ITTC Quality System Manual
Recommended Procedures and Guidelines

Podded Propulsor Model Scale Cavitation Test

Alves Pereira F., Boucheron R., Boucetta D., Fetherstonhaugh C., Krol P., Pang Y., Park C., Sato K., Straka W. A., Viitanen V.

7.5	Process Control
7.5-02	Testing and Extrapolation Methods
7.5-02-03	Propulsion
7.5-02-03-03	Cavitation
7.5-02-03-03.6	Podded Propulsor Model Scale Cavitation Test

Disclaimer

Updated / Edited by	Approved
Specialist Committee on Cavitation and Noise of the 30th ITTC	30th ITTC 2024
Date 05/2024	Date 09/2024
© 2024 ITTC.A Switzerland	DOI:

Table of Contents

1. PURPOSE OF PROCEDURE........... 3

2. PROPULSORS MODEL-SCALE CAVITATION TESTS 3

2.1 Introduction 3

2.2 Propulsor Operating Conditions ... 3

2.3 Propulsor Model Accuracy............ 4

2.4 Wake Simulation............................ 4

2.4.1 Pushing configuration 5

2.4.2 Pulling configuration................. 5

2.5 Calibrations.................................... 6

2.6 Test Measurements 6

3. PARAMETERS LIST........................ 6

3.1 Data Reduction Equations............. 6

3.2 Definition of Variables................... 7

4. REFERENCES 7

5. KEYWORDS 7

Abstract:

This guideline describes the set up and methodology, including wake simulation, for carrying out model-scale cavitation tests with azimuthing podded propulsor(s). It gives also results which are consistent, reliable and comparable amongst ITTC organizations.

Podded Propulsor Model – Scale Cavitation Test

1. PURPOSE OF PROCEDURE

To carry out model-scale cavitation tests with azimuthing podded propulsor(s) so as to give results which are consistent, reliable and comparable amongst ITTC organizations.

Also to provide a common base for the description of the appearance of typical model-scale cavitation observed on these propulsors model-scale cavitation tests.

2. PROPULSORS MODEL-SCALE CAVITATION TESTS

2.1 Introduction

Model scale cavitation tests are routinely conducted in conventional cavitation tunnels, some with free surface simulation. A few member organisations operate depressurised towing tanks. The goal of all these facilities is to operate the propulsor within the simulated velocity distribution of the inflow and the static pressure field. Exact simulation is not achievable due to insufficient knowledge of the actual full-scale flow field and hull boundary layer thickness, and difficulties due to Reynolds Number effects at Froude Number similarity and non-geosim hull representations.

All tests are intended to achieve geometric scaling of the propulsor. Therefore, the complete podded propulsor (also known as "unit") model (including pod body, strut, fin, flap, duct etc.) must have high rigidity and geometric accuracy at the specified test conditions to ensure sufficiently accurate results.

Readers may refer to the ITTC Procedure 7.5-02-03-03.2 section 3 dealing with Visual description and measurement of cavitation events. This procedure, containing notably the different sketches related to pod, is a useful complement of the present Guideline.

2.2 Propulsor Operating Conditions

The propulsor operating conditions investigated should be mutually established between the testing organisation and the customer. The customer specifies the ship operating conditions of interest for the cavitation investigation. Some example conditions are:

- full (design) displacement, full power,
- full displacement, 80% full power (endurance speed),
- ballast displacement, full power,
- towing load,
- trial and service condition,

Some of the above conditions may be required to be tested at various azimuthing (or helm) and tilt (i.e. inclination in horizontal and/or vertical planes) angles of the podded propulsor depending upon the sophistication of the model and test set-up employed. Tests at various tilt angles may not be essential but may be required for the optimisation of the propulsor orientation.

The detailed test parameters required for setting test conditions are taken from the results of model propulsion tests in towing basins, scaled to the ship pod propulsion powering points.

During the cavitation test the propulsor is tested at a prescribed set of parameters:

- cavitation number, σ,

- advance coefficient, J_A,
- and full-scale propeller thrust coefficient, K_T.

At a particular propulsion operating point, the setting of the tunnel flow conditions to achieve a model simulation for this operating point is usually made on the basis of "thrust identity". However, by considering the current uncertainty in an accurate measurement of thrust on the propeller of a podded propulsor due to the gap effect between the propeller and pod housing it is recommended to run a cavitation test:

- at a "torque identity" condition, satisfying a target full-scale torque coefficient, K_Q, value of the propulsor.

When testing in a depressurized towing tank, conditions can be set based on propulsor angular velocity and tow speed, from a previously conducted propulsion test performed with a geosim model.

The choice of propeller angular velocity and tunnel speed should result in sufficiently high blade Reynolds Number (the minimum value for $Re_{0.7}$ is 0.5×10^6 based on the blade chord length at 0.7R. The target value for $Re_{0.7}$ is 1.0×10^6) in order to avoid effects of laminar flow on cavitation, particularly for pulling type propulsors. If low blade Reynolds number cannot be avoided, such as when following Froude scaling in a depressurised towing tank, artificial leading-edge roughness should be utilised to ensure turbulent flow over the propeller blades as recommended for conventional propeller cavitation tests, as described in the document 7.5-02-03-03-.2 in section 5.

