Polski Rejestr Statków

INFORMATIVE PUBLICATION NO. 25/I

EXPLANATORY NOTES TO THE STANDARDS FOR SHIP
MANOEUVRABILITY

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The present Publication was accepted by Director for External Co-operation of Polski Rejestr Statków on 4 July 2008. It is based on IMO MSC/Circ.1053 of 16 December 2002.

This Publication refers to Sub-chapter 2.7 – *Standards for Ship Manoeuvrability* in *Part III – Hull Equipment* of the *Rules for the Classification and Construction of Sea-going Ships.*

CONTENTS:

1   GENERAL

1.1   Aim

This *Publication* contains guidelines and explanations to the requirements in sub-chapter 2.7 – *Standards for Ship Manoeuvrability*, *Part III – Hull Equipment, Rules for the Classification and Construction of Sea-going Ships.*

1.2   Application

1.2.1   The Manoeuvrability Standards (called the Standards hereafter) should be applied to ships of all rudder and propulsion types, of 100 m in length and over, and chemical tankers and gas carriers regardless of the length.

    Standards should not be applied to high-speed craft (see the definition in sub-chapter 1.2 of *Part I - Classification Regulations, Rules for the Classification and Construction of Sea-going Ships).*

1.2.2   In this *Publication*, the assumption is made that the ship has normal actuators for the control of speed and heading (i.e., a stern propeller and a stern rudder). However, most of the definitions and conclusions also apply to ships with other types of control actuators.

2   ADOPTED ASSUMPTIONS FOR MANOEUVRABILITY STANDARDS ELABORATION

2.1   General information

2.1.1   The Standards have been selected so that they were simple, practical and did not require a significant increase in trials time or complexity over that in current trials practice. Standards are based on the premise that the manoeuvrability of ships can be adequately judged from the results of typical ship trials manoeuvres.

2.1.2   It is assumed that the right arrangements adopted during the design stage can determine manoeuvring performance in such a way that the requirements in the *Standards* are complied with. Upon completion of ship trials, the shipbuilder should examine the validity of the manoeuvrability prediction methods used during the design stage.

    Alternatively, the compliance with the Standards can be demonstrated based on the results of full-scale trials only, although PRS may require remedial action if the ship is found in substantial disagreement with the Standards.

2.2   Conditions at which the Standards apply

2.2.1   Trials for the assessment of compliance with the manoeuvring criteria should be carried out under the standard conditions for standard trials given in 2.7.2.2 , *Part III – Hull Equipment, Rules for the Classification and Construction of Sea-going Ships*. The standard conditions provide a uniform basis against which the inherent manoeuvring performance of all ships may be assessed.

2.2.2 Standards cannot be used to evaluate directly manoeuvring performance under non-standard, but often realistic, conditions.

2.3 Improved manoeuvring characteristics

2.3.1 Some of manoeuvrability characteristics are considered to be especially typical of ship manoeuvring performance and therefore should be required to meet a certain minimum standard.

A ship operator may choose to ask for a higher standard in some respect, in which case it should be remembered that some requirements may be mutually incompatible within conventional designs. For similar reasons the formulation of the *Standards* for ship manoeuvrability involves certain compromises.

2.4 Definitions

2.4.1 Terminology associated with ship's geometry:

L e n g t h *(L)* – the length measured between the aft and forward perpendiculars.

M i d s h i p p o i n t – the point on the centreline of a ship midway between the aft and forward perpendiculars and on the summer load waterline.

2.4.2 Terminology associated with standard manoeuvres

A d v a n c e – the distance travelled in the direction of the original course by the midship point of a ship from the position at which the rudder order is given to the position at which the heading has changed 90° from the original course.

F u l l a s t e r n s t o p p i n g t e s t – the manoeuvre to determine the track reach of a ship from the time an order for full astern is given until the ship stops in the water.

O v e r s h o o t a n g l e (t h e f i r s t a n d t h e s e c o n d) – the additional heading deviation experienced in the zig-zag test (following the second execute and the third execute, respectively – the executes are described in detail in 7.1.2).

T a c t i c a l d i a m e t e r – the distance travelled by the midship point of a ship from the position at which the rudder order is given to the position at which the heading has changed 180° from the original course. It is measured in a direction perpendicular to the original heading of the ship.

T e s t s p e e d (*V*) – a speed of at least 90% of the ship's speed corresponding to 85% of the maximum engine output.

T r a c k r e a c h – the distance along the path described by the midship point of a ship measured from the position at which an order for full astern is given to the position at which the ship stops in the water.

T u r n i n g c i r c l e m a n o e u v r e – the manoeuvre to be performed to both starboard and port with 35° rudder angle or the maximum rudder angle permissible at the test speed, following a steady approach with zero yaw rate.

Z i g - z a g   t e s t – the manoeuvre where a known amount of helm is applied alternately to either side when a known heading deviation from the original heading is reached.

3   SHIP MANOEUVRING CHARACTERISTICS

3.1   Manoeuvring characteristics description

The Standards identify significant manoeuvring characteristics for the quality assessment of ship manoeuvrability:

3.1.1   *Inherent dynamic stability* – A ship is dynamically stable on a straight course if it, after a small disturbance, soon will settle on a new straight course without any corrective rudder.

3.1.2   *Course-keeping ability* – The course-keeping ability is a measure of the ability of the steered ship to maintain a straight path in a predetermined course direction without excessive oscillations of rudder or heading. In most cases, reasonable course control is still possible where there exists an inherent dynamic instability of limited magnitude.

3.1.3   *Initial turning/course-changing ability* – The initial turning ability is defined by the change-of-heading response to a moderate helm, in terms of heading deviation per unit distance sailed or in terms of the distance covered before realizing a certain heading deviation.

3.1.4   *Yaw checking ability* – The yaw checking ability of the ship is a measure of the response to counter-rudder applied in a certain state of turning. The response measure can be e.g. the heading overshoot reached before the yawing tendency has been cancelled by the counter-rudder in a standard zig-zag manoeuvre.

3.1.5   *Turning ability* – Turning ability is the measure of the ability to turn the ship using hard-over rudder. It is expressed by a minimum "advance at 90° change of heading" and "tactical diameter" defined by the "transfer at 180° change of heading". Analysis of the final turning diameter is of additional interest. Hard-over turning ability is mainly an asset when manoeuvring at slow speed in confined waters. A small advance and tactical diameter will be of value in case emergency collision avoidance manoeuvres at normal service speeds are required.

3.1.6   *Stopping ability* – It is measured by the "track reach" and "time to dead in water" realized in a stop engine-full astern manoeuvre performed after a steady approach at full test speed. Lateral deviations are also of interest, but they are very sensitive to initial conditions and wind disturbances.

4   MANOEUVRABILITY VERSUS DYNAMIC STABILITY

4.1   Phenomena occurring at manoeuvres

4.1.1   At a given engine output and rudder angle δ, the ship may take up a certain steady motion.

In general, this will be a turning motion with constant yaw rate ψ, speed V and drift angle *β*. The radius of the turn is then defined by the following relationship, expressed in consistent units:

$$R = V/\dot{\psi}$$

This particular ship-rudder angle configuration is said to be "dynamically stable in a turn of radius R". Thus, a straight course may be viewed as part of a very wide circle with an infinite radius, corresponding to zero yaw rate.

4.1.2   Most ships, perhaps, are "dynamically stable on a straight course" (usually referred to as simply "dynamically stable") with the rudder in a neutral position close to midship. In the case of a single screw ship with a right-handed propeller, this neutral helm is typically of the order δ = -1° (i.e., 1° to starboard). Other ships which are dynamically unstable, however, can only maintain a straight course by repeated use of rudder control. While some instability is fully acceptable, large instabilities should be avoided by suitable design of ship proportions and stern shape.

4.1.3   The motion of the ship is governed mainly by the propeller thrust and the hydrodynamic and mass forces acting on the hull. During a manoeuvre, the side force due to the rudder is often small compared to the other lateral forces. However, the introduced controlling moment is mostly sufficient to balance or overcome the resultant moment of these other forces. In a steady turn there is complete balance between all the forces and moments acting on the hull. Some of these forces seeming to "stabilize" and others to "destabilize" the motion. Thus the damping moment due to yaw, which always resists the turning, is stabilizing and the moment associated with the side force due to sway is destabilizing. Any small disturbance of the equilibrium attitude in the steady turn causes a change of the force and moment balance. If the ship is dynamically stable in the turn (or on a straight course) the net effect of this change will strive to restore the original turning (or straight) motion.

4.1.4   The general analytical criterion for dynamic stability may be formulated and evaluated with the appropriate coefficients of the mathematical model that describes the ship's motion. The criterion for dynamic stability on a straight course includes only four "linear stability derivatives" which together with the centre-of-gravity position, may be used to express the "dynamic stability lever".

This lever denotes the longitudinal distance from the centre-of-pressure of the side force due to pure sway (or sideslip) to the position of the resultant side force due to pure turning, including the mass force, for small deviations from the

straight-line motion. If this distance is positive (in the direction of positive x, i.e. towards the bow) the ship is stable. Obviously "captive tests" with a ship model in oblique towing and under the rotating arm will furnish results of immediate interest.

