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PERFORMANCE OF MARINE PROPELLERS
IN ICE-CLOGGED CHANNELS

by Valter Kostilainen

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FOREWORD

The Winter Navigation Research Board presents its research report no. 33. This report deals with the problem of estimating the performance of a propeller in an ice-clogged channel. It should be regarded as a preliminary attempt to attack this question, which up to now has received comparatively little attention.

The Winter Navigation Research Board expresses its sincere thanks to Professor Kostilainen and those who have assisted him.

Helsinki and Norrköping, March 1981

Jan-Erik Jansson

Kaj Janérus

ABSTRACT

Most of the research work on cold region marine technology so far has been directed toward ice impact loads on structures and propellers and methods of reducing the resistance of ice-transiting ships. Very few studies have been made on the hydrodynamic performance of propellers in a mixture of ice fragment and water.

This paper presents a method of predicting the performance of marine propellers in ice-clogged channels by means of model tests in a mixture of water and plastic pieces.

The difficulties in experiments caused by the high impact loads of plastic material have been overcome by the introduction of a new method of making model propellers and by the development of a new propeller dynamometer.

The results of tests with four propeller models are presented. The importance of disregarding the scaling of the modulus of elasticity and the strength of plastic material to that of natural ice is considered. The laws of similitude are discussed.

1. INTRODUCTION

The benefits of commercial marine transportation in ice-covered waters are real. This has led to the extension of the shipping season in cold regions and to denser traffic. In these conditions most of the ships are operating in broken ice channels with only a slightly refrozen ice cover. This commercial mode of operation is a significant change from typical icebreaker operations and in turn leads to different performance requirements of marine propellers.

The prediction of the ship performance in ice-covered waters is at present more and more based on model tests in saline ice or in artificial material simulating the properties of scaled ice. Full-scale values are predicted with different methods and a certain degree of success in correlating the model data with full scale data is recognized.

Corresponding for the three principal modes of operation, model tests are made in level ice, ice-clogged channels and ice-ridges.

The majority of the experiments and analyses have been concerned with performance of ship hull in some of the three modes of operation. Some of these tests are made with self-propelled models and an estimate of the quasipropulsive coefficient can be obtained. Model propellers in self-propelled tests work at low Reynolds-numbers and this results in a certain uncertainty in fullscale predictions. To the knowledge of the author, no attempts have been made to study systematically the performance of propellers of ice-transiting ships. This situation is a consequence of the fact that systematic tests require great numbers of test runs and tests in scaled model ice are expensive and time consuming. The scatter of the test results is large and the maintenance of permanent conditions difficult.

Considering the inter-action of propeller and ice in the continuous mode of icebreaking, propeller blades also hit large ice blocks and cut them into pieces. Thus the modulus of elasticity and strength of ice have a prominent effect on the performance of the propeller and model tests should be made in scaled saline or artificial ice. In this case, if the immersion of the propeller is large, the frequency of ice blocks reaching the propeller is low.

The situation remains nearly the same from the point of view of propeller operation, when the ship is navigating in a newly broken channel, there are still large ice-blocks left and the number of ice blocks is low, as can be seen from Fig.1.



Fig. 1. Newly broken channel in the Baltic



Fig. 2. Typical old channel in the Baltic

The increase in commercial transportation in ice-covered waters has led to the situation, that during the winter most of the time commercial ships at least in the Baltic, are operating in old channels. A typical old channel is presented in Fig.2. There are no large ice blocks left and the dimensions of the ice-blocks in different directions are of the same order. The thickness of the layer of ice-blocks is continuously increasing as long as the temperature remains below 0°C . Even when the immersion of the propeller is large the propeller blades, at least in their upper positions, are working in the two-phase medium of the water and solid ice-blocks. The frequency of ice-blocks hitting the blades is large. From the point of view of propeller performance the elasticity and the strength of the ice are then of minor importance. Therefore the prediction of propeller performance in these conditions by means of systematic model tests in scaled ice pieces can be considered somewhat overparticular. If scaled ice techniques is used for systematic tests, it will involve difficulties in the maintenance of permanent conditions. Therefore this new propeller model testing technique has been developed and results of systematic tests with two propeller models are reported.

2. EXPERIMENTAL DETAILS

2.1. Simulation of Ice Blocks

A study of the size distribution of ice blocks was made by P. Tuovinen [1]. In this study the size of ice blocks in three different ice-clogged channels in the Baltic Sea was measured. Two channels were new, one broken by an icebreaker, the other by a tanker. The third was an old channel of a ferry. The measurement was done on the photographs of the channels. The results were presented as size distributions with histograms. A size distribution function was found which fits all the three distributions surprisingly well.

The size distribution of the old channel is reproduced in Fig.3. This distribution was the basis of the size distribution of simulated ice-blocks. Finally the size distribution presented in

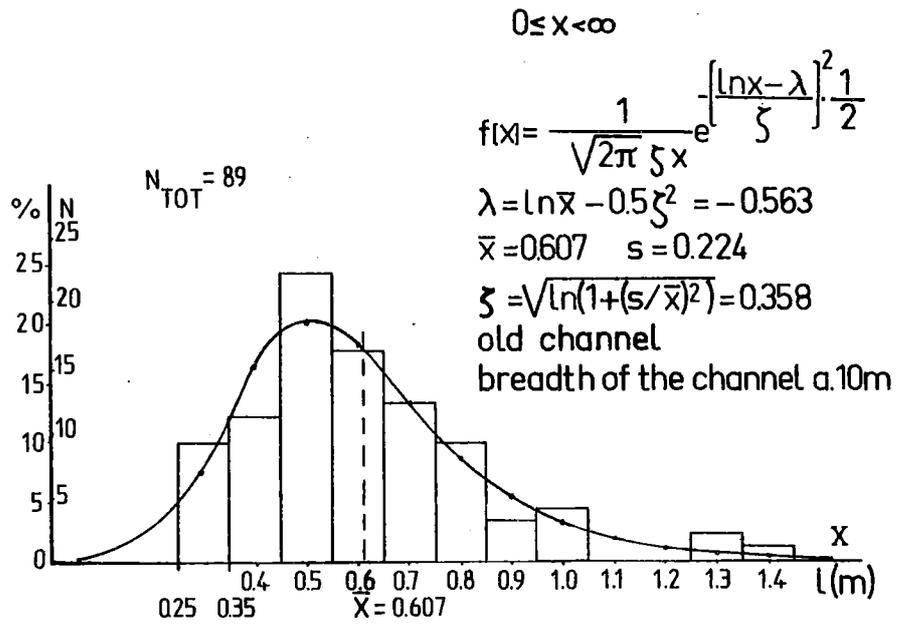


Fig. 3. The size distribution of ice blocks in an old channel according to [1]

