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Cavitation Induced Erosion Damages Soft Paint Model Scale Experiments

1. PURPOSE OF PROCEDURE

The purpose is to provide guidelines and to ensure the best possible quality of test results in terms of accurate data on the performance characteristics of ship propellers, rudders and appendages concerning the danger of cavitation induced erosion.

The considered procedure of the erosion model tests of propellers, rudders and appendages is intended to be conducted in a cavitation tunnel. The principal part of the procedure consists in the application of the soft paint coating on the surfaces of the investigated objects (i.e. propeller, rudder or appendage model). Therefore the description of the model test of the erosion risk assessment of propellers /rudders /appendages conducted in differently sized cavitation tunnels consists of the following relevant parts:

- Selected guidelines concerning the additional, detailed cavitation observation techniques, which are not included in any other, recommended ITTC procedure
- Preparation of the models for the tests including model handling and application of the soft paint coating onto their surface
- Guidelines how to perform and analyze model erosion tests in a cavitation tunnel

The main aim of the experimental procedure of erosion risk assessment based on the soft paint method application shall provide the answers to the following questions:

- What is the expected location of the potential erosion zones on the propeller/rudder surface?
- Does the focus of the cavitation collapse occur to that degree close to the propeller/rudder surface that the cavitation should be considered as dangerous?
- Is the action of cavitation collapse sufficiently systematic and repeatable to provide a risk of erosion?

The procedure does not in particular provide any hints concerning the duration of the cavitation erosion incubation period and erosion rate in steady state. However, it gives the immediate answer if erosion is to be expected or not.

2. MODEL SCALE EXPERIMENTS ON CAVITATION INDUCED EROSION

The detailed observations of the cavitation phenomena on a propeller and rudder operating in a non-uniform inflow velocity field representing the flow behind the ship serve as complementary actions with respect to the soft paint test. These observations can be done visually under stroboscopic lighting, by time laps video and by high speed video observations. It should be kept in mind that the aim of the experimental procedure of cavitation erosion risk assessment is not limited to the statement that the soft paint coating has been damaged but also is to give an explanation of the correlation of those damages with the occurrence of certain forms of cavitation, their dynamic behaviour and location with respect to the propeller/rudder surface.

2.1 Test Set-Up

2.1.1 Propeller Model

The size of the model propeller should be determined within the capacity constraint of the test facilities and not exceed an acceptable extent of test-section blockage and be as large as reasonable to achieve the highest possible Reynolds number. The propeller model must have sufficient and consistent geometry accuracy for the high quality database of measurements, and therefore application of numerical controlled machining may be helpful to maintain a consistent geometric accuracy. Model propeller blades are usually made of either strong aluminum alloys or brass. The surface of the propeller model during the erosion test should be covered by a single, uniform layer of soft paint and it should be kept in mind that the coating may bring some differences in cavitation appearances compared to the clean surface. The soft paint test should then be accompanied with the cavitation observations and the results of the observations should be compared with those obtained during any other cavitation test of the propeller. A thrust/disc-area loading of about 70 kPa is a useful upper limit value for strength considerations, as mentioned in ITTC 22nd Quality Manual.

2.1.2 Rudder/Appendage Model

The size of the rudder/appendage is determined by the scale of the propeller model. Similar constraints as in case of the propeller model also apply to the rudder/appendage model. The rudder/appendage model when subjected to the soft paint erosion model test should be manufactured of strong aluminum, alloy, or brass.

2.1.3 Wake Field Simulation

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.

2.1.3.1 Dummy Models

The main issue is to provide a realistically simulated wake velocity pattern which will also give the proper speed of advance at the propeller disk location. Usual practice is to use the nominal wake distribution (either for the model or scaled to full scale) as the target wake for the experiment.

For differently sized cavitation tunnels alternative model schemes are used.

In **small** water tunnels (in case of single screw ship):

- Wire mesh screen placed perpendicular to the flow in front of a flat plate ‘hull’
- Parallel plate wake generator, in front of a flat plate ‘hull’

For small to **medium size test sections**, the alternatives could include:

- Inclined shaft with struts and bossing, mounted below a flat plate or bump-like dummy model hull (in case of twin screw ship with propeller operating outside the ship boundary layer)
- Dummy model ('after body model')

Large test sections may allow:

- Shortened, but otherwise scaled ship models
- Half complete or shortened ship model attached on a side wall (in case of twin screw ship)
- Completely scaled ship models

For all model configuration options, it is recommended to include as many of the stern appendages as possible, such as the rudder, in the correct location behind the propeller.