4.1.5   It is understood that a change of trim will have a marked effect mainly on the location of the centre-of-pressure of the side force resulting from sway. This is easily seen that a ship with a stern trim, a common situation in ballast trial condition, is likely to be much more stable than it would be on an even draught.

4.1.6   Figure 1 gives an example of the equilibrium yaw-rate/rudder angle relation for a ship which is inherently dynamically unstable on a straight course. The yaw rate is shown in the non-dimensional form for turn path curvature discussed above. This diagram is often referred to as "the spiral loop curve" because it may be obtained from spiral tests with a ship or model. The dotted part of the curve can only be obtained from some kind of reverse spiral test. Wherever the slope is positive, which is indicated by a tangent sloping down to the right in the diagram, the equilibrium balance is unstable. A ship which is unstable on a straight course will be stable in a turn despite the rudder being fixed in the midship or neutral position. Loop height, width and slope at the origin may all be regarded as a measure of the instability.

4.1.7   If motion is not in an equilibrium turn, which is the general case of motion, there are not only unbalanced damping forces but also hydrodynamic forces associated with the added inertia in the flow of water around the hull. Therefore, if the rudder is left in a position the ship will search for a new stable equilibrium. If the rudder is shifted (put over "to the other side") the original yaw tendency will be checked. By use of early counter-rudder it is fully possible to control the ship on a straight course with helm angles and yaw rates well within the loop.

4.1.8   The course-keeping ability or "directional stability" obviously depends on the performance of the closed loop system including not only the ship and rudder but also the course error sensor and control system. Therefore, the acceptable amount of inherent dynamic instability decreases as ship speed increases, covering more ship lengths in a given period of time. This results because a human helmsman will face a certain limit of conceptual capacity and response time. This fact is reflected in the IMO Standards for ship manoeuvrability where the criterion for the acceptable first overshoot in a zig-zag test includes a dependence on the ratio L/V, a factor characterizing the ship "time constant" and the time history of the process.
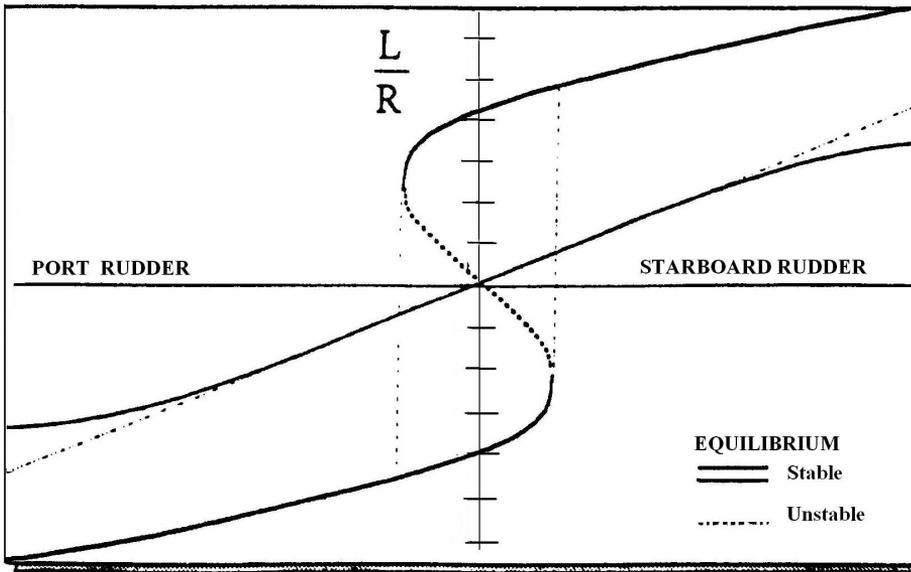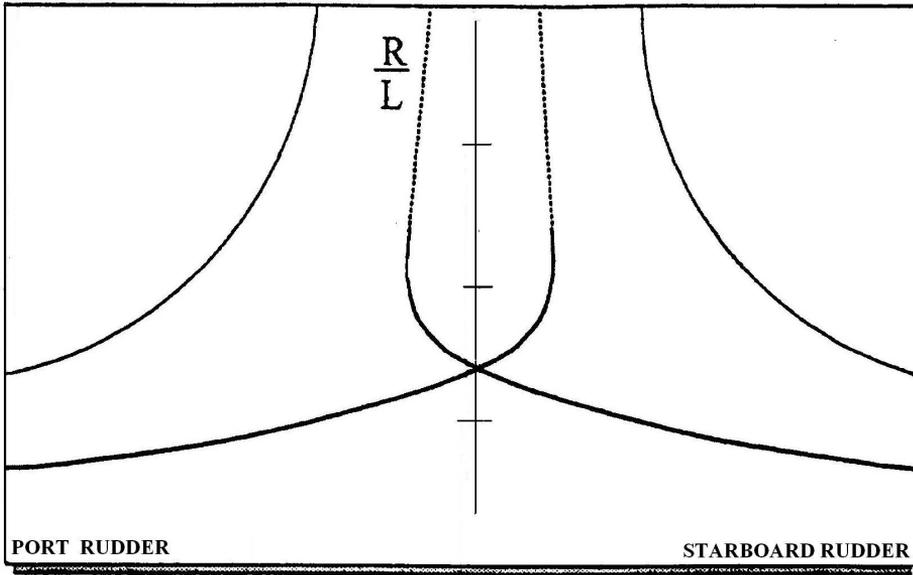
Figure 1

The equilibrium yaw rate/rudder angle relation

4.1.9   Obviously the course-keeping ability will depend not only upon the counter-rudder timing but also on how effectively the rudder can produce a yaw checking moment large enough to prevent excessive heading error amplitudes. The magnitude of the overshoot angle alone is a poor measure for separating the opposing effects of instability and rudder effectiveness, additional characteristics should therefore be observed. So, for instance, "time to reach second execute", which is a measure of "initial turning ability", is shortened by both large instability and high rudder effectiveness.

4.1.10   It follows from the above that a large dynamic instability will favour a high "turning ability" whereas the large yaw damping, which contributes to a stable ship, will normally be accompanied by a larger turning radius. This is noted by the full-drawn curve for a stable ship included in figure 1.

5   FACTORS INFLUENCING THE RESULTS OF SEA TRIALS

5.1   Kind of trial area

Manoeuvrability of a ship is strongly affected by interaction with the bottom of the waterway, banks and passing ships. Trials should therefore be conducted preferably in deep, unconfined but sheltered waters. The water depth should exceed four times the mean draught of the ship.

5.2   Load and trim condition

5.2.1   The Standards apply to the full load and even keel condition. The term "fully loaded" refers to the situation where the ship is loaded to its summer load line draught (referred to hereafter as "full load draught"). This draught is chosen based on the general understanding that the poorest manoeuvring performance of a ship occurs at this draught. The full load draught, however, is not based on hydrodynamic considerations but rather statutory and classification society requirements for scantlings, freeboard and stability.

5.2.2   Where it is impractical to conduct trials at full load because of ship type, trials should be conducted as close to full load draught and zero trim as possible. Special attention should also be given to ensuring that sufficient propeller immersion exists in the trial condition.

5.2.3   Where trials are conducted in conditions other than full load, manoeuvring characteristics should be predicted for trial and full load conditions using a reliable method (i.e. model tests or reliable computer simulation) that ensures satisfactory extrapolation of trial results to the full load condition. It rests with the designer/owner to demonstrate compliance at the final full load condition.

5.3 Calm environment

Trials should be held in the calmest weather conditions possible. Wind, waves and current can significantly affect trial results, having a more pronounced effect on smaller ships. The environmental conditions should be accurately recorded before and after trials so that corrections may be applied. Specific environmental guidelines are outlined in 8.4.2.

6 TESTS REQUIRED BY THE STANDARDS – BASIC INFORMATION

6.1 Necessary testing conditions

6.1.1 General

The test procedures given in the following guidelines were established to support the application of the manoeuvring standards by providing to shipyards and other institutions standard procedures for the testing trials of new ships, or for later trials made to supplement data on manoeuvrability.

6.1.2 Testing conditions

6.1.2.1 Environment

Manoeuvring trials should be performed in the calmest possible weather conditions. The geographical position of the trial is preferably in a deep sea, sheltered area where accurate positioning fixing is possible. Trials should be conducted in conditions within the following limits:

.1 Deep unrestricted water: more than 4 times the mean draught;
.2 Wind: not to exceed Beaufort 5;
.3 Waves: not to exceed sea state 4;
.4 Current: uniform only.

Correction may need to be applied to the test results following the guidance contained in 8.4.2.

6.1.2.2 Loading

The ship should preferably be loaded to the full load draught and even keel, however, a 5% deviation from that draught may be allowed by PRS.

Alternatively, the ship may be in a ballast condition with a minimumof trim, and sufficient propeller immersion.

6.1.2.3 Ship speed

The test speed is defined as equaling at least 90% of the ship's speed corresponding to 85% of the maximum engine output.

6.1.2.4 Engine

Engine control setting to be kept constant during the trial if not otherwise stated in following procedures.

6.1.2.5   Approach run

The conditions mentioned above must be fulfilled for at least two minutes preceding the test. The ship is running at test speed up wind with minimum rudder to keep its course.

6.1.2.6   Metacentric height

The Standards apply to a situation where the ship is loaded to a reasonable and practicable metacentric height for which it is designed at the full load draught.

