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COMMENTS OF THE ICE COMMITTEE OF 22nd ITTC

Again the committee feels that this section is heading in the correct direction, but needs substantial revision before being acceptable. It is in general not very accessible to the reader, and the main message does not get through well. Again, depending on the review and revision process, it may be possible to publish this section with a disclaimer, subject to editorial revision by the committee.

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Date	Date

Propulsions Tests in Ice

1. PURPOSE

- Definition of standards for performing ice propulsion tests in level ice
- to assist in making the test results from different test series and different laboratories more consistent.

2. PROPULSION TESTS IN ICE

The purposes to conduct propulsion tests are generally

a) To determine the required propulsion power in specific ice conditions
b) To obtain information about the propulsive coefficients and determine the effectiveness of the whole hull-propulsion system
c) To estimate the ice interaction with appendages and propulsion system
d) To design the stern configuration of the vessel

The direct measurements form only a part of the outcome of propulsion tests. As important as the measured results, are the observations about the flow of ice pieces around the ship hull. Thus the underwater photographs and videos must be taken during the propulsion tests. The quantities to be measured during propulsion tests are given in section 3.1.

Most recommendations about conducting the tests given in the procedure 7.5-02-04-02.1 „Ice resistance tests in level ice“ are valid also in the case of propulsion tests. Propulsion tests can be performed with a *free running model* or with a more or less *captive model*. The latter type of test is sometimes called *towed propulsion test*. The model’s degrees of freedom may change from one facility to another, but it is important that the principles of the tests arrangements are presented. Basically the model should be free to pitch, heave and roll.

In propulsion tests, all hull appendages, such as rudders, nozzles, ice deflecting fins, which may have been left out during the resistance tests should be attached to the model. The test report should give good description of their geometry and location.

Propellers or any other propulsive devices are recommended to be correctly scaled models. If stock propellers are used, their geometry should be as near as possible to the correct one. Diameter of the propeller and the distance to the hull are the most important parameters. Information about the number of propellers and propeller data is necessary. Direction of propeller rotation is also important, because inwards or outwards running propellers may encounter different ice loads due to their effects on the flow etc. On order to scale the flow to the propeller in a proper manner, it is recommended to adjust the propeller rpms in the test so that the thrust or net thrust, $T_{\mathrm{NET}} = (1-t) * T$, t is the thrust deduction factor, is scaled correctly.

The number of propeller driving motors in the model should be noted in the report. Although it is recommended to have one motor for each propeller, there are sometimes practical reasons (e.g. lack of available room in the model) to have only one motor running two propellers. In that case, heavy ice loads on one shaft may have some influence on the other shaft too.

The propeller speed control can be based on constant rpm, constant torque or constant power. The control system may also include a microcomputer that makes it possible to simulate the behaviour of the propulsion machinery. Thrust and torque are controlled by propeller rpm and if the model is free, the model speed depends on the resistance and net thrust. Ice blocks, which may hit the propeller or the nozzle, may sometimes make sudden changes in the balance between these quantities (n, Q, P, T, R_{IT}). If the motor is powerful enough and a constant rpm mode is selected, rpm remains stable in spite of the ice load. However, it is not very realistic, if the rpm does not drop during heavy ice loads. Thus, this type of propeller speed control (constant rpm) may lead to unnaturally high torques on the shaft.

A more realistic control system is a constant torque motor speed control, which keeps the shaft torque constant and drops the rpm if necessary. However, to make everything correctly scaled in this case, the mass inertia and flexural stiffness of the whole shaft line should be scaled. The constant torque method drops propeller rpms during heavy ice loads, which is more realistic if compared with strictly stable rpm. Only fixed pitch propellers have been scaled and used in ice model tests as the pitch control of controllable pitch propellers is difficult.

The measurements in a propulsion test depend on the test type. If the test is a towed propulsion test instead of a test with a free model, there is one additional quantity to be measured, namely the towing force. Figures 2-1a and 2-1b present the acting (longitudinal) mean forces in these two test types. Rpm, torque and thrust measurements (propeller thrust and nozzle thrust) are to be performed on each propeller shaft in both test types.

