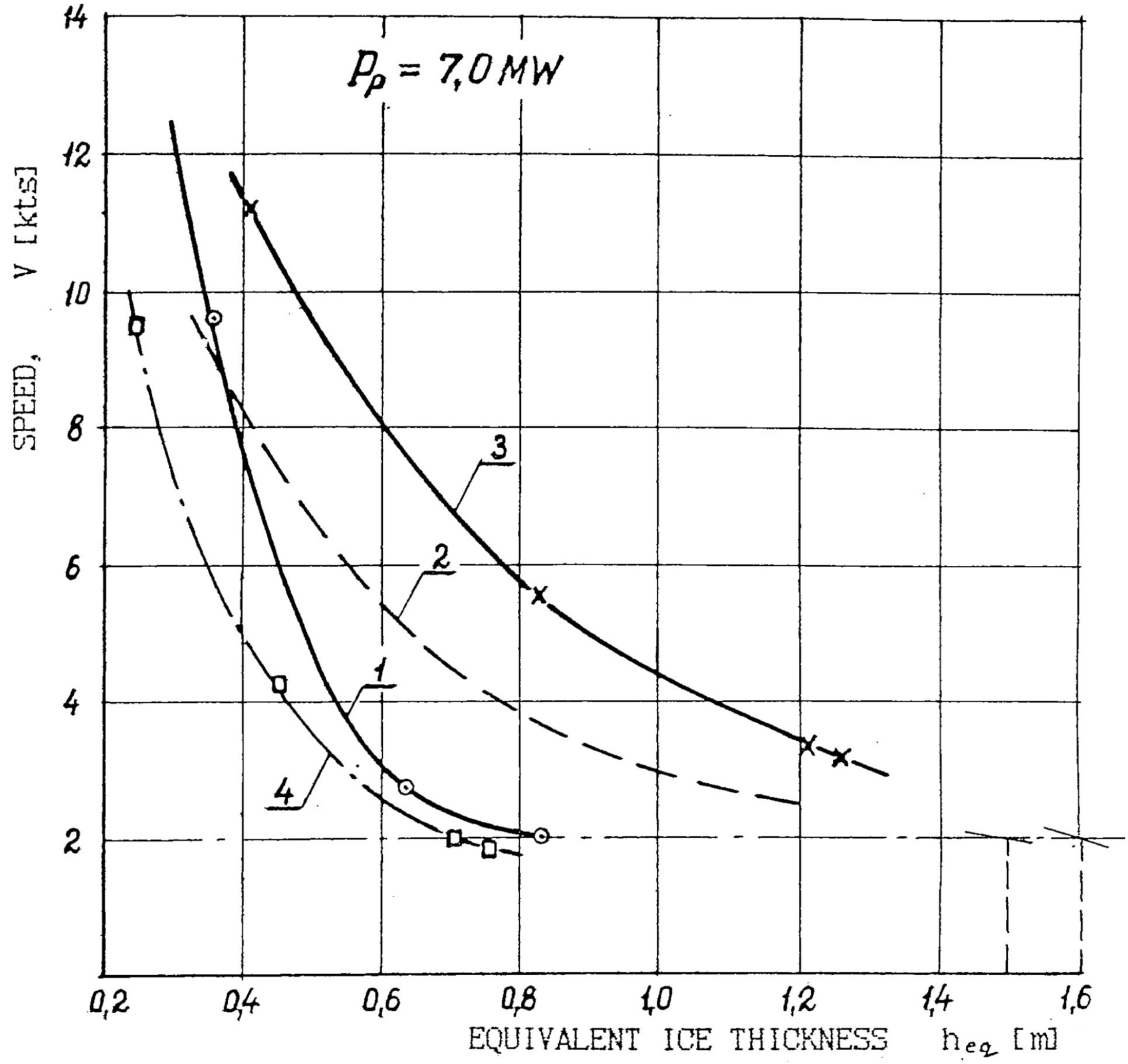
2.3.1. Continuous forward motion.

Figure 2.1 shows the results of tests of the icebreaker of "Mudyug" type and figure 2.2 of "Kapitan Sorokin" type with different forebodies. Table 2.2. shows

Table 2.1

Ice conditions of tests

Icebreaker	Period of tests	Area of tests	Ice Thickness, cm	Snow Thickness, cm	Air temperature C	Ice ultimate bending strength kPa
Mudyug	February, 1983	Morozova Strait (Kara Sea)	50 - 70	15 - 20	-25	450-400
Dikson	March, 1983	Gulf of Bothnia (Baltic Sea)	50 - 70	10 -20	+2	350
Mudyug 86	April, 1987	Spitsbergen	70 - 125	5 - 25	-2 ÷ -12	350-540
Dikson **with LLP - 20**	December, 1985	Yenisei River	40 - 70	10 - 20	-30 ÷ -40	700
Dikson **with LLP - 20**	December , 1986	Yenisei River	50 - 70	5 - 20	-30 ÷ -48	700-900
Tug "*Dunaisky-35*" **with LLP-14**	December, 1975 - March, 1976	Rybinsk Reservoir (Volga River)	65-70	25-30	0 ÷ -4	400-500
Kapitan Sorokin	January-May,1978	Yenisei River	90 -160	25 - 65	-2 ÷ -28	700-800
	April-May, 1979	Yenisei River	130 - 240	10 - 50	-2 ÷ -12	700
Kapitan Nikolaev 90	May, 1990	Yenisei River	150 - 200	20 - 60	0 ÷ -4	900-1350
Kapitan Sorokin 91	May, 1991	Yenisei River	100 - 200	20 - 70	-4 ÷ -14	370-1450



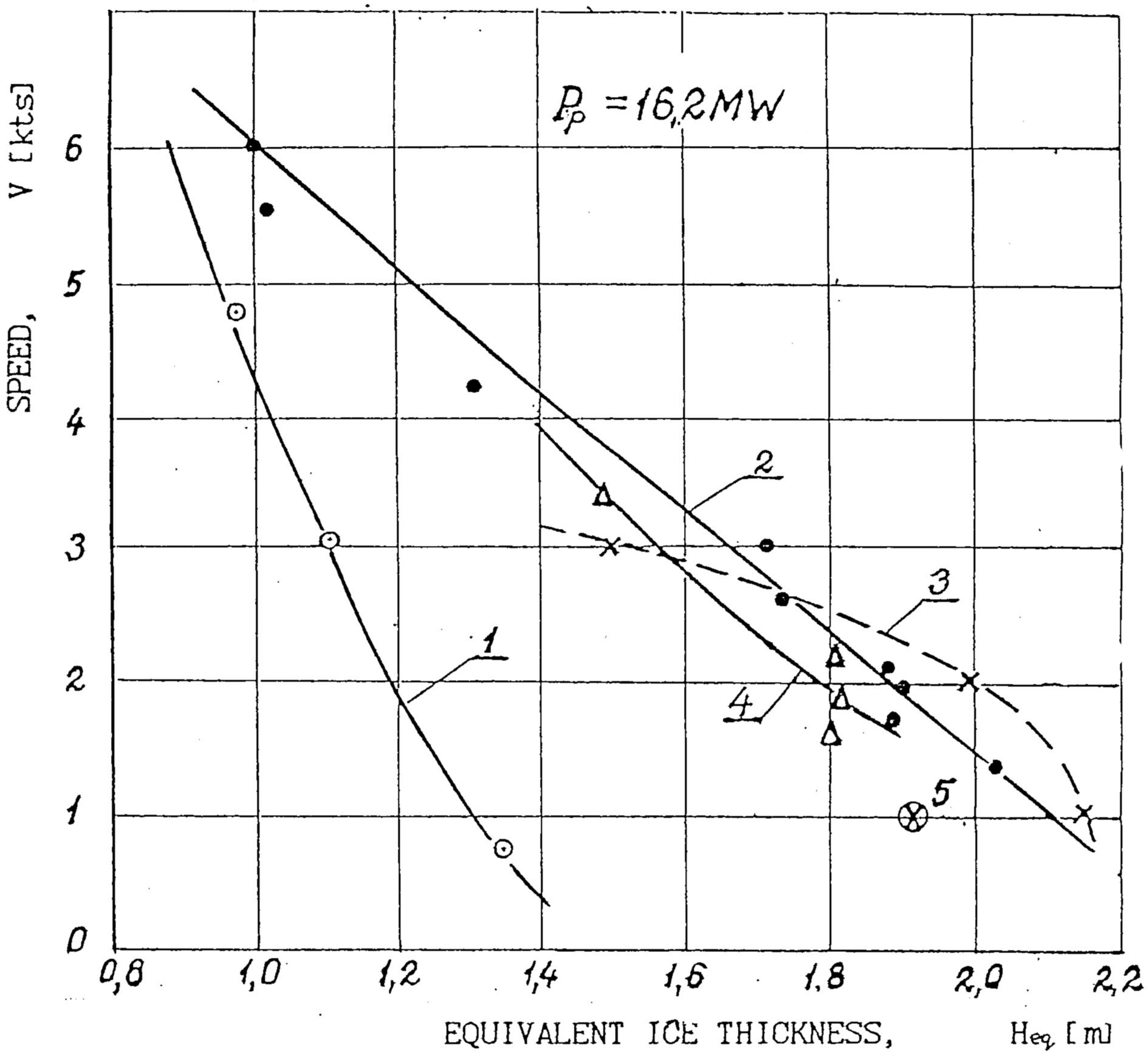
1 - With original bow 1983;

