ITTC Quality System Manual

Recommended Procedures and Guidelines

Procedure

Free Running Model Tests

7.5	Process Control
7.5-02	Testing and Extrapolation Methods
7.5-02-06	Manoeuvrability
7.5-02-06-01	Free Running Model Tests

Disclaimer

Prepared by	Approved
Seakeeping Committee of the 29th ITTC	29th ITTC 2021
Date 10/2020	Date 06/2021

Table of Contents

Free Running Model Tests

1. PURPOSE OF PROCEDURE

Free running 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 and reliability of test results. The procedure is to be used for surface ships only, where Froude scaling law 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).

2. DESCRIPTION OF PROCEDURE

2.1 Preparation

2.1.1 Ship model characteristics

The following considerations should be made for selecting the scale and, therefore, the model dimensions.

Scale

Principally, the scale should be chosen as large as possible, meaning the model size should be 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.

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 the 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. According to an old rule of thumb the sum of the diameter and pitch (P+D) should be as close to full scale as possible if the correct diameter is not available. The number of blades should be considered as third priority.

Ship model

The ship model must have sufficient material strength and geometric accuracy. The geometry of the 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 modelled 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 $\overline{GM}$) should be checked before experiments and verified before and after the tests. The $\overline{GM}$ should be within 5% accuracy and the roll period (if known) as near as possible to the desired corresponding full scale values. When contradictory, a correct $\overline{GM}$ should prevail. I_{xx} is usually tuned through roll decay tests at zero speed in which the roll period is adjusted, alternatively the roll radius of gyration k_{xx} can be tuned to $0.35B$. The yaw and pitch radii of gyration k_{zz}, respectively k_{yy} are usually tuned to a typical value around 0.25 L_{PP}.

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.

2.1.2 Tank dimensions and water depth

The size of the ship model should be selected such that the tank width is sufficient to prevent tank wall interference in the free running model test. On the other hand, for finite width cases the size of the ship model should be selected considering the size of the restricted water model.

Tests in deep water should be performed with a depth to draft ratio that is large enough to be free from shallow water effects. Referring to IMO (MSC/Cir 644), a minimum value of h/T = 4 is considered as acceptable. This figure, which accounts for practical issues of full scale trials, must be considered as a strict minimum for deep water model tests. The critical speed is defined as $(gh)^{1/2}$. In deep water the test speed should be below 50% of the critical speed.

For shallow water tests (h/T < 4) the depth should be scaled correctly; this may impose a restriction on the maximum draft. At very small h/T, the vertical variations of the tank bottom should be less than 10% of the under keel clearance, which may determine the minimum draft.

Some towing tanks use a false bottom to execute shallow water tests. In this case attention should be paid to a sufficient stiffness of the false bottom. Also water recirculation around the boundaries of the false bottom can jeopardize the measurements. For the latter Li et al. (2019) showed that the width of the false bottom should preferably be larger than the influence width, see Eq. 1, on each side of the ship model at that the steadiness of the measurements has to be checked in case the false bottom has a limited length.

Shallow water implies a finite water depth. Lateral restrictions are also possible, which are referred to as *restricted water* (e.g. banks, other ships, harbour layout). Restricted water mostly implies shallow water, but not always (e.g. ship lightering or replenishment at sea).

Based on a comprehensive set of model tests using 11 different ship models and 25 different lateral bank geometries, Lataire (2014) introduces an influence width of

$$y_{\text{infl}} = 5B(Fr_{\text{h}} + 1) \quad (1)$$

If the distance between ship and tank walls is larger than y_{infl}, ship-bank interaction effects can be neglected.

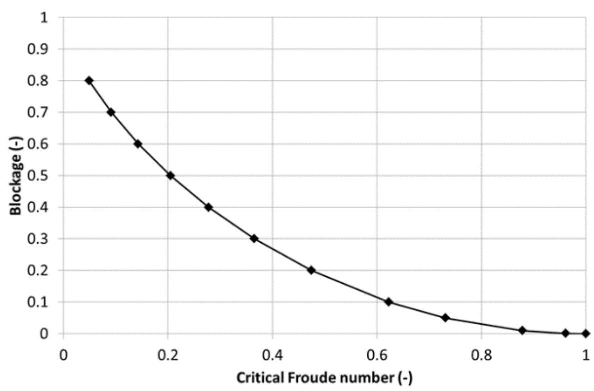

Figure 1: Effect of the blockage on the critical Froude number.

