ITTC Quality System Manual
Recommended Procedures and Guidelines

Procedure

Ship Models

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Updated / Edited by	Approved
Resistance Committee of the 30th ITTC	30th ITTC 2024
Date 05/2024	Date 09/2024

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Ship Models

1. PURPOSE OF PROCEDURE

The purpose of the procedure is to ensure the correct manufacture and preparation of hull and propeller models for Resistance (including High Speed Marine Vehicle Resistance), Propulsion and Propeller Open Water Tests.

The tolerances of propeller models for manoeuvring, seakeeping and ice tests can generally be larger (typically 1.5 to 2 times) than those used for propulsion or open water tests whilst those for cavitation tests may be smaller.

2. DESCRIPTION OF PROCEDURE

2.1 Model Sizing

The model should generally be as large as possible for the size of the towing tank. However, an excessively large model will have adverse effects on the resulting resistance and powering tests. It is important to consider the size of the model relative to the tank and the maximum model speed to determine if there exists a restricted waterway. A restricted waterway can cause blockage and finite depth effects. Assess the appropriate size of a model through evaluation of blockage relationships and the following criteria.

2.1.1 Blockage Relationship Criteria

The criteria proposed by the 1987 ITTC, regarding restricted waterways includes model speed and geometric relations dependent on tank and model geometries. The relations of interest are Froude depth number (Fr_h), water-depth/model-draught (h/T), water-width/model-length (b/L_{pp}), water-width/model-width (b/B), and the tank/mid-model cross-sectional area ratio (A/A_x), which are respectively defined with satisfactory conditions as

(i) Froude depth number

$$Fr_h = \frac{V}{\sqrt{gh}} \leq 0.70$$

(ii) Waterway-depth / model-draught

$$\frac{h}{T} \geq 4$$

(iii) Waterway-width / model-length

$$\frac{b}{L_{PP}} \geq 0.35$$

(iii) Waterway-width / model-width

$$\frac{b}{B} \geq 4$$

(iv) Waterway section / mid-model section

$$\frac{A_T}{A_X} = \frac{b * h}{B * T} \geq 15$$

These relations must be met in order to eliminate waterway restriction concerns (i.e. blockage effects). The following influences were presented in the 1987 ITTC; for Fr_h exceeding 0.7, the wave resistance is affected; if the h/T <4 there exists an influence on the flow surrounding the model, independent of Fr_h; if b/L_{pp}<0.35, there is an influence of bow wave reflection from the lateral boundary on the stern flow; b/B<4 signifies that the flow surrounding the model is affected; and A_T/A_x<15 is the beginning of a general restriction of the waterway. A single relation cannot unconditionally identify a waterway restriction, thus two or more relations are necessary to unquestionably classify the occurrence of waterway restriction.

2.2 Model Manufacture

2.2.1 Hull model

General

The basic requirement is that the model should be geometrically similar to the ship wherever it is in contact with the water. This may not be possible in all cases owing to different systems and materials of construction on model scale and full size and it is desirable that any departures from similarity should be known and documented.

Materials and construction

Materials used for ship hull models include wax, wood, high-density closed cell foam and fibre reinforced plastic (FRP).

Models are normally cut from a lines plan redrawn from the ship plan, or from a numerical definition of the hull surface stored electronically in an appropriate graphical format (e.g. IGES file or similar).

After cutting, the model is finished by hand. In the case of FRP construction, a foam or wooden plug of the model will be manufactured in a similar manner.

Surface finish

The model surface should be homogeneously smooth and equivalent to that achieved with a 300 to 400 grit wet and dry paper.

Particular care should be taken when finishing the model to ensure that geometric features such as knuckles, spray rails, chines and boundaries of transom sterns remain well-defined (i.e. sharp edges), especially where flow separation and/or production of lift is to be expected. The finished radii of these features should be measured and documented. The aforementioned features are known to significantly affect trim characteristics and therefore resistance.

In general, the surface finish of items produced using rapid prototyping techniques does not meet the surface finish requirement, thus further attention may be required.

A review of model surface roughness, including items produced using rapid prototyping techniques, is given in Resistance Committee report for the 28th ITTC (2017).

