ITTC Quality System Manual

Recommended Procedures and Guidelines

Guideline

Podded Propulsor Model Scale Cavitation Test

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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.

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 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.

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 rpm and tow speed, from a previously conducted propulsion test performed with a geosim model.

The choice of propeller rpm and tunnel speed should result in sufficiently high blade Reynolds Number (a min value of 0.5×10^6 based on the blade chord length at $0.7R$) 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.

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 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 the testing facility should not be greater 0.25.

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.

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 to inspect. ITTC Recommended Procedure 7.5-01-02-02 is addressing the model propeller accuracy.

Tolerances for stationary parts of the propulsor unit are expected to be similar to the blade tolerances.

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 "pull" or "push" 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.

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, 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 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 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
- Static pressure
- Temperature
- Air content, water quality measurement

2.7 Propulsor Model Marking

Marking is made on certain model components to facilitate the interpretation of cavitation extent and location, mainly on propeller blades, but in some cases on other components of the propulsor unit, as follows:

- Paint or mark blade numbering on each side of each blade.
- Paint or mark along constant radius lines at selected r/R ratios, suction side (SS) and pressure side (PS), typically at 0.5, 0.7, and 0.9 radius.
- Paint or mark the mid-chord line and/or the reference line, SS and PS.
- Mark the hub and bossing to determine a blade position angle.
- Paint or mark a suitable grid, as recommended in Section 3.2, for the interpretation of the cavitation extent and location at other parts of the propulsor unit.

Great care must be exercised to use very thin paint 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 and distribution, liquid tension as well as dissolved gas content. Previously measured nuclei size and distribution / liquid tension data can be corrected 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 and Cavitation.

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 Observation

The whole propulsor including the suction side (SS) and the pressure side (PS) of the propeller blades as well as other components of the propulsor must be viewed, if required, at a prescribed range of azimuthing and flap angles, if the latter exist.

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

2.10 Setting Static Pressure at Propulsor

The representative static pressure at the propulsor, p_A, is selected at its propeller to match the full-scale cavitation number. The full-scale static pressure at the propeller is typically determined from the still water submergence depth and the additional hydrostatic head of the stern wave.

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

In water tunnel testing, generally, when Froude numbers are not satisfied, it is preferred to operate propellers at as high a Reynolds number as possible. Consequently, full scale cavitation numbers are only matched at one vertical location. If cavitation predominantly occurs at a vertical location other than shaft depth, then another vertical location can be selected. Often the cavitation occurs near the propeller blade tip, at the top of the disk; in such case, a location of 0.8 to 0.9R at the top of the propeller disk would be selected to match model and full scale cavitation numbers.

The location on the propeller disk or on another location of the propulsor at which the representative static pressure is satisfied should be clearly stated in the test report.

2.11 Selecting Representative Velocity for Computing Cavitation Number

A number of options are used to define the representative velocity, V_0, used in the computations of the cavitation number and the Reynolds Number. Typical velocities are V, V_A, nD, ωr, and $\left(V_A^2 + \omega^2 r^2\right)^{1/2}$ where r is the respective 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

Since a podded propulsor consists of propeller and other components, the inception of cavitation on the prominent locations of these components (e.g. strut leading edge, fore and tail end of pod body, flap and fin tips etc) will be of interest in addition to the inception of cavitation on the propeller blades.

This experiment consists of identifying the cavitation inception of each form of cavitation and of plotting observed cavitation inception points in a diagram of cavitation number, σ, versus advance coefficient, J. It will be of great interest to repeat the inception test for several prescribed pod azimuthing angles, δ, and/or flap angles if any movable flap exists. Points for the same type of cavitation are connected to determine inception boundaries of each form of cavitation concerned. 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 propulsors should be Reynolds Number scaled. Scaling of other forms of cavitation is not considered routine, and would require justification supported by credible data.

The cavitation inception test should be performed 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. For cavitation inception on blades, 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 at 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 concerning a podded propulsor 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 at specified azimuthing and/or flap angles, if the latter two are required.
b) display of still photographs or sketches of cavitation observed on other components of the propulsor (i.e. strut, pod body, fin, flap etc) at specified azimuthing/flap angles, if latter two are required.
c) notes as to the character of the fluctuations and unsteadiness associated with the above patterns;
d) video presentation of both suction side and pressure side cavitation on the blades and cavitation on other components of the propulsor unit relating them to each other (e.g. trajectories of blade tip vortex striking the strut, fin etc.)
e) display of any special cavitation regions on the propeller such as at the blade roots, hub (in pushing type) and on other parts of the propulsor such as pod body tail vortex, fin tip vortex etc.
f) 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. DESCRIPTION OF CAVITATION APPEARANCES

3.1 Introduction

Description terms used to identify the various types of cavitation observed during tests, typified in Figure 1.

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.