When using dummy model, the simulated wake shall be documented to verify that the deviation from the target wake can be neglected (criteria for the dummy model wake acceptance Should be stated). Measurement of the wake can be performed by using any suitable velocimetry techniques. When using Pitot tube or laser Doppler Velocimetry, ITTC procedures can be adopted

2.1.3.2 Ship Model

The full ship model for cavitation erosion tests comes normally from previous resistance and self propulsion tests performed in the towing tank. Normally the model construction specification shall comply with the ITTC 7.5 01-01-01 Recommended Procedure. Furthermore it shall comply with the low pressure environment or the higher velocity encountered in the cavitation facility.

The ship model shall be completed with all the required appendages, fin stabilizer, rudder and turbulence stimulators that can influence the inflow to the propeller.

High quality mechanical components shall be adopted for the transmissions with respect to the self propulsion test in order to reduce the level of vibration and noise generated by the motor, gearbox or any rotating part used in the transmission mechanism. An accelerometer shall be installed on the ship model to monitor the levels and the frequency distribution of the induced hull vibrations.

The alignment of the shaft and joints shall be accurate in order to reduce propeller rotational speed variation during the revolution. Propeller rotational speed fluctuation shall be maintained within 1%. In order to check the rotational speed of the propeller the mounting of a multi-pulse encoder (at least 1000 pulses per revolution) on the propeller shaft shall be preferred.

For the above reasons in case of a twin screw ship a two motors configuration (one for each propeller) shall be preferred because it reduces the number of mechanical components required in the transmission and hence the induced hull vibration. Furthermore a two motor configuration allows for the possibility of investigating the effect of phase rotational angle between the propellers.

For the case that the installation of cameras is required to view the cavitation the presence of the window must not influence the flow.

For the case that electrolysis is used for cavitation stabilization the electrodes should be mounted on the ship model at least 1 meter upstream of the propeller plane.

2.1.3.3 Full Scale Wake

Sometimes the full scale wake can be used for erosion tests. This is mainly possible by use of shortened model sections or with flow liners. The estimated full scale wake should then be based on flow calculations, but a universal law for the full scale wake, which can be applied to all kinds of vessels, has not been developed yet.

2.2 Test Conditions

In a variable pressure water tunnel facility, the model test conditions should satisfy the same propeller working conditions as predicted for the full scale.

Three basic parameters of propeller working conditions are:

- Propeller loading condition,
- Realistic wake velocity pattern, and
- Corresponding pressure field.

(a) Propeller loading condition

The propeller loading through the kinematical condition for $J = V_A/(nD)$ needs to achieve the predicted full scale K_T or K_Q (thrust or torque identity). Here V_A = propeller speed of advance, D = propeller diameter (m), n = rotational speed (rps), $K_T = T/(\rho n^2 D^4)$, and $K_Q = Q/(\rho n^2 D^5)$. Usual practice in water tunnel testing is to satisfy thrust identity, although there are circumstances where the torque identity approach is used.

(b) Realistic wake velocity pattern

Provide a realistically simulated wake velocity pattern which will also give the proper speed of advance at the propeller disk location. Usual practice is to use the nominal wake velocity distribution (either for the model or scaled to prototype size) as the target wake for the experiment.

(c) Corresponding pressure field

Set the facility pressure and flow velocity to obtain the correct full scale cavitation number $\sigma = (p_0 - p_v)/(1/2 \rho V_{ref}^2)$; where p_0 = total static pressure consisting of atmospheric pressure plus submergence depth pressure taken to a reference location on the propeller blade, and with the reference velocity V_{ref} taken as V_A or nD. The reference submergence depth used in the calculation of cavitation number is usually taken at a point approximating the centre of expected cavitation extent in the upper part of the disk, such as $0.8R$ above the propeller centre line.

For Froude scaled cavitation testing in a facility with a free surface, such as a depressurized towing tank or a free surface circulating water channel, the standard results of a Froude scaled towing basin powering test may be used directly to set the propeller RPM and speed for the various operating conditions of the experiment. It is noted that the usual procedure for scaling model powering results to full scale is based on satisfying the thrust loading coefficient at full scale Reynolds number, which is equivalent to a thrust identity approach.

