ITTC Quality System Manual
Recommended Procedures and Guidelines

Procedure

High Speed Marine Vehicles Propulsion Test

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High Speed Marine Vehicles: Propulsion Test

1. PURPOSE OF PROCEDURE

The main purpose of performing tests on High Speed Marine Vehicles (HSMVs) is to estimate the power required to propel the vehicle over a range of speeds.

High Speed Marine Vehicles are defined to be vessels with a design speed corresponding to a Froude number above 0.45, and/or a speed above $3.7\nabla^{1/6}$ (m/s) and/or where high trim angles are expected or for dynamically supported vessels

In the context of these procedures, the term "High Speed Marine Vehicles" is used to cover the following types of vessels:

A) Mono-Hull

- planing vessels
- semi-displacement craft

B) Multi-Hull

- small waterplane area twin hulls (SWATH)
- catamarans
- trimarans

C) Hydrofoil
D) Air Cushion Supported Vehicles

- air cushion vehicles (ACV)
- surface effects ships (SES)

It should be noted that this procedure does not cover waterjet propelled ships.

2. TEST TECHNIQUES AND PROCEDURES

2.1 General

The ITTC recommended procedures peculiar to high-speed craft are given as separate procedures for each test type. The procedures are:

- Resistance (Procedure 7.5-02-05-01)
- Waterjet (Procedure 7.5-02-05-03)
- Seakeeping (Procedure 7.5-02-05-04)
- Manoeuvring (Procedure 7.5-02-05-05)
- Structural Loads (Procedure 7.5-02-05-06)
- Dynamic Instability (Procedure 7.5-05-02-07)

Issues of importance for different types of high speed craft are covered in separate sections in each procedure when needed.

2.2 Propulsion Tests

Important issues relevant to propulsion experiments should be considered. The most important are:

- model size;
- the change of running attitude between resistance and propulsion test;
- scaling of wake;
- scaling of propeller efficiency η_O;
- cavitation and ventilation;

Recommended codes of practice are outlined after each issue when possible.

2.2.1 Model Size

For propulsion tests the model should be as large as possible. The upper limits of the model size are given by the highest carriage speed and by tank depth and width. Care should be taken when tests at high length Froude numbers are conducted at depth Froude numbers greater than 0.7 as shallow water effects will exist, particularly with low water depth to draft ratios (if h/T is less than approximately 16 then shallow water effect becomes significant) (Lewis 1998).

The lower limit of model size depends on the weight of the propulsor device, the driving axis, gears, motor and the measurement devices. To avoid increase in model size the weights of the propulsion units and measuring equipment should be minimised.

For craft having screw propellers, the model size depends mainly on the scale ratio of the full scale propeller to the available stock propeller diameter. The sum of stock propeller diameter and pitch (P + D) should also be considered. The scale ratio should maximise the section Reynolds number at $0.7R$ of the blades. To avoid scale effects a minimum model propeller diameter of 150 mm is recommended.

2.2.2 Change of Running Attitude Between Resistance and Self Propulsion Test

The large variety of propulsion devices in use for HSMVs and their different arrangements have considerable influence on the running trim and sinkage. Thus they influence the craft’s performance, such as powering, manoeuvring and high speed dynamic stability.

Experimental results coming from propulsion tests, as well as predictions, are subject to various influences like propulsor/hull interaction, cavitation, ventilation, and scale effects due to inequality of Reynolds numbers for model and full scale.

In designing and testing HSMVs and in predicting their power performance, the induced effects of appendages and their influence on the equilibrium running condition must be taken into account to obtain reliable predictions of full-scale trim and powering data. Although upstream appendages (shafts, brackets, struts) have a relatively small effect on the hull, their wake fields affect the propulsor performance directly.

It is important to evaluate correctly the drag of the appended hull. That can be done experimentally by making large models with appendages and propulsors having significant dimensions (higher Reynolds numbers). If the facility permits to perform tests at high speed on a large model, the experiments to determine the appendage drag can be carried out with appended model first and then repeated without appendages, with the model locked at the same running attitude.

If that is not possible, as already discussed in Procedure 7.5-02-05-01, the appendage drag can be determined analytically with a method such as that proposed by Hadler (1966).

2.2.3 Scaling of Wake

Past experience and some full-scale data indicate that for exposed, raked shafts the model wake is essentially the same as the full-scale wake.

The propellers of a semi-displacement craft, for instance, operate largely or completely outside the hull boundary layer; scale effects can therefore be ignored for most inclined shaft propeller arrangements.

Although the conventionally obtained wake fraction obtained using open water characteristics for a non-inclined shaft is easier to determine, for more accurate full-scale prediction of propulsion factors the analyses should be based on the effective wake fraction for the appropriate inclined shaft.

The main problem seems to be which values of wake fraction should be taken into account when making full-scale predictions or designing the propellers. The wake fractions are influenced by trim, free-surface effects, appendages, hub shape etc. Oblique inflow to the propeller can have noticeable effect if axial flow propeller data are used. Hence effective wake fractions analysed by traditional procedures like ITTC Method 78/88 cannot be regarded as a true measure of the inflow retardation due to the influence of the ship's hull. The traditional wake is largely a propeller rather than a hull characteristic.

Since the inclined shaft propeller characteristics in the behind condition are different from those of the axial shaft case, the analyses based on oblique open water characteristics can provide more reliable predictions.

It is considered that more full-scale data is required for the different HSMV types with different propulsor devices before a code of practice can be proposed.