2.3 Propulsor Model Accuracy

The test must be performed with a strictly scaled, complete podded propulsor model unit with or without a hull model or a shortened hull model. The size of the propulsor should be such that the highest possible Reynolds Number $\Re_{0.7}$ is achieved within an acceptable level of test-section blockage and within the capacity constraint of the test facility. For the level of blockage, based on a general rule, it is recommended that the ratio of the maximum cross section area of the propulsor/hull model to that of the measuring section of 0.2.

The geometry of the whole propulsor model (including its housing and other components e.g. fin, flap, duct etc.) is to be inspected prior to testing. This should include a visual inspection for nicks and local damage and subsequent repair. Manufacturing accuracy should be verified to ensure that the geometry is within prescribed manufacturing tolerances. For the case of a controllable pitch propeller the adjusted pitch must be carefully verified. Effort should be made to ensure that the whole propulsor model does not deform under test operating conditions beyond what would be expected to occur at full-scale.

A propeller diameter tolerance of +/- 0.1mm for a typical 250 mm diameter propeller is considered is acceptable. Tolerances for stationary parts of the propulsor unit are expected to be similar to the diameter tolerances. For all of the other tolerances, such as leading edges, refer to the ITTC Recommended Procedure 7.5-01-02-02 .

2.4 Wake Simulation

The wake simulation adopted for the tests should be mutually established between the testing organization and the customer. More realistic wake simulations will produce representative cavitation, but often require larger facilities or more complicated test configurations. Facility experience is an important consideration, due to the often lengthy iterative procedures required to develop new wake generation techniques.

All wake field simulations shall comply with ITTC Recommended Procedures and Guidelines, 7.5-02-03-02.5: Experimental Scaling of a Wake to a Target Wake, which describes guidelines for experimental wake scaling and simulation. These simulations shall also be documented with wake survey procedures or verified to be similar to the towing tank wake or previously measured configurations. Nominal wake surveys are generally performed although determination of the effective wake, including the influence of the propeller is preferred, but difficult to determine.

Section 2.4 of ITTC-Recommended Procedures (7.5-0.2-03-03.1) describes the wake simulation for conventional propellers with “Open shaft and strut Configurations” and “Single screw configurations”. The podded propulsors are designed to operate either in the “pulling” or “pushing” mode. The pulling (or tractor) type podded drive systems have flow similarities with the conventional open shaft and strut configurations while the pushing type podded drives are similar to the conventional single screw configurations. Within this framework the following recommendations are made for these two configurations.

2.4.1 Pushing configuration

In this configuration boundary layer flow in which the propeller operates is dominated by the geometry of the pod housing as well as the hull for some cases, particularly for a classical single screw afterbody. Therefore, the wake will show strong velocity deficit contours in the top sector of the propeller plane, in general stronger than for conventional single screw ships. This will be further complicated by strong variations in the transverse and radial velocity component distributions which will adversely influence propeller cavitation. This implies that the scale effects in the model wake will play an important role in the simulation of the full scale wake and thus much attention should be paid to create sufficiently high turbulence of the flow over the pod housing. In these circumstances testing at an as high as possible Reynolds number and means to stimulate turbulence (e.g. artificial roughening of the pod housing etc.) are recommended.

As for the simulation of the hull wake the reader may refer to the recommended procedures (7.5-0.2-03-03.1) for conventional drives which include several options e.g. parallel plate/variable density screen wake generators, foreshortened/full length complete hull models etc.

2.4.2 Pulling configuration

This configuration is less complicated compared to the pushing one. This is because the propeller operates in a more or less uniform flow with possibly some effect of the hull boundary layer at the top sector of the propeller plane and with a certain blockage effect of the pod housing behind the propeller. The presence of the model pod housing behind the propeller is believed to be sufficient for a good simulation of the blockage of the full-scale propeller. It is also believed that the magnitude of the scale effects associated with the propulsor housing is smaller compared to the pushing configuration due to increased turbulence caused by the propeller flow.

In the case that the propeller is outside the hull boundary layer, the wake is dominated by the inclination of the flow to the propulsor shaft line and the blockage effect of the pod housing. Therefore, the compliance with these requirements (i.e. presence of the properly scaled propulsor housing with proper alignment relative to the flow) should be sufficient to create a good wake simulation.

If part of the propeller operates in the hull boundary layer, the resulting axial wake deficit may contribute to cavitation. This will require one of the above-mentioned options to simulate the model-scale hull wake properly, in addition to the other requirements.

2.5 Calibrations

In the following the basic calibrations are listed that are to be performed as part of the preparation and set up of the cavitation test. It is recalled that all the sensors used for an experimental campaign have to be properly calibrated and linked to National Measurements Standards before and/or during the tests. A check of calibration is sometimes performed at the end of the test campaign to ensure that no drift happened during the tests.