2.3 Air Content, Cavitation Nuclei and Stabilizing Model Cavitation

The effect of the water quality has been a subject of continuous discussion in the ITTC. The cavitation-nuclei concentrations in the water have a remarkable influence on the tensile strength of the water, and therefore the cavitation characteristics, especially inception characteristics, on the propeller blade. However, the modelling of the detailed nature of the cavitation nuclei is not necessary and it is not practical to represent the nuclei spectra of the seawater at full scale in model test. However, it is very important to reduce the tensile strength of the water.

Generally it is accepted that testing at relative high air content, modifies the nuclei, in a water tunnel facility and reduces the tensile strength and improves the correlation of model / full scale results. When there are insufficient concentrations of the nuclei, all forms of cavitation behave intermittently which may result in the lack of paint removal and thus provide misleading results. On the other hand, too high air content may introduce a cushioning effect to the cavitation collapse and will reduce its effects on the soft coating as well as providing unreliable results.

When testing in a depressurized towing tank the generation of the nuclei by sand grain roughness on the leading edges of the model propeller blades or electrolysis in the boundary layer flow past the hull stabilize the cavity on the model blade (Ligtelijn, 1992 and van der Kooij, 1979).

However, too high a level of air may deteriorate the visibility inside the tunnel and make the observation of e.g. focusing cavities rather difficult or even impossible.

Hence, the optimum air content for a given cavitation facility should be determined by long-established experience. To enhance the consistency of measured results, it is recommended that the tensile strength of the water in the facility should be checked periodically.

2.4 Special Consideration for Tests in Small Cavitation Tunnels

It is difficult to scale the flow around a real propeller properly in small size tunnels. It is especially difficult if not nearly impossible to simulate the transverse velocity components in acceptable agreement with those components of full ship model wake, even if a dummy model is used in conjunction with wire meshes.

Also, the wire meshes in the upstream of a propeller may have an influence on the cavitation behavior on the propeller blades, the local turbulent characteristic of the propeller inflow being governed by the mesh size and spacing.

Furthermore, in a severe condition, the small sized bubble cavity generated on the wire mesh may appear as cavitation nuclei on the blade, which is dependent on the pressure level inside the tunnel. A low ratio of air content may be helpful in avoiding these phenomena, but it does have an influence on the characteristics of the cavitation.

Erosion test experiments within a small cavitation tunnel should take into account the risk of the test section blockage effect. The same restrictions as for the normal cavitation tests also apply to the erosion tests.

2.5 Calibration

For a successful erosion test, the cavitation pattern on the propeller blade must be simulated properly. As part of the preparation and set-up of the test the following items are to be calibrated:

The thrust and torque dynamometer, load response calibrations should be carried out with applied loads, and also long term stability of the calibrated data are to be confirmed.

Thrust and torque of the bare hub are to be measured and corrected for each test condition; especially at low revolution condition it is recommended that the effects of internal friction and gearing in the dynamometer are checked as the shaft RPM approaches zero.

	Absolutely required	**Worthwhile to have**
General information (Ship, propeller operating conditions)	Type of ship Engine power and RPM Propeller/rudder main particulars Shaft immersion Tip clearance Rudder geometry details	Ship main particulars Propeller geometry data (Section, Pitch Chord distribution etc) Propeller design conditions Drawing of stern shape including arrangement of appendages
Model propeller/rudder operating conditions	Propeller/rudder model material Flow velocity including wake distributions Static pressure Propeller thrust and torque Propeller RPM Rudder angle	Detailed inspection of blade geometry Pressure drop through test section Level of turbulence upstream propeller
Water quality	Water temperature Air contents as % saturation or % oxygen saturation	Tensile strength of the water Nuclei distribution number and size
Instrumentation	Type of video camera Type and way of illumination Type of High Speed Video system Number of frames per second	
Paint	type of paint the way of model painting number of paint layers duration of paint test	Thinner used Mixture Thinner / Paint Preparation of the propeller model before painting

Table 1: Desired Information

Basic measured data		Derived parameters	
Representative static pressure at propeller radius 0.8	p	Cavitation number	$\sigma_{n,\mathrm{M,irtl,KE}} = \dfrac{p_{\mathrm{Tunnel}} - p_{\mathrm{V}}}{\frac{\rho_{\mathrm{Tunnel}}}{2}\left(\pi n_{\mathrm{M}} D_{\mathrm{M}}^{2}\right)^{2}}$.
Rotational velocity rps	n	Torque coefficient	K_{Q}
Tunnel speed m/s	V_{tunnel}	Thrust coefficient	K_{T}
Propeller thrust N	T	Advance coefficient	J_{A}
Propeller torque Nm	Q	Vapor pressure	p_{V}
Water temperature ° C	t	Dimensionless pressure amplitude	$K_{P(\varphi)} = \dfrac{p_{\mathrm{M}(\varphi)}}{\rho_{\mathrm{Tunnel}} n_{\mathrm{M}}^{2} D_{\mathrm{M}}^{2}}$.
Air Content / Oxygen Content	$\forall / \forall_{\mathrm{S}}$	Phase angle	ν

Table 2 Engineer's checklist.