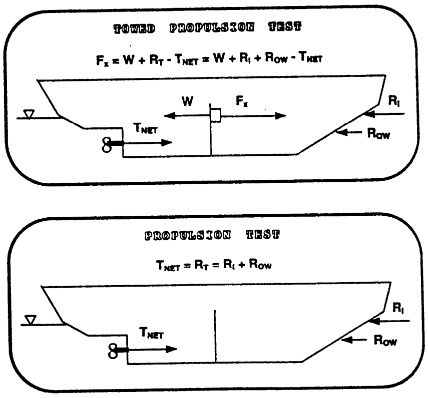

Fig. 2-1 The forces acting on a model in towed propulsion test and a free propulsion test

2.1 Towed Propulsion tests.

In this type of test the model speed is constant and it can be selected to be the same as in the resistance test. The towing force is measured. A counterweight is needed to keep the towing wire tight even in a bollard pull condition. Bollard pull tests are recommended to be performed at three different rpms to find out the correct zero level of towing force, thrust and torque signals. It is recommended to adjust the propeller rpms in the test so that the thrust or net thrust, $T_{\text{NET}} = (1-t)*T$, is scaled correctly. This is possible by comparing the rpms and thrust in bollard pull condition.

The following equations (2.1) present how the ice resistance and propulsion tests with a towed model can be used to find out the change in net thrust due to ice.

$$R_{\mathrm{OW}} = F_x - W \qquad (2.1)$$
$$R_{\mathrm{I}} = F_x - W - R_{\mathrm{OW}}$$
$$T_{\mathrm{NET}} = W + R_{\mathrm{OW}} - F_x$$
$$dT_{\mathrm{NET}} = W + R_{\mathrm{I}} + R_{\mathrm{OW}} - T_{\mathrm{NET}} - F_x$$

where the two first equations are from resistance tests and the two last equations from propulsion tests. If the ice conditions in resistance and propulsion tests above are identical, then the net change in thrust due to ice, dT_{NET}, can be obtained without thrust measurement. dT_{NET} takes into account the changes in the thrust as well as the changes in thrust deduction, since:

$$dT_{\mathrm{NET}} = \left[(1-t)*T\right]_{\mathrm{OW}} - \left[(1-t)*T\right]_{I} \qquad (2.2)$$

The towed propulsion test method allows large deviations from the self propulsion point. This may introduce a scaling distortion as the size of ice floes broken in bending depends on the ship speed, the higher the speed the smaller the pieces. The floe size influences the propeller-ice interaction and thus could influence propulsive coefficients. Some observations suggest that the thrust coefficient decreases and the torque coefficient increases in ice.

The reporting from propulsion tests should include the time histories of the measured V, rpm, n, propeller thrust, T_{P}, nozzle thrust ,T_{N}, and torque, Q, (see Fig. 2-2) as well as statistical data (maxima, minima, mean value and standard deviation) of these signals. The towing force and its time-integral are recommended to be published with the other signals. The length of the test section should be reported, too. Thrust and torque coefficients, K_{TI} and K_{QI}, based on mean values during a sufficiently long test run, are also recommended to be reported and plotted against J_V.

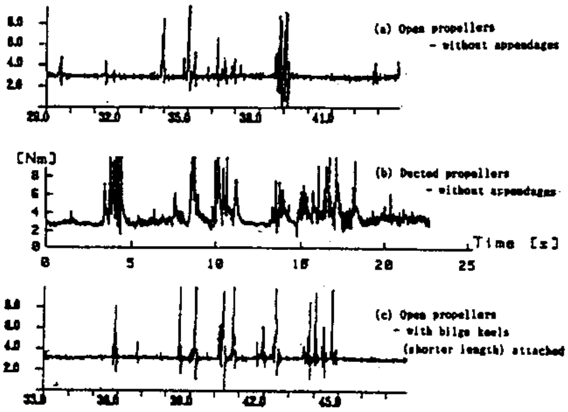

Fig. 2-2 Measured torque signals from an ice model test (Jones & al. 1994)

