SESSION ON CAVITATION

Chairman: Dr. W.B. Morgan

Cavitation Committee Memberships: T.T. Huang (Chairman) - G. Kuiper (Secretary) - K. Alexandrov - W. Ball - M.L. Billet - P. Ligneul - K.J. Minsaas - T. Sasajima - Y. Ukon.

Discussion of the Report and the Draft Recommendations of the Report of the Cavitation Committee (cf. Proceedings, Volume 1, pp.161-233)

I. DISCUSSIONS

CV-1

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COMMENT ON THE WAKE SIMULATION IN CAVITATION TUNNEL

The wake simulation is essential for the cavitation prediction and propeller induced hull pressure measurement in a cavitation tunnel. Hyundai Maritime Research Institute (HMRI) constructed a cavitation tunnel with three kinds of measuring sections in 1984. The main characteristics of the cavitation tunnel are indicated in Table 1.

Most of the propeller tests have been performed in No. 2 section for commercial vessels. We simulate the axial flow velocity distribution, which is measured from model ship in towing tank, using both wire mesh screen and dummy model.

A wire mesh screen method is frequently employed only for the cavitation observation. But, we prefer dummy model method for the cavitation test and the fluctuating hull pressure measurement.

We'd like to comment some wake simulation technique that gave us more stable and reliable test results.

Table 1 Main Characteristics of Cavitation Tunnel

Section Type	No. 1	No. 2	No. 3
Section Shape	Square	Square	Rectangle
Dimension (L×B×D)	2.6m×0.6m×0.6m	2.6m×0.85m×0.85m	6m×1.45m×0.7m
Max. Velocity	12 m/sec	6.0 m/sec	4.3 m/sec

We have investigated the dummy model method in two ways, small and large dummy models, in a same No. 2 section. Two kinds of dummy models which were designed on the consideration of tunnel dimension are compared at Table 2 and were sketched in Figure 1 and 2 with dynamometer.

Most of the institutes that employ the dummy models for their propeller tests make an arrangement of dummy model like Fig. 1. Main difficulty of small dummy system is the wake simulation since the flow is easily separable from the leading part of dummy and became unstable on the propeller position. Then, the cavitation pattern became unsteady and the fluctuating pressure signals are unstable. Also, the rudder has to be deformed because the dynamometer shaft has to cross the rudder plane and the propeller boss does not affect on the stern flow as shown in Fig. 1.

We introduced the large dummy system as shown in Fig. 2 to overcome the difficulties of small dummy system. The large dummy was designed in two parts, bow and stern, and lengthened to two times of the small dummy. The dynamometer was inserted to the large dummy completely and the rudder and propeller

Table 2 Comparison of Small and Large Dummy Models

Type	Small Dummy	Large Dummy
Test Section (L×B×D)	No. 2 (2.6m×0.85m×0.85m)	No. 2 (2.6m×0.85m×0.85m)
Size (L×B×D)	1.0m×0.2m×0.53m	2.0m×0.25m×0.65m
Dynamometer	H44(Kempf & Remmers)	H44(Kempf & Remmers)
Water Speed	5 m/sec	5 m/sec
Reynolds No.	4.39×10^6	8.77×10^6

