ITTC Quality System Manual

Recommended Procedures and Guidelines

Procedure

Model – Scale Cavitation Test

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Model - Scale Cavitation Test

1. PURPOSE OF PROCEDURE

To ensure consistent, reliable model-scale cavitation test results, comparable amongst ITTC organizations.

2. 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 propeller velocity and static pressure field. Exact simulation is not achievable due to insufficient knowledge of the actual full-scale flow field and simulation approximations due to Reynolds Number, Froude Number, and non-geosim hull representations.

All tests are intended to achieve geometric similitude of the propulsor. Therefore, the propeller model must have sufficient material strength and geometric accuracy at the specified test conditions to ensure sufficiently accurate results.

2.2 Propeller Operating Conditions

The propeller operating conditions investigated should be mutually established between the testing organization 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, or
- towing load,
- trial and service condition.

The detailed test parameters required for setting test conditions are taken from the results of model powering tests, scaled to the ship self-propelled powering points. These are typically obtained from towing basin powering experiments. The propeller is tested at a prescribed set of parameters: cavitation number, σ, advance coefficient, J_A, and thrust coefficient, K_T. At a particular propulsion operating point, the procedure for setting the tunnel flow conditions to achieve a model simulation of this operating point is usually made on the basis of the "thrust identity." In the absence of thrust data or by special request, a cavitation test will be run at a "torque identity" condition, satisfying a target full-scale torque coefficient value. When testing in a depressurized towing tank, conditions can be set based on propeller rpm and tow speed, from a previously conducted powering test performed with a geosim model.

The choice of propeller rpm and tunnel speed should result in sufficiently high blade Reynolds Number as to avoid adverse effects of blade laminar flow on cavitation. If low blade Reynolds numbers cannot be avoided, such as when following Froude scaling in a depressurized towing tank, then artificial leading edge roughness can be utilized to ensure turbulent flow over the propeller blades. For typical model size, 60 μm distributed roughness can be applied to the blade leading edges. Care must be taken to account for effects of artificial roughness on propeller thrust and torque. Alternatively, tests can be conducted at model speeds higher than Froude scale

In a depressurized towing tank, to compensate for the deficiency in number of cavitation nuclei at model scale, a cloud of tiny gas bubbles is generated upstream of the propeller by means of electrolysis of the tank water. To this purpose a cathode and an anode are glued to the ship model in the form of metal strips of 0.5 mm thickness and 3.5 mm wide.

2.3 Propeller Model Accuracy

The geometry of the propeller model 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 the geometry is within prescribed manufacturing tolerances. For the case of a controllable pitch propeller the selected pitch must be carefully verified. Effort should be made to ensure the propeller model does not deform under test operating conditions beyond what would be expected to occur full-scale.

Blade surface global tolerance of ±0.05 mm for a typical 250 mm diameter propeller is considered acceptable. Leading edges and tip edges require a higher level of accuracy, which is very difficult to manufacture and inspect. The 23rd ITTC Propulsion Committee has initiated planning of an ITTC QM procedure addressing this topic.

2.4 Wake Simulation

The wake simulation adopted for the tests should be mutually established between the testing organization and the customer. 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. More realistic wake simulations will produce more 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. Wake simulations shall be documented with wake survey procedures or verified to be similar to the towing tank wake or to previously measured configurations especially when a dummy model is used to simulate the propeller inflow. Nominal wake surveys are generally performed, although determination of the effective wake, including the influence of the propeller is preferred, though difficult to determine. Measurement of the wake can be performed by using any suitable velocimetry techniques. When using Pitot tube or laser Doppler Velocimetry, ITTC procedures should be adopted. The degree of difficulty in achieving a sufficiently representative wake flow depends in part on the type of ship hull involved.

2.4.1 Open Shaft and Strut Configurations

Wakes for combatant hulls with open shaft and struts are relatively simple to simulate if the propeller operates outside the hull boundary layer. In that case, the wake is dominated by the flow inclination angle to the shaft line. Inclined shaft tunnel set-ups with geosim shaft and strut configurations create a reasonably good wake simulation. The wake is predominately a variation in the tangential inflow. This velocity distribution can only be approximated with wake screens, which produce axial wake variation. An appropriate propeller unsteady performance analysis can be used to match the unsteady blade loading for the specified inclined flow wake. If part of the propeller operates in the hull boundary layer the resulting axial wake deficits may contribute to cavitation. Prior to testing, wake survey data can be used to assess its importance.

