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REVOLUTIONARY OBLIQUE ICEBREAKER

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ABSTRACT

The cargo vessels are getting bigger and bigger. A traditional icebreaker in the Baltic makes channels that are 20-25 m in width. To answer the call of a 40 m wide oil tanker, which desires to be assisted for instance, one must start thinking the production of a channel in a new way. This paper describes the development work of the Oblique icebreaker, which can break channels to all needs from 20 m to 40 m. This innovation won the first price in the Kvaerner Innovations Competition in 1998. The potential of such a vessel is big. For instance instead of using two icebreakers to assist a wide vessel, only one is needed. This requires new thinking both in operational and economical.

1. INTRODUCTION

For solving of the problem how to assist an oversized vessel in ice situation efficiently and economically a project was established in 1997 by Kvaerner Masa-Yards Technology. The purpose of the project was to develop an icebreaker which alone could provide assistance in ice for vessels up to 40 meters broad, still not herself being a 40 meters broad giant. Today most icebreakers used for this kind of operation have a beam of abt. 23 to 25 metres and so basically two 'normal' icebreakers are needed to create a channel wide enough, or a single icebreaker doing a multiple mission. In principle the aim of the project was then to develop one compact size icebreaker which could do the job of two big vessels.

The questions put down for answering in the beginning of the project were: if such a vessel was possible at all to do, and if the answer was yes, to evaluate the new design against the requirements of the real world, seakeeping problems, steering capability, economics and needs of ship owners.

As an initial phase of the project a study of the winter traffic in the Gulf of Finland was done to determine the required main dimensions of the new vessel. Then a new oblique hull form equipped with a suitable novel propulsion arrangement was designed and a model was built to be tested in ice conditions and open water.

After successful tests finally some potential ship operators and other institutions were approached to incorporate the requirements of eventual multipurpose use in the design.