6.2   Kinds of tests

6.2.1   Turning tests

A turning circle manoeuvre is to be performed to both starboard and port with 35° rudder angle or the maximum design rudder angle permissible at the test speed. The rudder angle is executed following a steady approach with zero yaw rate. The essential information to be obtained from this manoeuvre is tactical diameter, advance, and transfer (see Figure 2).
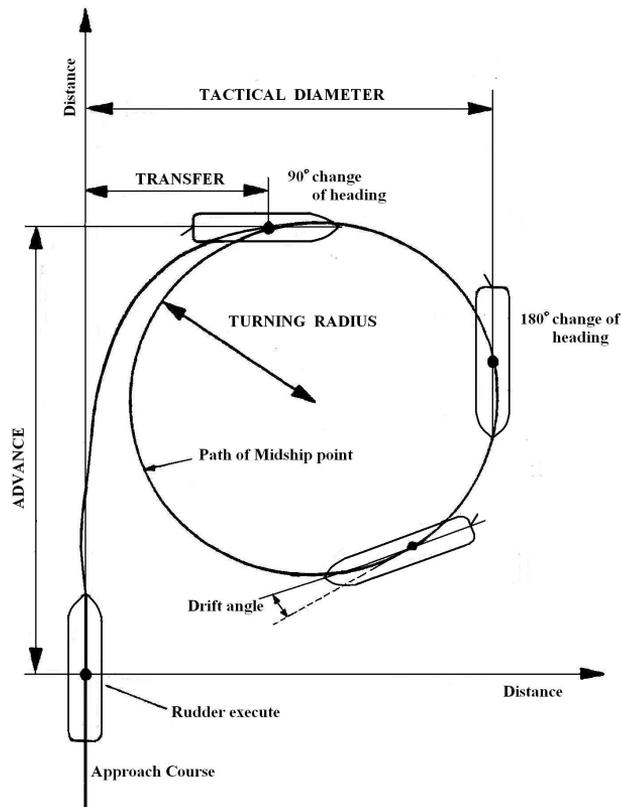

Figure 2
Definitions used in turning circle test

6.2.2 Zig-zag tests

6.2.2.1 A zig-zag test - the manoeuvre where a certain amount of helm is applied alternately to either side when a heading deviation (equaling the amount of helm) from the original heading is reached.

6.2.2.2 Two kinds of zig-zag tests are included in the Standards, the 10°/10° (see Figure 3) and 20°/20° zig-zag tests. The 10°/10° zig-zag test uses rudder angles of 10° to either side following a heading deviation of 10° from the original course. The 20°/20° zig-zag test uses 20° rudder angles coupled with a 20° change of heading from the original course. The essential information to be obtained from these tests is the overshoot angles, initial turning time to second execute and the time to check yaw.
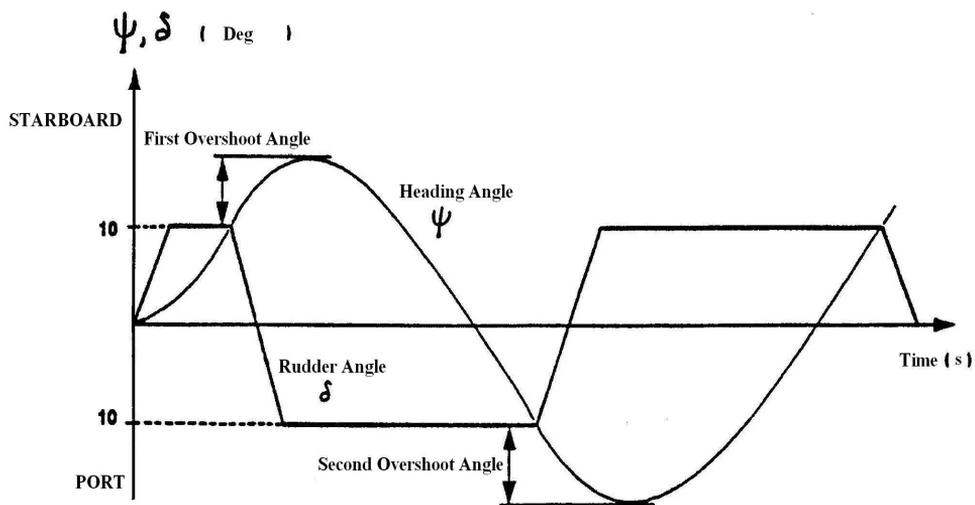
Figure 3

Zig-zag 10º/10º test

6.2.3 Stopping tests

A full astern stopping test is used to determine the track reach of a ship from the time an order for full astern is given until the ship is stopped dead in the water (see Figure 4).

The "crash-stop" or "crash-astern" manoeuvre is mainly a test of engine functioning and propeller reversal. The stopping distance is essentially a function of the ratio of astern power to ship displacement. A test for the stopping distance from full speed has been included in the Standards in order to allow a comparison with hard-over turning results in terms of initial speed drop and lateral deviations.

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Figure 4

Definitions used in stopping test

7 GUIDANCE FOR REQUIRED TRIALS PROCEDURES AND THEIR RESULTS RECORDING

7.1 Test procedures[*]

7.1.1 Turning circle manoeuvre

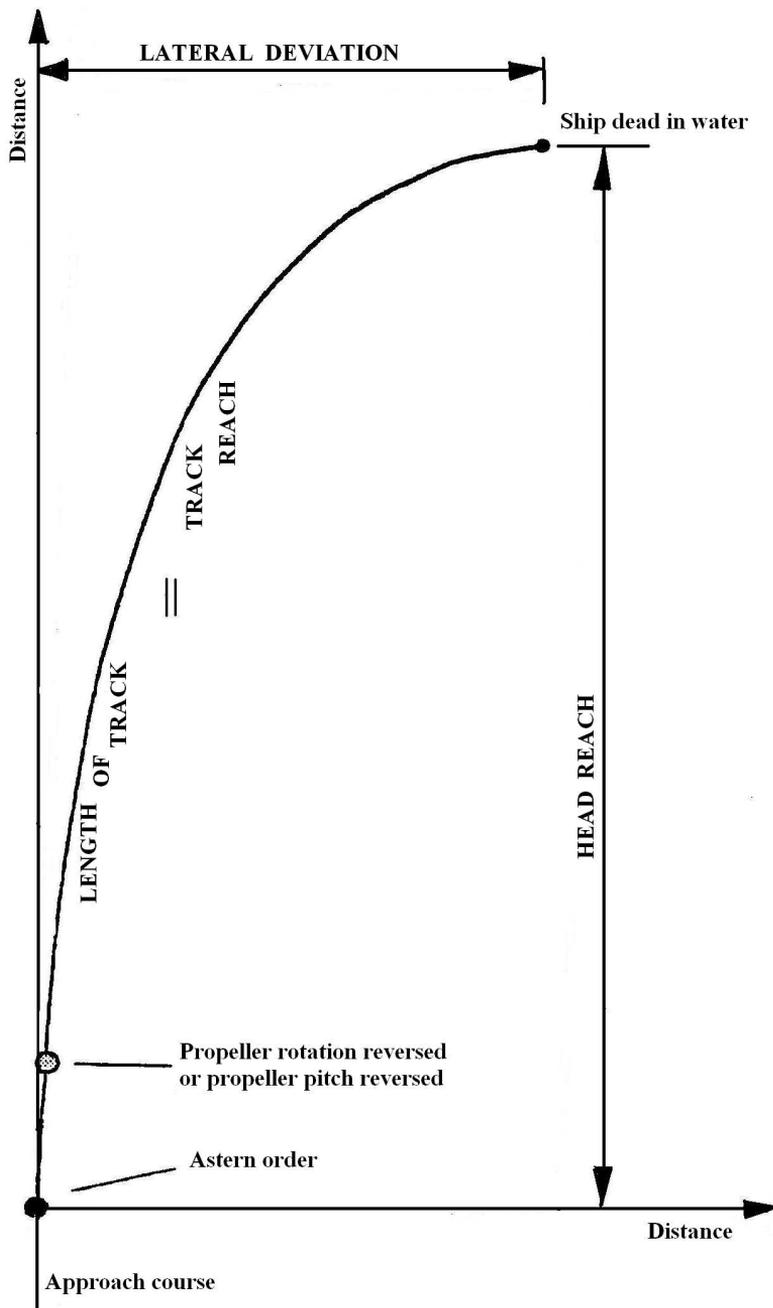Trials shall be made to port and to starboard using maximum rudder angle without changing engine control setting from the initial speed. The following general procedure is recommended:

- **.1** The ship is brought to a steady course and speed according to the specific approach condition;
- **.2** The recording of data starts;
- **.3** The manoeuvre is started by ordering the rudder to the maximum rudder angle. Rudder and engine controls are kept constant during the turn;
- **.4** The turn continues until 360° change of heading has been completed. It is, however, recommended that in order to fully assess environmental effects a 720° turn be completed (8.4.2 refers);
- **.5** Recording of data is stopped and the manoeuvre is terminated.