Significant wake complexity may require a full hull model to properly simulate the flow, however this wake would be at model scale and not corrected for higher *Re*.

2.4.2 Single Screw Configurations

Wakes of propellers operating well inside the hull boundary layer, such as single screw ships, often have deep velocity deficit contours, and also often have complexities present in the tangential and radial velocity component distributions that influence propeller cavitation. Options for model wake simulations for these types of hull forms are:

- parallel plate wake generator,
- variable density screen wake generator,
- foreshortened hull model,
- full-length, complete hull model.

Three dimensional wake simulations are preferred over two dimensional screen type wake generators.

2.5 Calibrations

The following is a list of the basic calibrations that are to be performed as part of the preparation and set up of the cavitation test.

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 static tunnel pressure.

Thrust and torque dynamometer load response calibration. It 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.

Thrust and torque correction loads are to be measured for the bare hub operated at the pressure, rpm, 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 model propeller shaft may have an influence on the steadiness of the cavitation on blades and the level of the pressure fluctuation. Attention should be paid to the vibration level of the shaft at each test condition. Propeller and shaft balancing is 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.

- Propeller shaft thrust and torque
- Shaft rotational speed
- Facility flow reference velocity
- Static pressure
- Temperature, the thermometer for the measurement of the water temperature should have an accuracy of not less than 0.1° C.
- Air Content, Water quality measurement

2.7 Propeller Model Markings

Marking is made on certain model components to facilitate the interpretation of cavitation extent and location as follows:

- Paint or mark blade numbering on each side of each blade

- Paint or mark along constant radius lines at selected *r/R* values, suction side (SS) and pressure side (PS), typically at 0.5, 0.7, and 0.9 radius
- Paint or mark the midchord line and/or the reference line, SS and PS
- Mark the hub and bossing to help determine a blade position angle.
- Blade position angle

Great care must be exercised to use very thin painted or marking pen lines to avoid providing artificial sites for initiation of sheet, bubble or streak cavitation.

2.8 Water Quality

An important part of the test set-up phase is to know the water quality of the test facility. This includes some knowledge of the nuclei size distribution/liquid tension as well as dissolved gas content. Previous measured nuclei distributions/liquid tension data can be correlated to on-line gas contents in most facilities to estimate water quality during cavitation testing. Systematic procedures must be implemented to consistently achieve a given water quality before testing. Cavitation inception curves should be correlated for water quality effects, as discussed in the report of the 23rd ITTC Specialist Committee on Water Quality.

More specific guidance on recommended air content levels may be obtained from a summary of survey results conducted by the 23rd ITTC Specialist Committee on Cavitation-Induced Hull Pressure Fluctuations. (Procedure No 7.5-02-03-03.3)

2.9 Cavitation Viewing

Both blade suction side (SS) and pressure side (PS) of the blades must be viewed. Options for the mode of observations could include viewing through ports in the tunnel walls, with video cameras located in pods positioned beside the hull near the propeller location, or through ports in the hull located close to and over the propeller. Sufficient lighting must be supplied to get the best possible observations and records of all blade cavitation. Stroboscopic lighting is needed to capture and freeze images of chosen blade passages at positions throughout the cavitating region of the disk. Back lighting can often illuminate cavitation inception, which cannot be seen with front lighting.

2.10 Setting Static Pressure at Propeller

The representative static pressure at the propeller, p_A, is selected to match the full-scale cavitation number. The full scale static pressure at the propeller is typically determined from the still water submergence depth. In some cases, when a large stern wave occurs at the propeller location, this additional hydrostatic head is taken into account.

When operating at Froude scaled speeds, as occurs in a depressurized towing tank, the selected static pressure results in equivalent full scale cavitation numbers at all water depths.

In water tunnel testing, generally, Froude numbers are not satisfied, preferring to operate propellers at as high a Reynolds number as possible. Consequently, full scale cavitation numbers are only matched at one depth. If cavitation predominately occurs at a vertical location other than shaft depth, then another vertical location can be selected. Often the cavitation occurs near the blade tip, at the top of the disk, in such case, a location of 0.8 to 0.9*R* at the top of the propeller disk would selected to match model and full scale cavitation number. The location in the propeller disk at which the representative static pressure is satisfied should be clearly stated in the test report.