2. CONCEPT DEVELOPMENT

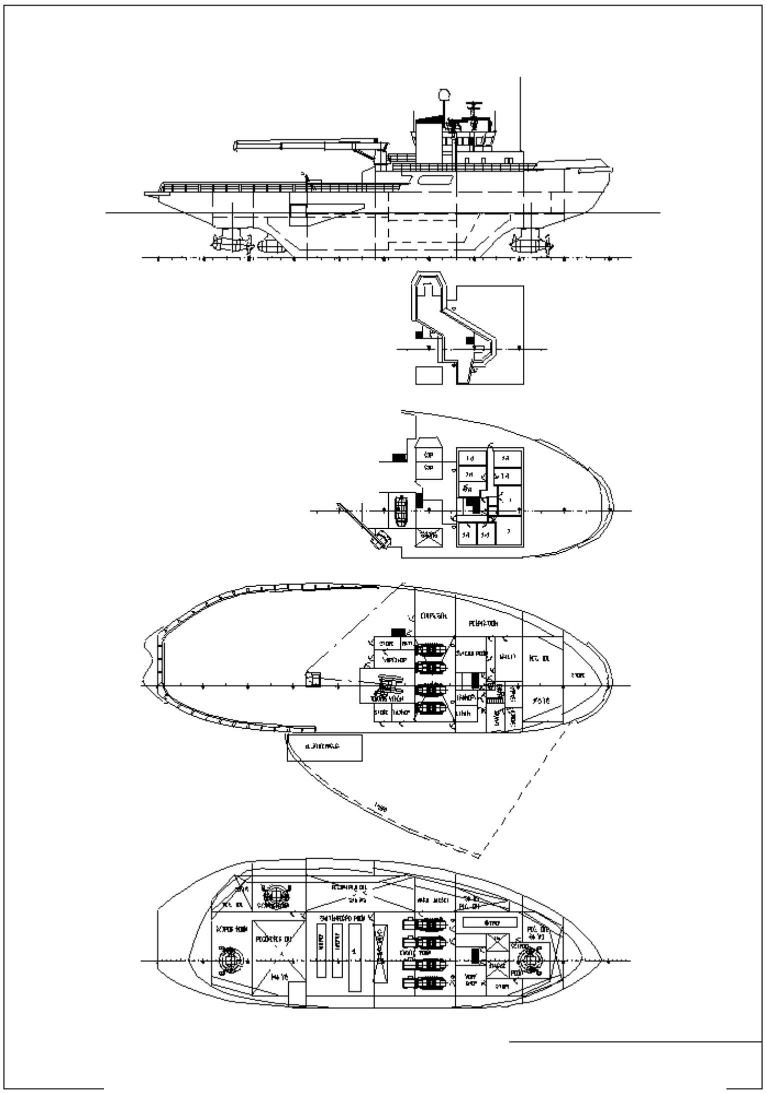

Figure 1. General arrangement of the oblique icebreaker

Table 1. Main dimensions of the vessel

Loa	60.5 m
Boa	20.5 m
Draught	6.0 m

To create an understanding of the desired main dimensions of the new vessel a study of the winter traffic and associated icebreaker assistance in the expected operation area, Gulf of Finland, was performed. Statistics of the harbours and icebreaker logbooks between 1.12.1995 - 30.4.1996 were reviewed and cross-checked with lists of vessel registers, and a comprehensive data base of the whole was accomplished. From this data base it is possible to plot number of vessels, port calls, icebreaker assists, assistance miles and hours, etc. against ship beam, size, deadweight, power, age, ice class and so on. Some of the most interesting plots are shown in Figure 2 and Figure

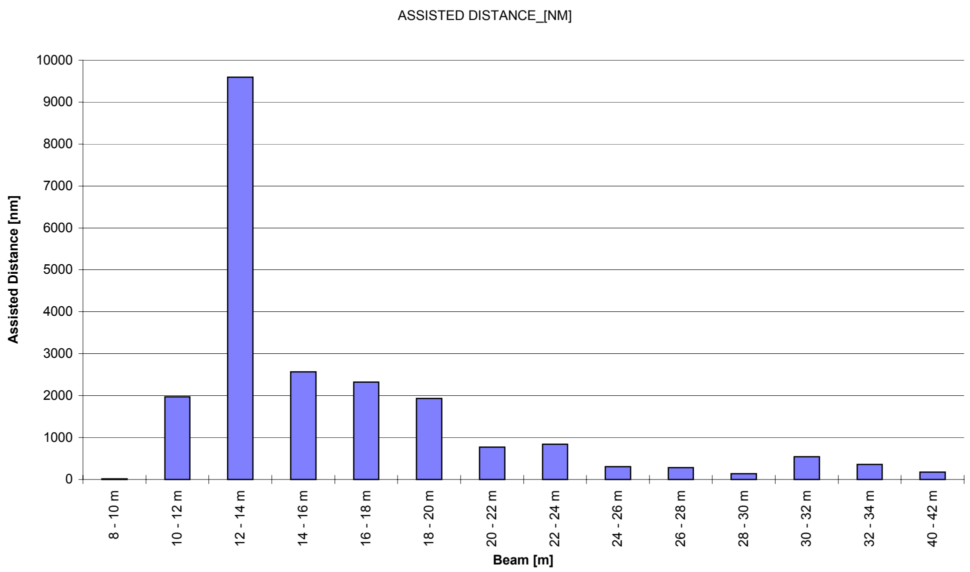

Figure 2 Assistance distance versus beam

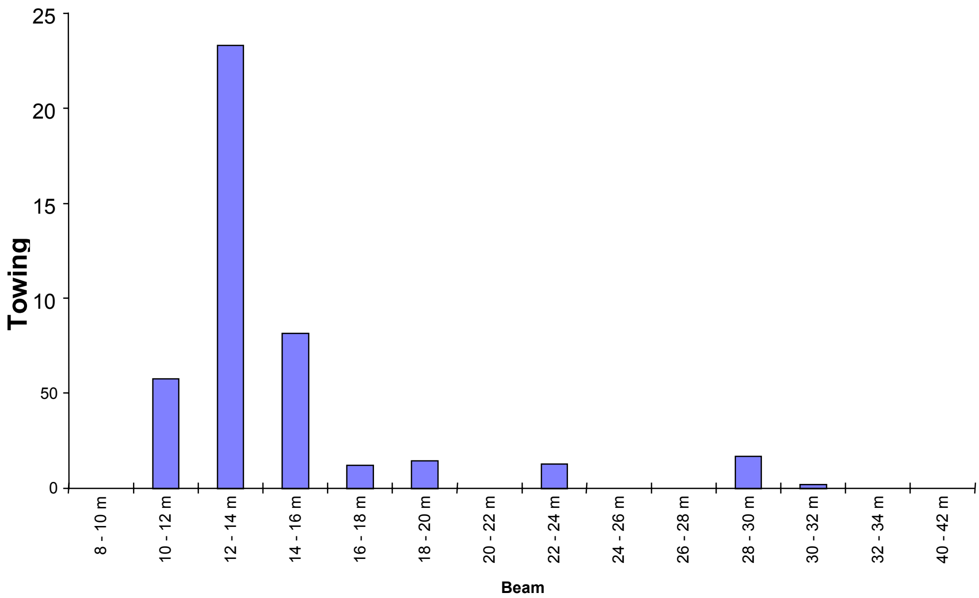

Figure 3 Towing hours versus beam

According to the study it was decided that the beam of the new vessel should be abt. 20 metres so that the great majority of the vessels in the Gulf of Finland could be assisted in the normal ‘head-on’ mode, while the beamier oversize vessels, which are very few in number, could then be taken care of by some other, rather ‘unconventional’ method.