7.1.2 Zig-zag manoeuvre

The given rudder and change of heading angle for the following procedure is 10°. This value can be replaced for alternative or combined zig-zag manoeuvres by other angles such as 20° for the other required zig-zag test. Trials should be made to both port and starboard. The following general procedure is recommended:

- **.1** The ship is brought to a steady course and speed according to the specific approach condition;
- **.2** The recording of data starts;
- **.3** The rudder is ordered to 10° to starboard/port (first execute);
- **.4** When the heading has changed by 10° off the base course, the rudder is shifted to 10° to port/starboard (second execute). The ship's yaw will be checked and a turn in the opposite direction; (port/starboard) will begin. The ship will continue in the turn and the original heading will be crossed;
- **.5** When the heading is 10° port/starboard off the base course, the rudder is reversed as before (third execute);
- **.6** The procedure is repeated until the ship heading has passed the base course no less than two times;
- **.7** Recording of data is stopped and the manoeuvre is terminated.

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[*] It should be noted that these procedures were developed for ships with conventional steering and propulsion systems.

7.1.3 Stopping test

Full astern is applied and the rudder maintained at midship throughout this test. The following general procedure is recommended:

.1 The ship is brought to a steady course and speed according to the specific approach condition;

.2 The recording of data starts;

.3 The manoeuvre is started by giving a stop order. The full astern engine order is applied;

.4 Data recording stops and the manoeuvre is terminated when the ship is stopped dead in the water.

7.2 Recording

For each trial, a summary of the principal manoeuvring information should be provided in order to assess the behaviour of the ship. Continuous recording of data should be either manual or automatic using analogue or digital acquisition units. In case of manual recording, a regular sound/light signal for synchronization is advisable.

7.2.1 Ship's particulars

Prior to trials, draughts forward and aft should be read in order to calculate displacement, longitudinal centre of gravity, draughts and metacentric height.

In addition the geometry, projected areas and steering particulars should be known. The disposition of the engine, propeller, rudder, thrusters and other device characteristics should be stated with operating condition.

7.2.2 Environment

The following environmental data should be recorded before each trial:

.1 Water depth;

.2 Waves: The sea state should be noted. If there is a swell, note period and direction;

.3 Current: The trials should be conducted in a well surveyed area and the condition of the current noted from relevant hydrographic data. Correlation should be made with the tide;

.4 Weather: Weather conditions, including visibility, should be observed and noted.

7.2.3 Trial related data

7.2.3.1 The following data as applicable for each test should be measured and recorded during each test at appropriate intervals of not more than 20 s:

.1 Position;

.2 Heading;

.3 Speed;

.4   Rudder angle and rate of movement;

.5   Propeller speed of revolution;

.6   Propeller pitch;

.7   Wind speed.

7.2.3.2 A time signal should be provided for the synchronization of all recordings. Specific events should be timed, such as trial starting-point, engine/helm change, significant changes in any parameter such as crossing ship course, rudder to zero or engine reversal in operating condition such as ship speed and shaft/propeller direction.

7.2.4   Presentation of data

The recordings should be analyzed to give plots and values for significant parameters of the trial. Sample recording forms are given in appendix 6. The manoeuvring criteria of the Standards should be evaluated from these values.

8   PREDICTION GUIDANCE

8.1   General

8.1.1   To be able to assess the manoeuvring performance of a new ship at the design stage, it is necessary to predict the ship manoeuvring behaviour on the basis of main dimensions, lines drawings and other relevant information.

8.1.2   PRS recommends the use of one of the three described below methods for prediction of ship's manoeuvrability:

   .1   Making a prediction based on experience and existing data related to the construction and operation of similar existing ships;

   .2   Making a prediction based on results from model tests. For the time being, model tests must be considered the most reliable prediction method. Model tests are described in section 8.2;

   .3   Making a prediction based on results from calculation/simulation using a mathematical model. Mathematical models are described in section 8.3.

8.2   Model tests

8.2.1   PRS permits the use of two model test methods for prediction of manoeuvring characteristics. One method employs a free-running model moving in response to specified control input (i.e. helm and propeller); the tests duplicate the full-scale trial manoeuvres and so provide direct results for the manoeuvring characteristics. The other method makes use of force measurements on a "captive" model, forced to move in a particular manner with controls fixed; the analysis of the measurements provides the coefficients of a mathematical model, which may be used for the prediction of the ship response to any control input.

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8.2.2   Manoeuvring test with free-running model

8.2.2.1   The most direct method of predicting the manoeuvring behaviour of a ship is to perform representative manoeuvres with a scale model. To reduce costs by avoiding the manufacture of a special model for manoeuvring tests, such tests may be carried out with the same model employed for resistance and self-propulsion tests. Generally it means that a relatively large model will be used for the manoeuvring tests, which is also favourable with regard to reducing scale effects of the results.

8.2.2.2   The large offshore, sea-keeping and manoeuvring basins are well suited for manoeuvring tests with free-running models provided they have the necessary acquisition and data processing equipment. In many cases, conventional towing tanks are wide enough to allow the performance of the 10°/10° zig-zag test.

Tests with a free-running model can be conducted on a lake. In this case measuring equipment must be installed and the tests will be dependent on weather conditions. In order to reduce the scale effects it is possible to use an air propeller on board the model. Another improvement is to make the drive motor of the ship model simulate the characteristics of the main engine of the ship with regard to propeller loading.

8.2.2.3   Manoeuvres such as turning circle, zig-zag and spiral tests are carried out with the free-running model, and the results can be compared directly with the standard of manoeuvrability.

8.2.2.4   Tests with free-running models can provide the coefficients of mathematical models. The mathematical model is then used for predicting the manoeuvring characteristics of the ship. Parameter identification methods have been used and this procedure has been combined with oblique towing and propulsion tests to provide some of the coefficients.

8.2.3   Manoeuvring tests with captive model

8.2.3.1   Captive model tests include oblique-towing tests in long narrow tanks as well as "circling" tests in rotating-arm facilities, but in particular such tests are performed by the use of a Planar Motion Mechanism (PMM) system capable of producing any kind of motion by combining static or oscillatory modes of drift and yaw. Generally, it may be said that captive model tests suffer from scale effects similar to those of the free-running tests, but corrections are more easily introduced in the analysis of the results.

8.2.3.2   In using captive model tests due account of the effect of roll during manoeuvring should be taken.

8.2.3.3   The PMM has its origin in devices operating in the vertical plane and used for submarine testing. The PMM makes it possible to conduct manoeuvring tests in a conventional long and narrow towing tank. The basic principle is to conduct various simpler parts of more complex complete manoeuvres. By analysis of the forces measured on the model, the manoeuvring behaviour is broken down into its basic elements, the hydrodynamic coefficients. The hydrodynamic coefficients are entered into a computer based mathematical model and the results of the standard manoeuvres are predicted by means of this mathematical model.

8.2.3.4   A rotating arm facility consists of a circular basin, spanned by an arm from the centre to the circumference. The model is mounted on this arm and moved in a circle, varying the diameter for each test. The hydrodynamic coefficients related to ship turning as well as to the combination of turning and drift will be determined by this method. Additional tests often have to be conducted in a towing tank in order to determine hydrodynamic coefficients related to ship drift. As in the case of the PMM the manoeuvring characteristics of the ship are then predicted by means of a mathematical model using the coefficients derived from the measurements as input.

8.2.4   Model test condition

The Standards are applicable to the full load condition of the ship. The model tests should therefore be performed for this condition. For many ships the delivery trials will be made at a load condition different from full load. It will then be necessary to assess the full load manoeuvring characteristics of the ship on the basis of the results of manoeuvring trials performed at a condition different from full load. To make this assessment as reliable as possible the model tests should also be carried out for the trial condition, meaning that this condition must be specified at the time of performing the model tests. The assumption will be that when there is an acceptable agreement between model test results and ship trial results in the trial condition, the model test results for the loaded condition will then be a reliable basis for assessing the manoeuvring characteristics of the ship.

8.3   Mathematical model

A "mathematical model" is a set of equations which can be used to describe the dynamics of a manoeuvring ship. But it may be possible to predict the manoeuvrability for the conventional ship's form with certain accuracy from the practical point of view using some mathematical models which have already been published. In this section, the method used to predict the manoeuvring performance of a ship at full load for comparison with the Standards is explained. The following details of the mathematical model are to be indicated:

    .1   when and where to use;
    .2   how to use;
    .3   accuracy level of predicted results;
    .4   description of mathematical model.

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8.3.1 Application of the mathematical model

8.3.1.1 In general, the manoeuvring performance of the ship must be checked by a sea trial to determine whether it satisfies the manoeuvring standards or not. The Standards are regulated in full load condition from the viewpoints of marine safety. Consequently, it is desired that the sea trial for any ship be carried out in full load condition. This may be a difficult proposition for ships like a dry cargo ship, for which the sea trial is usually carried out in ballast or heavy ballast conditions from the practical point of view.

8.3.1.2 In such cases, PRS will require the prediction of the manoeuvring performance in full load condition by means of some method that uses the results of the sea trial. As an alternative to scale model tests, usually conducted during the ship design phase, a numerical simulation using a mathematical model is a useful method for predicting ship manoeuvring performance in full load condition.

