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High Speed Marine Vehicles: Propulsion Test

1 PURPOSE OF PROCEDURE

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

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)
☐ Propulsion (Procedure 7.5-02-05-02)
☐ Sea Keeping (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;
- thrust measurement for waterjet propelled vehicles.

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

2.2.1 Model Size

Generally speaking, 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. The maximum carriage speed should be somewhat lower than for resistance tests to provide time for adjusting the propulsor's revolutions.
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 dynamometers should be very small.

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 scale ratio should guarantee supercritical Reynolds numbers at 0.7R of the blades. In this case, if a model propeller with a correct pitch ratio is not available, a stock propeller should be selected that has a geometrically similar sum of pitch and diameter as the prototype.

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. In fact, even if the velocity and pressure fields on the appendages have relatively small effect on the hull, their wake fields affect the propulsor performance directly.

To avoid or minimise errors in model test data evaluation and in predicting performance, 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 trim and heave.

If that is not possible, as already discussed in Procedures 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 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 is easier to determine, nevertheless, for more accurate full-scale prediction of propulsion factors the analyses should be based on the effective wake fraction.

The main problem seems to be which values of wake fraction should be taken into account when making full-scale predictions. The wake fractions are influenced by trim, free-surface effects, appendages, etc. Oblique inflow to the propeller can have noticeable effects 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

As already said one of the main issues in propulsion experiments is the scaling of propeller efficiency is a problem. In fact 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_O coefficients and minor scale effect on C_D. To overcome this there are two approaches:

- 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 several past ITTC reports but it is far from being solved.

The method of controlling the flow over the propeller blades should be treated with extreme care. The results of model tests carried out in the past indicate that turbulence tripping on the propeller blades is not recommended for application in routine practice.

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

$$\eta_H \cdot \eta_R = \eta_D / \eta_0 = \text{const}$$

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.

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 performances. 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, super-cavitating propellers.
Cavitation and ventilation effects on power performance predictions can be divided into:

- influence on propulsor characteristics;
- 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 tests in a towing tank and by tests in cavitation tunnel or depressurised circulating water channel.

As already mentioned 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 channel. The test procedure and treatment of data have been presented extensively in the proceedings of preceding ITTC Conferences. For those organisations 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.

The traditional open water approach has been suggested in the past. In fact there are complexities regarding the experiments and procedures involved and there are uncertainties with respect to the techniques for unconventional propulsors. More work is required on this matter.

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.

2.2.6 Thrust Measurement for Waterjet Propelled Vehicles

This subject can be a matter of opinion. The Specialist Committee on Waterjets has worked on the development of the waterjet self-propulsion test standardisation. However, as an illustration of common practice, the method used at HSVA for predicting the thrust of waterjet propelled ships is described briefly. It is developed starting from the Momentum Flux Method (Procedure 4.9-03-03-05.2) proposed by the Waterjet Group of the 21st ITTC (1996).

According to this method the thrust is not measured directly, but obtained by assuming the rate of change of momentum to be equal to the sum of all forces (with appropriate simplifications) acting on a given control volume. The method is based both on calculations and measurements. The main steps are:

- the calculation of the momentum velocity at nozzle exit;
- the calculation of the momentum velocity upstream of the inlet;
- the determination of the effective inlet;
- the determination of the flow velocity upstream of the inlet.

A detailed description of the method is reported in the HSVA Report ”Performance and Analysis of Ship Powering Tests, Waterjet Propulsion Test Evaluation Method”.

3 PARAMETERS

3.1 Parameters to be Taken into Account

- model size;
- the change of running attitude between resistance and propulsion test;
- scaling of wake;
- scaling of propeller efficiency η_0;
- cavitation and ventilation;
- thrust measurement for waterjet propelled vehicles.

3.2 Recommendations of ITTC for Parameters

None

4 VALIDATION

4.1 Uncertainty Analysis

None