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COMMENTS OF THE ICE COMMITTEE OF 22nd ITTC

The committee has a major concern that this section does not consider the use of PMM (Planar Motion Mechanisms) for these tests, and is thus inherently incomplete. There was also concern expressed that this was very much a developing field and that a substantial change may be needed to the section. Nevertheless, 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

Manoeuvring Tests in Ice

1. PURPOSE OF PROCEDURE

- Definition of standards for performing ice manoeuvring tests in level ice
- Ensure recommended procedure follows a defined structure and format

2. MANOEUVRING TESTS IN ICE

Manoeuvring test is a common name for all those tests in which the rudder is turned or the turning forces and moments are obtained by other means e.g. azimuthing thrusters, tunnel thrusters in bow, different rpms at twin propellers etc. The primary purpose of manoeuvring tests is to investigate the effectiveness of the hull in making turns. The other primary purpose is to investigate the effectiveness of the turning devices like rudders, thrusters or azimuthing propulsors. Manoeuvring tests are also used to investigate the flow of ice floes around the hull in various manoeuvres. The design of aft shoulders down to baseline is especially important for turning capability. Typical manoeuvring tests include turning circle tests, star manoeuvres and breaking out of channel. All these tests are performed in model scale with a free model under its own propulsion.

Data to be reported from manoeuvring tests is mainly the same as in the case of propulsion tests with a free model. In section 3.1 the quantities to be measured or recorded are listed. The underwater photography or videos are important in manoeuvring tests to record the track of ice pieces around the hull. Fig. 2-1 gives the definitions of quantities used in the turning tests.

It is important to note at which instant the rudder was turned. The rudder angle can either be set to a fixed position before the test or it can be turned during the test The selected method may have influence on the results. The turning rate of the rudder may be important too if the rudder is turned when the model has reached its intended velocity. Therefore the test procedure used should be reported.

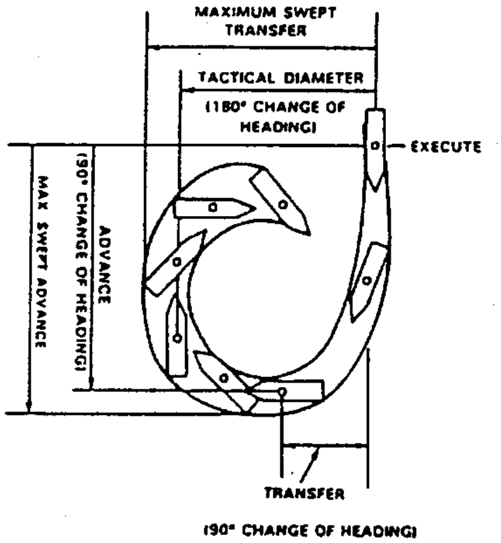

Fig.2-1 Definition of quantities used in turning circle tests

2.1 Turning circle test.

The purpose of the turning circle test is to find out how much area is needed to turn the ship. In practice, the result of this kind of test may look as shown in Fig. 2-1. The circle may be not a perfect circle, but a spiral. If the turning diameter, D, or radius, R, is determined, the method by which it was obtained should be described.

Some modern icebreaker designs are able to turn the ship in level ice so effectively, that the diameter of the broken area in ice is almost the same as the waterline length of the vessel. In this case the selection of the point on the vessel which defines the track from which the diameter is determined is of crucial importance. The centre of gravity of the model is the recommended point. Some misunderstandings can be avoided, if the length of the vessel is specified more explicitly. The difference between length overall and length between perpendiculars may be as big as 25%! The waterline length of the model is the recommendation.

Another question that has arisen with the newest designs is how large is the turning diameter if the model turns on the spot? If the turning diameter is defined to be the same as the tactical diameter (see Fig. 2-1), the diameter D may be less than 10 % of the length of the vessel However, the vessel needs at least 1.10* L_{OA} of free area for this manoeuvre. Thus, there is a vast difference in results, if the measurement of D is based on the outer edge of the broken channel or if it is based on the track of the centre of gravity of the model. Both values can be measured and it is therefore recommended to use the following definitions:

D Tactical diameter of the turn, determined from the path of the centre of gravity of the vessel (see Fig.2-1)
D_0 Outer diameter of the broken channel
D_i Inner diameter of the broken channel

The radius R of a circle can be determined if co-ordinates of three points on the circle $\{(x_1, y_1), (x_2, y_2)$ and $(x_3, y_3)\}$ are known The radius is then

$$R = \sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2} \tag{2.1}$$

and the centre of the circle is

$$x_0 = k_2 - n_2 y_0 , \; y_0 = \frac{k_2 - k_1}{n_2 - n_1} \tag{2.2}$$

where the intermediate results are

$$k_1 = \frac{1}{2}\left[(x_1 + x_2) + n_1(y_1 + y_2)\right] \tag{2.3}$$

$$k_2 = \frac{1}{2}\left[(x_1 + x_3) + n_2(y_1 + y_3)\right]$$

$$n_1 = \frac{y_1 - y_2}{x_1 - x_2}, \qquad n_2 = \frac{y_1 - y_3}{x_1 - x_3}$$

Using at least three measured points (x- and y - co-ordinates) from the path of the model and some averaging or smoothing procedure, if necessary, it is possible to determine the diameter of the circle. By this method the radius of a circle can be determined also from less than 180° turns. However, as the channels that are broken in turning circle tests sometimes resemble a spiral rather than a regular circle, it is better to let the model proceed as long as possible (or until a 180° turn is reached).