8.4 Corrections from non-standard trial conditions

8.4.1 Loading condition

8.4.1.1 PRS recommends the application of one of the two methods described below for predicting manoeuvrability of a ship in full load condition with the use of the mathematical model through the sea trial results in ballast or heavy ballast condition:

8.4.1.2 Option 1: The manoeuvring performance in full load condition can be obtained from the criteria of measured performance during the sea trial in ballast condition (T) and the interaction factor between the criteria of manoeuvrability in full load condition and in a trial condition (F/B), that is as given below;
$R = TF/B$
where,
B: the estimated performance in the condition of sea trial based on the numerical simulation using the mathematical model or on the model test;
F: the estimated performance in full load condition based on the numerical simulation using the mathematical model or on the model test;
T: the measured performance during the sea trial; and
R: the performance of the ship in full load condition.
    It should be noted that the method used to derive B and F should be the same.

8.4.1.3 The manoeuvring performance in the condition of sea trial such as ballast or heavy ballast are predicted by the method shown in Appendix 2, and the predicted results must be checked with the results of the sea trial.

8.4.1.4 Afterwards it should be confirmed that both results agree well with each other. The performance in full load condition may be obtained by means of the same method using the mathematical model.

8.4.2 Environmental conditions

8.4.2.1   Ship manoeuvrability can be significantly affected by the immediate environment such as wind, waves, and current. Environmental forces can cause reduced course-keeping stability or complete loss of the ability to maintain a desired course. They can also cause increased resistance to a ship's forward motion, with consequent demand for additional power to achieve a given speed or reduces the stopping distance.

8.4.2.2   When the ratio of wind velocity to ship speed is large, wind has an appreciable effect on ship control. The ship may be unstable in wind from some directions. Waves can also have significant effect on course-keeping and manoeuvring. It has been shown that for large wave heights a ship may behave quite erratically and, in certain situations, can lose course stability

8.4.2.3   Ocean current affects manoeuvrability in a manner somewhat different from that of wind. The effect of current is usually treated by using the relative velocity between the ship and the water. Local surface current velocities in the open ocean are generally modest and close to constant in the horizontal plane.

8.4.2.4   Therefore, trials shall be performed in the calmest weather conditions possible. In the case that the minimum weather conditions for the criteria requirements are not applied, the trial results should be corrected.

8.4.2.5   Generally, it is easy to account for the effect of constant current. The turning circle test results may be used to measure the magnitude and direction of current. The ship's track, heading and the elapsed time should be recorded until at least a 720° change of heading has been completed. The data obtained after ship's heading change 180° are used to estimate magnitude and direction of the current. Position $(x_{1i}'\ y_{1i}'\ t_{1i})$ and $(x_{2i}'\ y_{2i}'\ t_{2i})$ in figure 5 are the positions of the ship measured after a heading rotation of 360°. By defining the local current velocity v_i for any two corresponding positions as:

$$\underline{v}_i = \frac{\left(x_{2i} - x_{1i'}, y_{2i} - y_{1i}\right)}{\left(t_{2i} - t_{1i}\right)} \qquad (8.4.2.5\text{-}1)$$

the estimated current velocity can be obtained from the following equation:

$$\underline{v}_c = \frac{1}{n}\sum_{i=1}^{n}\underline{v}_i = \frac{1}{n}\sum_{i=1}^{n}\frac{\left(x_{2i} - x_{1i'}, y_{2i} - y_{1i}\right)}{\left(t_{2i} - t_{1i}\right)} \qquad (8.4.2.5\text{-}2)$$

8.4.2.6   If the constant time interval, $\delta t = (t_{2i} - t_{1i})$, is used, this equation can be simplified and written:

$$\underline{v}_c = \frac{1}{n\delta t}\left(\sum_{i=1}^{n}x_{2i} - \sum_{i=1}^{n}x_{1i'}\sum_{i=1}^{n}y_{2i} - \sum_{i=1}^{n}y_{1i}\right) \qquad (8.4.2.6\text{-}1)$$

The above vector, v_c, obtained from a 720° turning test will also include the effect of wind and waves.

8.4.2.7 The magnitude of the current velocity and the root mean square of the current velocities can be obtained from the equations:

$$v_c = |\underline{v}_c| \tag{8.4.2.7-1}$$

$$v_c(\text{RMS}) = \left[\frac{1}{n} \sum_{i=1}^{n} \left| \underline{v}_i - \underline{v}_c \right|^2 \right]^{\frac{1}{2}} \tag{8.4.2.7-2}$$

(RMS) represents the non-uniformity of v_i which may be induced from wind, waves, and non-uniform current.

8.4.2.8 All trajectories obtained from the sea trials should be corrected as follows:

$$\underline{x}'(t) = \underline{x}(t) - \underline{v}_c t \tag{8.4.2.8-1}$$

where $x(t)$ is the measured position vector and $x'(t)$ is the corrected one of the ship and $\underline{x}'(t) = \underline{x}(t)$ at $t = 0$.
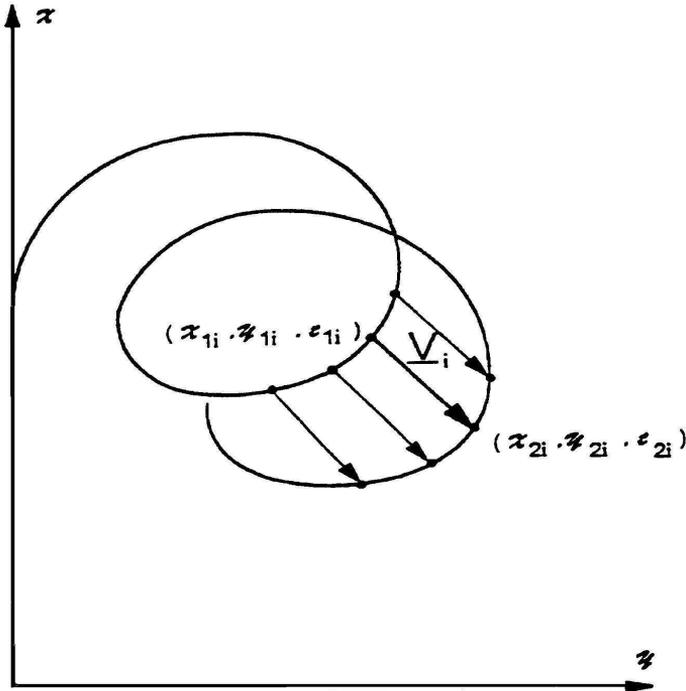

Figure 5

Turning trajectory in wind, waves and current

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8.5 Uncertainties

8.5.1 Accuracy of model test results

8.5.1.1 The model may turn out to be more stable than the ship due to scale effects. This problem seems to be less serious when employing a large model. Consequently, to reduce this effect model scale ratios comparable to that considered acceptable for resistance and self-propulsion tests should be specified for manoeuvring tests that use a free-running model. Captive model tests can achieve satisfactory results with smaller scale models.

8.5.1.2 While the correlation data currently available are insufficient to give reliable values for the accuracy of manoeuvring model test results, it is the intent of the Standards to promote the collection of adequate correlation data.

8.5.2 Accuracy of predicted results using the mathematical model

8.5.2.1 The mathematical model that can be used for the prediction of the manoeuvring performance depends on the type and amount of prepared data.

8.5.2.2 If there is no available data, under assumptions that resistance and self-propulsion factors are known, a set of approximate formulae for estimation of the derivatives and coefficients in the mathematical model will become necessary to predict the ship's manoeuvrability.

8.5.2.3 If there is enough experimental and accumulated data, it is desirable to use a detailed mathematical model based on this data. In most cases, the available data is not sufficient and a mathematical model can be obtained by a proper combination of different parts derived from experimental data and those obtained by the estimated formulae.

APPENDIX 1

NOMENCLATURE AND REFERENCE SYSTEMS

1   The manoeuvres of a surface ship may be seen to take place in the xoyo-plane of a right-handed system of axes $O_o(x_oy_oz_o)$ "fixed in space", the z_o-axis of which is pointing downwards in the direction of gravity. For the present discussion let the origin of this system coincide with the position at time $t = 0$ of the midship point O of the ship, and let the x_o-axis be pointing in the direction of ship's heading at the same moment, the y_o-axis pointing to starboard. The future orientation of the ship in this system is given by its heading angle ψ, its angle of pitch θ, and its angle of roll ϕ (see Figure A1-1).

2   In calm conditions with no tide or current, ship speed through water (V) equals the speed over the ground, and the progress along the ship track is equal to the time integral $\int V \, dt$.

3   This distance may conveniently be expressed by the number of ship lengths sailed (i.e. by the non-dimensional time):

$$t^* = \int_0^t (V / L) dt$$

4   In general the ship's heading deviates from the direction of the speed vector by the sideslip or drift angle □. The advance and transfer parallel to and at right angles to the original line of course (and ideal line of approach) are given by the integrals:

$$X_0(t) = \int_0^t V \cos(\psi - \beta) dt$$

$$Y_0(t) = \int_0^t V \sin(\psi - \beta) dt$$

5   Mathematical models of ship dynamics involve expressions for the forces acting on the hull, usually separated in their components along the axes of a system $0(xyz)$ moving with the body. The full six-degrees-of-freedom motion of the ship may be defined by the three components of linear velocities (u, v, w) along the body axes, and by the three components of angular velocities (p, q, r) around these axes. Again, for the present discussion it is sufficient to consider the surface ship, moving with forward velocity a and sway velocity v in the $0(xy)$ plane, and turning with yaw velocity r around the z-axis normal to that plane. On these assumptions the speed $V = (u^2 + v^2)^{1/2}$, the drift angle is $\beta = - tan^{-1}(v/u)$, and the yaw rate is equal to the time rate of change of heading angle □, i.e. $r = \dfrac{d}{dt} \psi = \dot{\psi}$

6   The non-dimensional yaw rate in terms of change of heading (in radians) per ship length sailed is $r* = \dfrac{d}{dt*}\psi = \psi* = (L/V)\,\dot{\psi}$ which is also seen to be the non-dimensional measure of the instantaneous curvature of the path of this ship L/R.