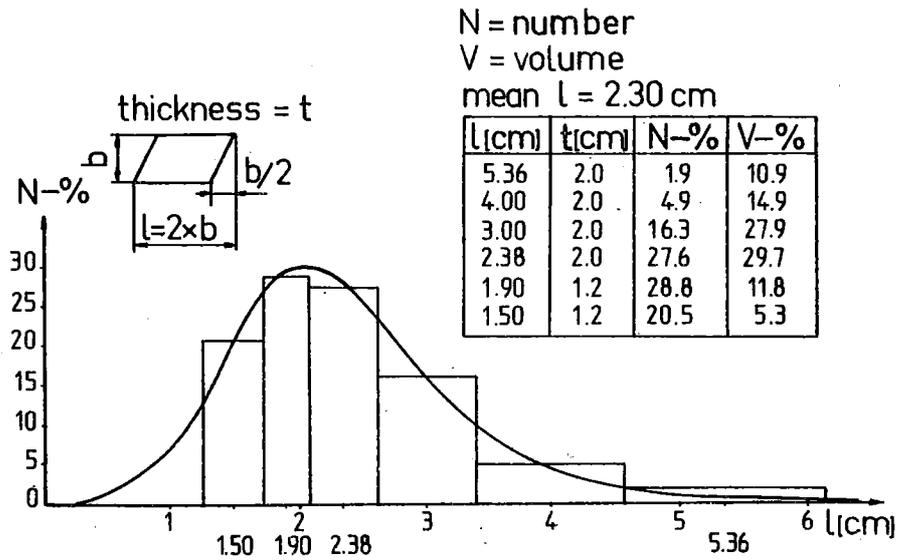


Fig. 4. The size distribution of plastic pieces used in the tests

Fig.4 was arrived at. The lengths of this distribution correspond to the lengths of full-size ice-blocks in the scale 1:25. The final form of the pieces is also presented in Fig.4. This form was selected to simplify the manufacture of the pieces. An inclined cut for two sides was chosen to prevent to compact formation of the layers of the pieces on the water surface.

The pieces were made of polypropene-plastic. This material has the same density and approximately the same surface friction as natural sea ice. The strength of this material is so high that the pieces withstand the impact of propeller blades.

2.2 Manufacture of Propeller Models

Owing to the high impact loads of plastic pieces, materials generally used for propeller models, such as white metal or aluminium, can not be used. Therefore a new method of manufacturing model propellers for these tests was developed [2]. By this method propeller blades are made of composite construction of metal plate and "Prestolith" plastic filler. At the beginning the core of the blade was made of bronze. These model propellers did however, have small local defects at the leading edge. Later the core and the edges of the propeller blades were made of stainless steel, which withstands the high impact loads of the plastic pieces.

The accuracy of these propeller models is not quite as good as propeller models manufactured by ordinary methods. Pitch was carefully measured at seven sections of each blade before and after the test runs to check that changes in the geometry of the propeller did not occur.

2.3. Dynamometer

The ordinary open water propeller dynamometer of the Laboratory could not be used in these tests. Therefore a new dynamometer which can withstand the high loads applied to propellers in these

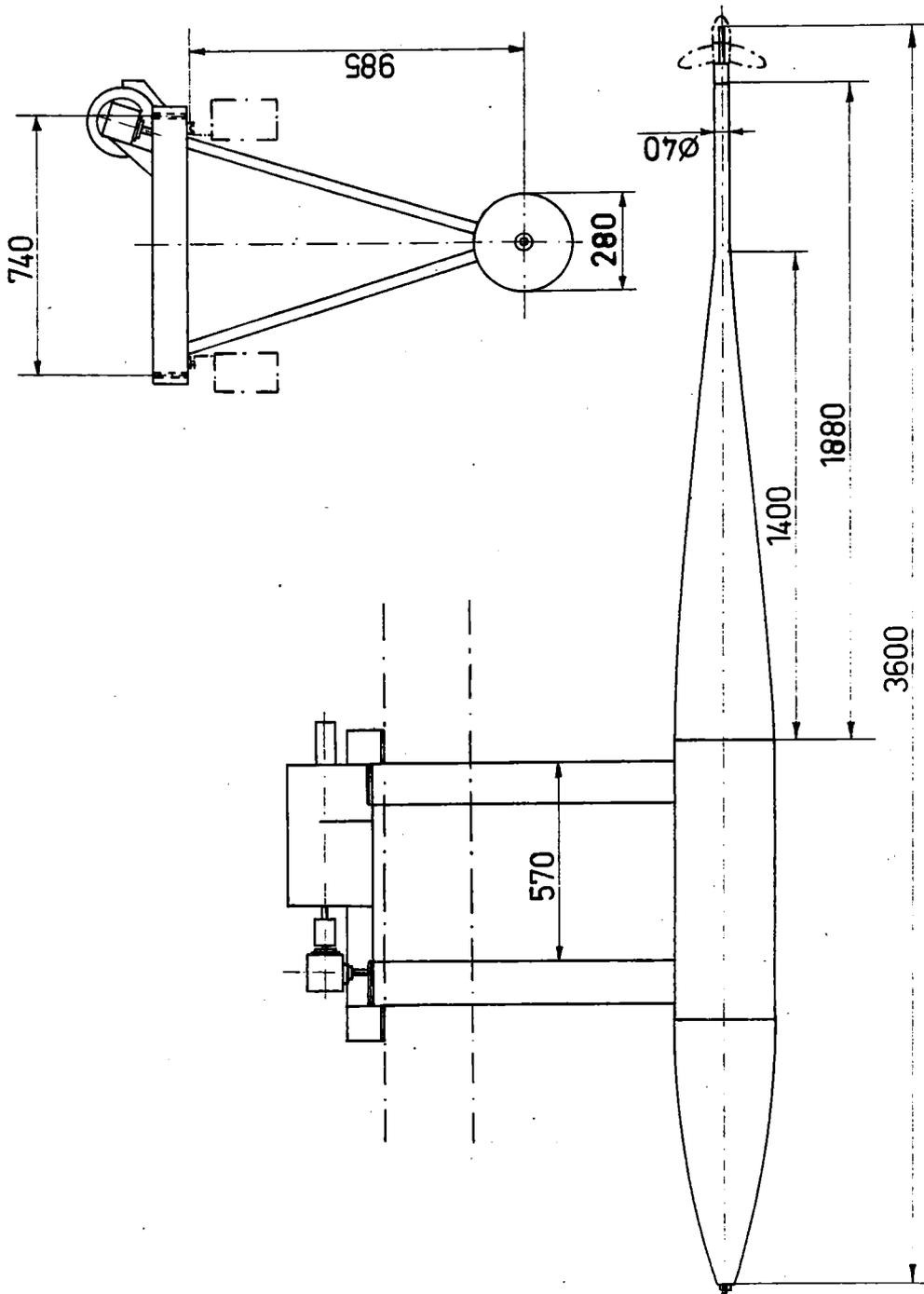


Fig. 5. Dynamometer arrangement

conditions, was designed.