Stations and waterlines

The spacing and numbering of displacement stations and waterlines should be properly defined. Displacement *sections* may be identified as follows:

- A ten section system numbering from aft with station 0 at the *AP*. The number of stations can also be 21 (20 equally sized intervals). The stations are counted from aft.
- Decimal fraction stations may be introduced at the ends as required (such as 9.5, 9.6, 9.7 etc.).
- Stations aft of the *AP* to be numbered negatively.
- Stations forward of the *FP* to be numbered positively in natural succession (10.1, 10.2 etc.).

It should be noted that there are other methods of numbering the displacement stations, which may be equally acceptable.

Waterlines are identified as follows:

- Waterlines should be spaced as required and identified by their height above the baseline.
- The baseline should be defined as the topside of keel. In the case of a raked keel the baseline is parallel to the design waterline and midway between the height above base at the *AP* and *FP* stations.

Moulded dimensions:

Ship lines are normally drawn to moulded dimensions and model hulls should also be constructed to moulded dimensions.

Manufacturing tolerances

Model hull tolerances for breadth (y) and depth (z) should be within ± 1.0 mm. The tolerance for model length should be within ± 0.05%L_{PP} or ± 1.0 mm whichever is the larger.

For multihull models, the tolerances for transverse and longitudinal spacing of hulls should be within ± 0.05%L_{PP} or 1.0 mm whichever is the larger.

Openings in the hull should be manufactured to within ± 1.0 mm. If lateral thrust units are modelled to include the associated power loss, then these can be represented using a cavity that does not go through to the other side. If thrust units are included to assess manoeuvring capability then both the thrust to be modelled and the expanded blade area ratio (A_E/A_O) should be considered.

Stability over time

The dimensions of the hull model should not move outside the recommended manufacturing tolerances. It should be noted that the dimensions of wax models can change appreciably with changes in temperature. For example, a change of 5^0C may alter the length of a model by about 0.15% (10 mm for a 7 m model). The model documentation should include any changes in dimensions, which may have arisen from this source. It is recommended that the model's documentation includes a record of the temperature at the time the model was measured for commissioning, particularly for materials with sensitivity to temperature changes.

2.2.2 Propeller model

Manufacturing tolerances (for self-propulsion and open water tests):

Propellers having diameter (D) typically from 150 mm to 300 mm should be finished to the following tolerances:

Diameter (D) ± 0.10 mm
Thickness (t) ± 0.10 mm
Chord length (c) ± 0.20 mm
Mean pitch at each radius (P/D): ± 0.5% of design value.

Special attention should be paid to the shaping accuracy near the leading and trailing edges of the blade section and to the thickness distributions. The propeller will normally be completed to a polished finish. The use of CAD/CAM processes further enhances the facility to achieve such tolerances.

The manufacture of model ducts, vane wheels and pre and post swirl vanes should follow the tolerances recommended above for model propellers used in self-propulsion and open water tests.

Materials such as nylon produced by rapid prototyping are not currently considered suitable for the manufacture of propeller/rotors that are required to remain rigid when under test conditions (Liu et al. 2015). This, however, is an area of rapid development and advances in manufacturing techniques could soon allow propellers to be manufactured using these techniques.

Gaps

The gap between the aft side of the model bossing and the fore side of the propeller boss should be the minimum required to allow sufficient forward movement of the propeller when calibrating the thrust dynamometer but should not exceed 2 mm with the propeller in its design position. Rope guards across the gap should not be produced at model scale.

Propeller / hull clearances

Propeller/hull aperture clearances should have tolerances within ± 1.0 mm and a maximum axial propeller movement of 1.5 mm. These tolerances should provide propeller clearances with less than 1.0% *D* error.

2.2.3 Appendages

Appendages in this context refer to items such as external shaft brackets, open propeller shafts, bossings, the struts and pods of podded propulsors, bilge keels, roll fins and rudders.