2 - With attached bow LLP-20, 1986;

3 - With Thyssen-Waas bow, 1987;

4 - With attached bow LLP-20 (P = 3.5 MW), 1985

Fig. 2.1. Icebreaking capability ahead of the icebreaker "Mudyug"



1 - WITH ORIGINAL BOW, 1978
2 - WITH THYSSEN-WAAS BOW, 1991
3 - WITH THYSSEN-WAAS BOW (TECHNICAL PERFORMANCE GUARANTY OF THE CONTRACTOR)
4 - WITH CONICAL BOW, 1990
5 - WITH CONICAL BOW (TECHNICAL PERFORMANCE GUARANTY OF THE CONTRACTOR)

FIG. 2.2. ICEBREAKING CAPABILITY AHEAD OF THE ICEBREAKER "KAPITAN SOROKIN"

relative increase of the icebreaking capability at a speed of 2 knots on account of use of non-traditional forms of lines.

Table 2.2.

Relative increase of the thickness of level ice (h_{eq}) broken through at a speed of 2 knots (times)

Icebreaker`s type	Original bow	Barge-like bow		Conical bow
		TYSSEN-WAAS bow	Attached bow LLP-20	
MUDYUG	1,0	1.8	1.7	-
KAPITAN SOROKIN	1,0	1.6	-	1.5

As can be seen from the graph the largest increase of icebreaking capability in compact level ice takes place when the "Thyssen Waas" shape is used. Other non-traditional solutions provide a similar level of icebreaking capability (5-6% difference).

It should be noted that in contracts for the conversion a speed of 1.0 knot was used as a criterion of icebreaking capability being apparently stipulated by the desire of shipbuilding companies to show a higher value of icebreaking capability. It is known from the practice of full scale tests that at this speed the movement is often of unstable character and therefore a minimum stable speed of 2 knots (in Russia) and 3 knots (in a number of countries) is used for the estimations. Trials of the icebreaker "Kapitan Sorokin 91" (with the Thyssen-Waas bow) have shown as well that movement at speeds less than 2 knots is not stable. So, in ice $h_{eq} = 2.03$ m average speed was 1.36 knots. However, during the trial the icebreaker stopped twice and could resume movement only after reversing.

2.3.2. Continuous backward motion.

The icebreaker "Mudyug" with the original bow continuously moved during the backward motion in ice of equivalent thickness of 63 cm at a speed of 1.0 knot, and the icebreaker "Dikson" in 1986 at a power of 5.6 MW moved at a speed 2.0-2.1 knots in ice of the equivalent thickness of 0.5 m (which corresponds to $h_{eq} = 0.54$ m at a shaft power of 7.0 MW). The converted icebreaker "Mudyug" in similar conditions is capable of moving astern only by ramming.

The results of tests of the icebreakers of "Kapitan Sorokin" series during the backward motion are presented in Fig. 2.3, where it is seen that the conversion of the icebreaker "Kapitan Nikolaev" led to a relatively insignificant decrease of the icebreaking capability during the backward motion (5-7%) at a speed of 2 knots. It may most probably be attributed to the additional resistance of ice dispersing staffs welded onto the icebreaker bottom.

More significantly, the icebreaking capability decreased during the backward motion of the icebreaker "Kapitan Sorokin 91" (1.2-1.3 times) despite special conversion of the after end, and change of reamer construction as compared with the icebreaker "Mudyug".

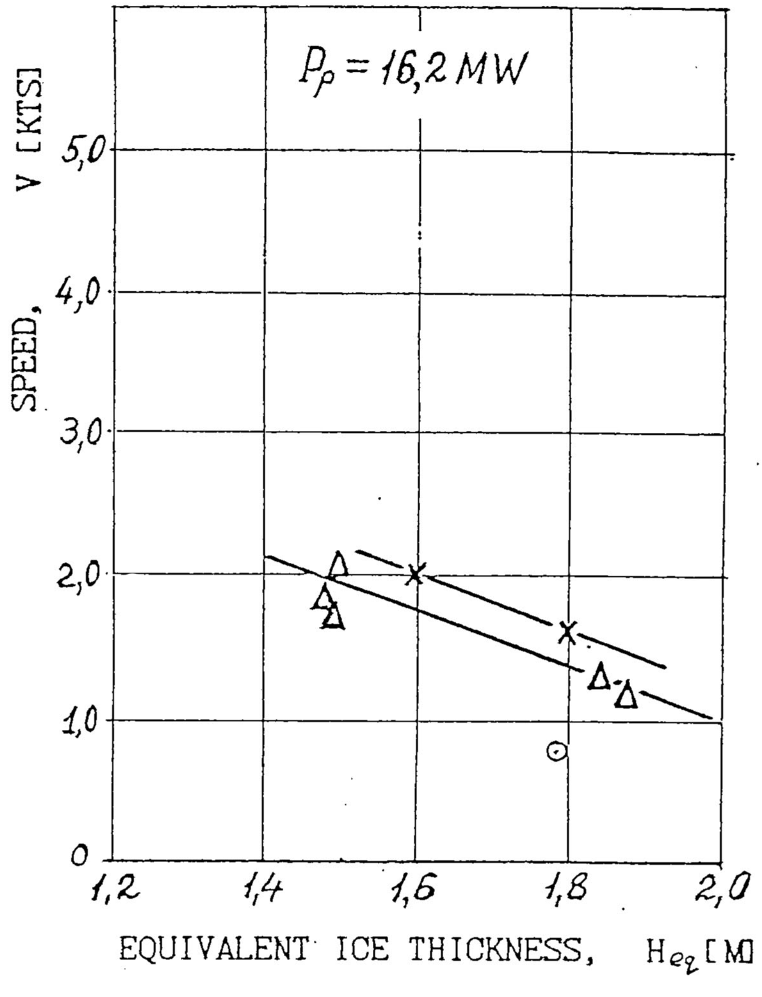
2.4. Tests in the freshly broken own channel.

Results of these tests conducted in channel broken by these ships are shown in Fig.2.4 , which shows that non-traditional forms of hull lines provide for an increase of speed in the channel proper. For icebreakers with barge-like bow shape higher speeds are caused by a clean channel. Best propulsion characteristics in own channel were shown by the icebreaker "Kapitan Nikolaev" as seen from the graph. The advantages of a bow of the Thyssen-Waas system in comparison with traditional ones have an effect only at ice thicknesses greater than 1.6 m.