For the initial creative phase it was the intention to forget all limitations, but in the end some restrictions cannot be avoided: breaking thick ice requires brute force and power, and mass, Azipod propulsion provides ideal means for producing these, and the Law of Archimedes must be obeyed.

So the result was a displacement vessel, asymmetric like a triangle in form, both ends designed for fair icebreaking resistance, a remarkably flat side for moving sidewards in ice and a ‘normal side’ for added displacement, three Azipod rudder propeller units located in the corners for propulsion. With following main dimensions, waterline length abt. 52 m, beam abt 21 m and 6 m draught the vessel was estimated to be able to fulfil the given icebreaking missions and to carry adequate deadweight, at estimated 3 * 3000 kW power and corresponding 110 tonnes bollard pull force.

After designing the lines for the vessel a model was built for ice performance model tests.

3. MODEL TESTS IN ICE

Model tests with the new icebreaker concept were performed at the Kvaerner Masa-Yards Arctic Research Centre (MARC) in 1997.

Experience from ship and model tests has shown that the ice resistance of a merchant vessel is very sensitive to the width of the channel when the beam of the merchant vessel is greater than that of the icebreaker. The reason for this is that the merchant vessel has to break ice with its shoulders which normally have rather bad angles for icebreaking.

Icebreakers normally assist vessels by breaking a channel through the surrounding icefield. The width of the channel depends to a large extent on the beam or breadth of the icebreaker. As the existing icebreakers have a beam of less than 22 meters they are not very suitable to escort tankers with a beam of up to 40 meters.

The objectives of the tests was to develop a concept that is able to break a 20 meter wide channel in normal operation mode and also be able to break a 40 meter wide channel when operating obliquely. The maximum bollard pull of the vessel was 1100 kN in all tests. The vessel is designed to be able to proceed in all ice conditions in the Gulf of Finland, thus the vessel was also tested in 1.2 m thick level ice.

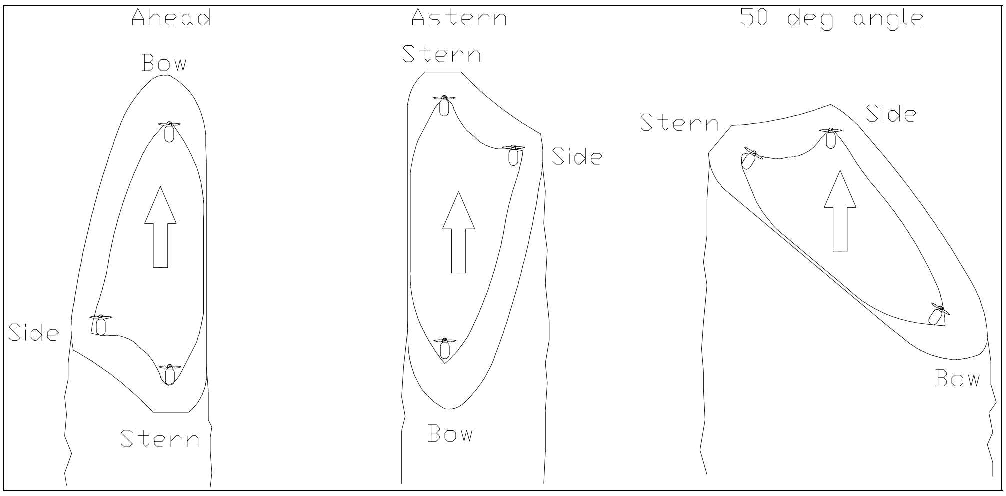

Figure 4. The three main modes of the vessel

3.1 Test results

Model tests in ice were performed in four different stages. In the first stage the existing model of a 70 m long and 20 m wide icebreaker was towed in the ice in different angles (0° to 60°). After these tests the model was equipped with one Azipod in the bow and one in the stern. During the self propulsion tests the model proceeded in a 20°-35° angle in 0.5 m thick level ice with the given thrust.