To eliminate the effect of friction and to facilitate the measurements of unsteady components of thrust and torque in possible subsequent studies, it was decided to measure the torque and thrust immediately after the propeller boss. The flecture consists of a stainless steel cylinder of 30 mm diameter and 1 mm thickness. On the outer surface of the cylinder a total of 8 miniature semiconductor strain gages are mounted. They form two full bridges, one for torque and another for thrust measurements. The installation of strain gages resembles the arrangement described by N. Brown [3].

The propeller fits on one end of the flecture and the other end fits into a socket in the end of the shaft and is connected to an electrical cable in the hollow shaft. Slip rings are used to supply the exciting voltages to the gages and to take the output signals from the rotating shaft.

General layout of the dynamometer can be seen in Fig.5. The main body of the dynamometer is of stainless steel except fairing shape on the after end, which was made of epoxy-reinforced glass-fibre. The V-struts were made of hollow aerofoil-profiles of aluminium.

2.4 Arrangement of the Experiments

The tests were made in the towing tank of the Helsinki University of Technology. The tank dimensions are 130 m x 11 m x 5,5 m. Only a narrow strip at the centerline of the tank was covered with plastic pieces. This strip was separated from the other parts of the tank by a removable channel consisting of net walls and bottom on light steel frames and tubular flotation elements. The cross-section of this channel is presented in Fig.6. To facilitate easy erection and removal of the channel it was made of ready-made sections of 6 m length. The ordinary measuring area is 24 m long thus consisting of 4 sections. These end sections were equipped with two double doors, which prevented the plastic pieces from getting out of the channel. These doors were opened