2.5. Movement in the old channel.

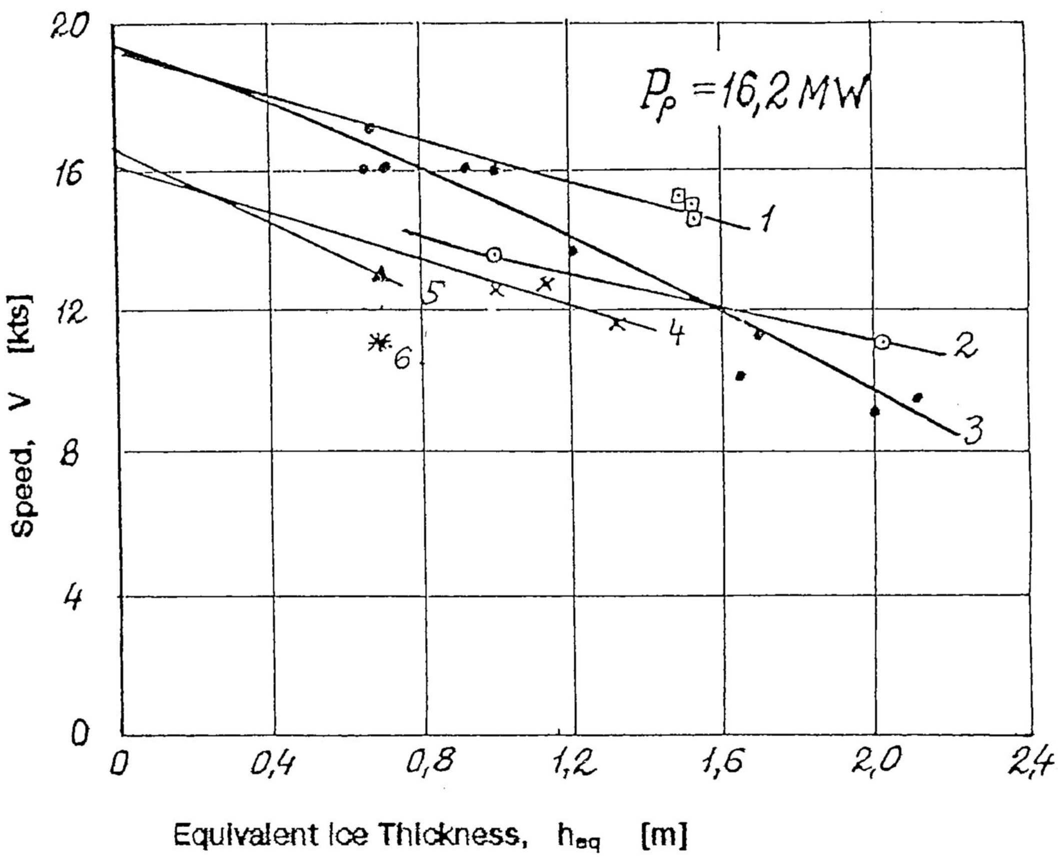
It is possible to qualitatively compare The performance in the old channel of icebreakers of all types being considered on the basis of visual observations. As these observations show, the icebreaker "Kapitan Nikolaev" with a conical bow steadily moves in heavy old channels much better than compared to the progress of the original version.

In similar conditions the progress of the icebreaker "Kapitan Sorokin" fitted with "Thyssen-Waas" forebody is appreciably worse in old channels. In a channel clogged with ice, the icebreaker when it is not capable of reaching a speed of 3-4 knots pushes the ice cake and separate large ice floes ahead. As a result of this action an impenetrable "jam" is formed which has to be broken through by ramming. A similar phenomenon was observed on the



x - WITH ORIGINAL BOW, 1978
Δ - WITH CONICAL BOW, 1990
o - WITH THYSSEN-WAAS BOW, 1991

FIG. 2.3. ICEBREAKING CAPABILITY ASTERN OF THE ICEBREAKER "KAPITAN SOROKIN"



1. KAPITAN NIKOLAEV with Conical Bow, 1990
2. KAPITAN SOROKIN with THYSSEN-WAAS bow, 1991
3. KAPITAN SOROKIN with Original Bow, 1978
4. MUDYUG with THYSSEN-WAAS Bow, 1986
5. MUDYUG with Original Bow, 1983
6. DIKSON with attachment LLP-20

Fig. 2.4. Test in the Own Channel

icebreaker "Mudyug" when using domestic attachments LLP-20 and LLP-14 (see fig. 2.5 and 2.6).

Along with masses of ice cake, the icebreaker "Kapitan Sorokin" tows by its bow separate large ice floes or large frozen blocks of ice. In the course of tests on the Yenisei in 1991, the icebreaker was pushing one such block during several hours working by rammings. If it is necessary to leave the old channel, the icebreaker breaks through its edge with difficulty. It is characteristic also of the attachment LLP-20 which is to be towed by the icebreaker in the case of necessity to cross the old channel, first leaving a berth and breaking a way by rammings.

2.6. Maneuverability

In the process of full-scale trials three types of maneuvers were evaluated: turning circle (see Table 2.3), "herring bone" turn by 180 (Fig.2.7) and leaving of the channel (Table 2.4).

Table 2.3

Turning circle diameter of an icebreaker of "Kapitan Sorokin" type and "Mudyug" type (m)

Ice Thickness m	"Mudyug"			"Kapitan Sorokin"		
	Original	With Tyssen-Waas bow	With LLP-20	Original	With conical bow	With Tyssen-Waas bow
Open water	250	210	470	538	426	648
0.35	300	-	-	-	-	-
0.75	430	-	1150	-	-	-
1.0	-	-	-	1407	-	2370
1.1	-	1050	-	-	-	-
1.2	-	1240	-	-	-	-
1.3	-	1340	-	-	-	-
1.6	-	-	-	-	2460	-

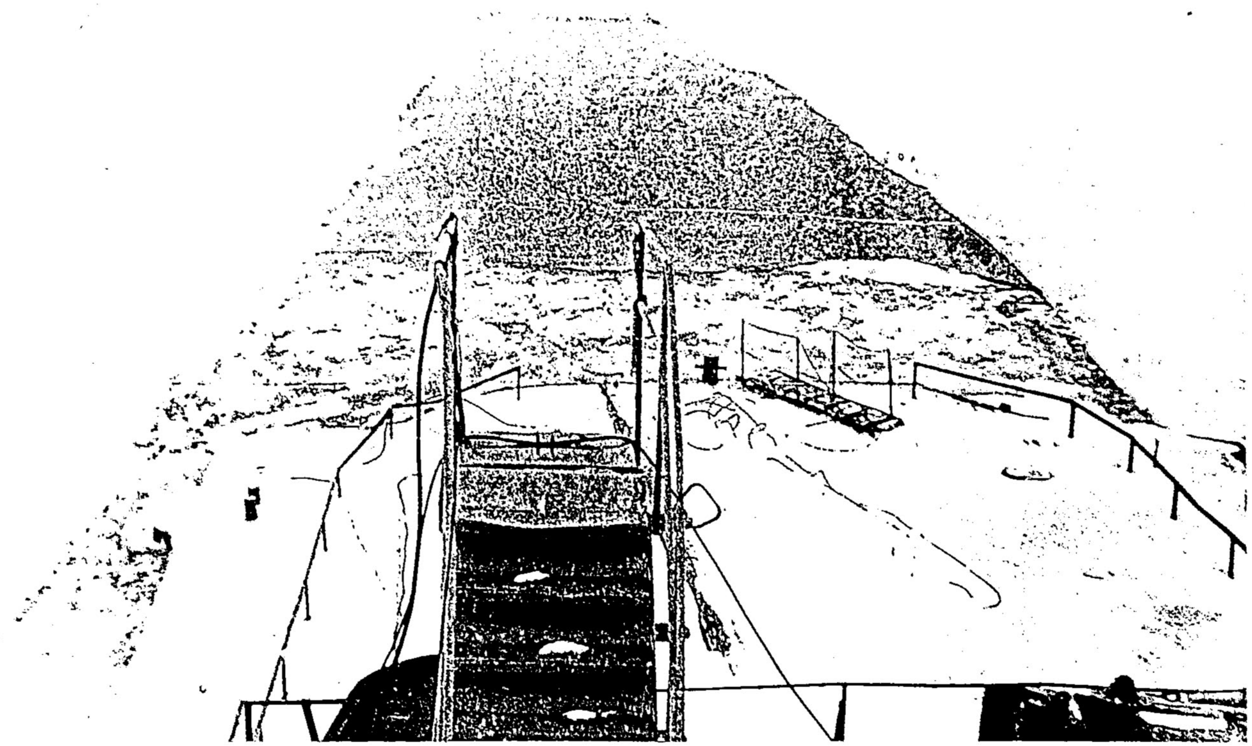


Fig. 2.5. Ice "jam" ahead of the attachment LLP-20 in the movement through the fresh channel at a slow speed