The encouraging results from these tests resulted in the development of the oblique icebreaker hull shape. The model tests with the oblique icebreaker were performed both as towed resistance tests and self propulsion tests. The self propulsion tests were done with two versions of the model as the hull shape needed some modifications to achieve better performance when running astern and when running obliquely. During the self propulsion tests the model was not attached to the carriage, i.e. the model was free to move in all directions in the tank.

The tested model was built in the scale 1:20. The model was equipped with three azimuthing propulsion devices (Azipods). The Azipods were equipped with steering motors that were controlled from the towing carriage. The Azipods could be turned 360 degrees. The three different modes the model was tested in are shown in Figure 4. The stern, side and bow Azipods are also marked in the figure.

Model tests in ice were done in 0.5 m, 1.0 m and 1.2 m thick level ice. The model was also tested in brash ice fields and in ridges.

The tests with the oblique icebreaker, MARC model M-218, show that the concept worked well in all the tested conditions. The vessel is able to proceed obliquely (50°) even in 1.0 m thick level ice with a speed of 1 m/s. When running ahead the speed is 2.7 m/s and 2.4 m/s when running astern in 1.0 m thick level ice. The vessel is also able to break 1.2 m thick level is in a continuous mode even when running obliquely.

In the tests where a large cylinder was towed through a brash ice field, the resistance of the cylinder in the channel broken by the oblique icebreaker was only about 50 % of the resistance in the unbroken brash ice field. When a tanker was towed behind the oblique icebreaker the towing force was less than 10 % of the towing force for the tanker alone in level ice.

The performance of the vessel gives an encouraging image of the concept. In this early development stage the concept worked well and no bigger changes need to be done from the icebreaking point of view.

4. OPEN WATER CHARACTERISTICS

Present day trend in icebreaker design is multipurpose use of the vessels. In order to make a successful concept the vessel should have a summer time use also. Therefore ideas for this oblique design was to use it for environmental protective purposes. The oblique vessel could be escorting oil and chemical tankers, taking part in fire-fighting and rescue operations and have the ability to clear oil-spills from the sea. To meet these rather wide spread requirements the open water behaviour of this peculiar shaped ship was studied.

The Ship Laboratory of Helsinki University of Technology (TKK) performed open water tests for the vessel. The test series included resistance, propulsion, manoeuvring and seakeeping tests. The objectives and results of these tests are briefly discussed in this chapter.

4.1 Test objectives

The asymmetric shape of the vessel brings interesting aspects to her open water behaviour. Firstly the towed resistance tests were performed in order to find a minimum resistance yaw angle. Propulsion tests were performed to find out the behaviour of propulsion units and to confirm the preliminary propulsion prediction characteristics. Estimation of thrust deduction and indications of manoeuvring complexities due to multiple propulsion units in asymmetric hull could be made. Seakeeping was expected to be problematic and simple test series were performed to see the difference with ordinary ship models.

4.2 Resistance and propulsion tests

The vessel has no 'real' centreline but in the design one was fixed to go through the foremost point of the hull and to be parallel with the straight side (starboard) of the vessel. The yaw angles from -10 to +10 degree in relation to this centreline were tested. Because the vessel influences the yaw moment and the side force as it is towed forward the model was connected to towing carriage with force transducers. As a result the towing force (R_t), the side forces (F_{aft}, F_{fore}) and the yaw moment were recorded. Minimum resistance force ($F_{optimum}$) was considered to be the minimum sum of towing and side forces at a certain speed.

$$F_{optimum} = \min_{\beta}(|R_t(v,\beta)| + F_{yaft}(v,\beta) + F_{yfore}(v,\beta)) \tag{1}$$

Yaw angle dependency of the speed was not known. The speed was varied from 0.10 to 0.35 Fn. Optimum yaw angle was not remarkably dependent of speed and with the design speed of 0.30 Fn the minimum resistance was at 5 degrees yaw to the counter-clockwise direction.

After the optimum open water resistance point was determined propulsion tests were performed with that specific yaw angle. Propulsion system design for the vessel is a challenging task. The vessel is equipped with three azimuthing propulsion units. Because of the asymmetric hull shape the angles and thrust values must be carefully chosen in order to keep the vessel on the pursued track. At the 5 degree yaw angle the hull produces a small side force but also a yaw moment. The propulsion units must compensate these forces. The propulsion strategy can be chosen in many ways. According to the propulsion tests it is advisable to load the fore propeller as little as possible in order to achieve good efficiency. The side propeller thrust is used to compensate yaw moment. Side force can be compensated with aft and side Azipod angles. Effect of the fore propeller is small due to minimal thrust. Two stationary set-ups were successfully achieved in the tests and these are shown in Table 2.