2.11 Selecting Representative Velocity, V_0, for Computing Cavitation Number

A number of options are used to define the representative velocity, V_0, used in the computation of the cavitation number. Typical velocities are V, V_A, nD, ωr, and $(V_A^2 + \omega^2 r^2)^{1/2}$ where r is propeller radius. Propeller angular speed is often used for controllable pitch propellers. The representative velocity should be clearly stated in the cavitation test report.

2.12 Cavitation Inception Test

This experiment consists of plotting observed cavitation points in a diagram of cavitation number (σ) versus advance coefficient (J_A) or thrust coefficient, K_T. Points for the same type of cavitation are connected to determine inception boundaries of each form of cavitation. At least three inception points should be determined to describe an inception curve. More inception points will reduce the uncertainty in definition of the inception curve.

The tip vortex cavitation inception for model propellers should be Reynolds Number scaled. Scaling of other forms of cavitation is not considered routine, and would require justification supported by credible data.

Cavitation inception should be called by experienced personnel in a consistent fashion. Inception is observed when an event is seen at a given interval, such as 1 or 10 seconds between events. Care must be taken if the interval between events is too long, to distinguish real from random events. Calls can be made on a set number of blades, i.e., a majority of blades, or on one blade. Care should be taken with first blade calls due to possible effects of geometric flaws. Determining dissidence of cavitation can be an acceptable alternative to inception determination. Inception criteria should be stated in the cavitation report.

Since the first form of cavitation occurring at model scale may not be the case full scale, care should be taken when using acoustic inception, since it only can be used to detect the first form of cavitation to occur.

2.13 Reporting Cavitation Patterns

Adequate reporting of model cavitation patterns should include some or all of the following:

a) display of still photographs or sketches of suction side and pressure side cavitation for all the pertinent blade positions;
b) notes as to the character of the fluctuations and unsteadiness associated with the patterns;
c) video presentation of both suction side and pressure side cavitation;
d) display of any special cavitation regions such as at blade roots, hub cavitation, or induced rudder cavitation; and
e) discussion and interpretation of each cavitation type encountered and range of accuracy. When using still photography, at least three photographs of each condition are recommended to document the level of cavity fluctuation.

3. PARAMETERS

3.1 Basic Measurement Quantities

D propeller diameter
n rotational velocity, rev/s, (ω, rad/s)
p_A representative static pressure at propeller (Sec. 2.10)
Q propeller torque
T propeller thrust
t water temperature
V_T tunnel velocity
Air content or measure of cavitation susceptibility

3.2 Derived Parameters

J advance coefficient
K_Q torque coefficient
K_T thrust coefficient
p_v vapour pressure
V ship speed
V_A advance velocity
V_0 representative speed: V, V_A, nD, ωr, or $(V_A^2+\omega^2 r^2)^{1/2}$ (Sec 2.11)
σ cavitation number,
$\sigma_v = (p_A - p_v)/((1/2)\,\rho(V_0^2))$

3.3 Recommendations of ITTC for Parameters

ITTC recommendations for the various parameters above are contained within the body of this procedure, section 2.

4. VALIDATION

4.1 Uncertainty Analysis

The 20th ITTC (1993) presented a list of the critical issues of scale effects, both with the fluid dynamics and the bubble mechanics that must be confronted directly in any attempt at estimating errors for a given experiment.

4.2 Benchmark Tests

1) Comparative Propeller Tests (7th 1955 pp.129-216)

The Completion of the Full Programme of Tests in One Tunnel

The Tests of At Least One Model Propeller in Each of the Eight Tunnels

The Completion of the Open-Water Tests of All the Model Propellers In Ship Tanks Measurement of All the Model Propeller, Including Surface Finish Propeller Models from 8 to 18 Inches Diameter at Reynolds' Number from 1.5 to 7.5 million

1.1) Cavitation Tunnel Tests of Series 1 Propellers (7th 1955 pp.131-135) Parent Model AEW/C2 (Diameter 9-12-15-18)