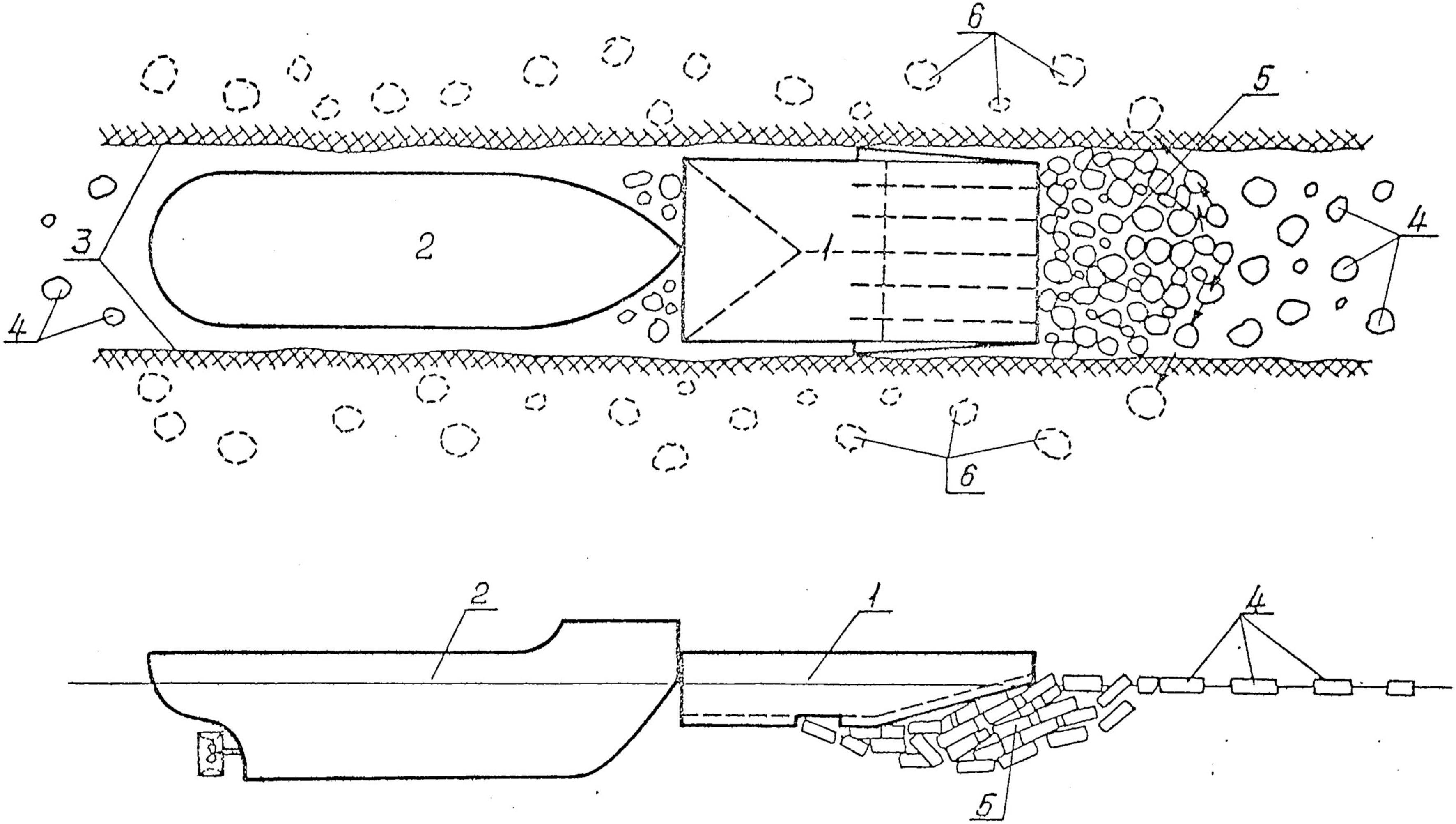
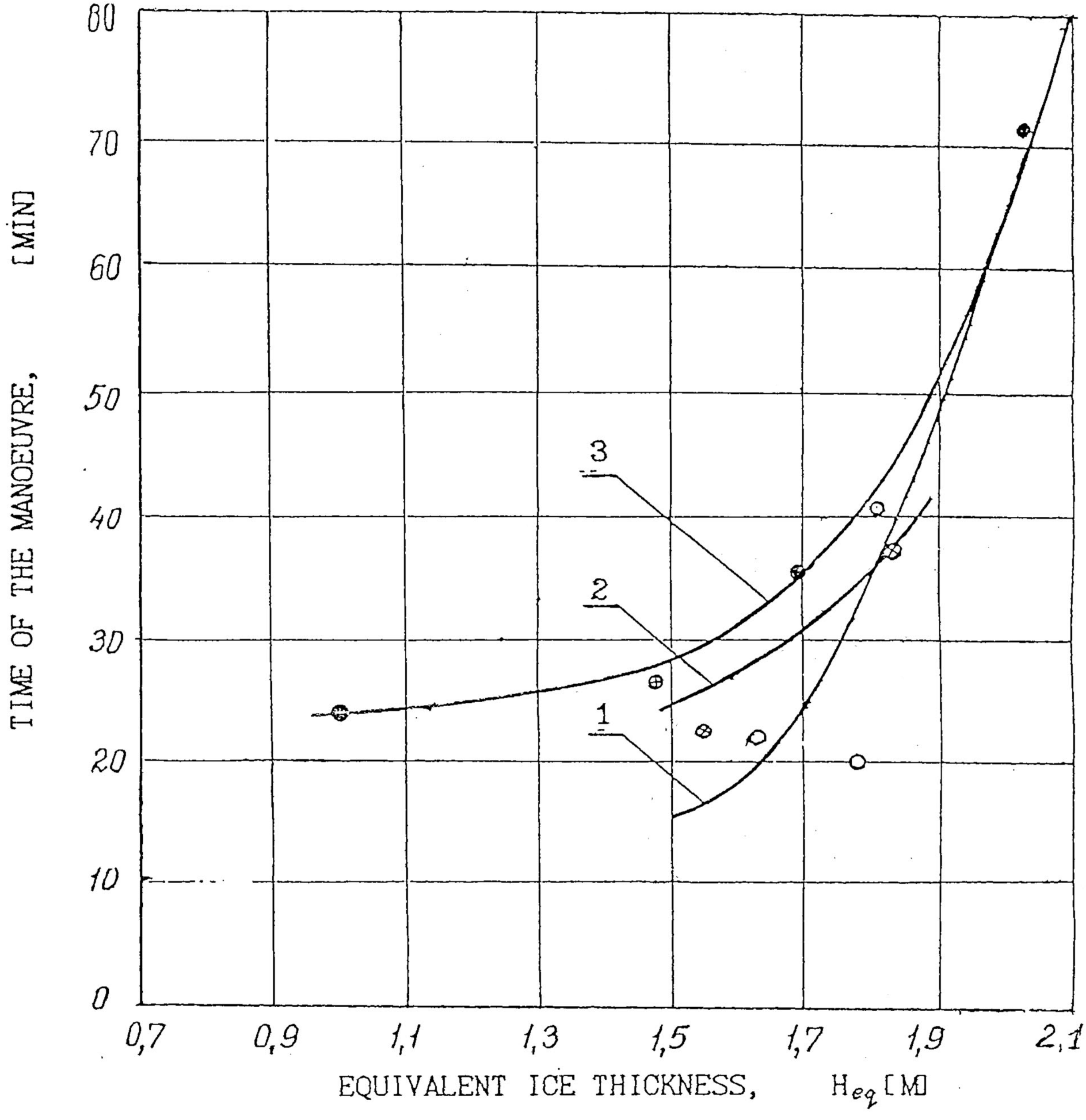


Fig. 2.6. Ice Floes Position Pattern in the Clearing of Non-frozen Channel by the Attachment at a Low Speed
(Ice Floes Paths are Designated by Arrows)
1- attachment; 2-push-boat; 3-channel edge; 4- ice in the channel; 5- ice jam; 6- ice floes driven under the channel edges



1. "KAPITAN SOROKIN" WITH ORIGINAL BOW, 1978
2. "KAPITAN NIKOLAEV" WITH CONICAL BOW, 1990
3. "KAPITAN SOROKIN" WITH THYSSEN-WAAS BOW, 1991

FIG. 2.7. STAR TURNING IN THE LEVEL ICE

Table 2.4

Maneuver of breaking out of the channel

Ice Thickness, m	"Mudyug"				"Kapitan Sorokin"					
	Original		"Mudyug 86"		Original		"Kapitan Nikolaev 90"		"Kapitan Sorokin 91"	
	Angle, degr.	Time, sec	Angle, degr.	Time, sec	Angle, degr.	Time, sec	Angle, degr.	Time, sec	Angle, degr.	Time, sec
0.65	65	78	-	-	-	-	-	-	-	-
0.75	-	-	-	-	60	90	-	-	-	-
0.9	-	-	-	-	65	146	-	-	-	-
1.1	-	-	65	92.5	-	-	-	-	-	-
1.2	-	-	66.5	63	-	-	-	-	-	-
1.3	-	-	66	97	-	-	-	-	58	160
1.6	-	-	-	-	-	-	65	60	-	-

As one can see from Tables 2.3 and 2.4 and from Fig.2.7, maneuvering characteristics of icebreaker with a barge-like forebody are worse than those of icebreakers of traditional type. Icebreaker with conical bow has better characteristics. So, relative radius of the turning circle in ice of the icebreaker "Kapitan Sorokin 91" about 1.0 m thick increased more than 1.5 times. At the same time, the diameter of the turning circle of the icebreaker "Kapitan Nikolaev 90" in ice 1.6 m thick turned out to be comparable with the diameter of the turning circle of the icebreaker "Kapitan Sorokin" in ice 1.0 m thick.