7   Many ships will experience a substantial rolling velocity and roll angle during a turning manoeuvre, and it is understood that the mathematical model used to predict the manoeuvring characteristics should then include the more stringent expressions as appropriate.
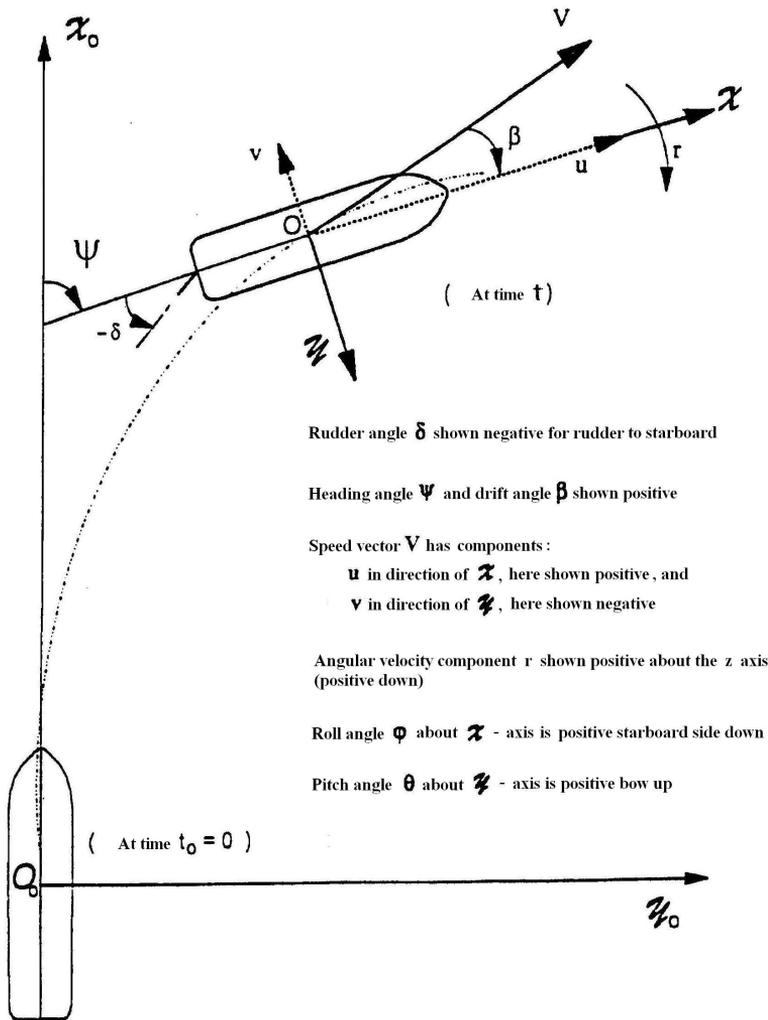
Rudder angle δ shown negative for rudder to starboard

Heading angle ψ and drift angle β shown positive

Speed vector V has components :
  u in direction of x, here shown positive, and
  v in direction of y, here shown negative

Angular velocity component r shown positive about the z axis (positive down)

Roll angle φ about x - axis is positive starboard side down

Pitch angle θ about y - axis is positive bow up

Figure A1-1
Surface ship with body axes O(xyz) manoeuvring within
space-fixed inertial frame with axes O_o ($x_o y_o z_o$)

APPENDIX 2

GENERAL VIEW OF PREDICTION OF MANOEUVRING PERFORMANCE

1   A mathematical model of the ship manoeuvring motion can be used as one of the effective methods to check whether a ship satisfies the manoeuvrability standards or not, by a performance prediction at the full load condition and from the results of the sea trial in a condition such as ballast.

2   Existing mathematical models of ship manoeuvring motion are classified into two types. One of the models is called a 'response model', which expresses a relationship between input as the control and output as its manoeuvring motion. The other model is called a "hydrodynamic force model", which is based on the hydrodynamic forces that include the mutual interferences. By changing the relevant force derivatives and interference coefficients composed of a hydrodynamic force model, the manoeuvring characteristics due to a change in the ship's form or loading condition can be estimated.

3   Furthermore, a hydrodynamic force model is more helpful for understanding the relationship between manoeuvring performance and ship form than a response model from the viewpoint of design. Certainly, the kind of mathematical model suitable for prediction of the performance depends on the kind of available data. There are many kinds of mathematical models.

4   In Figure A2-1, the flow chart of prediction method of ship manoeuvring performance using a hydrodynamic force model is shown. There are in general various expressions of a hydrodynamic force model in current practice, though their fundamental ideas based on hydrodynamic considerations have little difference. Concerning the hydrodynamic force acting on a ship in manoeuvring motion, they are usually expressed as a polynomial term of motion variables such as the surge, sway and angular yaw velocities.

5   The most important and difficult work in performance prediction is to estimate such derivatives and parameters of these expressions to compose an equation of a ship manoeuvring motion. These hydrodynamic force coefficients and derivatives may usually be estimated by the method shown in Figure A2-1.

6   A/m coefficients and derivatives can be estimated by the model test directly, by data based on the data accumulated in the past, by theoretical calculation and semi-empirical formulae based on any of these methods. There is also an example that uses approximate formulae for estimation derived from a combination of theoretical calculation and empirical formulae based on the accumulated data. The derivatives which are coefficients of hydrodynamic forces acting on a ship's hull, propeller and rudder are estimated from such parameters as ship length, breadth, mean draught, trim and the block coefficient. Change of derivatives due to a change in the load condition may be easily estimated from the changes in draught and trim.

7   As mentioned above, accuracy of manoeuvring performance predicted by a hydrodynamic force model depends on accuracy of estimated results by hydrodynamic forces which constitutes the equation of a ship manoeuvring motion. Estimating the hydrodynamic derivatives and coefficients will be important to raise accuracy as a whole while keeping consistency of relative accuracy among various hydrodynamic forces.

8   A stage in which theoretical calculations can provide all of the necessary hydrodynamic forces with sufficient accuracy has not yet been reached. Particularly, non-linear hydrodynamic forces and mutual interferences are difficult to estimate with sufficient accuracy by pure theoretical calculations. Thus, empirical formulae and databases are often used, or incorporated into theoretical calculations.
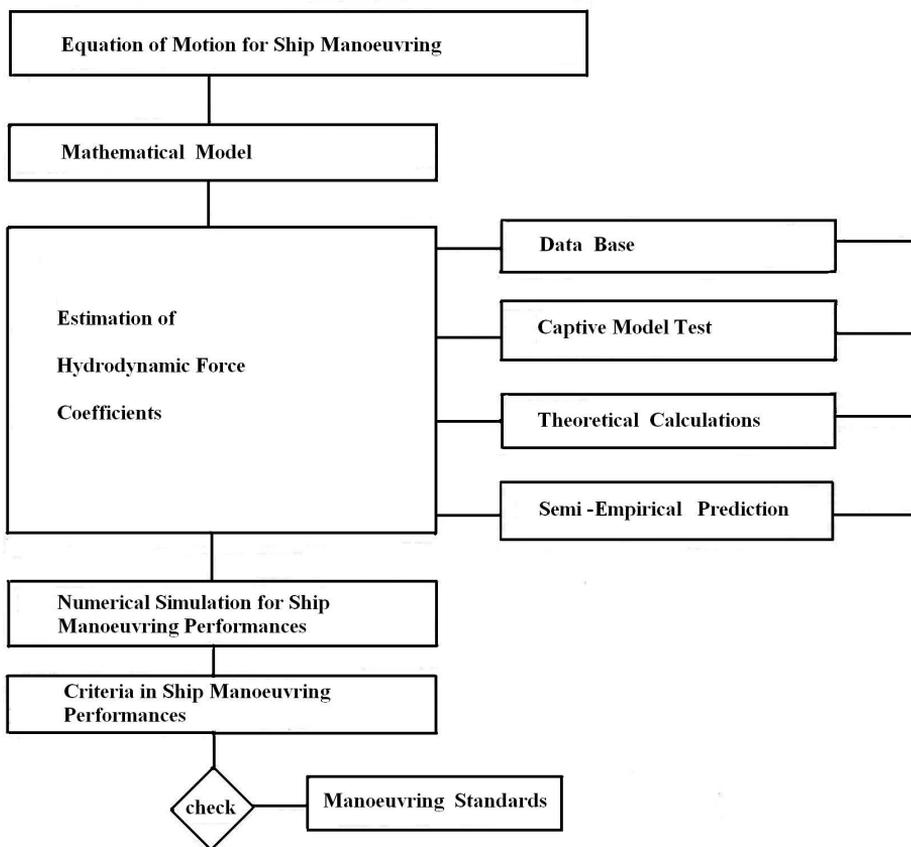

Figure A2-1

Flow chart for prediction of ship manoeuvring performance

APPENDIX 3

STOPPING ABILITY OF VERY LARGE SHIPS

1   It is stated in the Standards for ship manoeuvrability that the track reach in the full astern stopping test may be modified from 15 ship lengths, at the discretion of PRS, where ship size and form make the criterion impracticable. The following example and information given in tables A3-1, 2 and 3 indicate that the discretion of PRS is only likely to be required in the case of large tankers.