Materials used for appendages must be sufficiently strong to remain rigid under test conditions. Materials that are flexible are not suitable for models of appendages that are required to remain rigid when under test conditions (Liu et al. 2015). Some materials used for rapid prototyping (e.g. Synthetic Laser Sintering) are now considered suitable for the manufacture of appendages, but care must be used both in material selection and manufacture strategy.

Appendages should be built to the full external shape as designed.

The manufacturing tolerances of appendages should be within ± 0.2 mm.

Surface finish should be at least as good as that recommended for the hull model.

Appendages should be located within ± 0.5 mm of their design position.

2.3 Turbulence Stimulation

The reasons that turbulence stimulation is applied to a ship model are (in decreasing order of importance):

1. ensure that the flow regime at model scale is equivalent to that at full scale
2. the model scale flow is constant and hence repeatable across the design Froude number and between repeat tests
3. a known scaling approach can be applied

2.3.1 Hull

The model should be fitted with a recognised turbulence stimulator, which should be clearly described in the model documentation and the report on the experiments. Given the variation in model geometry the turbulence stimulator device should be chosen following consideration of its effectiveness and convenience for the individual purpose. Four different kinds of turbulence stimulators are currently in common use for maritime applications: studs, Hama strips, sand strips, and trip wires.

Typical combinations of model/appendage length and Froude number where most of the model would remain in the laminar flow regime are identified in Figure 1. Special care should be taken when selecting turbulence stimulator devices for these cases.

A review of progress into the mechanisms of laminar-turbulent boundary layer transition and appropriate selection of devices for turbulence stimulation is given in Resistance Committee report for the 26th ITTC (2011) and 28th ITTC (2017). The conclusions from these reviews are summarised in the procedures provided here.

Studs used for turbulence stimulation will be typically between 1.6 and 3.2 mm in diameter, 0.5 to 3.0 mm high and spaced between 12 and 25 mm apart. Figure 2, from Hughes and Allan (1951) and NPL Report 10/59 (1960), gives guidelines for the dimensions of studs and the location of the studs as turbulence stimulators on a raked stem of conventional type.

Wires used for turbulence stimulation will be typically between 0.5 mm and 1.0 mm diameter, depending on position and model speed, and be situated about 5% L_{PP} aft of the *FP*.

Sand strips used for turbulence stimulation will typically comprise backing strips/adhesive of 5 mm to 10 mm width covered with sharp edged sand with grain size around 0.50 mm, with its leading edge situated about 5% L_{PP} aft of the *FP*.

Sand strips are the preferred method of turbulence stimulation for long slender hulls, such as high speed catamarans.

Wires are often preferred over sand strips for convenience, due to their dimensional accuracy and ease of fitting. Some sand strips have been found to be vulnerable to deterioration during testing.

A bulbous bow will additionally have turbulence stimulators situated typically at ⅓ of the bulb length from its fore end.

In the case of bulbous bows with S shaped waterlines the turbulence stimulator should be applied in a position shortly before a positive pressure gradient can be expected. Care has to be taken that the size and number of turbulence stimulation devices used does not fundamentally alter the bow wave and thus the progressive accumulation of pressure and skin friction resistance along the hull.