2.2.4 Scaling of Propeller Efficiency

One of the main issues in propulsion experiments is the scaling of propeller efficiency. The power and rotation rate prediction on the basis of model tests requires an accurate assessment of scale and roughness effects on propeller characteristics.

The ITTC 78 method incorporates a correction rule based on scale effects on the drag of the blade section only. The rule, for propeller scale effect, ignores the difference in extent of the laminar flow over the propeller blades between model and full size. The result is that the method predicts greater scale effect on K_T and η_0 coefficients and minor scale effect on K_Q, although the K_Q correction is usually the largest, in a relative sense.

There are two approaches to overcome this:

- to control the flow over the propeller blades;
- to develop a more accurate scaling procedure that accounts in a better way for the mixed type of flow.

Both approaches require that the scaling rule takes into account the effect of Reynolds number on the lift. The influence of Reynolds number on the lift has been discussed in previous ITTC proceedings but it is far from solved.

The method of controlling the flow over the propeller blades should be treated with extreme care.

A method proposed by the HSMV Committee of 19th ITTC as ”Alternative Analysis and Prediction Procedure” is especially useful if wake, thrust deduction and efficiency elements are influenced by oblique inflow. This method analyses the product

$$\eta_H \eta_R = \eta_D / \eta_O = \text{const.}$$

as a function of the propeller loading. The product can be considered unaffected by scale effects. The propeller efficiency of the model propulsion test may be replaced by that of a large scale geosim propeller with small scale effect corrections applied. (Although this method has not been widely accepted, since for many cases this expression will not be constant, it should therefore be validated by the use of model test and full scale trials.)

The method works well for non cavitating and partially cavitating propellers. For fully cavitating propellers additional corrections should be applied.

2.2.5 Cavitation, Ventilation and Propeller Shaft Inclination

Cavitation and ventilation effects on propeller driven HSMVs have a large influence on their dynamic behaviour and on their resulting performance. For that reason alternative and unconventional means of propulsion are used in such types of craft. The majority of high-speed craft in operation utilise alternatives such as waterjet propulsion systems, surface piercing propellers, and super-cavitating propellers.

Cavitation and ventilation effects on powering performance predictions can be divided into:

- influence on propulsor characteristics; and
- influence on thrust demand and running condition.

To account for these phenomena tests should be carried out in a vacuum facility. Because it is very difficult to perform such tests at high speed, the prediction on HSMVs is usually made in two steps: by resistance tests in a towing tank and by supplementary tests in a cavitation tunnel or in a depressurised towing tank.

Cavitation and ventilation influence the performance of the propulsor. The best method to account for this influence is to carry out cavitation tests with a model fitted with all the appendages in a large cavitation tunnel or a depressurised towing tank. The test procedure and treatment of data have been presented extensively in the proceedings of preceding ITTC Conferences. For those organizations that do not have at their disposal large cavitation facilities, different approaches were proposed in the Report of the HSMV Committee of 19th ITTC.

Furthermore, cavitation and ventilation influence the forces and moments induced on the hull by the propulsors, especially for ships with inclined shaft arrangements. Therefore the resulting trim is different compared with that measured during tests without these phenomena. It means that results from model self-propulsion tests in a towing tank at atmospheric pressure are in most cases not representative for full scale HSMVs. In that case the effects of cavitation have to be accounted for separately.

In this respect in propeller driven craft, the most severe effects are induced by the shaft inclination. In these craft inclined shafts are commonly used to place the propellers well below the hull to avoid or reduce the risk of air suction or ventilation at all trim angles.

The oblique flow on the propeller causes a cyclic variation of the angle of attack on the propeller blade sections. As a result, thrust and torque fluctuations become larger and cavitation phenomena are intensified. In making full scale evaluations starting from model results, an analysis procedure that uses open water propeller characteristics measured in oblique flow conditions should be adopted.

It is well known that the disadvantages of using traditional axial flow open water tests are due to the influence of interaction effects and to the difficulties in determining the normal force and its change due to cavitation affecting thrust and efficiency.

For hydrofoil ships, in most cases, the propulsor-hull interaction effects can be neglected. Thus, ordinary propulsion tests are usually not required. On the other hand, there might be important propulsor-foil interaction effects, where cavitation plays an important role, since hydrofoils operate at high speeds. It is therefore recommended to test the propulsor together with the relevant parts of the foil system in a cavitation tunnel. Depending on the maximum obtainable Reynolds number and available measurement equipment, the cavitation tunnel experiments might also be used to determine lift and drag on the foil system. In the cavitation experiments, it is important that any flaps are modelled and set to realistic angles during the experiments. The foil-hull interaction can be quite important when determining the lift and drag of the foil system. This would need resistance testing in a towing tank.

3. PARAMETERS

3.1 Parameters to be taken into account

- model size;
- the change of running attitude between resistance and propulsion test;
- running length and wetted surface area;
- scaling of wake;
- scaling of propeller efficiency η_0;
- cavitation and ventilation;

4. VALIDATION

4.1 Uncertainty Analysis

Uncertainty analysis should be performed in accordance with .Uncertainty Analysis in EFD, Uncertainty Assessment Methodology. as described in QM 7.5-02-01-01.

5. REFERENCES

Hadler, J.B., 1966, “The Prediction of Powering Performance on Planing Craft”, Trans. SNAME, Vol. 74, pp. 563-610.

Lewis, E.V. (Ed.), 1998, “Principles of Naval Architecture”, Vol. 2, Society of Naval Architects and Marine Engineers, ISBN 0939773015.