ITTC Quality System Manual

Recommended Procedures and Guidelines

Guideline

Experimental Wake Scaling Methods

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Experimental Wake Scaling Methods

1. PURPOSE OF GUIDELINE

The aim of this guideline is aid model basins in generating a wake field for cavitation test, which represents as good as possible the propeller inflow conditions as expected in reality. The final result of a cavitation experiment, however, – may it be cavitation extent, cavitation inception, or pressure pulse generation, is additionally influenced by many other uncertainties perhaps canceling out each other to some extent. Consequently, this increased propeller inflow realism will not necessarily result in an increased reliability of those final results.

Simulation of wake fields in general has been addressed already by ITTC recommended procedures.

- 7.5 -02 03-03.1:
  Testing and Extrapolation Methods
  Propulsion, Cavitation
  Model - Scale Cavitation Test
- 7.5-02 03-03.3:
  Testing and Extrapolation Methods
  Propulsion; Cavitation
  Cavitation Induced Pressure Fluctuations
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- 7.5-02 03-03.5:
  Propulsion; Cavitation
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- 7.5-02 03-03.6:
  Testing and Extrapolation Methods
  Propulsion, Cavitation
  Podded Propulsor
  Model - Scale Cavitation Test.

The recommendations given there, however, apply independently of the question of whether a model scale or a full scale wake field shall be simulated.

The present procedure deals with considerations regarding experimental methods to tune a model scale wake field in a cavitation tunnel towards a full scale wake field. This full scale target wake field may have been either calculated directly by RANS calculations, or – under consideration of the ITTC recommended procedure XXX (new procedure) – from application of scaling procedures to a model wake field. Very rarely would it have been obtained from full scale wake measurements.

2. PARAMETERS

2.1 Basic Measurement Quantities

R	Propeller radius
r_h	Propeller hub radius
V_T	Tunnel Velocity in the test section
v_x	Axial component of local flow direction
v_t	Tangential component of local flow direction
v_r	Radial component of local flow direction

2.2 Derived Parameters

v_x/V_T, v_t/V_T, v_r/V_T	Non-dimensional flow components
w_{nom}	Nominal wake fraction

$$w_{nom} = 1 - \frac{1}{\pi} \cdot \frac{1}{1-\left(\frac{r_h}{R}\right)^2} \cdot \int_{r_h/R}^{1} x \cdot \left(\int_0^{2\pi} \frac{v_x}{V_T}\, d\Theta \right) dx$$

3. DIRECT SIMULATION OF A TARGET WAKE FIELD

There are mainly two methods in use for cavitation testing, that allow – with more or less accuracy – simulation of any kind of target wake field, i.e. independent of whether it is a model wake field, a full scale wake field or even any kind of generic wake field (e.g. for research purposes) that is to be simulated. Those methods are:

- wake simulation by wire screen technique
- wake simulation by parallel plate wake generator.

For these methods, considerations regarding the target wake and the accuracy of its simulation are necessary indeed, but have been addressed in the procedures mentioned in section 1. Experimental wake scaling techniques, as they are focus of the present guideline, are not an issue when using one of these two methods.

4. EXPERIMENTAL WAKE SCALING

The means for tuning a model wake field towards a full scale wake naturally depend on the method used for the model wake field generation itself.

4.1 Model Wake Field from a Complete Model

4.1.1 Scaling by Water Speed Increase

Wherever possible, the preferred method for wake field generation in a cavitation experiment is the installation of the complete ship model in the test section (see ITTC recommended procedure 7.5-02-03-03.5, section 2.1 from 2008). This setup still does not necessarily generate a model wake as it would be measured in a towing tank under Froude conditions. One reason is that cavitation tests in a large cavitation tunnel without free surface are normally conducted at much higher speed than would result from Froude's scaling law. One has to be aware of the fact that this speed increase results in a higher Reynolds number generating a more full scale-like wake field. Since principally propeller load and cavitation number can be adjusted at any tunnel water speed in a cavitation tunnel (of course resulting in different tunnel pressures and model propeller speeds and therefore limited by technical constraints of the facility), this freedom gives the opportunity to tune the wake field towards the full scale wake. A high tunnel water speed can therefore be regarded as one efficient mean for wake scaling, and the recommendation is simply to chose the speed as high as possible to come as close as possible to the full scale Reynolds number.

