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Free Sailing Model Test Procedure

PURPOSE OF PROCEDURE

Free-sailing model test techniques are applied to predict manoeuvring characteristics of a full-scale ship in a direct way. The results can also be used to develop a computer simulation model for further studies.

Standard procedures for these types of tests are presented, together with recommended quantitative guidelines in order to ensure the quality of test results and to obtain reliable results. The procedure is to be used for surface ships only, where Froude scaling is applied.

These guidelines are mainly based on the results of a questionnaire distributed among ITTC member organisations in 2000 and 2001 (23rd ITTC Manoeuvring Committee Report, 2002).

1. DESCRIPTION OF PROCEDURE

2.1 Preparation

2.1.1 <u>Ship model characteristics</u>

2.1.1.1 Scale

Principally, the scale should be chosen as large as possible, keeping in mind that scale effects in manoeuvring are not yet fully understood, and the larger the model the smaller the scale effect. Minimum model dimensions may be based on considerations about rudder and propeller mounting, and on a minimum Reynolds number for appendages and propeller

Also the size of the actual test basin in relation to the required area for the tests to be carried out as well as the capability of other test equipment are governing factors.

Generally stock propellers are used and the scale is chosen with respect to a suitable propeller design. First the diameter should be scaled correctly and then the propeller pitch and blade area ratio should be as close to the real propeller as possible (P+D as near as possible to full Scale). Number of blades comes as third priority.

2.1.1.2 Ship model

The ship model must have sufficient material strength and geometric accuracy. Geometry of ship model, including rudder and propeller, is to be checked by inspection of its manufacturing accuracy, and by inspecting it for any obvious damage. All appendages should be made according to their originally designed shape.

The turbulence stimulation device used, if any (wire, sand strips, or studs) should be described.

The loading condition of the model (draft fore/aft and GM) should be checked before experiments and verified before and after the tests.

Since manoeuvring tests require similarity in the dynamic behaviour between the model and the full scale ship, the moments of inertia of the model should be scaled from full scale.

2.1.1.3 Tank dimensions and water depth

The tank should be wide enough to avoid tank wall interference against the model in the free-sailing model test.

For the deep water case, the depth to draft ratio should be large enough to be free from shallow water effects; referring to IMO, a minimum value h/T=4 is generally accepted. The test speed should be below 0.75 $(gh)^{½}$.

For shallow water tests the depth should be scaled correctly; this may impose a restriction on the maximum draft. At very small h/T, the waviness of the basin bottom should be less than 10% of the under keel clearance, which may determine the minimum draft. The smoothness and stiffness of the bottom should be sufficient to not affecting the results significantly.

2.1.1.4 Scale effects

In manoeuvring tests with free-sailing models, the propeller(s) is used to give the model the desired speed, i.e. to produce the thrust to keep the desired speed, and also to produce the propeller induced flow over the rudder(s). Froude scaling of speed is generally applied and a tripping device (wire, sand strips, or studs) should be fitted, as it probably will give a more realistic boundary layer development and pressure distribution along the hull. Scale effects may generally be neglected, at least for conventional merchant (displacement) vessels with a propeller working in the wake of the hull and the rudder positioned in the propeller slipstream. Fortunately two phenomena - the larger model wake fraction and the larger model resistance - tend to even out in the rudder force.

As a result of these scale effects, rudder effectiveness of a model may generally be overestimated compared with that of a real ship. Accordingly, free running models tend to be more stable (or less unstable) with respect to course-keeping ability. This effect is typically less significant for fine ships because of their inherent stable course keeping ability.

Sometimes, especially for high-speed ships with low wake fraction, it might be necessary to compensate the larger frictional resistance of the model with an additional propulsion device, generally a wind fan,.

Since the rudder(s) are normally positioned in the wake field behind the ship and in the propeller race, i.e. in a very disturbed and turbulent flow, the Reynolds number effect for the rudder force may be neglected. Nevertheless sand strips or studs are sometimes applied to the rudder.