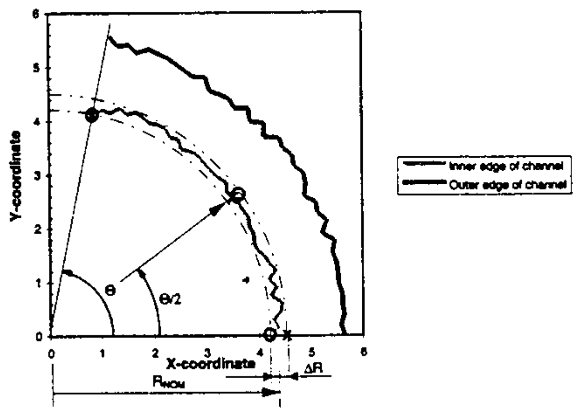

Fig. 2-2. The possible error sources in determining the turning circle.

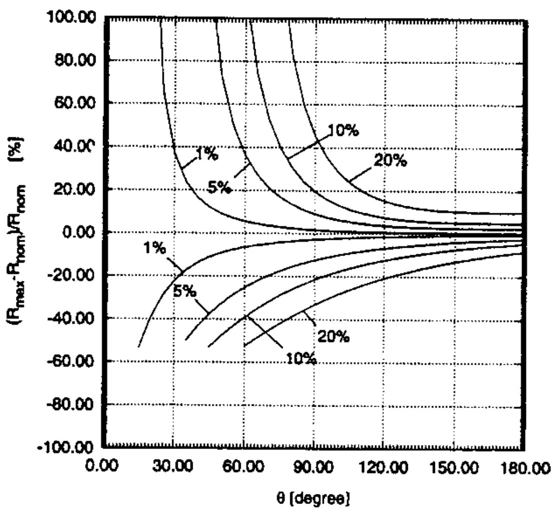

Fig. 2-3. The relative error in determining the turning circle presented versus the turning diameter size and using the error band of the points used as a parameter.

Considerable errors may appear, if the determination of D or R is based on a too small turn. Figure 2-2 presents an example of the broken track left after a turning circle test. To illustrate the possible maximum error in diameter D_i, when determined based on three points on the inner circle, as a function of the turning angle. The smallest diameter results if the circled points are selected and largest if the points marked with asterisks are selected. The resulting error is presented in Fig. 2-3. It can clearly be seen from this figure, why the recommended turn is about 135° .

The above error estimate is based on the assumption that only three points are used to determine the turning circle. If the number of points used is larger then a least squares routine can be used. This leads to iterative equations as follows. If there are N points (x_i,y_i), i=1,...,N and the turning circle's centre point and radius are denoted (x_o,y_o) and R, respectively, then the iterative equations for the centre point are

$$x_0 = \frac{\sum x_i - \sum x_i \frac{R}{R_i}}{N - R\sum \frac{1}{R_i}} \tag{2.4}$$

$$y_0 = \frac{\sum y_i - \sum y_i \frac{R}{R_i}}{N - R\sum \frac{1}{R_i}}$$

where all the sums are from i =1 to N and the radius related to each point is

$$R_i = \sqrt{\left(x_i - x_0\right)^2 + \left(y_i - y_0\right)^2} \tag{2.5}$$

and the final radius (which is used also in the iterative equations (2.5) is

$$R = \frac{\sum_{i=1}^{N} R_i}{N} \qquad (2.6)$$

Full scale tests have revealed that the heeling angle of the ship has a large influence on the turning capability. Therefore the recommendations concerning the documentation of the initial trim, heeling angle and GM_0 of the model are emphasized.

The scaling of the turning radius should follow the geometric scale if no scale distortions exist in the ice parameters. The scaling of turning time is determined by the Froude's law. The shape of the aft shoulders of the vessel is important in determining the radius as the vessel tends to crush ice there. Thus influence of the compressive strength of model ice may be more important in manoeuvring tests than in propulsion tests. No comparative data exist, however, about the turning radius.

2.2 Breaking out of channel test.

The merchant vessels navigate mostly in channels made by icebreakers or other ships. Therefore the turning circle is not a relevant description of the agility of the vessel but the ability of the vessel to turn out from a channel. If the bow is too blunt, then the vessel bounces off from the channel side.

Breaking out of channel is a test which can be performed from zero speed or some other specified speed. As in a turning circle test the rudder angle can be pre-set before the test or the rudder can be turned during the test. The channel width and local pattern of ice floes and shapes of the channel edges (before the test) have big influence on the results. If this test is performed from zero speed in the channel made by the test in presawn ice, the result may differ from that in naturally broken channel. A proper documentation considers all these aspects with clarifying pictures and photos.

The data that should be recorded from a channel test and include all the data presented in the parameter list in section 3. Some additions exist because the turning rate of the propeller is important as the ship may gather rotational inertia before hitting the channel edge. Also the point of first contact with the channel edge is important and should be recorded as well as the distance the bow slides on the channel edge before penetrating the ice field.

3. PARAMETERS

3.1 Parameters to be Measured

Parameter	Priority
Rudder angle d_R (or thruster angle)	1
Yaw angle	1
Ship’s track	1
Ship's heading	1
Rudder forces in x- and y-direction	2
Rudder torque	2
Roll angle	2
Velocity of the model on the curved path	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) (17^{th} 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(18^{th} 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 (18^{th} 1987 pp.532-543)
   (1) Resistance Tests (18^{th} 1987 pp.532-540)
   (2) Self Propulsion Test (18^{th} 1987 pp.540-543)

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

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

7) Repeatability Tests for Quality Control (20^{th} 1993 pp.488-490)

8) Model Propulsion Tests in Ice (21^{st} 1996 pp.252-263)