For cavitation experiments carried out in a depressurized towing tank or any other facility with free surface the deviation from Froude's scaling law has to be handled with extreme care, since it will spoil the full scale similarity of the wave wake. The latter, however, is the main reason for performance of cavitation tests in a free surface facility.

4.1.2 Scaling by Flow Guiding

Besides the different speeds, another difference to the towing tank situation is that the test section of a cavitation tunnel normally offers a much more restricted cross section. In a distance from the ship model where in the towing tank the water particles are still able to form natural flow lines as in reality, the tunnel walls of a cavitation tunnel already force the particles to go straight along the tunnel wall. To avoid this wake deformation, one can install so-called flow liners. These devices can also be used to tune the flow not only towards the unrestricted (tank) situation, but even towards the high Reynolds number full scale situation. This correction, however, requires a careful flow liner layout based on RANS calculations. It is recommended that flow lines be calculated at full scale Reynolds number in an unlimited flow regime and to shape the flow liner along these calculated flow lines around the afterbody. The liners should range from the aft shoulder of the ship model sufficiently far behind the propeller plane (at least three propeller diameters) as illustrated in Figure 1. Since each hull form naturally leads to a different flow liner geometry, this expensive technique might be restricted to research purposes.

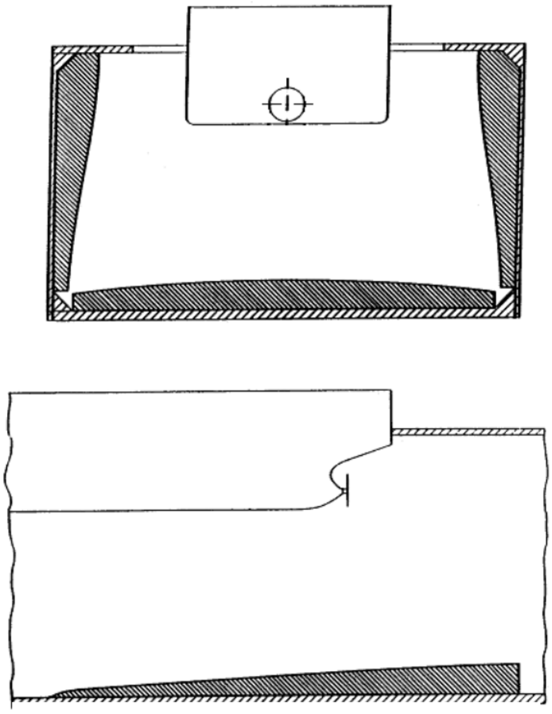

Fig. 1: Flow Liners in a Cavitation Tunnel Using a Complete Ship Model for Wake Simulation

4.1.3 Scaling by Model Shortening

Shortening the ship model is a well known technique to reduce the boundary layer thickness, making the frictional model wake more similar to full scale. In cases of ships having a considerable parallel midship section, it is recommended to shorten this section to achieve the best results. In cases where this region is not long enough to achieve a sufficient shortening, it is recommended to (additionally) reduce the model length in the forebody rather than in the afterbody. For this purpose it is reasonable to replace the original forebody by a shorter dummy piece as shown in Figure 2. An easy relation to estimate the required shortening can be derived from simple flat plate boundary layer considerations according to Johannsen (1992):

$$l_{shortened\ model} = l_{ship}\left(\frac{V_{tunnel\ water}}{V_{ship}}\right)^{0.111} \cdot \lambda^{-1.111}$$

where l [m] is the length of ship and model respectively, V [m/s] is the tunnel water or ship speed and λ is the model scale factor.