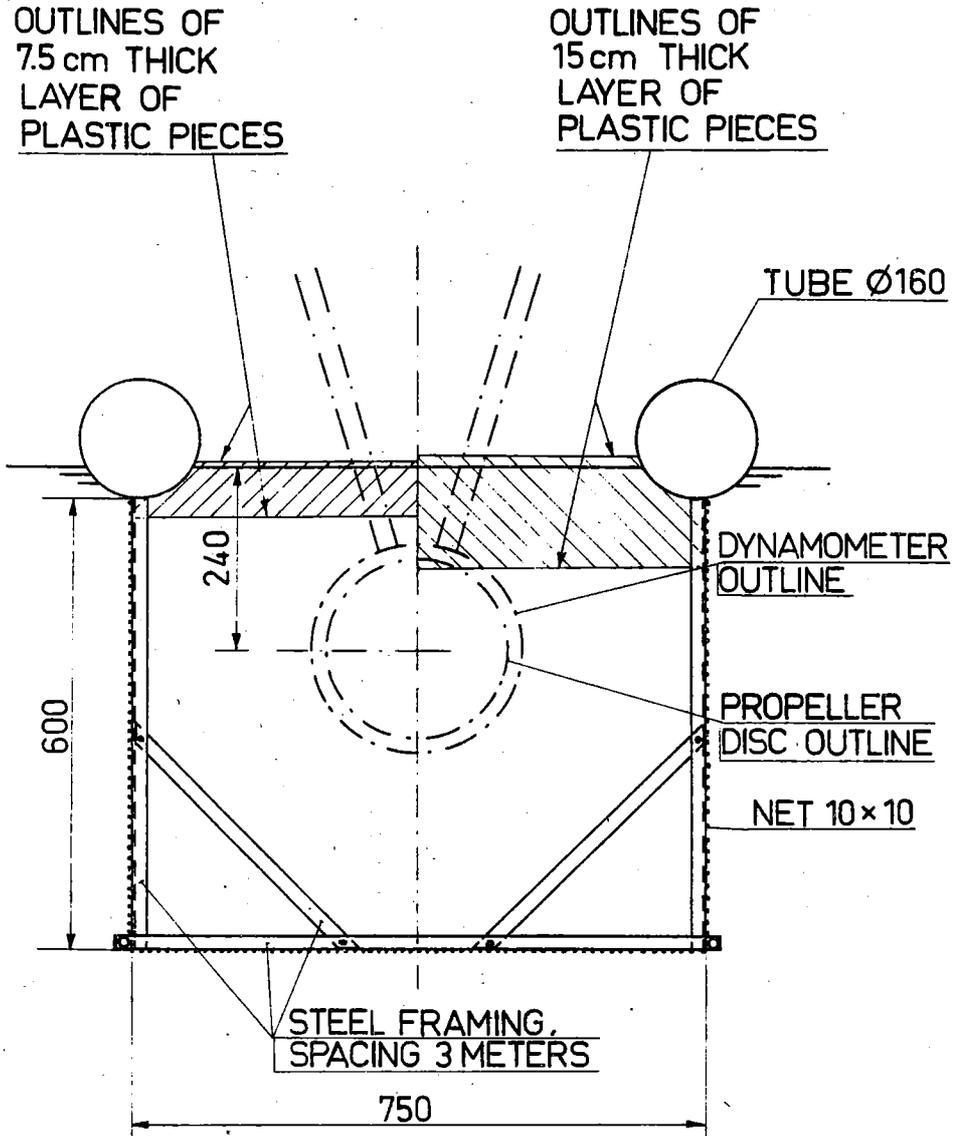


Fig. 6. Cross section of the testing channel

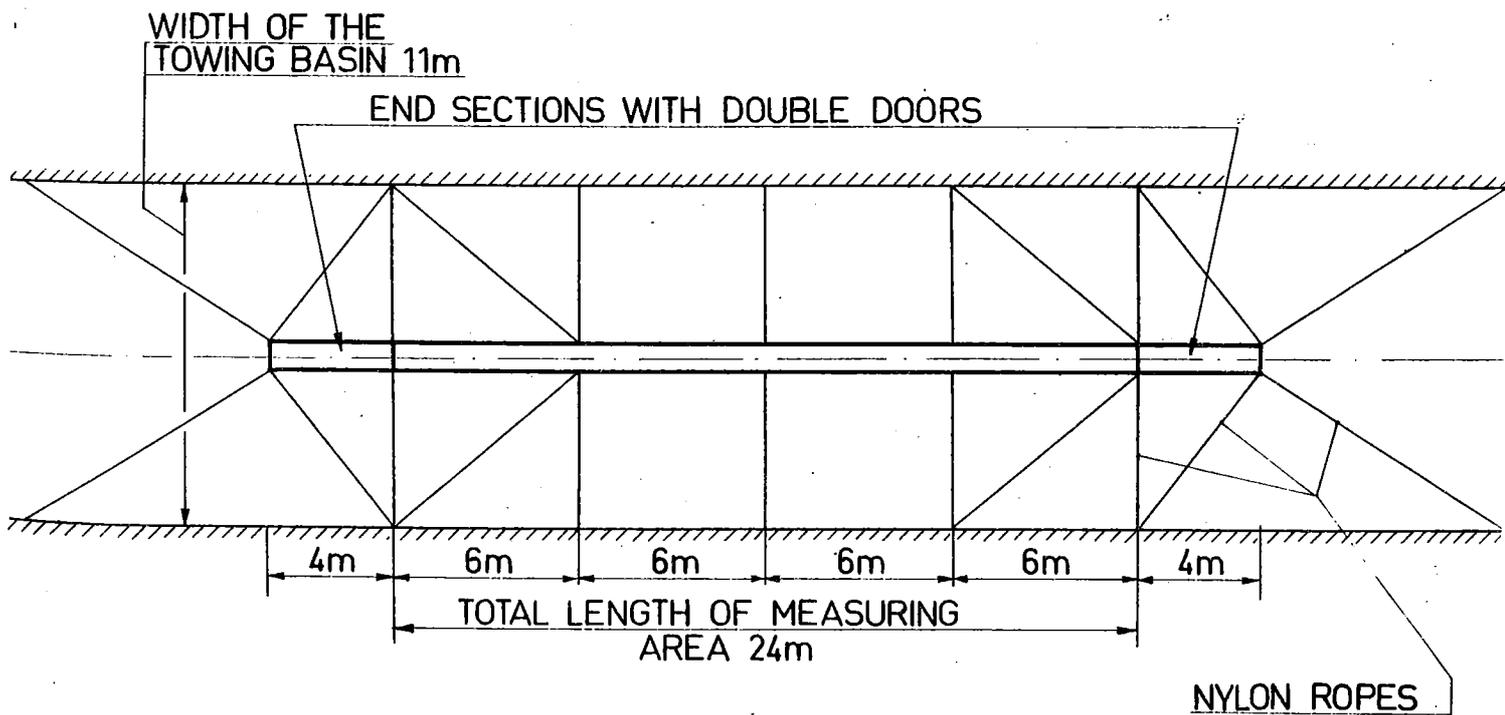


Fig. 7. General arrangement of the testing channel

during the run into and out of the channel by a frame installed in front and at the sides of the propeller and dynamometer arrangement. The whole arrangement was finally kept in position by nylon ropes fastened to the sides of the basin. The placing of the test channel in the towing basin is presented in Fig.7.

So far only two thicknesses of the layer of plastic pieces on the surface of the test channel have been used, 7,5 m and 15 m.

3. TEST PROCEDURE

The tests with four propeller models were carried out in open water and in the testing channel with two thicknesses of the layer of plastic pieces 7,5 and 15 m. The immersion of the propeller shaft was equal to the screw diameter. The usual routine for open-water tests was followed; the revolutions of the screw was kept constant, and by varying the speed of advance the desired value of the advance coefficient J was obtained. All the tests were made at $10 \frac{1}{s} = 600$ RPM.

After each run in the test channel the layer of plastic pieces was leveled manually.