2.1.2 <u>Model inspection.</u>

The model should be inspected, prior to launching and testing, for:

- principal dimensions
- hull configuration
- model mass
- centre of gravity position
- moments of inertia

2.1.3 Model equipment and set-up.

The model should be free to move in all 6 DoF and equipped with adequate propulsion and steering arrangement. The direction of rotation of the propeller should be correct. Generally the propeller is run at a constant rpm throughout the complete test. However, the real engine characteristics may be simulated by controlling rpm with a computer, e.g. torque limitation.

Free-sailing models can either be designed to run autonomously with wireless remote control or be positioned under a carriage, which follows the model during the manoeuvre. Thus motor power, control and measuring signals can easily be transferred between model and carriage. In this case, the power, data, and control cables should be arranged so that they do not affect the manoeuvre of the vessel.

2.1.3.1 Wireless controlled models

The testing system onboard a wireless controlled free-sailing model may generally consist of the following devices.

(1) Driving and manoeuvring control units (propulsion and rudder operation)

(2) Computer which controls driving units and records measured results (when required)

(3) Sensors for yaw angle and yaw rate (and for roll angle if necessary)

(4) Telemeter with which control signals are transmitted from the shore

(5) Batteries for power supply

In addition the position of the model has to be measured by an appropriate system. In open-air facilities, DGPS or KDGPS can be used. In enclosed facilities, optical or acoustic tracking systems are used.

2.3.1.2 Wire controlled models

The testing system on board a wire controlled free-sailing model may generally consist of the following devices:

Driving and manoeuvring control units (propulsion and rudder operation)

(1) Sensors for yaw angle and yaw rate (and for roll angle if necessary)

In this case the data acquisition and driving unit controllers are installed on the carriage. The position of the model can then be measured through optical or mechanical means from the carriage; the absolute position of the model is then obtained by including the carriage position.

The capacity of load cells and other measuring equipment should be chosen to be appropriate to the loads expected. Calibration of sensors and driving units should be carried out immediately before and immediately after testing.

2.2 Execution of Procedure

General Considerations.

Distinction can be made between three phases of a free-sailing manoeuvring test. The first is to establish the initial conditions for the actual test, the second is the test itself and the last the capture of the model when the test is finished.

The waiting time between tests should be sufficient to ensure that the next test is not disturbed by waves or remaining vortices in the water.

The water temperature should be measured at some selected points at depth of *T*/2.

2.2.1.1 Initial test condition

Most manoeuvring tests start from a straight course condition with as steady as possible values of heading, speed, rpm and rudder angle or corresponding (POD angle, water-jet steering nozzle angle, etc.). Straight-line speed runs should be carried out in order to find the propeller rpm corresponding to the desired test speed.

Different methods are used to accelerate the model to the test speed:

- by model's own propulsion system, maybe most common but requires relatively long distance.
- by catapult system
- by a carriage which follows the model after release.

Of course the water in the basin should be reasonably calm in order to avoid disturbance of the test. For the same reason the wind at outdoor testing should be negligible.

2.2.1.2 Execution of Tests

The test is initiated by the order to the steering system to execute the actual test. The most common tests are those referred to in IMO Resolution A.751(18).

- turning (circle) test, generally started with a hard over rudder angle (generally 35° starboard and port) and finished by a pull-out by putting the rudder back to neutral angle after completing the turning test i.e. steady yaw rate.
- zig-zag test (10/10°, 20/20°, or modified), the first 2 overshoots should be accomplished when possible. These tests are conducted to port and starboard.
- full astern stopping test is seldom carried out due to the scale effect (viscous resistance part) having a significant impact on the result.
- spiral test, recommended by IMO in case of suspected course instability (could be determined from the residuary yaw rate at a pull-out test). The test should start with large rudder angle (abt 25°) until steady state yaw rate is achieved. The rudder angle is then decreased stepwise to the opposite value (abt -25°). The steps are chosen abt 5° from +/-25° to +/-5° and abt 1° from +/-5° to 0° after the yaw rate achieves a constant value.
- reverse spiral test is performed to acquire the complete hysteresis loop when the ship is found unstable. An autopilot is used to steer at a constant yaw rate stepwise similar to the above direct spiral test. In order to assure that the complete spiral curve is obtained, the rudder angle step around the neutral or zero rudder angle should be small enough, i.e. less than or equal to 1°.