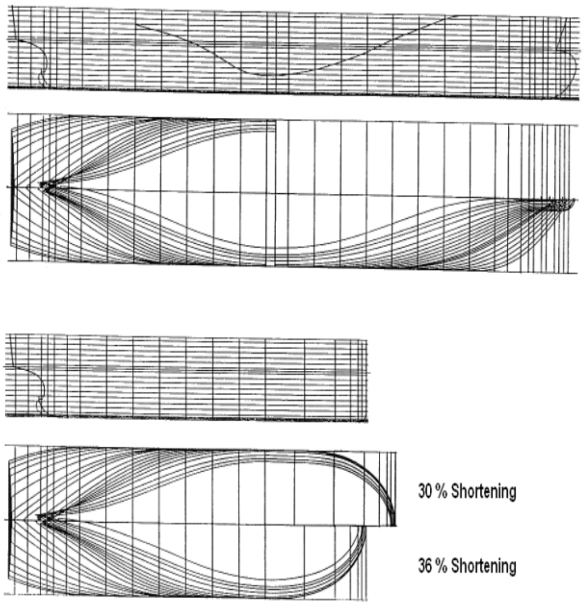

Fig. 2: Shortening of a Container Vessel Model

4.1.4 Scaling by Adjustment of a Local Significant Advance Coefficient

When performing cavitation tests at high tunnel water speed, i.e. violating Froude's scaling law, the identity of model and full scale cavitation number can be achieved in one horizontal plane only at the same time. According to ITTC recommended procedure 7.5-02 03-03.1, section 2.10, this horizontal plane should be located in a depth, where the cavitation predominantly occurs. This is normally around 0.8 to 0.9 R at the top of the propeller disk. It can be reasonable, to do something similar with respect to the inflow velocity. Normally, the tunnel water speed is adjusted to meet a certain K_T-value for the model propeller (thrust identity, see above procedure, section 2.2). This K_T, however, is an integral value, and for wake scaling purposes it can be worthwhile to deviate from the resulting speed to achieve full scale identity of a local advance coefficient J instead. If so, J-identity should be achieved in the same region as described above with respect to the cavitation number, i.e. in the region of maximum wake. Due to scale effects the 12 o'clock wake peak behind the ship model is generally deeper than at full scale and compensation of this scale effect will require a higher tunnel water speed than obtained from K_T-identity. When applying this wake scaling method it is recommended to determine the correct tunnel water speed by comparative RANS calculations of the model and full scale wake field of the ship under consideration.

With respect to free surface facilities the caveats mentioned under "Scaling by Water Speed Increase" apply here as well.

4.1.5 Scaling by Hull Surface Treatment

Due to the low Reynolds number at model scale, flow separation may occur earlier on the hull than on the real ship. Similar to the dents in a golf ball it is possible to reduce this scale effect to some extent by surface treatment of the model hull. Sand roughening or wire screens along the surface are in use for this purpose. This technique, however, should be handled with care since the unrealistic surface roughening might also stimulate unrealistic cavitation. Furthermore theoretical considerations are nowadays still impossible to quantify the effect of this technique. Even more than with the other techniques described in this procedure, it is recommended to check its outcome by a wake measurement when applying it to a cavitation experiment (see also section 4).

4.2 Model Wake Field from a Dummy Model

A dummy model should be used in medium sized cavitation tunnels for cavitation tests and pressure fluctuation measurements. The afterbody of the dummy model must be similar to the ship. The length of the geometric similar after body depends on the dimension of the test section and the blockage factor. The test section blockage should not exceed 25 %.

Attention should be paid to the design of the fore body. The first step of the wake field simulation should be a check that no flow separation on the dummy model occurs.

The wake field of the dummy model at a given inflow speed should be measured to get the necessary information regarding the wake field simulation. Typically, the wake of a small dummy model results in a wake peak that is even less pronounced than in full scale. Wire mesh screens can therefore be mounted perpendicular to the hull to simulate the predicted full scale propeller inflow. The configuration used strongly depends on the skills of the model basin and on existing correlation data between model and full scale.

The wake scaling by additional wire screen patches is a time consuming iterative process of wire screen modifications and wake measurements to achieve the target propeller inflow. During the wake field simulation the rudder should be dismounted. Measurement of the wake can be performed by using any suitable velocimetry technique. When using pitot tube or Laser Doppler Velocimetry, ITTC procedures should be adopted.