1.2) Cavitation Tunnel Tests of Series 2 Propellers (7th 1955 pp.135-168)
3-Bladed Propeller; The Developed Blade Area Ratio 0.655,
The Pitch Diameter Ratio 1.333
Constant Ogival Sections with Sharp Leading Edges
The Design Advance Coefficient J=0.925

1.3) Cavitation Tunnel Tests of Series I 12 Inch Propellers and Series III 12 inch Propellers (7th 1955 pp.169 - 189)
Series I: 12 Inch Propeller in All Tunnels
Series III: 12 Inch Propeller in Tunnels
Tunnel Wall Effect: less than 0.14

Open Water Tests of Model Propellers (7th 1955 pp.190 -199)
Series I: Tested in No.2 Ship Tank Haslar
Series II: Tested at Carderock
Series III: Tested at Gothenburg

1.5) Tolerance and Surface Finish of Model Propellers (7th 1955 pp.200-216)

2) Cavitation Inception on Head Forms Comparative Experiments (11th 1966 pp.170)

2.1) Cavitation Inception on Head Forms ITTC Comparative Experiments (11th 1966 pp.219-232)

a) Cavitation Number for Cavitation Inception on the Body

b) Cavitation Number when Bubbles are Clearly Visible in the Test Section in Front of the Body i.e. when the Resorption Power of the Tunnel is No Longer Sufficient.

3) ITTC Standard Screw Cavitation Tunnel Tests at Brodarski Institute (12th l969 pp.523-525) 228.6 mm Diameter

4) Nuclei Measurement and "Standard Cavitator" (13th 1972 pp.642-646)
4.1) Air Content- and Nuclei Measurement
4.2) "Standard Cavitator"

5) Comparative Hydrofoil Experiments and Development of a Standard Cavitator
(14th 1975 Vol.2 pp.76-93)
(1) Results of Tests with Three-Dimensional 19-012 and 16-1512 Hydrofoils in Different Cavitation Facilities
(2) Progress in the Development of a 'STANDARD CAVITATOR’

6) Appendix A (Hydrofoils) (15th 1978 pp.340-347)
Foil F: Symmetrical Profiles NACA 19-012
Foil G: Cambered Profiles NACA 19-1512

7) Comparative Tests with the Foil-Head form Combination (16th l981 pp.420-424)

8) Comparative Noise Measurements with the Sydney Express Propeller Model
(16th 1981 pp.447-453)

9) Comparative Tests on Soft Surface Techniques (16th 1981 pp.436-443)
The SSPA Stencil Ink Method, Modified by SRI-MHI Test Procedure

10) Comparative Tests with Foil-Headform Combination (17th 1984 pp.245-248)

11) Comparison of Hull Pressure Amplitudes for Sydney Express Propeller
(17th 1984 pp.248-252)

12) Comparative Erosion Tests with Propeller Model (17th 1984 pp. 252-255)

13) Comparative Noise Measurement with Sydney Express Propeller Model
(17th 1984 pp.255-256)

14) Comparative Cavitation Observations on Propeller with and without Leading Edge Roughness (18th 1987 pp.207 -208)
Model Propeller; NSMB Model 6091, as the '18th ITTC Propeller'

15) Comparison of Propeller-Induced Hull Pressure Measurements for the "SYDNEY EXPRESS" Propeller Models
(18th 1987 pp.209-210)

16) Comparative Noise Measurements with "SYDNEY EXPRESS" Propeller Models (18th 1987 pp.210~-211)

17) Cavitation Nuclei Measurements
(19th 1990 pp.166-175)

Propeller-Induced Hull Pressures
(19th 1990 pp.182-187)

Further Measurement of Pressure Fluctuation on 'SYDNEY EXPRESS' Propeller
(19th 1990 pp.213-219)

20) Joint Bassin d’Essais des Carènes and Cavitation Committee Tests (20th 1993 pp.206-213)
Measurement of Liquid/Nuclei Distribution Determination of Cavitation Inception Scale Effects.
Minimizing the Liquid Tension in a Water Tunnel or Towing Tank.

21) 20th ITTC Comparative Model Measurements (20th 1993 pp.230-231)
Measurements on German Tanker "St. Michaelis" and the "Sydney Express"

21.1) Comparative Measurement of Pressure Fluctuation on "St Michaelis" (20th 1993 ~pp.236-240)

22) Measurements of Hull Pressure Fluctuation (21st 1996 pp.65-69)