Visual observations were made with underwater photography and video tape recorder.

All measured signals were electronically registered and handled by the on-line computer located in the carriage.

4. GEOMETRY OF THE TESTED PROPELLER MODELS

The main particulars of propeller models tested so far are presented in Table 1. Blade profiles and outlines for all propellers were taken from the corresponding Wageningen B-propeller. The thickness of leading and trailing edges from .5 to 1.0 R was increased to .5 mm.

TABLE 1. Main Particulars of Propeller Models.

Propeller Nr	D m	A_E/E_0	P_{MEAN}/D	d/D
P-34	.24	.55	.80	0.167
P-35	.24	.85	.90	0.167
P-38	.24	.55	1.17	0.167
P-40	.24	.85	1.26	0.167

Pitch distribution of the propeller models is presented in Fig.8.

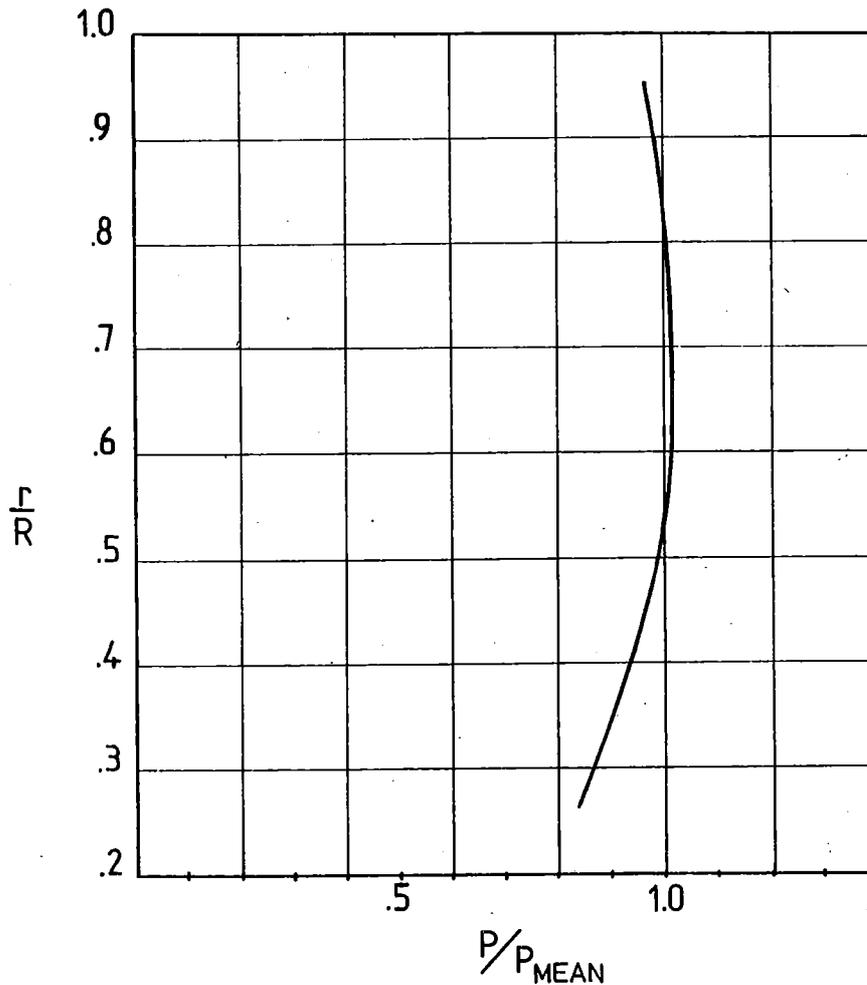


Fig. 8. Pitch distribution of the propeller models

5. RESULTS

The results of the tests were faired and conventionally plotted with the coefficients:

$$K_T = \frac{T}{\rho n^2 D^4}$$

$$K_Q = \frac{Q}{\rho n^2 D^5}$$

$$\eta_0 = \frac{J}{2\pi} \cdot \frac{K_T}{K_Q}$$

as functions of the advance coefficient $J = V_A/\eta D$

No Reynolds-number correction was applied to the results.

