8. MODEL PROPELLER TESTS

Model propeller tests can be categorized in four groups:

1. Open water tests
2. Self propulsion tests
3. Cavitation tests
4. Others (wake surveys, hull pressure tests, noise measurements, etc.)

a) Open Water Tests

Open water tests of propellers can be performed either in a cavitation tunnel or in a towing tank. Although the test procedure applied to obtain open water characteristics of a propeller in a cavitation tunnel is different from those in a towing tank, these characteristics are the same used in the analysis of the Propulsion Tests and the estimation of the required power.

Non-dimensional terms expressing the general performance characteristics are:

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

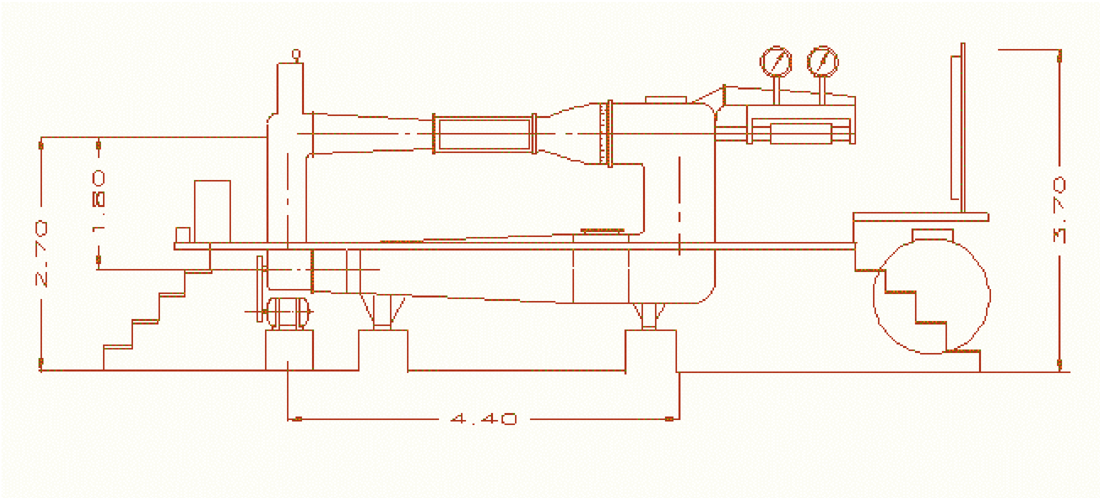
Torque coefficient $$K_Q = \frac{Q}{\rho n^2 D^5}$$

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

Open water efficiency

$$\eta_0 = \frac{P_T}{P_D} = \frac{TV}{2\pi Q n} = \frac{K_T \rho n^2 D^4 V}{2\pi K_Q n^2 \text{"} D^5 n} = \frac{K_T}{2\pi}\frac{V}{nD}\frac{1}{K_Q} = \frac{K_T}{K_Q}\frac{J}{2\pi}$$

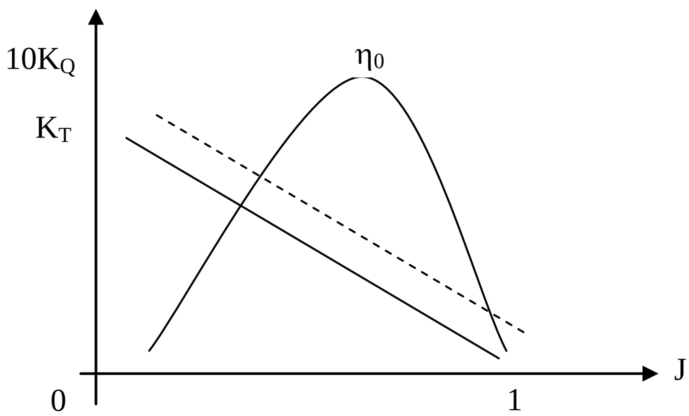
i. Cavitation tunnel



A typical cavitation tunnel (Ata Nutku Cavitation Tunnel)

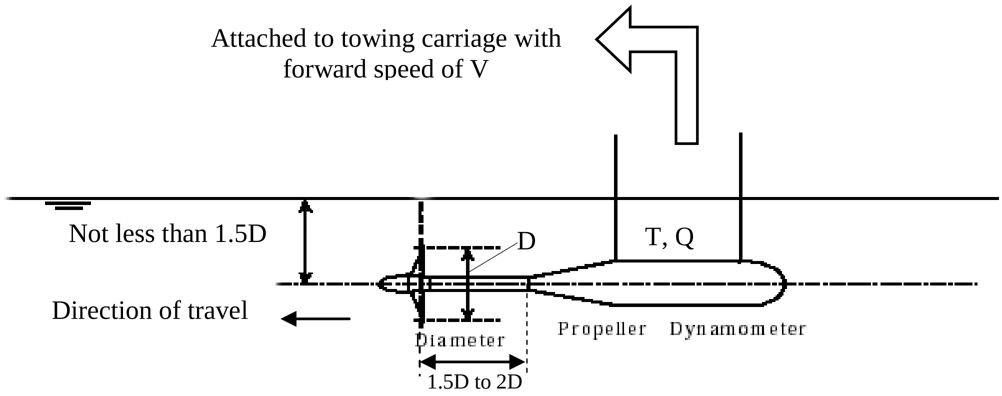
In a cavitation tunnel the procedure is applied as follows:

1. The range of measurements should cover tested propeller operating range in terms of advance coefficient, J, such that the advance coefficient, J, should be varied form 0 to 1.
2. In general the tunnel water; V, is kept constant while the propeller rate of rotation, n, increases or vice versa.
3. In each run the water velocity, propeller rotation, thrust, torque values are recorded.
4. If any cavitation occurrence on the propeller blades is observed, it will be recorded.
5. The above coefficient are obtained analysing the test results and plotted as in the below figure.



ii. Towing tank

In a towing the model propeller is run without any hull ahead of it, as shown in the figure.



Typical set up for open water tests in a towing tank

The drive shaft housing should not be too close to the model propeller blades. A distance of not less than 1.5 D to 2.0 D is recommended, where D is the propeller diameter. The drive shaft should be arranged parallel to the calm water surface and the carriage rails. A typical set up is shown in the above figure.

The propeller immersion has to be selected such that air drawing from the water surface is avoided at any test condition. As a guideline, an immersion of the propeller shaft of at least 1.5 D is recommended.

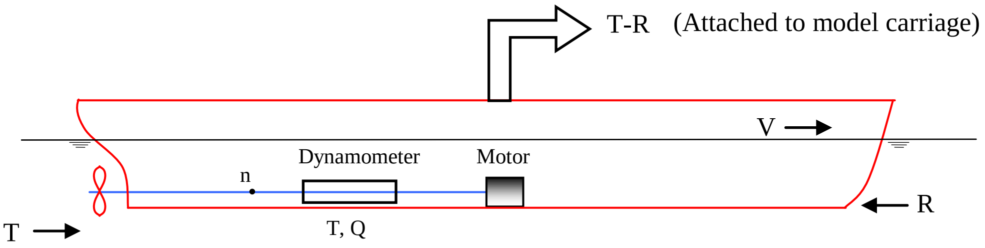
The test procedure is as follows:

1. The propeller advances through undisturbed water with a known forward speed, V, which is the speed of the towing carriage. Values of thrust, T and torque, Q are taken from the dynamometer, and rate of rotation, n is recorded using a tachometer.
2. Usually measurements are taken during series of runs for T & Q at varying J numbers so that n is kept constant and V is varied from zero speed (i.e. J=0) to a high value ($\approx$J=1).
3. The results are analysed and coefficients are derived as similar to those in cavitation tunnel.

b) Self Propulsion Tests

Self propulsion tests are carried out to estimate ship power at various speeds and to derive propulsion factors, w_t, t, η_R.

The hull model is equipped with an electric motor mounted inside the hull and respective devices (dynamometer) fitted inboard to enable the measurement of thrust, torque and rate of revolutions of the model propeller(s). Appendages, such as rudders, single brackets or A-brackets, propeller shafts, shaft protection tubes, short bossings or bossings, extracted stabilisers and openings in the hull such as for bow thrusters, should be in the same condition as for the resistance experiment.



The size of the propeller/propulsion unit model for propulsion tests is determined automatically by the size of the ship model and its scale ratio; this in turn means that the size of the model propeller, or say a stock propeller, is also to be taken into consideration when the scale for a ship model is selected.

During a self propulsion test, an external tow force in propulsion experiments should be applied along the same line of action as the tow force in the resistance experiment. This external force comes from the skin friction correction such that the skin friction coefficient of the model C_{Fm} is greater than skin friction coefficient of the ship, C_{Fs}.

Three test procedure for the self propulsion tests are available:

1. Load varying (or constant speed) method
2. Constant loading method
3. Mixed loading method.

1. Load varying (or constant speed) method

Before beginning each test the model speed and the desired propeller loading should be selected Repeat runs at the same speed should be made at different loadings and the whole series of runs then repeated at each of the speeds within the test range.

The loading range should extend from the lowest to the highest load factors at which ship performance estimates are required, providing always that this range includes a load factor of unity. It is further recommended that, in all cases, the loading should cover the condition of model-self-propulsion (zero tow force).