The simulated wake shall be documented to verify that the deviation from the target wake can be neglected.

Since – depending on its dimensions – the dummy hull model alone normally generates a wake peak, which is less pronounced than at full scale, the scaling techniques described in section 4.1 must be regarded as counterproductive with respect to full scale wake similarity. In spite of this fact an increased tunnel water speed (resulting in a higher model propeller speed) may be reasonable to achieve a high propeller Reynolds Number during the cavitation test as recommended by ITTC procedure 7.5-02-03-03.1, section 2.2.

5. GENERAL REMARKS REGARDING EXPERIMENTAL WAKE SCALING

When applying one or more of the experimental wake scaling techniques described here, it is strongly recommended to verify the final outcome by wake measurements under consideration of ITTC recommended procedures 7.5-02-03-02.3 or 7.5-02-03-02.4 respectively.

Independent of that, one should always keep in mind that the wake field adjusted in a cavitation tunnel is only one little piece of the complicated chain leading to a cavitation or pressure pulse prediction at its end. Many other aspects contribute to the accuracy of this prediction and their individual inaccuracies may to some extent cancel out each other. For this reason the use of a wake scaling method should not be justified by achievement of a particularly good similarity between model and full scale wake alone, but by achievement of a particularly good similarity of model and full scale cavitation behavior or pressure pulse level. One should for example be aware of the fact, that the exaggerated model wake field might help to compensate for the under prediction of cavitation that might result from a too low gas content as it is usual in the tunnel water. If so, a more realistic wake simulation would even reduce the accuracy of a cavitation prediction. So it can be stated that an experimental wake scaling procedure has to be carefully adjusted to the individual cavitation testing facility.

All techniques for wake scaling applied in a cavitation experiment should be documented in the corresponding test report.

6. LIMITATIONS

In cases where no experimental wake scaling can be used in the cavitation experiment, one should at least be aware of the effects, which this deficiency may cause

- Over prediction of suction side cavitation extent,
- Inception of suction side cavitation at lower cavitation numbers,
- Under prediction of pressure side cavitation extent,
- Over prediction of safety margin against face cavitation inception,
- Over prediction of first harmonic hull pressure pulses,
- Influence on higher harmonic pressure pulses in either direction.

While most of the above mentioned deviations lead to a full scale prognosis on the safe, conservative side, one should be particularly aware of the fact that higher harmonic pressure pulses as well as pressure side cavitation phenomena might appear less critical in the experiment than in full scale.

7. BENCHMARK TESTS AND VALIDATION

Benchmark tests in a way that different model basins would have compared their wake simulations for the same case with respect to its similarity to a given full scale wake distribution are not known.

For validation purposes the report of the specialist committee on wake scaling of the 26th ITTC contains a comprehensive list of full scale wake measurements that may be used to check the ability of different experimental wake scaling methods to arrive at the full scale propeller inflow. Since almost all these full scale measurements represent the total wake, i.e. the wake in presence of the working propeller, the comparison should be handled with care. It can either be made on the basis of the nominal wake, which requires to correct the full scale results for the influence of the working propeller. Or it can be made on the basis of the total wake. In the latter case the model wake measurement needs to be carried out in front of the working propeller or the propeller influence has to be considered subsequently by numerical corrections.

In case that numerical calculations of a nominal full scale wake shall be used for validation, it is recommended to make sure that the calculation method is able to properly capture the main features of the wake in question (e.g. vortex structures). Therefore it is recommended to per-form a calculation of the nominal model wake field first and to compare this with the measured one.

Another option is to validate the wake simulation on the basis of the final result of the cavitation experiment that it was used for. This means comparison of cavitation extent, cavitation inception or pressure pulse generation obtained in the cavitation experiment with correspond-ing full scale results. This comparison, however, validates rather the experimental chain in total than the wake scaling technique alone.

8. REFERENCES

Johannsen, C., 1992, "Correlation Investigations on Cavitation, Pressure Pulses and Noise with Ship Models of Regular Length and Shortened Models in HYKAT", Part A: "Wake, Cavitation and Pressure Pulses", Report No. 1575, Hamburg Ship Model Basin (in German)