2   The behaviour of a ship during a stopping manoeuvre is extremely complicated. However, a fairly simple mathematical model can be used to demonstrate the important aspects which affect the stopping ability of a ship. For any ship the longest stopping distance can be assumed to result when the ship travels in a straight line along the original course, after the astern order is given. In reality the ship will either veer off to port or starboard and travel along a curved track, resulting in a shorter track reach, due to increased hull drag.

3   To calculate the stopping distance on a straight path, the following assumptions should be made:
  .1   the resistance of the hull is proportional to the square of the ship speed.
  .2   the astern thrust is constant throughout the stopping manoeuvre and equal to the astern thrust generated by the propeller when the ship eventually stops dead in the water; and
  .3   the propeller is reversed (the direction of its rotations or pitch) as rapidly as possible after the astern order is given.

4   An expression for the stopping distance along a straight track, in ship lengths, can be written in the form:

$$S = A \log_e(1 + B) + C$$

where:
S –   the stopping distance, in ship lengths.
A –   a coefficient dependent upon the mass of the ship divided by its resistance coefficient.
R –   a coefficient dependent on the ratio of the ship resistance immediately before the stopping manoeuvre, to the astern thrust when the ship is dead in the water.
C –   a coefficient dependent upon the product of the time taken to achieve the astern thrust and the initial speed of the ship.

5   The value of the coefficient *A* is entirely due to the type of ship and the shape of its hull. Typical values of *A* are shown in table A3-1.

Table A3-1

Ship type	Coefficient A
Cargo ship	5-8
Passenger/car ferry	8-9
Gas carrier	10-11
Product tanker	12-13
VLCC	14-16

6   The value of the coefficient B is controlled by the amount of astern power which is available from the power plant. With diesel machinery, the astern power available is usually about 85% of the ahead power, whereas with steam turbine machinery this figure could be as low as 40%.

7   Accordingly, the value of the coefficient B is smaller if a large amount of astern power and hence astern thrust, is available. Typical values of the coefficient B are given in table A3-2.

Table A3-2

Type of machinery	Percentage power astern	Coefficient B	$\text{Log}_e\,(1+B)$
Diesel	85%	0,6 – 1,0	0,5 – 0,7
Steam turbine	40%	1,0 – 1,5	0,7 – 0,9

8   The value of the coefficient C is half the distance travelled, in ship lengths, by the ship, whilst the engine is reversed and full astern thrust is developed. The value of C will be larger for smaller ships and typical values are given in table A3-3.

Table A3-3

Ship length [m]	Time to achieve astern thrust [s]	Ship speed [knots]	Coefficient C
100	60	15	2,3
200	60	15	1,1
300	60	15	0,8

9   If the time taken to achieve the astern thrust is longer then 60 seconds, as assumed in table A3-3, or if the ship speed is greater than 15 knots, then the values of the coefficient C will increase pro rata.

10   Although all the values given for the coefficients A, B and C may only be considered as typical values for illustrative purposes, they indicate that large ships may have difficulty satisfying the adopted stopping ability criterion of 15 ship lengths.

11 Considering a steam turbine propelled VLCC of 300 metres length, travelling at 15 knots, and assuming that it takes 1 minute to develop full-astern thrust in a stopping manoeuvre, the results using tables A3-1, 2 and 3 are:

$A = 16$,

$B = 1.5$, and

$C = 0.8$

12 Using the formula for the stopping distance S, given above, then: $S = 16 \log_e(1 + 1.5) + 0.8 = 15.5$ ship lengths, which exceeds the stopping ability criterion of 15 ship lengths.

13 In all cases the value of A is inherent in the shape of the hull and so cannot be changed unless resistance is significantly increased. The value of B can only be reduced by incorporating more astern power in the engine, an option which is unrealistic for a steam turbine powered ship. The value of C would become larger if more than one minute was taken to reverse the engines, from the astern order to the time when the full-astern thrust is developed.

APPENDIX 4

ADDITIONAL MANOEUVRES

1   Additional methods to assess course keeping ability

1.1   The Standards note that additional testing may be used to further investigate a dynamic stability problem identified by the standard trial manoeuvres. This appendix briefly discusses additional trials that may be used to evaluate a ship's manoeuvring characteristics.

1.2   The Standards are used to evaluate course-keeping ability based on the overshoot angles resulting from the 10°/10° zig-zag manoeuvre. The zig-zag manoeuvre was chosen for reasons of simplicity and expediency in conducting trials. However, where more detailed analysis of dynamic stability is required some form of spiral manoeuvre should be conducted as an additional measure. A direct or reverse spiral manoeuvre may be conducted. The spiral and pullout manoeuvres have historically been recommended by various trial codes as measures that provide the comprehensive information necessary for reliably evaluating course-keeping ability. The direct spiral manoeuvre is generally time consuming and weather sensitive. The simplified spiral can be used to quickly evaluate key points of the spiral loop curve.

2   Spiral manoeuvres

2.1   Direct spiral manoeuvre

2.1.1   The direct spiral manoeuvre is an orderly sequence of turning circle tests to obtain a steady turning rate versus rudder angle relation (see Figure A4-2).

2.1.2   Should there be reasons to expect the ship to be dynamically unstable, or only marginally stable, a direct spiral test will give additional information. This is a time-consuming test to perform especially for large and slow ships. A significant amount of time is needed for the ship to obtain a steady rate of change of heading after each rudder angle change. Also, the test is very sensitive to weather conditions.

2.1.3   In the case where dynamic instability is detected with other trials or is expected, a direct spiral test can provide more detailed information about the degree of instability that exists. While this test can be time consuming and sensitive to weather conditions, it yields information about the yaw rate/rudder angle relation that cannot be measured by any other test.

2.1.4   The direct spiral is a turning circle manoeuvre in which various steady state yaw rate/rudder angle values are measured by making incremental rudder changes throughout a circling manoeuvre. Adequate time must be allowed for the ship to reach a steady yaw rate so that false indications of instability are avoided.

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2.1.5   In cases where the ship is dynamically unstable it will appear that it is still turning steadily in the original direction although the rudder is now slightly deflected to the opposite side. At a certain stage the yaw rate will abruptly change to the other side and the yaw rate versus rudder angle relation will now be defined by a separate curve. Upon completion of the test the results will display the characteristic spiral loop as presented in Figure A4-3.

2.1.6   A direct spiral manoeuvre can be conducted using the following general procedure:
- **.1**   the ship is brought to a steady course and speed according to the specific initial condition;
- **.2**   the recording of data starts;
- **.3**   the rudder is turned about 15 degrees and held until the yaw rate remains constant for approximately one minute;
- **.4**   the rudder angle is then decreased in approximately 5 degree increments. At each increment the rudder is held fixed until a steady yaw rate is obtained, measured and then decreased again;
- **.5**   this is repeated for different rudder angles starting from large angles to both port and starboard; and
- **.6**   when a sufficient number of points is defined, data recording stops.

2.2   Reverse spiral manoeuvre

2.2.1   The reverse spiral test may provide a more rapid procedure than the direct spiral test to define the instability loop as well as the unstable branch of the yaw rate versus rudder angle relationship indicated by the dotted curve as shown in Figure A4-2. In the reverse spiral test the ship is steered to obtain a constant yaw rate, the mean rudder angle required to produce this yaw rate is measured. and the yaw rate versus rudder angle plot is created. Points on the curve of yaw rate versus rudder angle may be taken in any order.

2.2.2   This trial requires a properly calibrated rate of turn indicator and an accurate rudder angle indicator. Accuracy can be improved if continuous recording of rate of turn and rudder angle is available for the analysis. Alternatively the test may be performed using a conventional autopilot. If instantaneous rate of turn should be visually displayed to the helmsman.

2.3   Simplified spiral manoeuvre

2.3.1   The simplified spiral reduces the complexity of the spiral manoeuvre. The simplified spiral consists of three points which can be easily measured at the end of the turning circle test. The first point is a measurement of the steady state yaw rate at the maximum rudder angle. To measure the second point, the rudder is returned to the neutral position and the steady state yaw rate is measured. If the ship returns to zero yaw rate the ship is stable and the manoeuvre may be terminated.

Alternatively, the third point is reached by placing the rudder in the direction opposite to the original rudder angle to an angle equal to half the allowable loop width. The allowable loop width may be defined as:

0 degrees   for $L/V \leq 9$ seconds
-3 + 1/3 (L/V) degrees   for $9 < L/V \leq 45$ seconds
12 degrees   for $45 < L/V$ seconds

2.3.2 When the rudder is placed at half the allowable loop width and the ship continues to turn in the direction opposite to that of the rudder angle, then the ship is unstable beyond the acceptable limit.