3.2 Descriptions

The following descriptive types of cavitation on each component of a typical podded propulsor (i.e. propeller, pod body, strut, flap and fin) are recommended:

- Vortex – attached and trailing detached; leading edge; hub (on pushing type); pod body tail (on pulling type)
- Sheet
- Bubble type – Large, small
- Streak
- Cloud
- Root/fillet

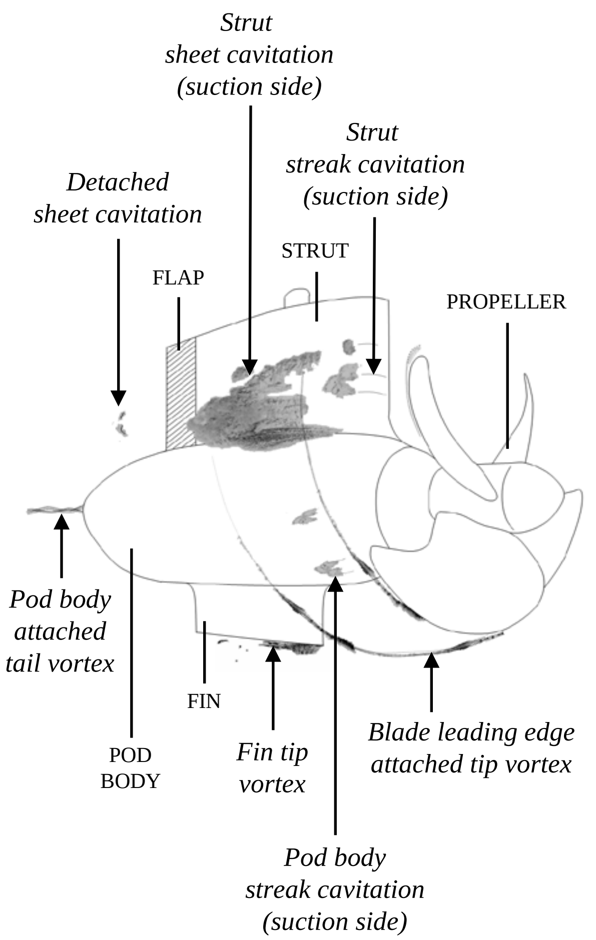

Figure 1. A representative pulling type podded propulsor at a high azimuthing angle and some cavitation types developed

Along with the categories mentioned above, information on cavity location should be specified. The same specification used for conventional propeller can be used for cavitation on the pod propeller which is described as follows:

- Propeller
  - Radial location
    - Fraction of tip radius
    - Blade tip
    - Root/fillet
    - Tip (duct) gap
    - Hub
  - Chordwise location
    - Fraction of chord

  - Leading edge
  - Trailing edge
- Suction side
- Pressure side
- Location in wake

For accurate location and extent of the cavitation to be developed on other parts of the propulsor, a suitable grid with required density can be marked on port and starboard side of the pod housing. A sample grid system based on "maximum strut length" is shown in Figure 2. Together with this, the following information can be used:

- Pod body, Strut, Flap, Fin
  - Chordwise and spanwise location
    - Fraction of chord and span
    - Leading edge and/or trailing edge
    - Top and/or bottom end
  - Suction side
  - Pressure side
  - Location in wake

Cavity size should be determined in terms of appropriate body dimensions of the respective component of the propulsor, if developed cavitation exists, e.g., defining the fraction of the area of propeller blade, fraction of the projected area of the strut/pod body/flap /fin etc which is covered by a certain type of cavitation.

Typical cavity types that are observed on a high speed podded propulsor model in a cavitation tunnel are shown in Fig 3 through 5.

Description of prominent types of cavitation (i.e. vortex, sheet, cloud, bubble etc) categorization of cavity dynamics (i.e. steady, unsteady, periodic etc.) and flow regime associated with certain cavitation phenomena (i.e. laminar/turbulent boundary layer, steady /unsteady flow, separated, ventilated etc) should be stated. The description should be as complete as possible

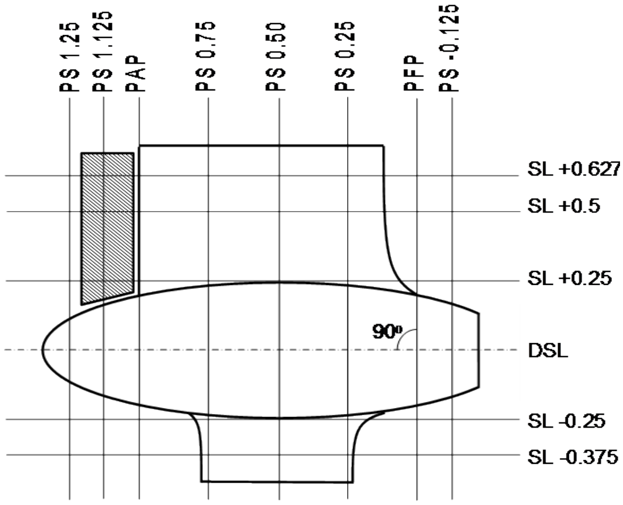

Figure 2. Sample grid definition to describe location and extend of cavitation on pod housing (to be applied on both sides of the housing)

All terms listed above relate to visual observations only. For other than visual observations techniques (e.g. High speed photography, video, acoustical methods etc) different terminologies apply.