Other common tests are

- pull-out test from the turning test by going back to the steady course rudder angle after the complete turning test
- accelerating turning test starting from zero or a low speed and using excessive propulsive power

For appropriate purposes free-sailing model tests can be performed to assess the performance of the ship in different conditions:
bow thruster tests
crabbing tests
manoeuvring in restricted waters
manoeuvring in wind and/or waves

2.2.1.3 Capture of model

After the test run is finished the model should be captured before preparing for the next test run. This is a more practical problem and can be solved in different ways and will not be treated here.

2.3 Data acquisition and analysis

2.3.1 Measured data

Performing free-sailing manoeuvring tests requires direct or indirect measurement of following data:

- time
- model position
- heading
- model speed, (axial and lateral or along track)
- yaw rate

and in some cases:

- roll angle
- sinkage and trim

The measurement of parameters characterising the control of ship model steering and propulsion equipment is convenient:
- rudder angle
- rpm of propulsor(s)
- other steering/manoeuvring devices' action.

Following data may be important as well:
- thrust/torque on propulsor(s)
- forces and moments on steering devices (rudder(s), pods…)

2.3.2 Data acquisition.

Data sampling rate and filter details should be determined on the basis of the response of the model, together with considerations of the primary noise frequencies. Sampling rates may vary between 4 and 250 Hz, 20 Hz being a mean value.

2.3.3 Visual inspection.

The measured real time data should be recorded. After each run the data should be inspected in the time domain to check for obvious errors such as transients caused by recording too soon after starting, additional unknown sources of noise, overloading or failure of one or more sensors. The records of the driving units should be checked to verify that the correct orders were applied.

2.3.4 Analysis methods.

Detailed analysis is to be carried out with the use of stored data after the tests are finished, noting that data in transient regions of starting and stopping should not be used in the analysis. For the following standard maneuvers the analysis is as follows:

1) Turning test

ices such as the advance, transfer, tactical diameter, which represent turning characteristics of a ship, should be analyzed on the basis of the turning trajectory measured. Change in advance speed may be analyzed also on the basis of the turning trajectory.

igzag test

Overshoot angles (usually for the 1st and 2nd oscillations), which represent course keeping ability and yaw checking ability of a ship, should be analyzed with the use of the time series of yaw angle change in the zigzag test. In addition, the *K-T* analysis may be made according to the testing purpose.

3) Spiral and reverse spiral test

Steady turning performance should be obtained on the basis of results of the spiral test, including the hysteresis loop characteristics if exists.

4) Stopping test

The stopping distance can be obtained from the trajectory of the test.

2.4 Documentation

At least the following information should be documented and included in the test report.

2.4.1 <u>Experimental technique</u>

2.5.1.1 Model.

- dimensions of hull, rudder, propeller, etc.
- mass
- centre of gravity
- moments of inertia
- turbulence stimulation method
- details of appendages
- body plan and contours
- principal characteristics
- engine type of the full scale ship
- motor type of model

2.5.1.2 Basin

- dimensions
- water depth
- smoothness and stiffness of the bottom (for shallow water tests)
- depth to draft ratio
- water temperature

2.5.1.3 Model set-up

- powering
- transfer of control signals
- transfer of measuring signals

2.5.1.4 Measurement.

- measuring equipment
- capacity of load cells
- filter characteristics

2.5.1.5 Test parameters

- test type
- model speed
- rudder angle or equivalent
- propeller rpm

2.5.1.6 Recording

- equipment
- sample time
- digitising rate

2.5.1.7 Calibration

- details of all calibrations conducted,
- information on linearity and repeatability of all sensors.

2.5.1.8 Analysis procedure

- method of analysis
- filtering technique

2. PARAMETERS

3.1 Parameters to be taken into account

3.1.1 General.

The following parameters should be taken into account for all free-sailing manoeuvring model tests:

- scale
- model dimensions
- ratios of model to basin dimensions
- water depth
- hull configuration
- propulsion and steering arrangements
- loading condition of ship model
- model mass
- position of centre of gravity of ship model
- moments of inertia of ship model

3.1.2 Ship control parameters

Propeller rates of revolution. Most tests should can be carried out either at the model self-propulsion point or at the full scale self-propulsion point. The latter method requires a towing force to be applied which corresponds to the difference in viscous drag. However, this correction will depend on the model scale and the ship type and it is not generally done (§ 2.1.1.4).