In *confined* (which is both shallow and restricted) *water* the blockage m (the ratio cross section of the ship to the cross section of the navigation area) has an influence on the critical speed. Based on Schijf (1949) the critical Froude number can be more generally written as (see Figure 1):

$$Fr_{\mathrm{h,crit}} = \left(2sin\left(\frac{arcsin(1-m)}{3}\right)\right)^{3/2} \leq 1 \qquad (2)$$

2.1.3 Scale effects

In manoeuvring tests with free running 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 a propeller induced flow over the rudder(s). Froude scaling of speed is generally applied and a tripping turbulence simulation 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.

Two scale effect phenomena occur: the larger model wake fraction and the larger model resistance. If the propeller is operated at the model self-propulsion point, the propeller loading condition may be excessive, hence the rudder effectiveness of a model may generally be larger 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. It is possible that the scale effects on the rudder can be neglected for some cases since the two scale effects may negate each other. This will be dependent on ship type and can be evaluated based on ship-model correlation data.

Sometimes it might be necessary to compensate the larger frictional resistance of the model with an additional propulsion device, e.g. a wind fan or air jet device. Guidelines for this still need to be established and there is no worldwide consensus.

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.

Besides the above mentioned scale effects, there are unknown scale effects. These affect the side force and turning moment that a hull develops while drifting and turning. There is no worldwide consensus on the magnitude or influence of these scale effects yet.

2.1.4 Model inspection

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

principal dimensions,
hull configuration,
model mass,
longitudinal and vertical centre of gravity positions,
moments of inertia about the three axes,
appendage alignment.

2.1.5 Model equipment and set-up

The model should be free to move in all 6 degrees of freedom and equipped with adequate propulsion and steering arrangement. The direction of rotation of the propeller should be according to the full scale ship. Generally, the propeller is run at a constant rpm throughout the complete test, except for the stopping test. However, the real engine characteristics may be simulated by controlling rpm with computing dynamic response of the engine including torque limit. In order to model the engine, an instantaneous measurement of the propeller torque is necessary. For a sufficient accurate measurement of torque, the propeller diameter should be larger than 10 cm. The instantaneous measured torque should be fed into the model control system, which may reduce the RPM of the vessel to achieve a constant torque, power or otherwise. The procedure of instantaneous modification of the propeller RPM is especially recommended for podded vessels and vessels equipped with multiple propellers.

Free running 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 the latter case, the power, data, and control cables should be arranged so that they do not affect the manoeuvre of the vessel.

The range of measuring equipment should be chosen to be appropriate to the expected values of the measurements. Calibration of sensors and driving units should be carried out immediately before and immediately after testing.

2.1.6 Wireless controlled models

The testing system onboard a wireless controlled free running 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, yaw rate, rudder angle and propeller rpm (and for roll angle if applicable)
4. Telemeter with which control signals are transmitted from the shore
5. Batteries and/or fuel for power supply

In addition, the position of the model has to be measured by an appropriate system. In open-air facilities, DGNSS or KGPS can be used. In enclosed facilities optical tracking systems are used. The important point of these measurements is the synchronizing between on board data and position data.

2.1.7 Wire controlled models

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

1. Driving and manoeuvring control units (propulsion and rudder operation)
2. Sensors for yaw angle, yaw rate, rudder angle and propeller rpm (and for roll angle if applicable)

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.

2.1.8 Restricted water model

For cases where finite water depth and/or finite width are to be modelled using an artificial bottom and/or wall(s) the depth and width should be scaled correctly and the smoothness, stiffness and water pressure tightness of the restricted water model should be sufficient to not affect the results.

2.2 Execution of Procedure

2.2.1 General considerations

Distinction can be made between three phases of a free running manoeuvring test. The first is to establish the initial conditions for the actual test, the second is the test itself and the last is 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 residual waves, current or remaining vortices in the water. It should be noted that the waiting time may be increased for restricted water cases. The wind at outdoor testing facilities should be negligible.

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

2.2.2 Initial test condition

The initial test condition is important. The limits of allowable deviation from the target initial test condition can be assessed following ITTC procedure 7.5-02-06-05 (Uncertainty analysis on free running model test).