Parameter	Recommended values	
Pressure adjustment to	0.8 R	
Blockage	Less than 20 % of test section size	
Number of revolutions of model propeller	As high as possible in accordance with tunnel speed	ITTC 1996 Cav. Com
Minimum Reynolds-number		
Minimum Time to run a paint test		
Air content / nuclei Distribution	As high as possible Values of total air content or Oxygen content should be mentioned	ITTC 1984
Reproducibility	At least two different rotation rates of the model propeller	ITTC 1993 Cav. Com.
Model propeller diameter	> 200 mm	

Table 3 List of Recommended ITTC Parameters

3. PARAMETERS

3.1 Parameters Taken into Account

The parameters that need to be considered performing erosion tests are basically the same as for cavitation tests (ITTC Procedure 7.5-02-03-03.1). They can be categorized into absolutely necessary data and in data that are worthwhile to have. If the latter are allowed for, the reliability and the quality of the measurements will considerably be improved.

4. TESTS METHODS

At any time and independent of the cavitation test facility, observation methods should be combined with soft surface techniques. This procedure focuses on observations by eye, time-lapse video and high speed video, combined with the paint test method.

It is always important, that the above mentioned test techniques must be optimized for the specific test set-up. It is concluded that for good results the user has to consider not only CCD's, lamps, lenses and paint but also the basic equipments like test section windows, windows inside ship models and the fitting of ship models with internal cameras and lamps.

4.1 Paint Test Method

The proposed erosion test method is a soft paint technique. The propeller/rudder model is covered by a single layer of soft paint and is subjected to the action of different types of cavitation in the behind condition in a cavitation tunnel for a certain time. The evaluation of the results of the test consists in the examination of the state of the paint layer shortly after the removal of the propeller/rudder model from the tunnel test section.

Any damage of the paint connected with the action of collapsing cavities should be considered as a risk of erosion occurrences in full scale. Nevertheless one has to assure that the cavitation appearance does not result from accidental, unwanted local surface irregularities and that it results exclusively from the thoroughly reproduced geometrical form of the model and testing conditions corresponding to the full scale.

4.1.1 Paint Used

A stencil ink is recommended to be used as the substance to cover the propeller/rudder model surface. As standard ink is too dense the paint should be a mixture of ink and an appropriate thinner. To make the evaluation of the test results easier and to obtain the most distinct traces of paint removal a black ink is recommended to be applied.

Stencil inks are either water-based thus water-soluble or solvent-based heavily pigmented paints. They can be used with a paint brush, paint roller or spray gun. However, chemical curing of water-soluble stencils can improve their resistance to water and therefore it is not recommended to apply water-based inks. In general a water-resistant paint layer must accompany a solvent-based ink, and a solvent-resistant paint layer must accompany a water-based ink.

Solvent-based stencil ink serves as a waterproof, permanent and fast-drying paint, which can be applied either to any porous (e.g. paper, cloth, wood, cardboard cartons, etc) or non-porous (e.g. metals, plastics or glass) surface. Solvent-based stencil ink can be based on petroleum, alcohol or glycol. It has to be emphasized that petroleum based inks are usually intended for the application on porous materials and they may not dry on metal surfaces. The alcohol or glycol based inks dry relatively quickly, i.e. from seconds to minutes on porous as well as on non-porous (including metal) surfaces. Usually carbon black serves as the black stencil ink pigment therefore the ink has to be shaken well before use.

4.1.2 Paint Handling

In order to maintain the relatively short drying time and the appropriate thickness of the paint layer, the stencil ink should be mixed with an appropriate thinner. The fraction of the thinner should not be higher than 50%. The thinner and the ink should be mixed exactly and immediately prior to the application of the paint.