K_T -, K_Q -J diagrams of all tested propellers are given in Fig. 9, 10, 11 and 12. The solid line represents the values of quantities in open water, without plastic pieces. The broken line represents the values in the testing channel with 7,5 cm thick layer of plastic pieces, the dotted line represents the values 15 cm thick layer of plastic pieces.

Measured torque signals specially in the 15 cm thick layer of plastic pieces varied, with large peak values compared with the mean. This together with the stochastic nature of the phenomenon resulted in considerable scatter in mean values as compared with the manually faired curves. An example of the plotted mean values of K_T , K_Q and η_0 is presented in Fig. 13 for propeller P-34 and a 15 cm thick layer of plastic pieces.

For comparison, some test runs were made by H. Segercrantz [5] with two of the propeller models P-34 and P-35 in Wärtsilä Ice Model Basin in two conditions: in open water and in a 15 thick layer of broken saline ice. The measured mean length of saline ice-pieces in these tests was 4,0 cm. In Figs 14 and 15 results are compared.

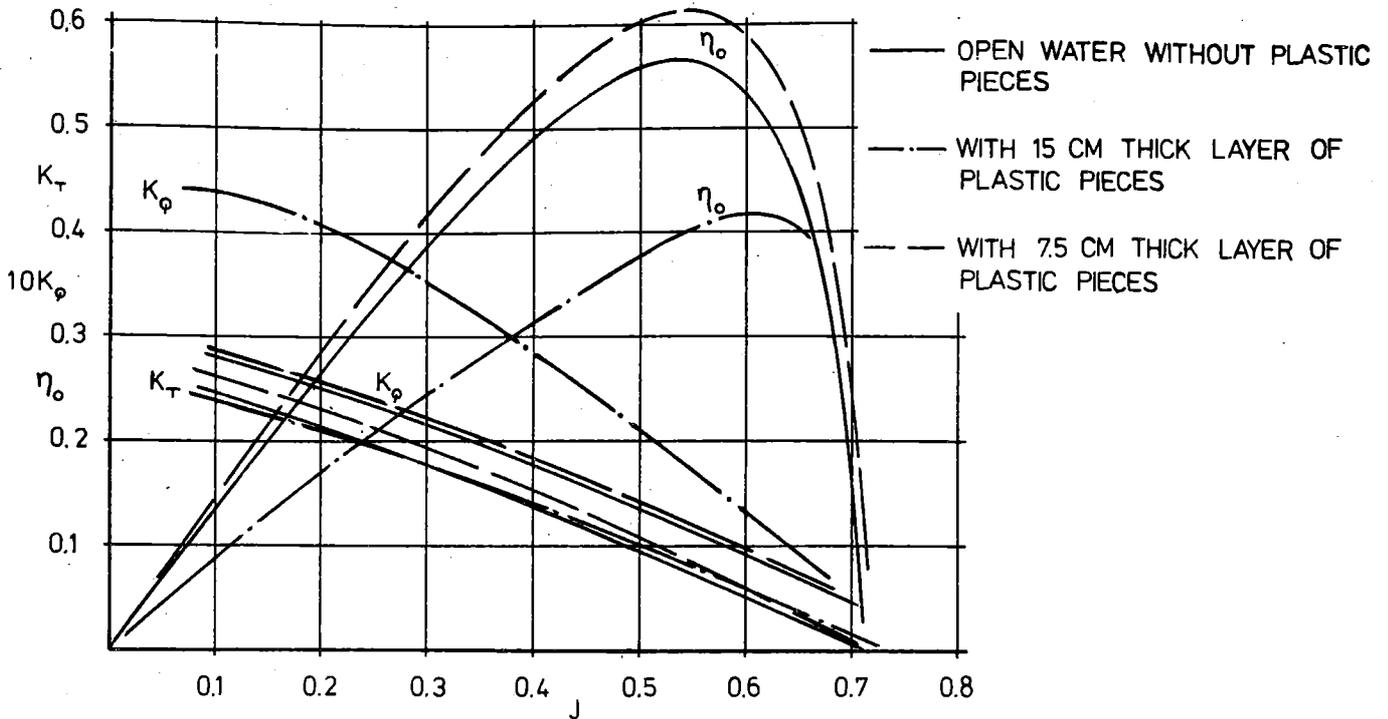


Fig. 9. K-J Diagrams of the propeller P-34, $P/D=.8$, $A_E/A_0=.55$

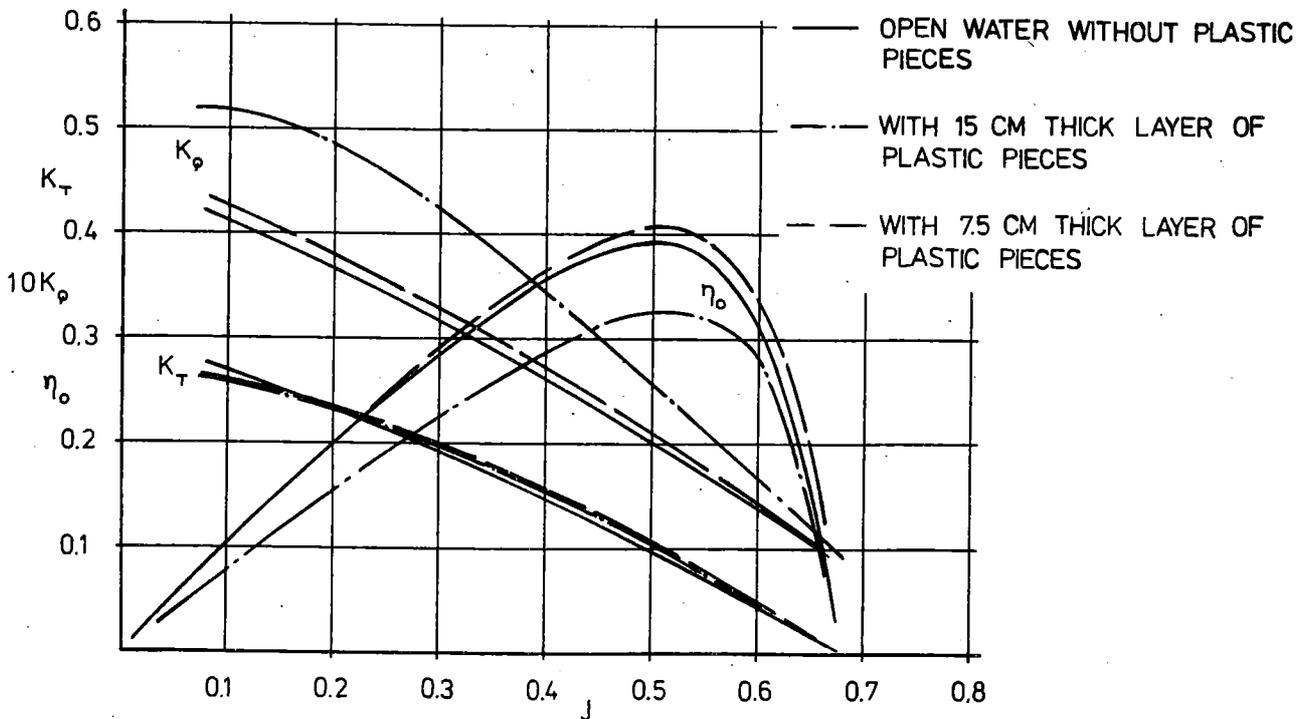


Fig. 10. K-J Diagrams of the Propeller P-35, $P/D=.9$, $A_E/A_0=.85$

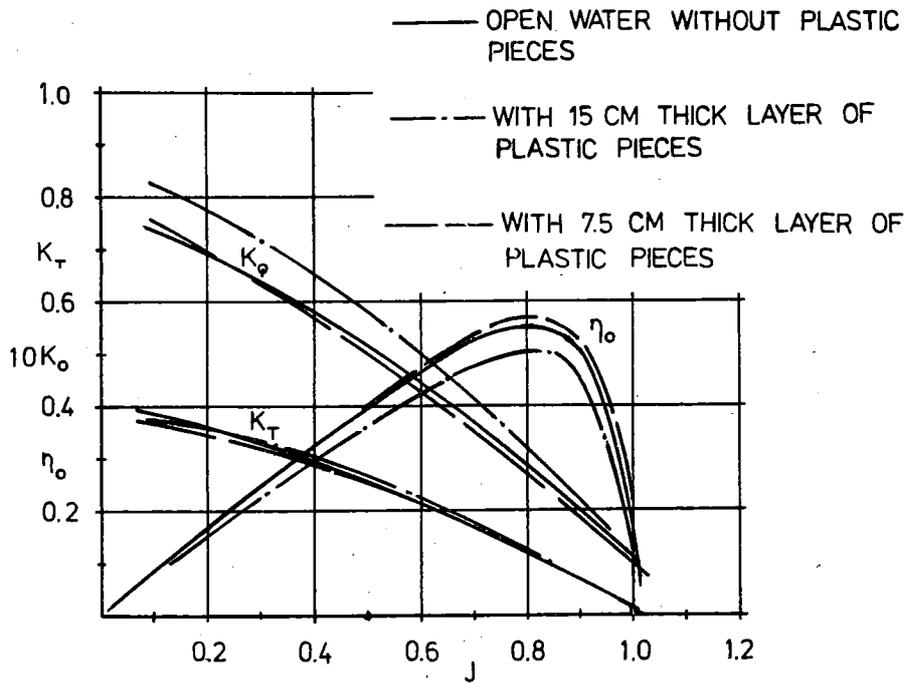


Fig. 11. K-J Diagrams of the propeller P-38, $P/D=1.17$, $A_E/A_0=.55$

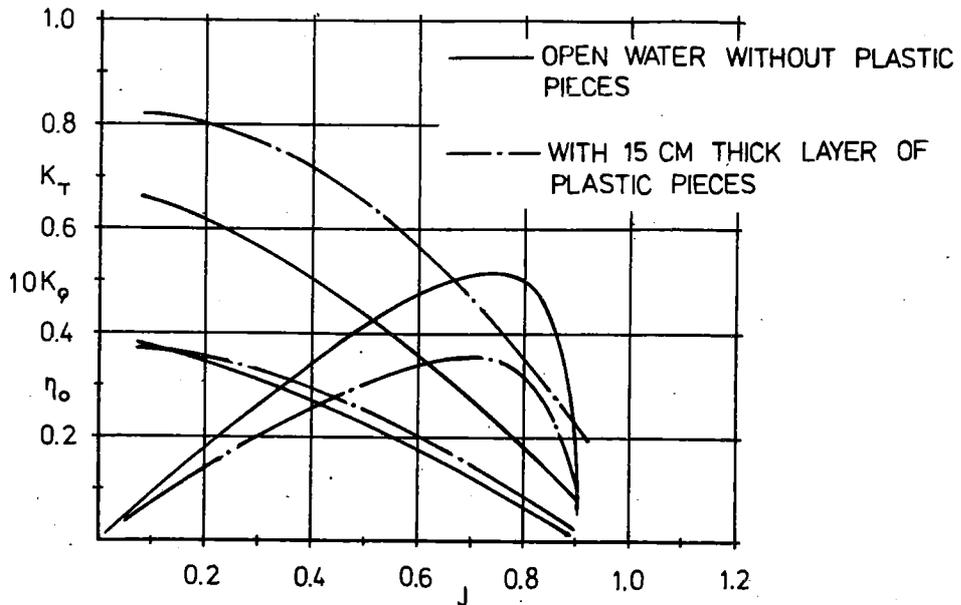


Fig. 12. K-J Diagrams of the propeller P-40, $P/D=1.26$, $A_E/A_0=.85$