It was impossible to make the turning circle by the icebreaker "Kapitan Sorokin 91" in ice with a thickness of h_{eq} = 190 cm, though the icebreaker is capable of continuously moving through this ice at a speed of about 2.0 knots strait ahead. Under similar conditions the icebreaker "Kapitan Nikolaev 90" is capable of making the turning circle.

2.7 Operation in drifting ice.

Under operation in drifting ice conditions, the pushing of ice by icebreakers with a barge-like forebody takes place at speeds up to 3-4 knots just as in the old channel. Propulsion of the icebreaker "Kapitan Nikolaev-90" in drifting ice improved.

As far as references of navigators are concerned, the capability to break through hummocks is as a whole improved on all icebreakers after their conversion. At the same time, icebreakers "Mudyug-86", and "Kapitan Sorokin 91" as well as all icebreakers with LLP-20 experienced perceptible difficulties in breaking through hummocks mainly in connection with the impossibility to return back while operating by ramming especially when simultaneous turning is to be performed.

Icebreaker "Kapitan Nikolaev-90" after its conversion was never jammed and this may primarily be attributed to the plate strake of steel clad with stainless coating and having a low friction coefficient.

It is difficult to consider as satisfactory the capability of the icebreaker "Kapitan Sorokin-91" of getting released from the sticking. So, for instance, after sticking in a hummock formation (that is in conditions of the absence of compression) during the tests in May 1991, it took the icebreaker more than 10.5 hours to work free, while hull washing, heeling and trimming systems were used.

2.8. Propulsion in open water and seaworthiness

All the icebreakers after their construction and updating were subjected to speed trials and their speeds in open water can be compared objectively (see Table 2.5).

Table 2.5

Speed during trials (knots)

"Mudyug"		"Kapitan Sorokin"		
Original	"Mudyug 86"	Original	"Kapitan Nikolaev 90"	"Kapitan Sorokin 91"
16.5	16.1	19.5	-	18.5
-	-	19.4	19.2	-

As one can see from the table, barge-like lines result in a decrease of speed in open water of up to 5% However of practical interest is the propulsion of icebreakers with non-traditional lines in waves.

The operation has shown that the icebreaker "Kapitan Nikolaev" after conversion experienced considerable slamming in a head sea. This causes serious problems when the icebreaker sails on the high seas. So, in December 1992 during the passage from Murmansk to

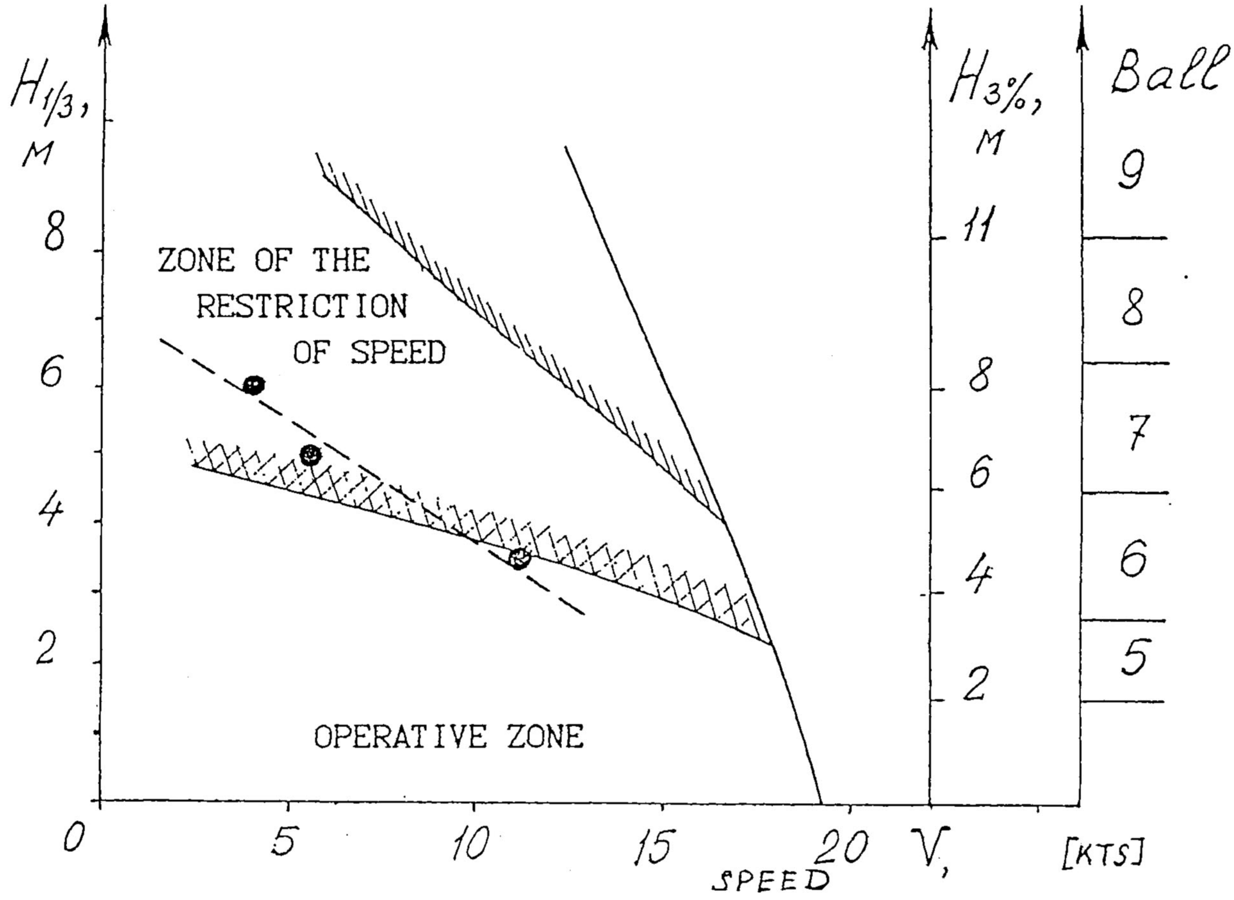
St.Petersburg the icebreaker "Kapitan Nikolaev" met heavy storm conditions in the Norwegian Sea, wave heights reaching 7-8 m and wind speed - 20-30 m/s. The icebreaker had to reduce speed up to 3-5 knots. After 27 hours of such stormy weather the icebreaker having suffered serious structural damages was forced to seek shelter in skerries for the sake of safety. Some 3.5 days were necessary for repair works. As a result, total time of the passage of the icebreaker to St.Petersburg was almost 13 days instead of a week scheduled for icebreakers with traditional shape of lines.

Among structural damages inflicted as a result of strong impacts onto the forebody and consequently shaking and vibration of hull and superstructure, there were cracks in angles of the fastening of superstructures to deck and in the ventilation duct of electrical propeller motors, deflection and breaking loose of the underdeck bulkhead framing, damages to auxiliary boiler fasteners etc. In a number of accommodation rooms the furniture was torn off fixtures and damaged, and ceiling fastenings broken. Also damaged were ship's aerial devices.

The commission which has investigated the causes of damage to the icebreaker "Kapitan Nikolaev 90" came to the conclusion that after conversion this icebreaker was not capable of making safe transits around Scandinavia in te autumn-winter period and recommended to coordinate with the Marine Register the appropriate restrictions as to area of navigation and wave heights.

Restrictions of speed in waves of the icebreaker "Kapitan Nikolaev" with a conical bow shape recommended by "Masa-Yards" are represented in Fig.2.8. Speeds during the storm in the Norwegian Sea in December 1992 are also indicated (dotted line). As one can see from the graph the restriction in terms of vibration turned out to be actually maximum for the hull structure and safety of ship and crew as a whole.