Hand drawn sketches of cavitation patterns are often used to describe cavitation in test reports. For such schematic patterns as well as the above mentioned generic cavitation appearance issues, refer to ITTC Recommended Procedures 7.5-02-03-03.2

4. PARAMETERS

4.1 Basic Measurement Quantities

D propeller diameter
p_A representative static pressure at the point under consideration
n rotational velocity, rev/s, (ω, rad/s)
V_T tunnel velocity

Q propulsor torque
t water temperature
α air content or measure of cavitation susceptibility.

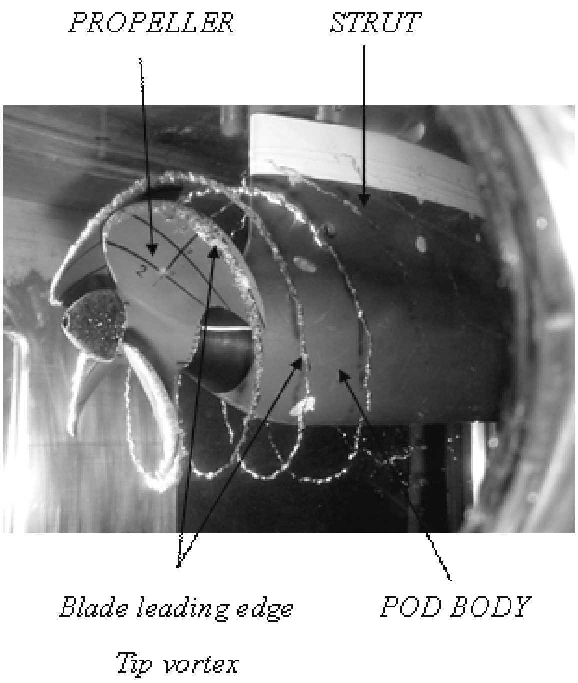

Figure 3. Attached blade leading edge tip vortex cavitation observed on a podded propulsor model set at 0° azimuthing angle

4.2 Derived parameters

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

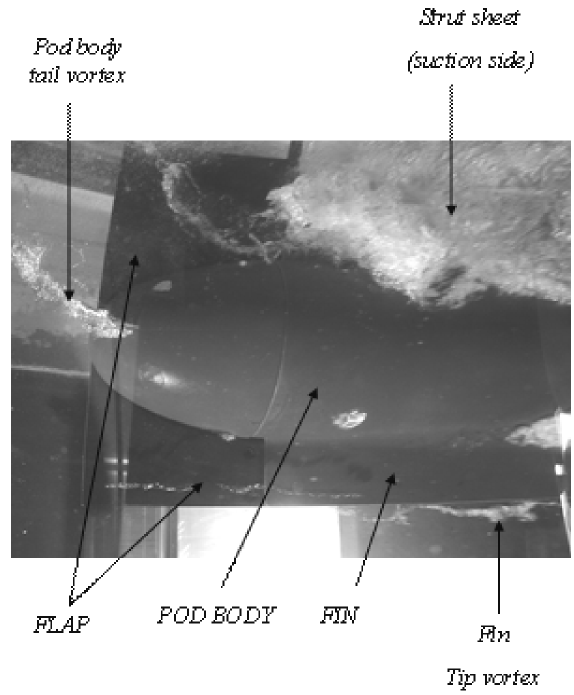

Figure 4. Some cavitation types observed at the aft part of a high speed podded propulsor model at 10° azimuthing angle.

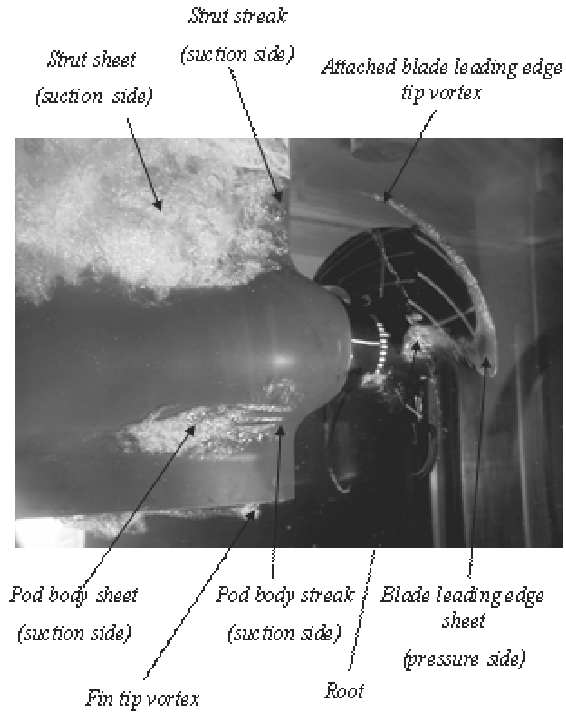

Figure 5. Some cavitation types observed at the fore part of a high speed podded propulsor model (shown in Fig. 4) at 10 deg azimuthing angle.