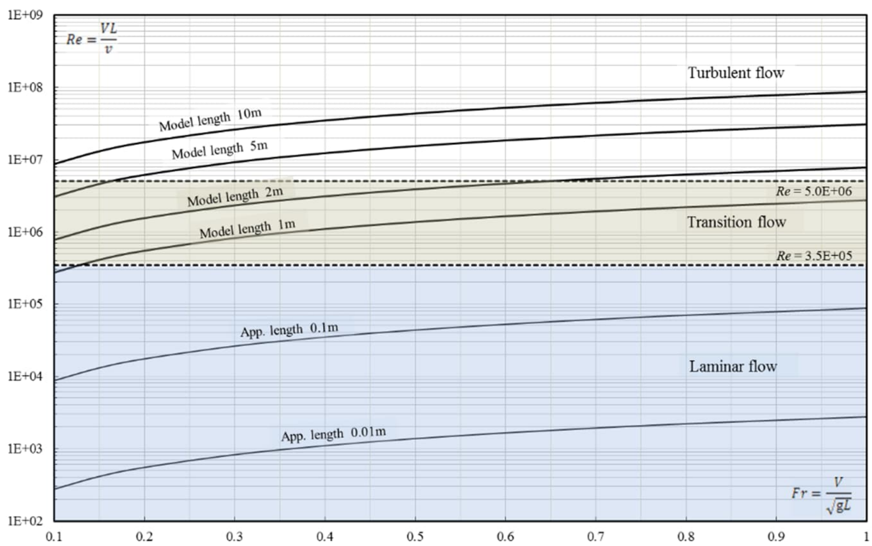

Figure 1 Contour plot of length-based Re for a range of model/appendage lengths and Froude numbers. This is an example for flow regime estimation for typical model/appendage length without turbulence stimulation devices (υ= 1.1386×10^{-6} m^2/s for 15℃ fresh water, g = 9.8067 m/s^2)

2.3.2 Appendages

Turbulence stimulation should be applied to appendages when laminar flow over the appendage is likely. The approach for the selection of appropriate turbulence stimulation devices for appendages is as follows:

1. For each appendage component classify the device as bluff, faired or lifting.
4. Evaluate the expected Reynolds number for the range of Froude numbers to be tested.
5. Select a suitable turbulence stimulator device that is of appropriate size and spacing to force transition without adding a significant amount of extra momentum loss that will alter the wake downstream.
6. For those devices where there is a risk of flow separation or which will remain mostly laminar, examine what is the chosen strategy to mitigate the altered flow regime. For example, by using a rough surfaced appendage or altering its section profile.
7. Conduct progressive component stripping process, progressively adding appendages starting with the furthest forward.
8. Evaluate the resistance increase due to each component.
9. Scale the correct resistance contribution.

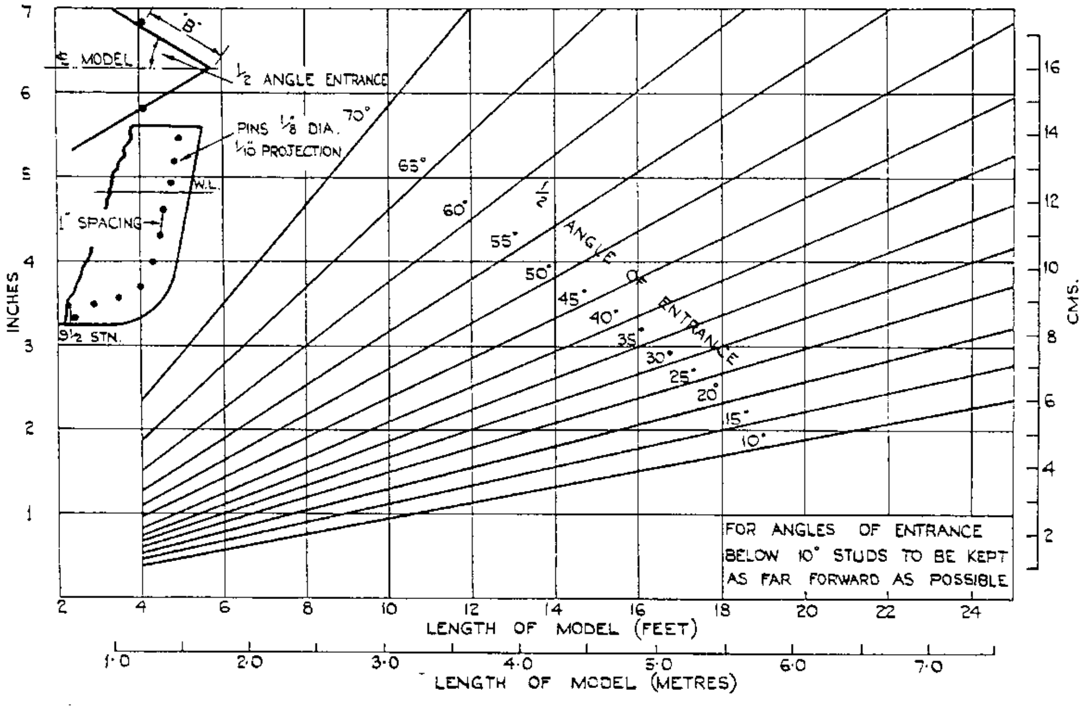

Figure 2 Location of studs as turbulence stimulators (Hughes and Allan, 1951)

2.3.3 Propeller

Turbulence stimulation will not normally be applied to propellers used in self-propulsion and open water tests. There is however evidence that turbulence stimulation may be necessary on model propellers used in cavitation tests, however care must be taken to ensure the trip itself does not instigate cavitation.