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.

The initial value of the rudder angle may not be zero, but may be the value needed to sail straight ahead (neutral angle). During the straight-line speed runs, the initial neutral rudder angle is determined. This rudder angle is never exactly zero. For single screw vessels, this can be explained by the asymmetry of the propeller force. For a twin screw ship, this may be a consequence of the asymmetry in model build, fitting of appendages or a slight asymmetry in propeller forces.

The desired rudder angle for manoeuvres should be taken relative to amidships and not taken relative to the neutral angle.

2.2.3 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 MSC.137(76):

- The 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. after reaching a steady yaw rate.
- The zig-zag test (10°/10°, 20°/20°, or modified), ideally the first two overshoots should be accomplished when possible. These tests are conducted to port and starboard.
- The full astern stopping test is seldom carried out due to the scale effect (viscous resistance

part) having a significant impact on the result. The inertia stop is an option if no information on the engine behaviour is available.

The 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 direct spiral test should be carried out as turning tests at a number of rudder angles and the steady rate of turn measured. The tested rudder angles are usually 25°, 20°, 15°, 10° and 5° to starboard and port side. Smaller rudder angles may be required for less stable and unstable ships.

The reverse spiral test is performed to acquire the complete hysteresis loop when the ship is found unstable. It can also replace the direct spiral test particularly if the test area does not allow a steady rate of turn to be established. For the reverse spiral test 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 should be steered in order to get sufficiently small constant yaw rate.

Other common tests are:

The pull-out test by going back to the steady course rudder angle after a short execute of the rudder (some 10°) to port and starboard.

The accelerating turning test starting from zero or a low speed and using full propulsive power. Maximum rudder angle to port and starboard should be applied.

For appropriate purposes free 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.

2.2.4 Test types in shallow and restricted water

Types of tests typically carried out in shallow water are for the most part the same tests as in deep water: turning circle and zig-zag tests are being carried out regularly. Additionally, in shallow water the “avoidance test” or “evasive test” for inland ships is being used. These specific manoeuvres for inland ships are valid for ships sailing on the River Rhine in shallow water (ITTC 2014).

The evasive manoeuvre is to be carried out as follows: At a constant speed of 13 km/hr and the ship well on its straight course, the steering angle is laid to the desired angle of 20 or 45 degrees. That is at time t_0. As soon as the rate of turn has achieved a limiting value in degrees per minute, the rudder is laid to the opposite side. This is time t_1. When the rate of turn has become 0 degrees per minute, the time t_2 is clocked. When the rate of turn has achieved the target value again, the time t_3 is noted, and the rudder is again reversed to the other side. When the rate of turn has become 0 again, the time t_4 is noted, and the manoeuvre can end by steering back to the original heading. A criterion is used for the value of t_4 depending on type of convoy and water depth.

The specific manoeuvres for restricted water are usually so that the ships are sailing either in the neighbourhood of a bank or in the neighbourhood of other ships. In that case, the model(s) are steered by an autopilot (which is programmed in the ship control parameters) to keep a heading and/or a track.

2.2.5 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 running manoeuvring tests requires direct or indirect measurement of the following data:

time,
model position,
heading,
model speed, (axial and lateral or along track),
yaw rate,
roll angle,
sinkage and trim.

The measurement of parameters characterising the control of ship model steering and propulsion equipment should be recorded:

rudder angle,
rpm of propulsor(s),
action of other steering/manoeuvring devices.

The following data may also be important:

thrust/torque on propulsor(s),
forces and moments on steering devices (rudder(s), pods…).

2.3.2 Data acquisition

Data sampling rate and filtering 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 10 and 250 Hz, 50 Hz being a mean value. Sampling rate should be at least twice the filter frequency according to the sampling theory.

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 have been finished, noting that data in transient regions of starting and stopping should not be used in the analysis. For the following standard manoeuvres the analysis is as follows:

1) Turning test

Indices such as the advance, transfer, tactical diameter, which represent turning characteristics of a ship, should be analysed on the basis of the turning trajectory measured. Change in advance speed and drift angle may also be analysed on the basis of the turning trajectory.