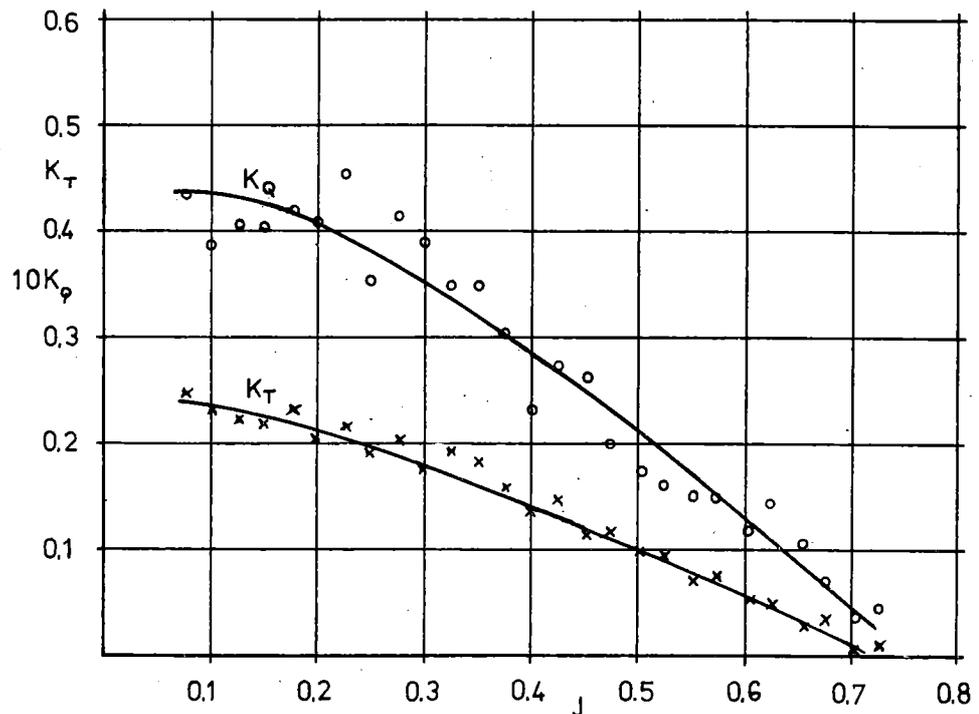


Fig. 13. An example of plotted test results and manually faired curves. Propeller P-34. Thickness of the layer of plastic pieces 15 cm.

6. DISCUSSION

The results presented in this paper should be considered as a preliminary attempt to attack the difficult problem of estimating the performance of a propeller in ice-clogged channels.

The most important finding of this study is the experimental evidence of the importance of the clearance of the tips of the propeller blades. The situation can be explained with the help of Fig. 6, where the propeller disc has been drawn in relation to the two layers of plastic pieces. When the thickness of the layer of plastic pieces is 7,5 cm, mean clearance between the tip of the propeller blade and the lower surface of the layer of plastic pieces is about 5 cm. In this case results of model tests indicate very small changes in thrust and torque coefficients even with higher loadings of the propeller. Visual observations confirm that very few of the plastic pieces were drawn by the suction of the propeller through the propeller disc. In the case of the 15 cm thick layer of plastic pieces, the tip of the propeller blades rotate through the layer of plastic pieces, the propeller tip is at rest about 1,5 cm above the lower surface of the layer of plastic pieces. As can be seen from Figs. 9 to 12, the K_Q -values are increased and η_0 decreased throughout. Changes in K_T -coefficients

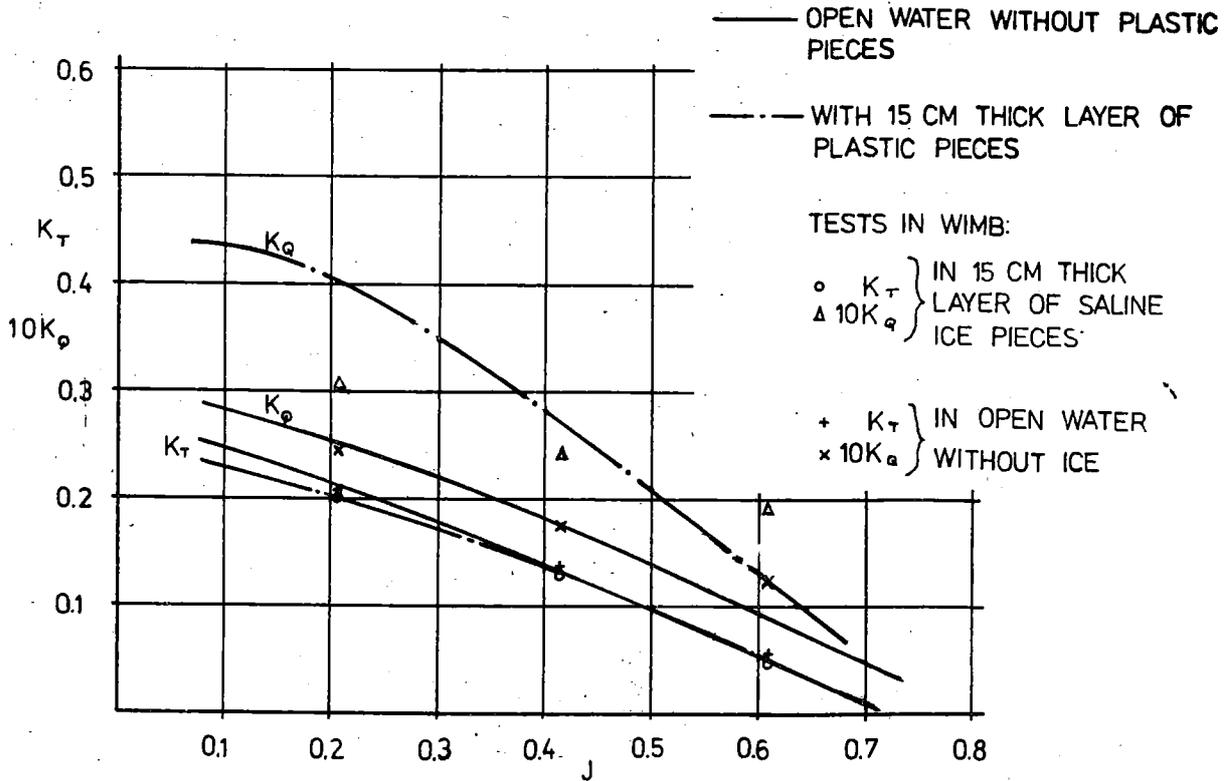


Fig. 14. Comparison of test results of propeller P-34 in saline ice and plastic pieces