Pressure gauges used to measure static and differential pressure should be calibrated to a recognised acceptable standard within an established time period prior to the test. Pressure gauge calibration checks during the test are recommended by varying the tunnel static pressure.

Thrust and torque dynamometer load response calibration should be carried out with applied loads that are traceable to a recognised acceptable standard. Calibrations should be performed within an established time period prior to the test. The long term stability of the calibrated data needs to be confirmed.

Thrust and torque correction loads are to be measured for the bare hub operated at the pressure, rotational velocity, and flow velocity determined for each test condition.

Establish instrument zeros for the thrust and torque measurement accounting for "friction" effects of internal friction and gearing as the shaft rpm approaches zero.

The torsional or lateral vibrations of the propulsor shaft and housing may have an influence on the steadiness of the cavitation on blades, other parts of the propulsor and the said level of pressure fluctuation. Attention should be paid to the vibration level of the propulsor and shaft at each test condition. Propeller and shaft balancing is highly recommended to reduce excessive vibration.

2.6 Test Measurements

Measurements of the following are to be made during the cavitation test. Recording of the quantities below should be in a fashion that is consistent with the facility's specified uncertainty levels.

- Propulsor (unit) thrust and/or torque
- Shaft rotational speed
- Facility flow reference velocity
- Pod angle
- Static pressure
- Temperature
- Air content, water quality measurement
- As evoked previously, a complete description of general cavitation tests could be found in ITTC-Recommended Procedure (7.5-0.2-03-03.2). All the instrumentation for a visual description of the cavitation and for the measurements of cavitation events and inception are described.

3. PARAMETERS LIST

3.1 Data Reduction Equations

Thrust coefficient

$$K_T = \frac{T}{\rho n^2 D^4}$$

Torque coefficient

$$K_Q = \frac{Q}{\rho n^2 D^5}$$

Advance coefficient

$$J = \frac{V_A}{nD}$$

Propeller Reynolds number at 0.7R

$$Re_{0.7} = \frac{c_{0.7}\sqrt{V_A^2 + (0.7\pi D)^2}}{\nu}$$

Vapour Cavitation number σ_v

$$\sigma_v = \frac{(p_A - p_v)}{\frac{1}{2}\rho V^2}$$

where, V = representative speed: V, V_A, nD, ωr, or $(V_A^2 + \omega^2 r^2)^{1/2}$

3.2 Definition of Variables

D	Propeller diameter	(m)
R	Propeller radius	(m)
$c_{0.7}$	Chord length at 0.7R	(m)
ρ	Mass density	(kg/m^3)
ν	Kinetic viscosity	(m^2/s)
T	Propeller thrust	(N)
Q	Propeller torque	(N·m)
n	Propeller frequency of revolution	(Hz)
ω	Propeller rotational velocity	(rad/s)
V_A	Propeller advance speed	(m/s)
p_A	Ambient pressure (representative static pressure at point of interest) as defined in detail in the Procedure 7.5-02.03.03.1 section 2.11	(Pa)
p_V	Vapour pressure of water	(Pa)
t_W	Water temperature	(°C)
α	Gas content	(ppm)

4. REFERENCES

Carlton, J. S. (2007), "Marine Propellers and Propulsion",Second edition, Elsevier.

Islam, M.-F., Veitch, B. & Liu, P. (2007), "Experimental research on Marine podded propulsors", Journal of Naval Architecture and Marine Engineering **4**:57—71.

Kim, S.-H., Choo, S.-H., Park, J.-Y. & Choi, G.-H. (2015), "Numerical simulation of cavitation phenomena for hybrid contra-rotating shaft propellers", 9th Int. Symposium on Cavitation CAV2015.

Lidtke, A. K., Lloyd, Th., Lafeber, F. H. & Bosschers J. (2022), "Predicting cavitating propeller noise in off-design conditions using scale-resolving CFD simulations", Ocean Engineering **254**:111176.

Putoshny, A.V., Kaprantsev, S.V. (2001), "Azipod propeller blade cavitation observation during ship maneuvering", International Symposium on Cavitation CAV2001.

Sampson, R., Atlar, M., Sasaki, N. (2009), "Cavitation analysis of a double acting podded drive during ice milling", 7th International Symposium on Cavitation CAV2009, Ann Arbor, Michigan USA.

Sampson, R., Atlar, M., St John, J.W. & Sasaki, N. (2013), "Podded propeller ice interaction in a cavitation tunnel", 3rd International Sympösiium on Marine Propulsors SMP'13, Launceston, Australia.

Shen Y.T., Gowing S. and Jessup S. (2009), "Tip vortex cavitation inception scaling for high Reynolds number applications". Journal of Fluids Engineering, Vol. 131.

Ye, J.M., Xiong, Y. (2008), « Prediction of podded propeller cavitation using an unsteady surface panel method". J. Hydrodyn. 20, 790—796.

5. KEYWORDS

TTC; Guideline; Procedure; Cavitation; Experiment; Pod; Podded propulsor; Model scale.