2.2 Propulsion test with a free model.

If the model is free, no towing force is applied. In this case the speed of the model depends on the propeller thrust which is not necessarily constant. Therefore it is important to have a rather long test section for this type of test, so that the mean speed will be representative. Otherwise, the dynamics of the model motion has to be taken into account. It is difficult to give any guidelines on selecting a proper length for this type of test, because the steadiness of the speed depends on many variables. After the test it is easier to see, e.g. from the time history of speed, if the test was long enough.

If self propulsion tests are performed with a free ship model, the resistance of the model should be extremely well scaled. Thus the requirements for the model-ice friction coefficient and other ice properties are even more demanding than in a towed self-propulsion test where the model speed can be selected independent from ice properties. In order to ensure a correctly scaled model speed the net thrust and total resistance should be in balance. In this case any deviation from target values in ice properties causes also a change in model speed and thereby a change in propeller inflow and propeller-ice interaction.

The length of the test run should be long enough for the model speed to get stabilized at a certain level. The model speed is controlled by the resistance, thrust and propeller/ice-interaction. The recommended length for a test run with a free ship model is at least two ship lengths in stabilized conditions. Quantities to be measured are the same as in the propulsion test with a captive model, except the towing force.

2.3 Propeller/ice-interaction

When using the equations (2.1)-(2.4), it is assumed that the average value of propeller rpm is the same in open water and in ice. The difference in torques on propeller shaft is $dQ = Q_{\mathrm{I}} - Q_{\mathrm{OW}}$ where the torques should be measured at the same average speed and rpm in ice and in open water. A so-called ice efficiency coefficient of propulsion in ice has been presented (cf. 17th ITTC 1984). It is defined with the following equation:

$$\eta_{\mathrm{I}} = \frac{1 - \dfrac{dT_{\mathrm{NET}}}{T_{\mathrm{NET}}}}{1 - \dfrac{dQ}{Q_{\mathrm{OW}}}} \qquad (2.3)$$

The problem in characterising the propeller-ice interaction with model tests is that the floe size and ice compressive strength must be scaled properly.

A standardised index on the frequency or intensity of propeller-ice- interaction would be very useful. Because of the nature of propeller ice interaction, which varies a lot according to different ice conditions and speed of the vessel, it might be useful to recommend several different indices instead of one. Thus, the following indices could be recommended:

Intensity of propeller-ice interaction	Index	Explanation
Low	$C_{\mathrm{TI}} = N/s$	N is the number of propeller interaction events in torque signal and s is the travelled distance during which N was counted. If this index is used, it is recommended that $s >> L_{\mathrm{WL}}$.
Low/High	$(t_{\mathrm{I}}/t_{\mathrm{TOT}})*100\%$	t_{TOT} - the total time of the test, t_{I} is the time, when the interaction occurs. This is determined by the measured torque or the rate of shaft revolutions e.g. as follows: $Q_{\mathrm{I}} > 1.10 - 1.15 * Q_{\mathrm{OW}}$ or $Q_{\mathrm{I}} < 0.85 - 0.90 * Q_{\mathrm{OW}}$ $n_{\mathrm{I}} < 0.95 * n_{\mathrm{OW}}$ or $n_{\mathrm{I}} > 1.05 * n_{\mathrm{OW}}$, where OW refers to the test in ice free conditions.
Low/High	$s_{Q\mathrm{I}}/s_{Q}$	$s_{Q\mathrm{I}}$ - standard deviation of measured torque on propeller shaft in ice, s_{Q} - standard deviation of measured torque on propeller shaft in open water at the same rpm and speed as in ice. This relationship could be used in constant rpm tests.