4.1.3 Application for Propellers, Rudders and Appendages

4.1.3.1 The Sequence of Activities

The first step of the procedure consists in the careful cleaning of the propeller/rudder model surface with a degreasing agent. After cleaning, the model should be thoroughly dried. Then the model should be covered (painted) using a spray gun with a single layer of paint. It should be assured that the air compressor is equipped with the grease/oil separator and the paint layer is uniform. If there are any spots of dried paint drops on the model surface then the surface should be cleaned and painted again. Before placing the model in the cavitation tunnel the paint should be dried. Usually 30 minutes of drying in a well ventilated room is sufficient. Touching the propeller model blades with bare fingers should be avoided. The state of the surface should be recorded before the model tests start. Any scratches or accidental paint damages should be documented.

4.1.3.2 Soft Paint Test

The required propeller operation condition in the tunnel test section should be achieved in the shortest possible time.

The recommended duration of the paint test should not exceed 120 minutes. During the entire period of the propeller model operation the state of the surface should be viewed (continuously when possible) visually in stroboscopic lighting in order to determine the initial moment of the paint's removal.

Any removal of the paint not related to the action of cavitation (e.g. paint separation due to the lowered pressure) should be recorded. After completion of the test the propeller model should be immediately removed from the test section of the cavitation tunnel. It is extremely important to avoid touching the propeller model blades as it can cause an unwanted damage of the soft paint layer. The state of the soft paint cover can be examined immediately after propeller removal from the tunnel test section or after propeller drying. The state of the paint cover should be compared with the original photos made before the tests. The picture of the propeller surface should be recorded in the same way as before the test.

4.2 Cavitation Observations

The propeller, rudder and the observed appendages should be visually checked on both, suction and face side. Options for the observation of the occurrence of cavitation are:

- visual observation through tunnel and wall windows,

- observation by time lapse videos, provided by cameras installed outside the tunnel or inside the ship - or dummy model, and

- high speed video recordings by cameras installed outside the tunnel or inside the ship - or dummy model.

The basic idea of video recordings is to support the analysis of the structure of the observed cavities. Usually high speed video is recommended but a combination of standard video and high speed video is even better. General requirements are:

- a camera position giving a good view on the whole propeller,

- a frame rate / stroboscopic stepping giving sufficient resolution in time, and

- a good arrangement of the lighting, to get a movie showing the cavitation process without disturbing reflections.

Sometimes it can become very time consuming to obtain quality high enough for good analysis of the observed cavities.

4.2.1 Arrangement of the Lighting

This is often one of the most critical parts of the work. For cavitation erosion tests, the lighting must be arranged with the aim of capturing if and when a re-entrant jet occurs and reaches the cavity interface.

The following guidelines should be taken into account.

1. Use as much light as possible to permit small lens aperture and short exposure times. For stroboscopic lighting the exposure time can be set by the stroboscopic flash.

2. To increase the effective output, at least one lamp should be able to be focused to a spot 10 -50 mm in diameter, for an overview first a wider area may be needed.

3. Backlighting should be used with care. It makes small bubbles visible but may result in speckle reflections in a sheet cavity with makes it impossible to look through the cavity and observe the re-entrant jet.

4. The lamp should not be visible in the image frame (CCD can be damaged).

5. Sometimes recordings of the same cavity can be repeated with different light sources, for example turn off a lamp and repeat the recording.

4.2.2 Time Lapse Video

Standard video in general is not a sufficient tool to analyze the dynamics and structures of the different cavities; nevertheless it is a useful supplement. Items to be considered are:

- The pixel resolution of a standard video is usually higher compared to high speed video.

- It is easier to switch between different sources of light during the recording thus giving more information on the cavitation process.

- The standard video is superior when concerned with the recording of intermittency and long terms fluctuations of the cavitation process. This is very important as a supplement to the paint tests.

- Make overview videos as a supplement to high speed videos to analyze the development of focusing cavities from the global cavity.

- Vary the exposure and lighting to show different details, thus allowing an inspection of the cavities in real time during recording.

4.2.3 High Speed Video

The true development of a specific cavity can only be seen by recordings of a high speed film or digital high speed video technique. For commercial use, the high speed video technique is recommended. The following guidelines should be considered:

1. The frame rate, exposure time of an individual frame and the duration of the total recording are the primary parameters that have to be selected. The exposure time is partly related to the frame rate. The requirements on these parameters are related to the water velocity and propeller rate of revolutions.