2. Constant loading method

Before beginning each test the model speed should be selected and the corresponding external tow force at the set loading computed. The computed skin friction correction force (F_D) is then applied to the model hull as an external assisting tow force which will be kept constant for all tests. Repeat runs should be made at each of several speeds. The speed range should extend from the lowest to the highest speeds at which propulsion data are required. An extension of the speed range of at least 5% below and above the lowest and the highest speeds is recommended.

3. Mixed loading method.

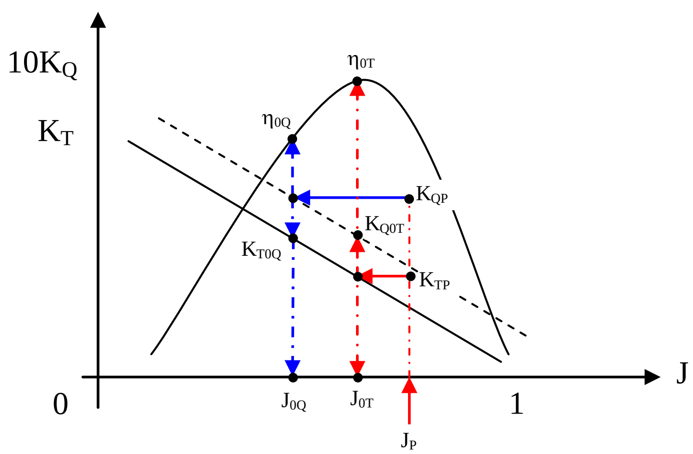
Combinations of the load varying (constant speed) and constant loading methods may be used. For example, a speed variation at constant (or close to constant) loading may be used, together with a supplementary load-variation test at one speed.

Analysis of Propulsion Factors

Thrust, torque, rate of rotation and speed of hull are measured during self propulsion tests. These values are used to derive propulsion factors. Ship model resistance values including appendages and open water characteristics of the same stock propeller are also required for the derivation of these factors. The analysis can be carried out in two ways:

1. Thrust Identity Analysis

Advance coefficient, J_P, are obtained from self propulsion test and the corresponding thrust coefficient K_{TP}, are calculated. From the open water diagram at the same thrust coefficient, K_{TP}, corresponding J_{0T}, K_{QT} and η_{0T} are read off.



Thrust identity wake fraction is then:

$$w_{tT} = \frac{J_P - J_{0T}}{J_P}$$

where subscript P denotes the value obtained from the self propulsion test and subscript 0 denotes the value obtained from open water test.

Thrust deduction fraction, t is obtained as:

$$t = \frac{T_{TP} + F_D - R_m}{T_{TP}}$$

Hull efficiency is as follows:

$$\eta_H = \frac{1-t}{1-w_{tT}}$$

Thrust identity relative-rotative efficiency

$$\eta_R = \frac{K_{Q0T}}{K_{QP}}$$

Propulsive efficiency η_D is then found:

$$\eta_D = \eta_{0T}\eta_H\eta_R$$

2. Torque Identity Analysis

Advance coefficient, $J_{P,}$ are obtained from self propulsion test and the corresponding torque coefficient K_{QP}, are calculated. From the open water diagram at the same torque coefficient, K_{QP}, corresponding J_{0Q}, K_{T0Q} and η_{0Q} are read off. The propulsion factors are calculated in the same manner as the thrust identity analysis.

Torque identity wake fraction is then:

$$w_{tQ} = \frac{J_P - J_{0Q}}{J_P}$$

where subscript P denotes the value obtained from the self propulsion test and subscript 0 denotes the value obtained form open water test.

Thrust deduction fraction, t is obtained as:

$$t = \frac{T_{TP} + F_D - R_m}{T_{TP}}$$

Hull efficiency is as follows:

$$\eta_H = \frac{1-t}{1-w_{Qt}}$$

Torque identity relative-rotative efficiency

$$\eta_R = \frac{K_{T0Q}}{K_{TP}}$$

Propulsive efficiency η_D is then found:

$$\eta_D = \eta_{0Q}\eta_H\eta_R$$

Both analyses should produce similar values.

c) Cavitation Tests

Model scale cavitation tests are routinely conducted in conventional cavitation tunnels, some with free surface simulation and, in 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 and Froude Number 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.