In some occasions the standard deviation of torque has also been used to characterize the propeller-ice interaction. However, in order to make comparisons more reliable it is better to use the ratio between standard deviations in ice and in open water instead of the standard deviation, as shown in the list above. The basic problem in characterizing the propeller-ice interaction with model tests is the correct compressive strength of model ice.

It has also to be noted, that reliability of these indexes depends on the length of the test runs, correct ice piece size, correct ice buoyancy and friction. Instead of the indexes above or in addition to them, the torque on the propeller shaft, caused by the ice blocks hitting the propeller or milled by the propeller, can be defined:

$$Q_{\mathrm{I}}(t) = Q_{\mathrm{meas}}(t) - Q_{\mathrm{OW}}(n(t), \mathrm{v}(t)) + J\frac{dn}{dt} \quad (2.4)$$

where J is the inertia of the propeller and shaftline behind the measuring point. Equation (2.4) can be used in constant rpm tests as well as constant torque tests. In the former case, if the rpm does not drop during ice loads, the last term becomes zero.

Equation (2.5) gives the definition for the instantaneous ice torque. In order to get a more representative view on the severity of the ice loads its use should be developed further. The average value of ice torque, Q_I, could be compared with the torque in open water, Q_{OW}, e.g. with the equation:

$$\frac{Q_\mathrm{I}}{Q_\mathrm{OW}} = \frac{1}{Q_\mathrm{OW} * (t_2 - t_1)} \int_{t_1}^{t_2} Q_\mathrm{I}(t)dt \qquad (2.5)$$

The time interval, $(t_2 - t_1)$, should be long enough in order to ascertain the reliability of the result. Propeller-ice interaction is stochastic by nature (see e.g. Figure 2-2).If different designs are compared, and the quantity compared is the maximum torque amplitude or any of the indices above, the time interval or perhaps the length travelled should be the same for both designs.

Once the scaling of model ice and propulsion parameters is correct, the statistical data of Q_I is very interesting. Maximum values and histograms of Q_I, calculated for different designs could be compared. This kind of data is also useful for the ship and propulsion system designers.

3. PARAMETERS

3.1 Parameters To Be Measured

Parameter	Priority
Towing Force	1
Model speed	1
Shaft thrust (every shaft)	1
Nozzle thrust (if any)	1
Shaft torque (every shaft)	1
Shaft rpm	1
Type of model restraints	1
Model motions	2

3.2 Parameters Of The Level Ice To Be Measured

Parameter	Priority
Ice thickness	1
Broken channel width	1
Piece size, breaking pattern	1
Model ice type	1
Elastic modulus	1
Flexural strength	1
Compressive strength	1
Underwater photography	1
Ice density	1
Ice crystal structure	2
Fracture toughness	2
Water density	2

4. VALIDATION

4.1 Uncertainty Analysis

None

4.2 Benchmark Tests

1) Report of Committee on Ships in Ice-Covered Water (16th 1981 pp. 363-372)
   (g) Catalogue of Available Model and Full Scale Test Data (16th 1981 pp. 370-371)

2) Standard Model Tests (Ice) (17th 1984 pp.591-601)
   (1) Model Tests with R-Class Icebreaker
   (2) Propulsion Tests
   (3) Full Scale Prediction

3) Reanalysis of Full Scale R-Class Icebreaker Trial Results (18th 1987 pp.528-531) To Get Reliable Full-Scale R-Class Data CCGS "Pierre Radisson“ and CCGS “Franklin“

4) Retest of R-Class Icebreaker Model at a Different Friction Level (18th 1987 pp.532-543)
   (1) Resistance Tests (18th 1987 pp.532-540)
   (2) Self Propulsion Test (18th 1987 pp.540-543)

5) Comparative Test Program with R-Class Model (19th 1990 pp.526-531))

6) Comparative Test Program with Basic Off-shore Model Structure (19th 1990 pp.534-540)

7) Basic Cylinder Tests(20th 1993 pp.470-481)

8) Repeatability Tests for Quality Control (20th 1993 pp.488-490)

9) Model Propulsion Tests in Ice (21st 1996 pp.252-263)