The experience of the operation of icebreakers "Mudyug" and "Kapitan Sorokin" has shown that the hull shape offered by "Thyssen" provides for smoother rolling in waves, with small amplitudes, on account of the damping effect of reamers. However, during the icebreaker motion at wave-to-course angles, there are strong jerks caused by the wave impacts against the bow counter, resulting in shocks and vibration of the hull,



100% OF THE POWER

RESTRICTIONS DUE TO GREEN WATER

DECLINE OF THE STANDART OF LIVING DUE TO WHIPPING

SPEEDS DURING THE PASSAGE ON 22-23.12.92

FIG.2.8. RECOMMENDATIONS OF THE "MASA-YARDS" COMPANY ON THE CHOICE OF SPEED OF ICEBREAKER "KAPITAN NIKOLAEV" AFTER CONVERSION IN A SEAWAY

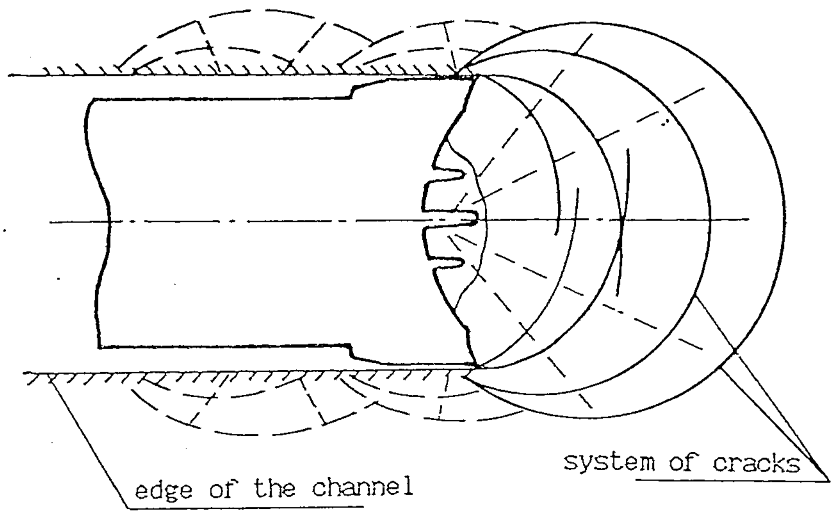
disruption of the normal work on board and violation of the safety of radio navigational equipment as well as in the deterioration of crew iving conditions. It is known that the ship met similar storm conditions in the Norwegian Sea as that by "Kapitan Nikolaev" during the voyage of the icebreaker "Kapitan Sorokin" in January-February 1992 from Murmansk to St.Petersburg. It took this icebreaker also 13 days to pass around Scandinavia. In the opinion of the shipowner, the sea-keeping capability of the icebreaker "Kapitan Sorokin 91" has on the whole deteriorated after conversion.

2.9. Hull / Ice interaction

2.9.1. Breaking of compact level ice

In the movement of the icebreaker "Kapitan Nikolaev" with conical forebody through thick level fast ice, the pattern of ice breaking does not differ fundamentally from that of icebreakers of traditional type. The interaction of the barge-like forebody with level ice produces externally a different pattern. Authors of icebreaking attachments of LLP type and designers of the "Thyssen-Waas" concept supposed that ice would be broken by cutting in places of contact with ice of side and intermediate "knives" and in the direction of movement a cut out key would be broken off under the effect of bending load. However, as far back as in 1975 during the trials on the Volga of the LLP-14 attachment, it was found that in reality the scheme of ice destruction was fundamentally different from the one supposed. This was also confirmed during the tests of LLP-20 and later of icebreakers "Mudyug-86" and "Kapitan Sorokin 91".

While making a channel in the ideally level fast ice, the forebody of the icebreaker crawls upon the ice, the trim measured being up to 0.8 m. Side knives (reamers) do not cut the ice through, but only cut into its upper surface at a depth, as a rule, not exceeding 5-10 cm. The ice cover is fractured by bending and a network of cracks characteristic of this type of defection . These cracks can easily be visually detected (see fig.2.9-2.10). Cracks originate mainly at reamers and usually occur in the center-line plane (but not always). In contrast to the ice failure by hull of the traditional shape, there is no submersion and turning of broken off ice segments. Instead, reamers chop off ice along the cracks and smooth out the channel



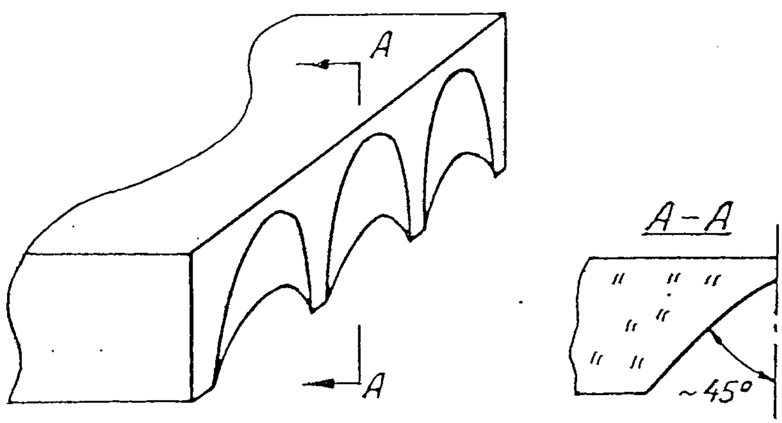


Fig. 2. 9. Scheme of ice breaking.
"Kapitan Soprokin" with Thyssen-Waas bow

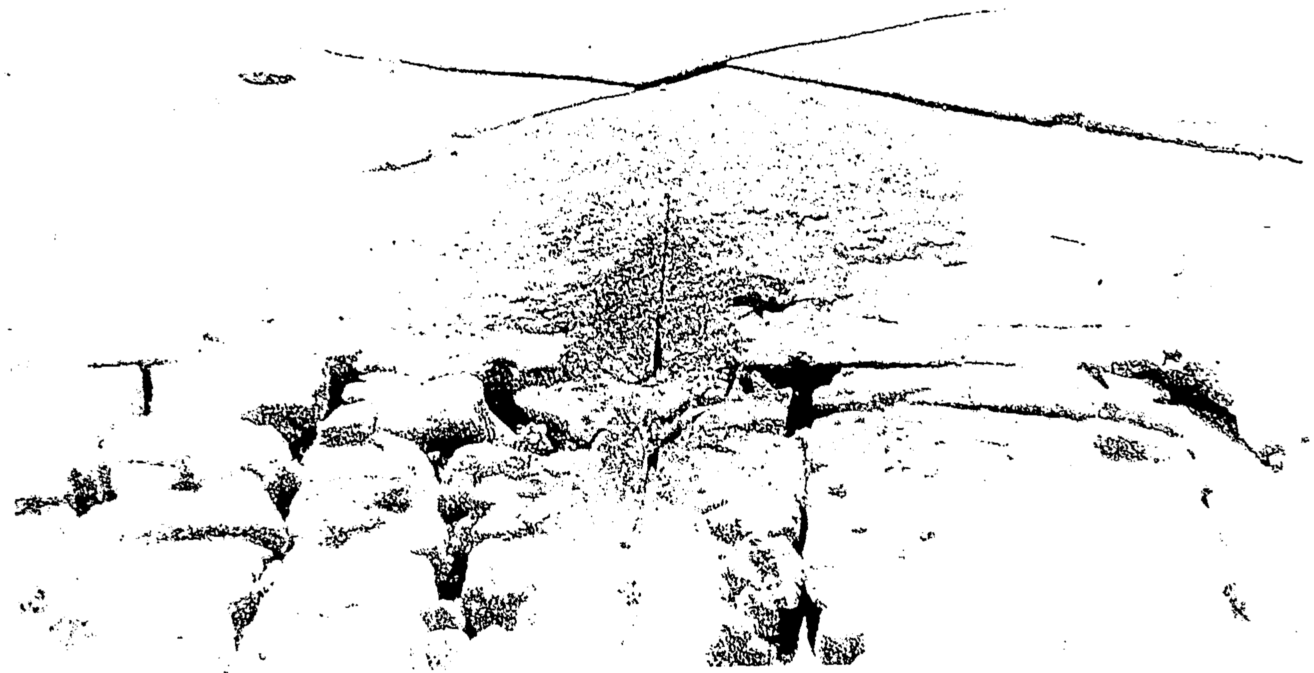


Fig.2.10. Ice Breaking.
Icebreaker ***Kapitan Sorokin*** with THYSSEN-WAAS bow

edges with the channel edge being bevelled by about 45° in relation to the vertical due to the separation of a chain of dents formed as a result of the development of cracks (see fig.2.9). During repeated passages along the channel the cracked segments along the edge frequently break off and get into the channel.