2. In a typical propeller experiment with an advance velocity of up to approximately 10 m/s exposure times from 1/10000 s or shorter are usually sufficient to avoid disturbing motion blur. A lower limit for the frame rate may be around 3000 frames/s but a value between 5000 and 7000 is significantly more useful. Frame rates as low as 1000 frames/s are found to be inadequate for analysis.

3. As for standard video small lens apertures are required for sufficient reduction of aberrations degrading the sharpness and for obtaining a sufficient depth of focus. The most effective way to control aberrations and depth of focus is to select a good camera position and to have enough light. Optical elements like prisms and correction lenses can also be helpful.

In practice the resolution of filming 3-D moving objects are influenced by:

1. The scale of reproduction,
2. The motion of the object,
3. The exposure time,
4. The extent of the object along the optical axis (depth of field),
5. The lens aperture (depth of field),
6. The CCD/film resolution,
7. The contrast of the object, and
8. The frame rate (revolution in time).

Some of the listed parameters are interrelated, in theory as in practice. Most of the parameters can be influenced by the operator and need to be optimized according to the specific test set-up.

4.3 Evaluation of Results

4.3.1 Visual Observations

The main applications of the visual methods are:

1. Detection and assessment of erosive cavitation, as an independent method.

2. Supplement to paint tests by bringing information not obtained in paint tests.

3. To analyze and gain understanding of the development towards erosive cavitation and its relation to the large-scale hydrodynamics in a way that can be applied in design for control of erosion.

Basic steps to analyze high-speed video recording should focus on:

- Detecting the existence of violent rebounds.
- Estimating the violence, the whiteness and the volume of the rebounded cavity.

  The whiter the rebounding cloud, the more erosive the collapse can be. A fast rebounding cavity is also regarded as potentially erosive.
- Estimating the position of the rebound and its distance from the body surface.

  The position is important to figure out if possible actions like blade cutting or redesigns to move the collapses outside of the blade can be successful.
- Checking the occurrence of foggy cavitation (a sparse distribution of very small bubbles). It normally can be used as a collapse indicator. Its production is more intense when violent collapses occur.
- Observing the structure of the focusing cavity (glossy, cloudy or mixed). This gives information on the presence of reentrant jets and contributes to the high risk assessment.
- Estimating the acceleration and the distribution in time of the collapses' motion of the focusing cavity.

4.3.2 Evaluation of Paint Test

In a paint test method, a soft surface coating is applied on the propeller or rudder surface. It is assumed that this soft surface will be damaged by erosive cavitation. Therefore the surface of the coated propeller needs to be investigated very carefully after the test and compared to the original appearance. By investigating the erosion damage on the coating (the form and the size) a prediction of the potential erosion damage can be made. If systematic correlation data exist between experimental and full scale results it yields a possibility to predict the risk of erosion for full scale.

The surface damage should be documented as soon as possible - after taking the propeller or rudder out of the tunnel - because the paint itself is rather weak.

All traces of paint removal should be checked, documented and related to the observed cavitation phenomena. All spots where paint is removed in combination with observed cavity collapses, should be considered to be very erosive.

5. VALIDATION

5.1 Uncertainty Analysis

The 20th ITTC (1993) mentioned critical issues concerning scale effects in cavitation testing. They were related to fluid effects (wake) and bubble dynamic effects. These must be taken into account when estimating errors of an experiment. Customers should be informed of the uncertainty assessment methodology used and which uncertainties can be expected for the tests. The uncertainty assessment methodology should inform about

- measurement systems,
- error sources considered, and
- all estimates for bias and precision limits and the methods used in their estimation (e.g., manufacturers specifications, comparisons against standards, experience, etc.).
- actual data uncertainty estimates.

The uncertainty analysis should be done in accordance with the following regulations/recommendations:

ISO, 1992, "Measurement Uncertainty," ISO/TC 69/SC 6.

ISO, 1993a, "Guide to the Expression of Uncertainty in Measurement," ISO, First edition, ISBN 92-67-10188-9.

ISO, 1993b, "International Vocabulary of Basic and General Terms in Metrology," ISO, Second edition, ISBN 92-67-01075-1.

ITTC, 1990, "Report of the Panel of Validation Procedures", 19th International Towing Tank Conference, Madrid, Spain, Proc. Vol. 1, pp. 577-603.

5.2 Benchmark Tests

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

6. REFERENCES

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(2) Bark, G., Friesch, J., Kuiper, G. and Ligtelijn, J.T.: "Cavitation Erosion on Ship Propellers and Rudders", PRADS 2004, Lübeck-Travemünde, Germany