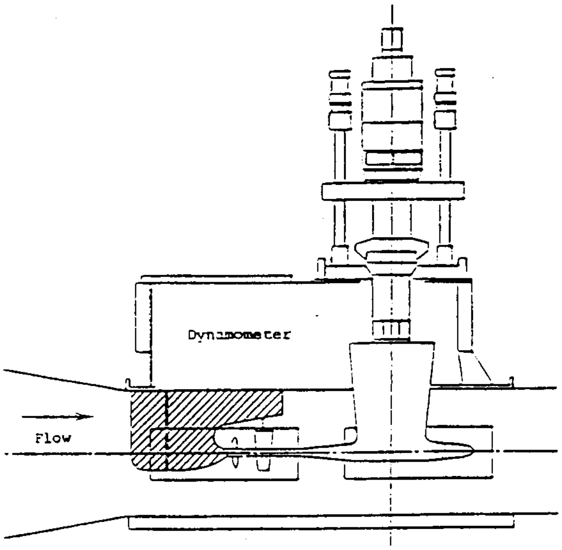

Fig. 1. Arrangement of Small Dummy Model and Dynamometer in Cavitation Tunnel

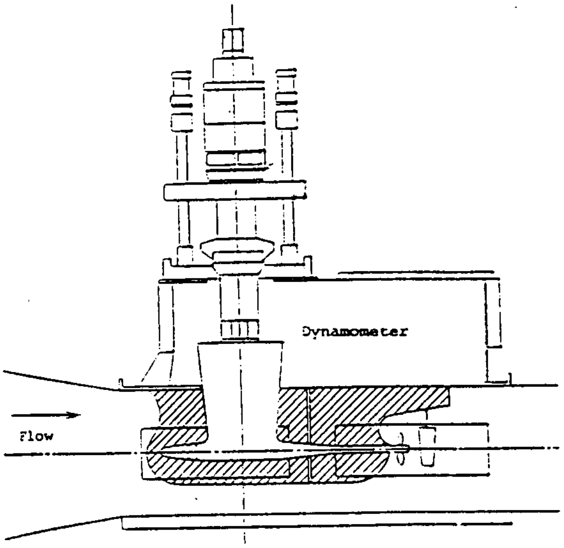

Fig. 2. Arrangement of Large Dummy Model and Dynamometer in Cavitation Tunnel

were fitted without difficulties. Then, the wake distribution became stable and some correction of the axial wake was made by the screen on the middle part of dummy.

Fig. 3 shows the axial wake velocity distribution measured from model ship in towing tank. Fig. 4 and

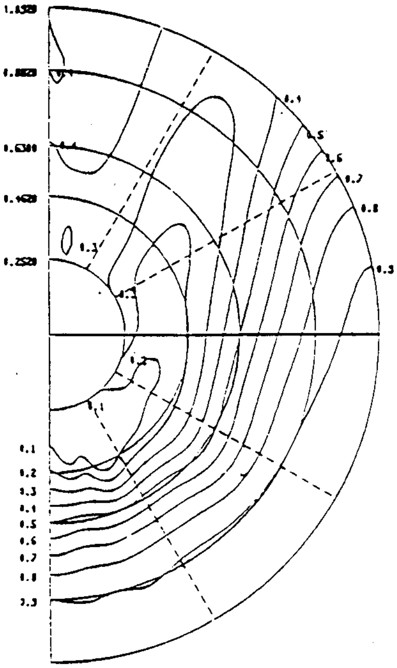

Fig. 3. Measured Axial Wake Distribution behind Ship Model in Towing Tank

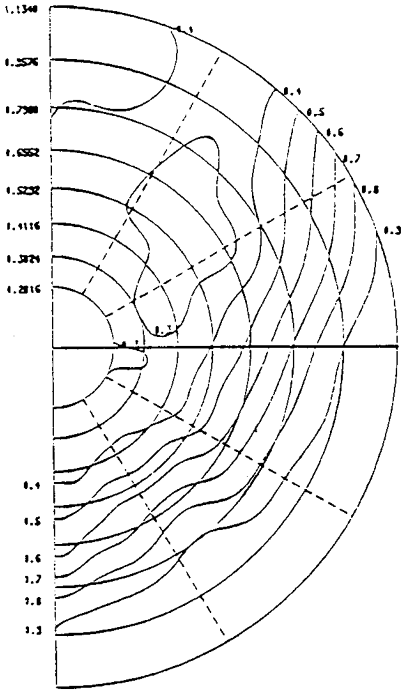

Fig. 4. Simulated Axial Wake Distribution behind Wire Mesh Screen in Cavitation Tunnel

5 show the simulated wake distributions by the wire mesh screen and the large dummy model respectively. The radial and tangential wake components were not confirmed in this simulation.

The wake simulation by the large dummy model coincide well with the results by the wire screen except the lower part of wake plane. The bottom peak of wake pattern is due to the bare dummy hull and seems to be corrected by the flow liner or some modification of stern shape of dummy. But, there is almost no effect on the cavitationn pattern due to the bottom peak of the wake.

Figs. 6 and 7 show the sketches of cavitation patterns observed with stroboscopic light. The cavitation extents by large dummy model are slightly larger than by wire screen. We can see the three dimensional flow effect on the cavitation performance by the large dummy model even though the radial and tangential flows were not exactly simulated.