Full-scale observations show that the character of ice destruction for an icebreaker with traditional and one with barge-like lines is essentially similar. The difference is in the position of cracks and segments.

2.9.2. Clearness of the channel

While making a channel in the fast ice its filling with broken ice beyond the icebreaker "Mudyug 86" as well as pushing the attachment LLP-20 did not exceed 20-30%. The filling of channel beyond the icebreaker "Kapitan Sorokin 91" was up to 40%, and beyond icebreakers of traditional type and with conical bow - not less than 80-90%. At the same time after the second passage a portion of ice floes was washed out from under the edges of the channel and filling of the latter increased by 10-20%. After several passages the channel around the icebreaker "Kapitan Sorokin 91" visually did not differ from the channel around an ordinary icebreaker.

2.9.3. Width of the channel

Channel beyond the LLP-20 attachment and icebreakers with forebody of the "Thyssen-Waas" type has a width practically equal to the distance between cutting reamer edges. For instance, the width is about 31 m for the icebreaker "Kapitan Sorokin 91". Under similar conditions, the icebreaker "Kapitan Nikolaev 90" made a channel with uneven edges, but not less than 30 m wide.

3. EXPERT ASSESSMENT OF THE EFFICIENCY OF DIFFERENT HULL SHAPES BY THE FACTOR ANALYSIS

This method was developed by CNIIMF jointly with "Masa-Yards" company for the comprehensive assessment of the expediency to refit icebreakers. Table 3.1 shows the results of the expert assessment using 5-grade system (5-highest, 1-lowest) of ice performance and sea-going ability of the icebreaker "Kapitan Sorokin" with different forebodies.

Table 3.1

Assessment of the efficiency of icebreakers by different concepts with the use of the factor analysis

Conditions	"Kapitan Sorokin-77"	"Kapitan Nikolaev-90"	"Kapitan Sorokin-91"	Significance of factors	
				sea	river
	a	b	c	d	e
Level ice					
headway	3	4.5	5	4	5
sternway	4	4	3.5	4	3
Old lead					
headway	3	4.5	2.5	3	5
sternway	4	4	3.5	3	5
Hummocks					
headway	3	4.5	3	4	1
sternway	4	4	3	3	1
Compacting					
headway	4	4.5	2	4	1
sternway	4	3.5	1.5	4	1
Circulation in ice	4	4	2.5	3	2
Herring bone turn	4	3.5	3	4	5
Lead width	2	2.5	3	4	4
Cleaning of lead	2	2	4.5	2	4
Degree of ice fragmentation	3	3.5	5	3	4
Leaving of the lead	2	4	3.5	3	5
Release out of jamming	4	4.5	3	5	3
Shallow water	2	2	3	1	5
Seaworthiness	4	1.5	3.5	4	1
Integral index Sea	Σa*d = 198	Σb*d = 214	Σc*d = 185		
River	Σa*e = 169	Σb*e = 196	Σc*e = 190		

As one can see from the table the final assessment is considerably influenced by the mission (operational conditions) of icebreakers. Under "river" icebreaker we mean an icebreaker designed for operation mainly in level fast ice. The factor analysis shows as a whole that the advantages of barge-like lines in level ice do not compensate for the deterioration of other icebreaker qualities.

4. RESULTS OF THE OPERATION OF ICEBREAKERS OF "KAPITAN SOROKIN" SERIES WITH DIFFERENT FOREBODIES

For estimation of the advantages and disadvantages of non-traditional hull lines in the process of real operation, icebreakers of the *Kapitan Sorokin* series were selected as the Murmansk Shipping Company operates now three icebreakers of this series with three different bows corresponding to all three concepts considered in this report.

For a comprehensive analysis of the work of icebreakers, there is so far not sufficient information because the converted icebreakers have been in operation for only about three years. Nevertheless the experience gained allows certain conclusions to be drawn. Speed of escorting, average power actually used as well as conventional index of icebreaker capacity determined by the below stated formula were analyzed:

$$V_{pr} = \frac{\sum_{1}^{n} T_i S_i}{P_f \sum_{1}^{n} t_i}, \quad \frac{\text{tons x miles}}{\text{kW x days}}$$

where: T_i - tonnage of ships escorted;

S_i - distance of escorting;

P_f - actually used average power;

t_i - duration of escorting

n - number of escorting for the period analyzed

Since 1993 icebreakers of this type work in the Arctic just partly. Results of the operation of icebreakers in 1990-1992 are summarized in table 4.1.

The most interesting aspect in the analysis is the work of icebreakers in the Yenisei gulf and Yenisei river where escorting is carried out along the channel in the fast ice between Dickson Island and the port of Dudinka (approximately 360 miles). As was known while designing icebreakers of the "Kapitan Sorokin" series this area of operation was considered for them as a principal one. April was chosen for the sake of comparison the heaviest month for navigation- (see Table 4.2).

Table 4.1

Results of the operation of icebreakers of "Kapitan Sorokin" type in 1990-1992

Characteristics	ICEBREAKER		
	Original	"Kapitan Nikolaev 90"	"Kapitan Sorokin 91"
Duration of the operation in the Arctic, days	407.7	272.1	315.6
including escorting	187.8	138.6	158.6
Number of Ships escorted	178	162	138
including those in conjunction wit other icebreakers	80	33	73
Average speed of escorting, knots	5.9	6.2	5.6
Average speed of escorting without participation of other icebreakers, knots	5.7	6.1	5.0
Power use ratio, %	52	41	66
Capacity (V_{pr})	182.9	270.9	169.4

Table 4.2

Results of the operation of icebreakers of "Kapitan Sorokin" type on Yenisei river in April 1990-1992

Characteristics	ICEBREAKER		
	Original	"Kapitan Nikolaev 90"	"Kapitan Sorokin 91"
Conditions	Fast ice about 150 cm thick, snow cover up to 50 cm, old continuously operating channel		
Average distance of escorting, miles	156,8	143,4	145,0
Average speed, knots	4.2	5.2	3.0
Power use ratio, %	45	35	70
Capacity (V_{pr})	126.2	203.4	37.5

Results of the work of icebreakers in 1990-1992 as a whole and data of table 4.2 show that the conversion of the icebreaker "Kapitan Nikolaev" resulted in noticeable improvement of its operational characteristics in ice and that icebreaker "Kapitan Sorokin" with the "Thyssen-Waas" bow is inferior in capacity and energy consumption to an icebreaker with the traditional bow. It should be noted, however, that "Kapitan Sorokin 91" on the Yenisei river worked principally in the old channel which was simultaneously used by other icebreakers with traditional lines. This circumstance did not allow realization of one of the main advantages of the "Thyssen-Waas" conception, namely a cleaner channel. At the same time the breaking of a certain number of new channels needed during the whole winter is practically impossible because of the intensity of ship traffic and width restrictions of the waterway on the Yenisei river.

CONCLUSIONS

1. Use of non-traditional hull lines leads to a substantial increase of the compact level ice thickness broken through in continuous motion. For conical lines this thickness increases by 1.5 times, for barge-like ones - by 1.6-1.7 times.

2. Conical lines provide for improvement of propulsion in fresh and old channels and retain other ice properties at the level corresponding to traditional lines. Barge-like lines are at a disadvantage in relation not only to conical lines but also to traditional ones as far as propulsion and maneuverability in conditions of an old channel and considerable thickness of snow cover are concerned.

3. Non-traditional hull lines result in higher resistance to the motion in open water and in waves. The worst speed characteristics are observed when a barge-like bow is used in calm water, the same being true for conical bow in waves.

4. Analysis of the results available of the operation in the Arctic revealed noticeable difference in the parameters of economical efficiency of icebreakers of "Kapitan Sorokin" series with different forebodies. So conical lines ensured the increase of speed of passages by 10-20%, decrease of power use level by about 20%, reduction of operational costs by 5%, increase of profitability - 1.4 times. These properties of the icebreaker with "Thyssen Waas" forebody deteriorated in relation to the original version.