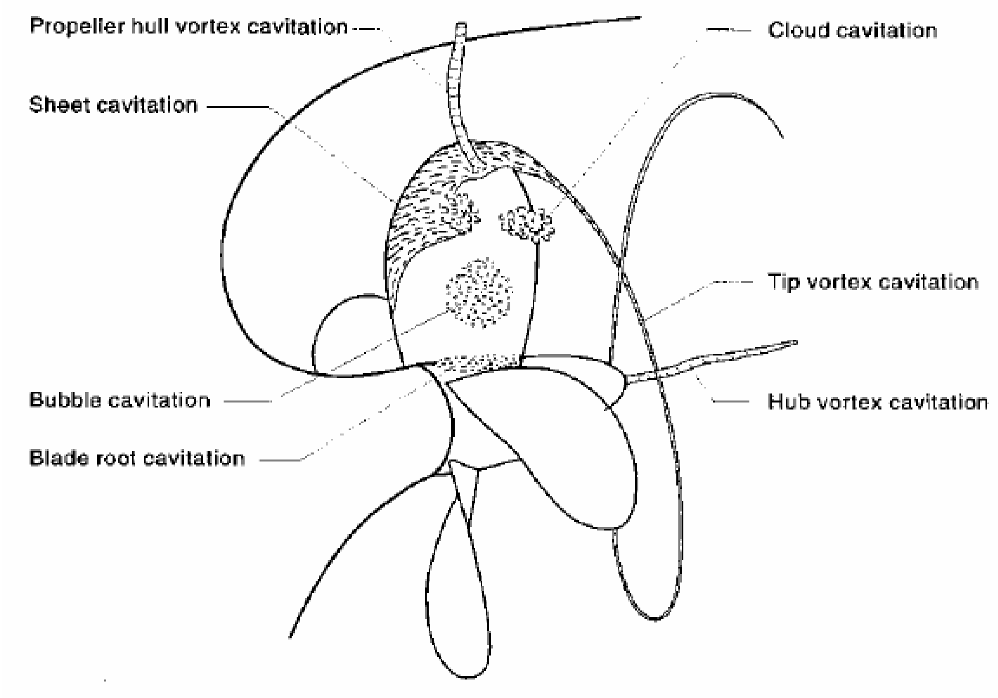
The propeller operating conditions investigated should be mutually established between the testing organization and the customer. The customer specifies the ship operating conditions of interest for the cavitation investigation. Some example conditions are:

- 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.

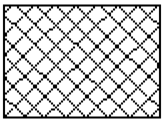
The propeller is tested at a pre-scribed set of parameters: cavitation number, σ, advance coefficient, J_A, and thrust coefficient, K_T. At a particular propulsion operating point, the procedure for setting the tunnel flow conditions to achieve a model simulation of this operating point is usually made 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.

It is standard practice in cavitation testing laboratories to include sketches or photographs of cavitation patterns in test reports. Descriptive terms are used to identify the various types of cavitation observed during tests, typified below figure.

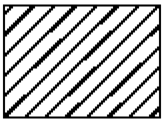


Description of cavitation appearances should contain information on cavity location, size, structure, and dynamics, as well as proper references to the prevailing flow dynamics. The number of alternative descriptions for cavity structure should be limited to the most commonly used.

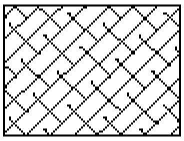
Hand drawn sketches of cavitation patterns are often used to describe cavitation in test reports. Schematic patterns are shown below for various cavitation types.



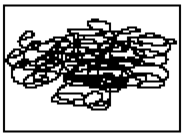
Stable sheet cavitation



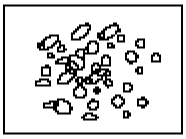
Temporarily unstable sheet cavitation



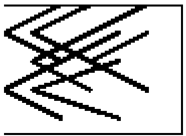
Unstable or fluctuating sheet cavitation



Cloud cavitation

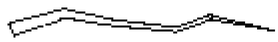


Bubble cavitation

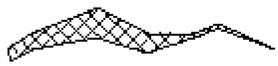


Streak cavitation

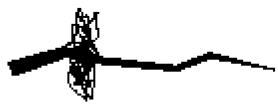
Thin stable tip/hub vortex cavitation



Unstable tip/hub vortex cavitation



Thick stable tip /hub vortex cavitation



Bursting vortex cavitation

The aim of cavitation tests is to observe the cavitation inception and development depending at the constant water flow velocity and the varying model propeller's rate of rotation. The procedure for the inception (first occurrence of cavitation) tests is such that

1. Constant amount of vacuum is applied to the tunnel.
2. Tunnel axial water velocity is kept constant.
3. Model propeller rate of rotation is increased until a visual appearance of the cavitation is observed, which is usually the tip vortex cavitation. The propeller speed is then decreased until the tip vortex cavitation is just flushing at the tip of the propeller. This point is accepted as the beginning of "unattached tip vortex cavitation.

During the cavitation tests, beside the unattached tip vortex cavitation, other types of cavitation can be observed and corresponding inception numbers are recorded.

During the start of every test the test conditions, such as atmospheric pressure, the water temperature in the tunnel and the oxygen concentration of tunnel water are recorded. The concentration of oxygen in the tunnel water can be measured by means of dissolved oxygen meters, Van slyke apparatus, holographic methods, etc.

The observation is usually performed by eye and the propeller is illuminated by a stroboscope which freezes the image of the cavitation development on the rotating propeller.