Steering devices. The maximum angle should be determined according to the purpose of the tests, and in most cases coincides with 'hard over', although a lower deflection could be sufficient for some purposes.

Thrusters (lateral and azimuthing thrusters). The thrust developed by the installed thruster unit at zero speed is regulated to match a design ship side force value. The corresponding rpm is then used in the tests. When required, the thrust of the unit is measured and used to determine the reference rpm value.

3.1.3 Turning circle tests

The following parameters should especially be taken into account:

- initial forward speed(s) u
- initial propeller rate(s) n
- ordered steering device angles δ

3.1.4 Zig-zag or modified zig-zag tests

Following parameters should especially be taken into account:

- initial forward speed(s) u
- initial propeller rate(s) of rotation n

- ordered steering device angles δ and heading angle ψ (δ/ψ i.e. 10/10 or 20/20)
- turning speed of steering device

3.1.5 Spiral and reverse spiral tests

Following parameters should especially be taken into account:

- initial forward speed(s) u
- initial propeller rate(s)of rotation n
- steering device angles δ or corresponding
- yaw rate r

3. VALIDATION

4.1 Causes of uncertainty

During free-sailing manoeuvring tests, a ship model is free to move in all 6 degrees of freedom. The manoeuvre is actuated by one or more steering devices, propulsors and thrusters.

The accuracy of test results is influenced by the following imperfections of the experimental technique:

- inaccuracy of ship model characteristics
- undesired facility related hydrodynamic effects
- unsteady approach conditions
- errors on ship model control equipment parameters (e.g. propeller rate, rudder angle)
- disturbance from test arrangement on model (e.g. power and signal cables)
- measurement inaccuracy

4.1.1 Inaccuracy of ship model characteristics.

The influence of some factors (e.g. errors on main dimensions, offsets, loading condition, moments of inertia) on the accuracy of test results is hard to estimate.

4.1.2 Undesired facility related hydrodynamic effects.

A ship model's dynamics and, therefore, test results may be affected by several influences caused by the limitations of the experimental facility, so that tests are not performed in unrestricted still water. Some examples:

1 Residual motion of the water in the basin may affect the model's dynamics if the waiting time between two runs is too short.

2 Non-stationary phenomena occurring during transition between acceleration and the real test may also affect the model's dynamics. In particular, the achievement of steady state running condition prior to the start of the manoeuvre can have large consequences on the results of free-sailing manoeuvring tests.

3 Basin width and length limitations induce undesired additional forces and modify the trajectory.

4 In shallow water tests, bottom profile variations affect the model's dynamics.

The influence of these effects on the accuracy of test results generally increases with decreasing water depth. Although complete prevention is principally impossible, the effects can be reduced by an adequate selection of test parameters.

4.1.3 Errors on ship control equipment parameters.

During a test run, a number of control equipment parameters (propeller rpm, steering device angle, ...) are controlled; setting or control errors have a direct influence on the motions of the model.

4.1.4 Measurement accuracy

The position and heading of the model are the most important information obtained from the free-sailing model test, hence the accuracy of these measurements should be documented.

4.2 Benchmark Tests

1) Preliminary Analysis of ITTC Co-operative Tests Programme (11th 1966 pp.486-508)
A Mariner Class Vessel

2) The Co-operative Free-Model Manoeuvring Program (13th 1972 pp.1000)

3) Co-operative Test Program - Second Analysis of Results of Free Model Manoeuvring Tests (13th 1972 pp.1074-1079)
A MARINER Type Ship

4) Ship Model Correlation in Manoeuvrability (17th 1984 pp.427-435)
To Conduct Model Tests and Compare Their Results with "ESSO OSAKA' Deep and Shallow Water Trials Joint International Manoeuvring Program (JIMP).
A Working Group Called JAMP (Japan Manoeuvrability Prediction)

5) Free-Running Model Tests with ESSO OSAKA
(18th 1987 pp.369-371)

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International Towing Tank Conference, 1996, "Manoeuvring Committee - Final Report and Recommendations to the 21st ITTC", Proceedings of 21st ITTC, Bergen / Trondheim, Norway, Vol. 1, pp. 347-398.

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