2.4 Preparation for Model Testing

Before ballasting the model, careful checks of the model dimensions should be made.

2.4.1 Ballasting and trimming (for resistance and self-propulsion tests)

The model should be loaded to give the correct volume displacement at model scale. This typically involves calculation of the full-scale volume displacement from knowledge of the full-scale weight and the appropriate water density; scaling of the volume displacement to model scale using the adopted scale factor; calculation of the model-scale weight using the water density appropriate for the tank; finally ballasting of the model to the calculated weight. The model weight should be correct to within 0.2% of the correct calculated weight displacement. Where practical, the model should be weighed in air using a calibrated scale.

The trim of the model should be such that the errors in draught, if any, from the design figure are the same at the forward and after perpendiculars. The model will normally be tested without heel. The mean of the four draughts, fore perpendicular, after perpendicular, port side amidships and starboard side amidships, should not differ from the designed figure by more than 2.0mm or 0.05% L_{PP}, whichever is the less.

Hog or sag deformation should not exceed acceptable tolerances, typically not > 2.0 mm or 0.05% L_{PP}, whichever is less.

For older models being re-tested, the choice of an acceptable tolerance may depend on resistance benchmark re-tests.

2.4.2 Wax models

The following applies to models manufactured predominantly out of wax, not wax-wood composite models.

Before running, wax models should be left fully sunk in the water, preferably for 36 hours and not less than 12 hours. On re-floating, the entire surface should be cleaned in the tank water with a sponge or soft brush, particular care being taken to remove all air bubbles and slime from the surface. If the model has been in the water for some weeks and has become encrusted with a crystalline deposit it should be re-scraped and re-soaked, not merely sponged.

2.5 Documentation

The particulars of the model(s) should be collated in a report and/or included in a test report, and should contain at least the following information:

Hull Model:
Identification (model number or similar)
Materials of construction
Principal dimensions
Length between perpendiculars (L_{PP})
Length of waterline (L_{WL})
Breadth (B)
Draught (T)
For multihull vessels, longitudinal and transverse hull spacing
Design displacement (Δ) (kg, fresh water)
Hydrostatics, including water plane area and wetted surface area
Details of turbulence stimulation

Details of appendages
Details of knuckles, spray rails, chines
Radii of sharp edges such as knuckles, spray rails, chines and boundaries of transom sterns

Propeller Model:
Identification (model number or similar)
Materials of construction
Principal dimensions
Diameter
Pitch-diameter ratio (P/D)
Expanded blade area ratio (A_E/A_0)
Thickness ratio (t/D)
Hub/boss diameter (d_h)

3. PARAMETERS

3.1 Definition of Variables

A_T	Waterway cross section Area	(m^2)
A_E	Expanded blade area	(m^2)
A_0	Propeller disk area	(m^2)
A_E/A_O	Expanded blade area ratio	(-)
AP	After perpendicular	(-)
A_x	Model x-section Area	(m^2)
b	Waterway-width	(m)
B	Breadth	(m)
c	Chord length	(m)
D	Propeller diameter	(m)
D_h	Boss or hub diameter	(m)
FP	Forward perpendicular	(-)
g	Gravitational Constant	(m/s^2)
h	Waterway-depth	(m)
P	Propeller pitch	(m)
L_{PP}	Length between perp's	(m)
L_{WL}	Length of waterline (X)	(m)
T	Draught	(m)
t	Blade section thickness	(m)
V	Model Speed	(m/s)
x, y, z	Coordinate directions	
Δ_m	Displacement mass	(kg)

4. REFERENCES

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