3   Pull-out manoeuvre

After the completion of the turning circle test, the rudder is returned to the midship position and kept there until a steady turning rate is obtained. This test gives a simple indication of a ship's dynamic stability on a straight course. If the ship is stable, the rate of turn will decay to zero for turns to both port and starboard. If the ship is unstable, then the rate of turn will reduce to some residual rate of turn (see Figure A4-1). The residual rates of turn to port and starboard indicate the magnitude of instability at the neutral rudder angle. Normally, pull-out manoeuvres are performed in connection with the turning circle, zig-zag, or initial turning tests, but they may be carried out separately.
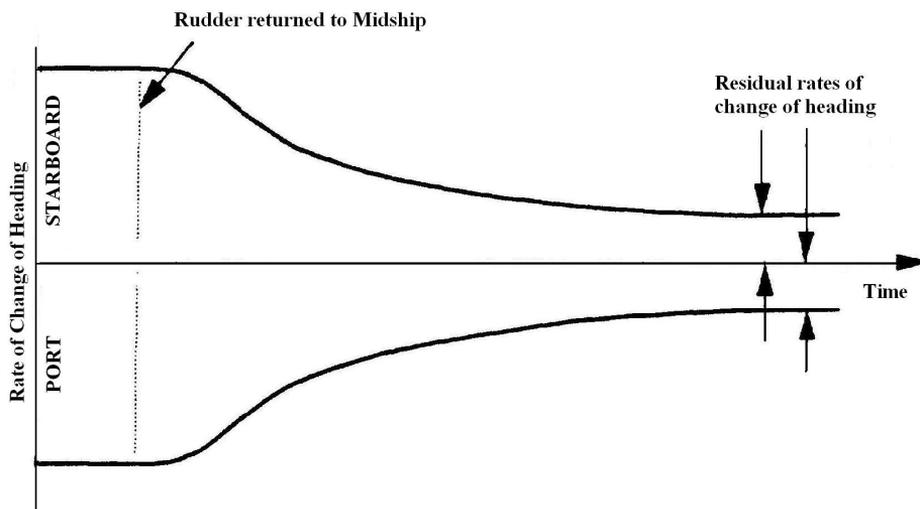
UNSTABLE SHIP

Figure A4-1
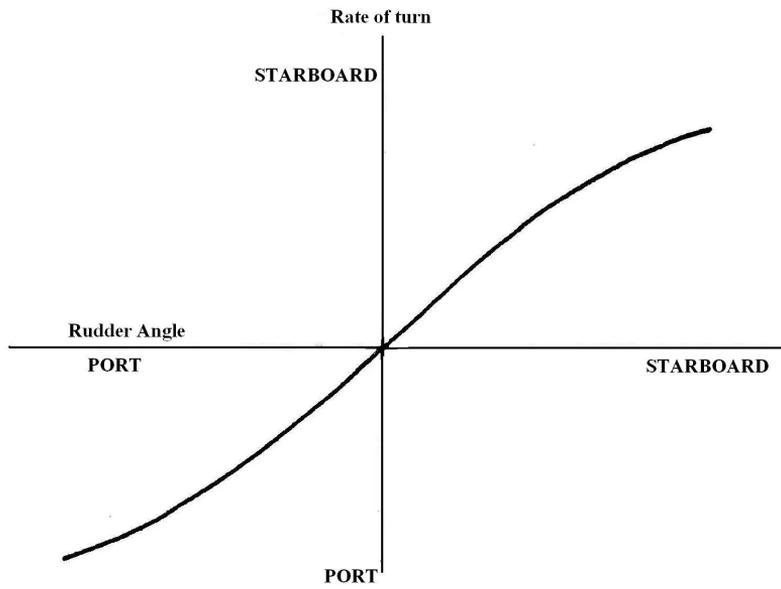
Presentation of pull-out test results

Figure A4-2

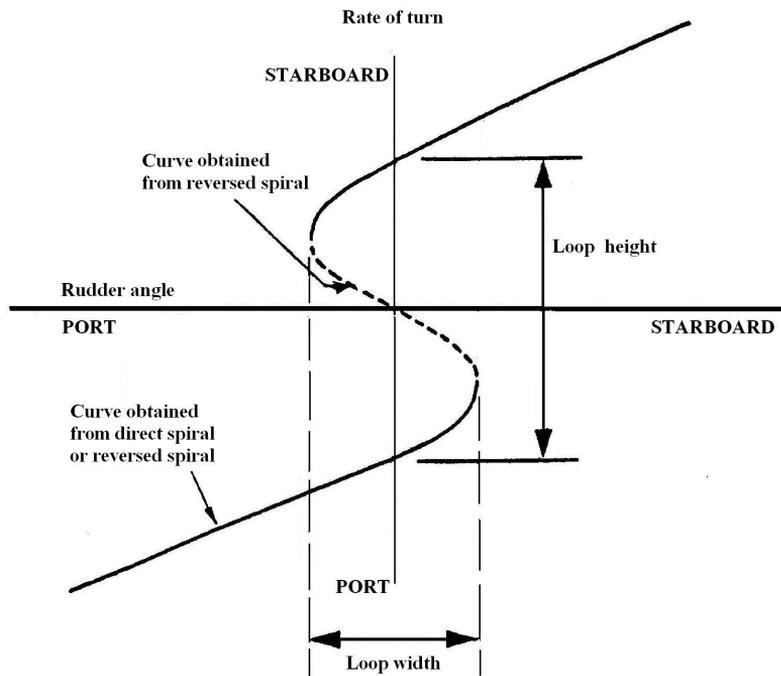Presentation of spiral test results for stable ship

Figure A4-3

Presentation of spiral test results for unstable ship

4 Very small zig-zag manoeuvre

4.1 The shortcomings of the spiral and 10°/10° zig-zag manoeuvres may be overcome by a variation of the zig-zag manoeuvre that quite closely approximates the behaviour of a ship being steered to maintain a straight course. This zig-zag is referred to as a Very Small Zig Zag (VSZZ), which can be expressed using the usual nomenclature, as 0°/5° zig-zag, where ψ is 0 degrees and δ is 5 degrees.

4.2 VSZZs characterized by 0°/5° are believed to be the most useful type, for the following two reasons:
.1 a human helmsman can conduct VSZZs by evaluating the instant at which to move the wheel while sighting over the bow, which he can do more accurately than by watching a conventional compass.
.2 a conventional autopilot could be used to conduct VSZZs by setting a large proportional gain and the differential gain to zero.

4.3 There is a small but essential difference between 0°/5° VSZZs and more conventional similar zig-zags, such as 1°/5° zig-zag. The 0°/5° zig-zag must be initialized with a non-zero rate-of-turn. In reality, this happens naturally in the case of inherently unstable ships.

4.4 A VSZZ consists of a larger number of cycles than a conventional zig-zag, perhaps 20 overshoots or so, rather than the conventional two or three, and interest focuses on the value of the overshoot in long term. The minimum criterion for course-keeping is expressed in terms of the limit-cycle overshoot angle for 0°/5° VSZZs and is a function of length to speed ratio.

APPENDIX 5
Exemplary form for reporting manoeuvring data to IMO

FORM FOR REPORTING MANOEUVRING DATA TO IMO

Administration: _____   Reference No.[1] [   ]

SHIP DATA: (FULL LOAD CONDITION)

Ship type[2]	[ ]	L/V	[sec]
L/B [ ]	B/T [ ]	C$_B$	[ ]
Rudder type[3]	[ ]		
Total rudder area/LT	[ ]	Number of rudders	[ ]
Propeller type[4]	[ ]	Trim	[ ]
No. of propellers	[ ]		
Engine type[5]	[ ]	Ballast condition	[ ]

TRIALS DATA: (ENVIRONMENTAL CONDITION)

Water depth/trial draught   [   ]
Wind: Beaufort number   [   ]
Wave: Sea state   [   ]

MANOEUVRING DATA:

Loading condition: Tested at Full load [   ]   Tested at partial load and corrected [   ]

	TEST RESULTS			IMO CRITERIA
Turning circle:	PORT	STBD		
Advance	[ ]	[ ]	Ship lengths	4.5
Tactical diameter	[ ]	[ ]	Ship lengths	5
Zig-Zag:				
10 deg/10 deg[6]	PORT	STBD		
1st overshoot angle	[ ]	[ ]	deg	[ ]
2nd overshoot angle	[ ]	[ ]	deg	[ ]
20 deg/20 deg	PORT	STBD		
1st overshoot angle	[ ]	[ ]	deg	25
Initial turning:	PORT	STBD		
Distance to turn 10 deg with 10 deg rudder	[ ]	[ ]	Ship lengths	2.5
Stopping distance:				
Track reach	[ ]	[ ]	Ship lengths	15 to 20

REMARKS:

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* See notes on the reverse of the page.

Notes:

1   Reference no. assigned by PRS for internal use.
2   Ship type such as container ship, tanker, gas carrier, ro-ro ship, passenger ship, car carrier, bulk carrier, etc.
3   Rudder type such as full spade, semi-spade, high lift, etc.
4   Propeller type such as fixed pitch, controllable pitch, with/without nozzle, etc.
5   Engine type such as diesel, steam turbine, gas turbine, diesel-electric, etc.
6   IMO criteria for 10°/10° zig-zag test vary with L/V. Refer to sub-chapter 2.7 of *Rules for the Classification and Construction of Sea-going Ships, Part III – Hull Equipment*.

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