5. The use of pushed attachments with barge-like lines provides to the "icebreaker-attachment" convoy ice propulsion, maneuverability and cleaning of the channel at the level of icebreakers with the forebody of the THYSSEN-WAAS system. At the same time such convoys have serious problems in the reverse movement and maneuvering resulting in the necessity for periodical unmooring and remooring of the icebreaker to the attachment.

6. The first experience of operation shows as a whole that as applied to the conditions of the Russian Arctic the use of barge-like lines for multi-purpose icebreakers is not advisable. Apparently pushed attachments or icebreakers with the "Thyssen-Waas" bow system may find restricted application for the fulfillment of special tasks in conditions of the compact level ice.

Among such tasks may be breaking of the fast ice on rivers in spring for the earlier start of navigation, single breakage of the channel in the level fast ice of straits or bays, water areas etc.

The icebreakers with conical bow lines have good icebreaking capabilities but their sea-going ability is unsatisfactory. The use of improved traditional lines the parameters of which approach conical ones but provide for admissible seaworthiness is preferable for home icebreakers having to make long sea voyages.

Patent investigations as well as the analysis of experimental research and data of operation of a number of new technical means permit the assessment of fields of application, advantages and disadvantages of non-traditional icebreaking lines.

Further on with the purpose of bringing to light fields of application and developing recommendations on use of different concepts of ice removal and increasing icebreaking capability of ships, it is recommended to perform the following works:

- Research on technical means of improving icebreaking capability and keeping it at the specification level in the course of operating ships in various navigation conditions (air and water bubbling systems for ship's hulls, anticorrosive iceresistant paints and other antifriction materials).

- Determination of rational field of using aircushion vehicles for the removal of ice cover.

- Examination of the prospects for improving conventional hull lines of icebreaking ships on the basis of operational experience and experimental investigations.

The above works provide for both summing up and analysis of the results of the studies thus far finalized and new developments, including model and full-scale experiments.

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13. Juurmaa K., Wilkman G., Shlachkov V., "The evaluation of different Icebreaker concepts using mission based approach", Advance copy of paper to be presented at the international conference, Tromso, Norway, March 30- April 1, 1992

Review for International Northern Sea Route Programme (INSROP)

Reviewer: Devinder S. Sodhi

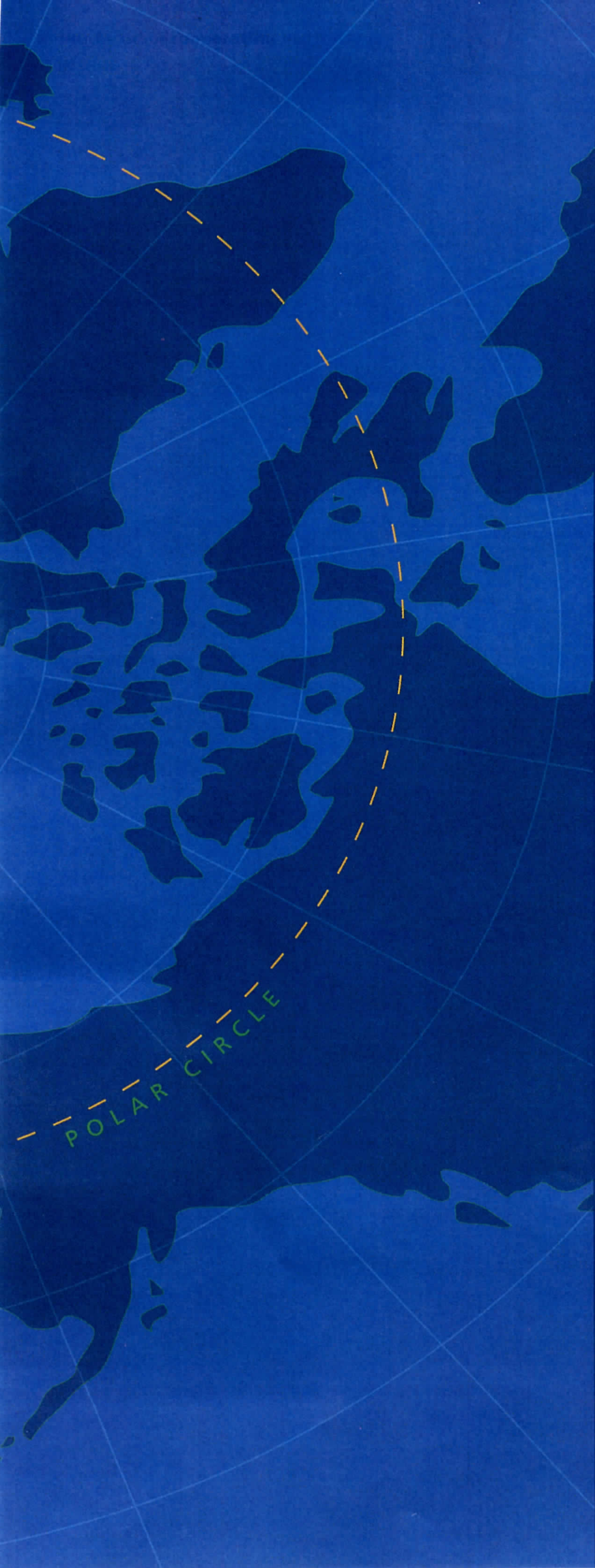
Sub-programme III: Trade and Commercial Shipping Aspects
Project 11.1: New concepts of removing ice: Investigation of the efficiency and advisability to use non-traditional shape of hull lines of icebreaking cargo ships of Arctic navigation.
Authors: A. V. Ierusalimsky, S. M. Pomarev and T. M Semenova.

The authors have presented the results of full-scale tests conducted on three Russian sister ships of the *Kapitan Sorokin* series, each with a different hull form, as well as on the icebreaker *Mudyug* before and after its conversion to a barge-like bow and icebreaking attachment (LLP-20). A part of this report (namely the comparison of the performance of the three Russian sister ships of the *Kapitan Sorokin* series with different hull forms) was published by Ierusalimsky and Tsoy in the proceedings of the 5th International Conference on Ships and Marine Structures in Cold Regions, held in Calgary, Alberta, Canada, in March 1994. This report contains more data and information than the one published in 1994.

The authors should be commended for conducting the tests not only in fast ice zones, but also in channels and in broken ice, and for reporting the results on the overall performance of the icebreakers having different hull forms. A study of this type is needed to illustrate for the designers of future ships that, while the performance of a particular hull form may improve in fast ice zones, its performance may suffer in broken ice fields. It is interesting to note that ships with non-traditional hulls must reduce their speed in severe seas without any ice to avoid damage from wave slamming. The authors have given a comparison of operating costs for ships of different hull forms. The conclusions stated by the authors are significant and should be useful to the designers of future icebreakers.

I fully understand and appreciate the difficulties the authors face in writing this report in a language considerably different than their own. However, it is essential to present the material in a clear and coherent manner for disseminating technical information. In the manuscript, I have suggested editorial changes to make the text read a little better. The authors may consider making these and other changes before final publication.

I recommend publication of this report after editorial changes have been made. The report is sound on technical matters and worthy of publication as an INSROP - Working Paper.



The three main cooperating institutions of INSROP

Ship & Ocean Foundation (SOF), Tokyo, Japan.
SOF was established in 1975 as a non-profit organization to advance modernization and rationalization of Japan's shipbuilding and related industries, and to give assistance to non-profit organizations associated with these industries. SOF is provided with operation funds by the Sasakawa Foundation, the world's largest foundation operated with revenue from motorboat racing. An integral part of SOF, the Tsukuba Institute, carries out experimental research into ocean environment protection and ocean development.

Central Marine Research & Design Institute (CNIIMF), St. Petersburg, Russia.
CNIIMF was founded in 1929. The institute's research focus is applied and technological with four main goals: the improvment of merchant fleet efficiency; shipping safety; technical development of the merchant fleet; and design support for future fleet development. CNIIMF was a Russian state institution up to 1993, when it was converted into a stockholding company.

The Fridtjof Nansen Institute (FNI), Lysaker, Norway.
FNI was founded in 1958 and is based at Polhøgda, the home of Fridtjof Nansen, famous Norwegian polar explorer, scientist, humanist and statesman. The institute spesializes in applied social science research, with special focus on international resource and environmental management. In addition to INSROP, the research is organized in six integrated programmes. Typical of FNI research is a multidisciplinary approach, entailing extensive cooperation with other *research institutions* both at home and abroad. The INSROP Secretariat is located at FNI.