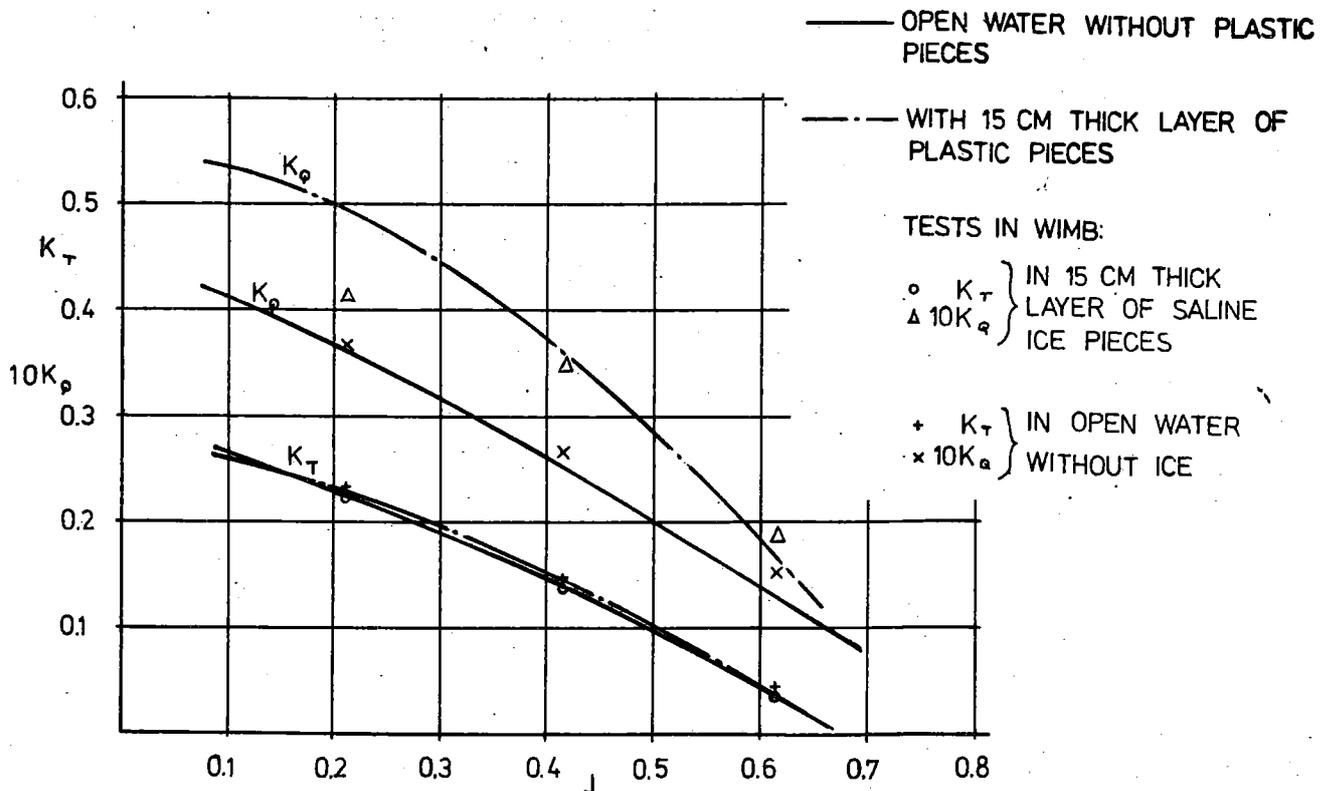


Fig. 15. Comparison of test results of propeller P-35 in saline ice and plastic pieces

are small. This means that thrust can be produced if the torque of the propeller motor can be increased. This is in general possible in icebreakers but not usually in commercial ships. Therefore the propeller of icetransiting commercial ships should be placed as low as possible.

K_T -values obtained with the tests with plastic pieces agree satisfactory with the values obtained in saline ice. Also the same phenomenon of increasing K_Q values could be noticed even with tests in saline ice pieces. The increase of K_Q in saline ice pieces was smaller with small values of J and larger with large values of J than the increase K_Q in the tests with plastic pieces.

Owing to the large scatter of the measuring points no further conclusions can be drawn from the results of these tests. The number of test runs for each thickness of the layer of plastic pieces should be increased in subsequent tests.

Tests were run in the usual way with as high Reynolds number as possible and results are presented in dimensionless form using the kinetic conditions. The buoyancy force of the plastic pieces is of great importance in these conditions. Before the application of the test results to the ship scale evaluation of propeller performance in ice clogged channel, scale effect studies should be made.

7. CONCLUSIONS

1. The immersion of the propeller in relation to the lower surface of the layer of ice blocks is of great importance. Propeller tips in their upper position should be well below the lower surface of ice-clogged layers.
2. If the penetration of the propeller blades into the layer of ice blocks cannot be avoided, drastic increase of torque results,

if the same thrust is required with the same values of speed of advance and revolutions.

3. Before any further application of these tests results, the obtained propulsion coefficients should be checked with an increased number of test runs and the magnitude of scale effect should be evaluated.

8. ACKNOWLEDGEMENT

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The kind co-operation of Wärtsilä Ice Model Basin in obtaining the information on ice block sizes in the channels of the Baltic and in arranging the possibility to compare the results with the saline ice test results, is gratefully acknowledged.

NOMENCLATURE

- d = hub diameter
- D = propeller diameter
- J = advance coefficient, $J = \frac{V_A}{nD}$
- K_T = thrust coefficient, $K_T = \frac{T}{\rho n^2 D^4}$
- K_Q = torque coefficient, $K_Q = \frac{Q}{\rho n^2 D^5}$
- n = number of revolutions per second
- Q = torque
- r = radius
- R = propeller radius
- T = thrust
- V_A = undisturbed stream velocity
- Z = number of screw blades
- A_E/A_0 = blade area ratio of screw
- P/D = pitch ratio of screw
- d/D = hub diameter ratio
- ρ = density of the water
- η_0 = open-water efficiency, $\eta_0 = \frac{J}{2\pi} \cdot \frac{K_T}{K_Q}$
- ν = kinematic viscosity of water

REFERENCES

1. Tuovinen, P., "The Size Distribution of Ice Blocks in a Broken Channel", Helsinki University of Technology, Ship Hydrodynamics Laboratory, Memorandum M- 78, Otaniemi 1979.
2. Pentsinen, E., "The Manufacture of Propeller Models of Composite Construction" (In Finnish) Helsinki University of Technology, Ship Hydrodynamics Laboratory, Memorandum M- 72, Otaniemi 1978.
3. Brown, N.A., "Periodic Propeller Forces in Non-Uniform Flow", MIT, Department of Naval Architecture and Marine Engineering, Report No 64-7 , 1964.
4. Lietepohja, M, "Construction and Trial Runs of Open Water Propeller Dynamometer" (In Finnish) M.Sc. Thesis, Helsinki University of Technology, Otaniemi 1980.
5. Segercrantz, H: "Tests in Broken Channel with Two Troost-B Propeller Models" (In Finnish) Wärtsilä Helsinki Shipyard, Interim Report Nr A 67, Helsinki 1979.

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