Table 2. Tested self propulsion set-ups.

	Fore Azipod	Aft Azipod	Side Azipod
J	1.131	0.696	0.530
Angle	-10 deg	-5 deg	-4 deg
Thrust/Total %	5 %	37 %	58 %

	Fore Azipod	Aft Azipod	Side Azipod
J	0.984	0.622	0.585
Angle	-10 deg	0 deg	-6 deg
Thrust/Total %	7 %	45 %	48 %

It was assumed in the propulsion tests that minimum power would be achieved at the 5 degrees yaw angle which was the minimum resistance point. However, this assumption may not be exactly correct as the propellers affect the flow around the hull. Interaction between the Azipod units has yet unknown effects and these will be further tested and studied in present development work.

4.3 Seakeeping tests

Seakeeping capability of the vessel was expected to be problematic. This is due to large beam/length ratio, high GM value and asymmetric icebreaking shape of the vessel. The tests revealed a tight connection between pitch, roll and heave motions.

Seakeeping tests were made at TKK and as a result of these tests transfer functions were developed. A linear approximation of these functions was used in the computer code when analysing accelerations on the ship. Tests were made only in head sea condition at the speed of 13.3 knots (0.30 Fn). Dummy Azipods without propellers were used in the tests. Due to the asymmetric shape of the vessel also rolling was excited in head seas. Motion components of heave, pitch and roll were used in the calculations.

Limiting to only head sea condition and only one ship speed are the shortcomings of this rather limited test series and seakeeping analysis. Calculations were done from transfer functions with linear approximation. Non-linearity was investigated in TKK model tests by varying wave amplitudes and wave lengths. The results did not diverge considerably.

Model tests revealed excessive pitching in head seas indicating strong bow slamming and potential air leak to fore propeller. Also at certain wave periods a rather high roll motion was developed. Natural frequencies of roll and pitch were quite close which yields to strong pitch and roll motions at certain wave periods. Non-dimensional motion amplitudes were clearly higher than with ordinary ship models thus indicating limitations in operability.

Operability approximation was calculated based on Baltic Sea and Gulf of Finland wave observation statistics (Kahma and Pettersson, 1993) which was applied with Jonswap wave spectrum. Having transfer functions from model tests the RMS vertical acceleration was calculated in ship deck level in different sea conditions. Vertical acceleration RMS values in different seasonal periods at some points on the ship are presented in Table 3. A maximum of 0.76g acceleration can be found which exceeds the high acceptable criteria by almost four times. Motions in Baltic were worse resulting to usability criteria which is presented in Table 4. At a higher limit 0.2g the usability is only 74% which is not acceptable for rescue, fire-fighting and pollution preventing purposes. Further development of the hull shape will be performed in order to both ease the motions in waves but also further improve the ice-breaking capability. Tests done so far have given the designers valuable information to perform these changes.

Table 3. RMS values (G) in the highest wave condition at Gulf of Finland

Season	MaxRMS	MinRMS	P1 (30,0)	P2 (10,0)	P3 (10,10)	P4 (50,0)
spring	0.41	0.013	0.037	0.20	0.27	0.26
summer	0.73	0.036	0.099	0.33	0.43	0.48
autumn	0.60	0.041	0.089	0.26	0.36	0.39
winter	0.76	0.042	0.11	0.33	0.45	0.49

Table 4. Usability percents according to Baltic Sea observations

Point at ship	Limit 0.2 G	Limit 0.1 G
P1 (30,0)	100 %	96 %
P2 (10,0)	74 %	52 %
P3 (10,10)	81 %	57 %
P4 (50,0)	81 %	52 %

5. CONCLUSIONS

The project work and tests done so far by Kvaerner Masa-Yards Technology have proved the technical viability of this brave effort to replace two large assisting icebreakers by one compact small size unit with the asymmetric design described in this paper. The problems arising from the icebreaking point of view have been resolved and the remaining problems can be overcome in the next stages of development. As many big new ideas this one still needs to pass also the two non-technical, but important and difficult tests to come through: the economical considerations of the real world in combination with the reluctance of the already existing doctrines and establishments; and the conservatism of the human mind.

6. REFERENCES

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