2) Zig-zag test

Overshoot angles (usually for the 1st and 2nd oscillations), which represent course keeping ability and yaw checking ability of a ship, should be analysed with the use of the time series of yaw angle change in the zig-zag test.

3) Spiral and reverse spiral test

Measurements of yaw rate, rudder angle and ship speed in steady conditions are necessary. These tests are mostly carried out for course unstable ships to check their degree of course instability (size of the hysteresis loop).

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. The most relevant data should be included in the test report.

2.4.1 Ship model

dimensions of hull, rudder, propeller, etc,
mass of model,
position of centre of gravity,
achieved $\overline{GM}$ value,
achieved roll period value,
moments of inertia,
turbulence stimulation method,
details of appendages,
body plan and contours,
engine/rpm control.

2.4.2 Basin

dimensions,
water depth,
smoothness and stiffness of the bottom (for shallow water tests),
average water temperature.

2.4.3 Restricted water model

configuration,
dimensions,
smoothness and stiffness of the restricted water model (walls and/or bottom).

2.4.4 Ship model set-up

powering,
transfer of control signals,
transfer of measuring signals.

2.4.5 Measurement

measuring equipment,
capacity of load cells,
filter characteristics.

2.4.6 Test parameters

test type,
complete time functions of:

- positions and heading in horizontal plane
- model speed u, v, r
- rudder angles or equivalent,

rudder turning rate or equivalent,
propeller rpm,
propeller law (how the rate is achieved: constant power, torque or rpm),
water depth to draft ratio,
location of ship in relation to restricted water setup.

2.4.7 Autopilot characteristics

general description of control law (e.g. PID)
control gains (e.g. P, I and D)

2.4.8 Recording

equipment,

sample time,
digitising rate.

2.4.9 Calibration

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

2.4.10 Analysis procedure.

method of analysis,
filtering technique.

3. PARAMETERS

3.1 General

The following parameters should be taken into account for all free running 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.

3.2 Ship Control Parameters

3.2.1 Propeller rates of revolutions

Most tests should 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 (friction deduction). However, this correction will depend on the model scale and the ship type and it is not generally done (See Section 2.1.1).

3.2.2 Steering devices

The rudder turning rate should be scaled according to Froude’s model law. 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.

3.2.3 Thrusters (lateral and azimuthing thrusters)

The thrust or power developed by the installed thruster unit at zero speed is regulated to match the design ship value. If the thrust is not measured, it is important that power and diameter are correct.

4. UNCERTAINTY

During free 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 imperfections of the experimental technique. This is addressed in a separate ITTC procedure 7.5-02-06-05 (Uncertainty analysis on free running model tests).

5. BENCHMARK TESTS

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

6. The Co-operative Free-Model Manoeuvring Program (13th 1972 pp.1000)
7. Co-operative Test Program - Second Analysis of Results of Free Model Manoeuvring Tests (13th 1972 pp.1074-1079) A MARINER Type Ship
8. Ship Model Correlation in Manoeuvrability (17th 1984 pp.427-435) Joint International Manoeuvring Program (JIMP), a Working Group Called JAMP (Japan Manoeuvrability Prediction)
9. Free-Running Model Tests with ESSO OSAKA, (18th 1987 pp.369-371)
10. SIMMAN 2008 Benchmark cases for KVLCC1, KVLCC2, KCS and 5415M.
11. SIMMAN 2014, Benchmark cases for KVLCC2, KCS and 5415M

6. REFERENCES

International Maritime Organization, “Standards for Ship Manoeuvrability”, Resolution MSC.137(76), 2002.

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.

International Towing Tank Conference, 1999, "Manoeuvring Committee - Final Report and Recommendations to the 22nd ITTC", Proceedings of 22nd ITTC, Seoul/Shanghai.

International Towing Tank Conference, 2014, "Manoeuvring Committee - Final Report and Recommendations to the 27th ITTC", Proceedings of 27th ITTC, Copenhagen.

Lataire, E., 2014, "Experiment based mathematical modelling of ship-bank interaction", PhD-thesis, Ghent University, Belgium.

Li, M., Yuan, Z. and Delefortrie, G., 2019, “Investigation of the false bottom effects on ship model tests”, AMT conference, Rome, Italy. Stern, F. and Agdrup, K.; Proceedings of SIMMAN2008, workshop on ship manoeuvrability, Copenhagen, 2008.