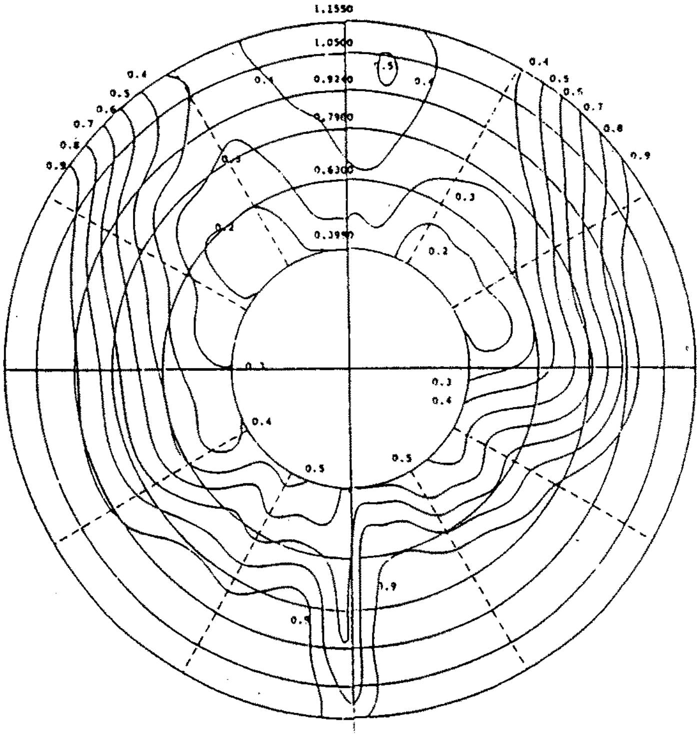

Fig. 5. Simulated Axial Wake Distribution behind Large Dummy Model in Cavitation Tunnel

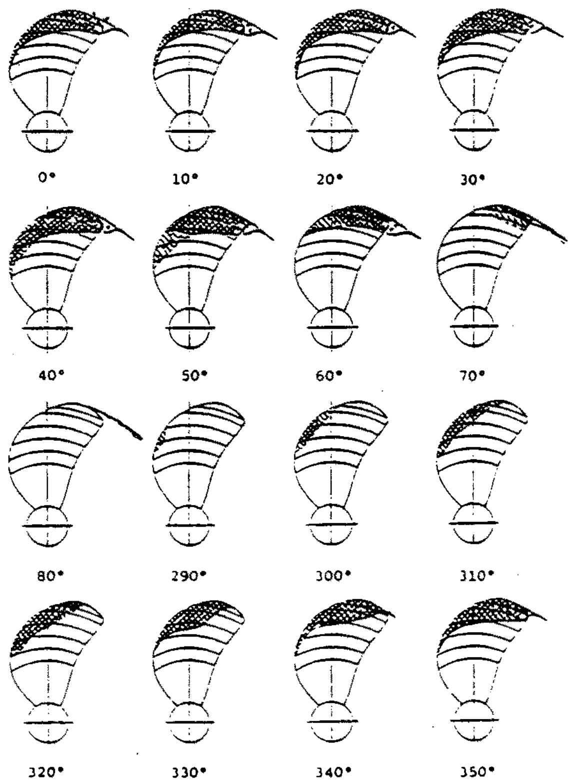

Figure 6 Cavitation Patterns in the Wake behind Wire Mesh Screen

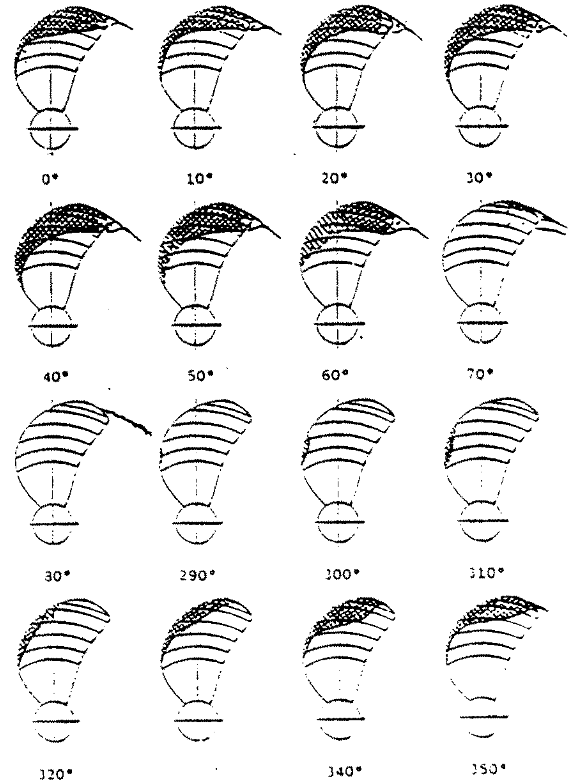

Figure 7 Cavitation Patterns in the Wake behind Large Dummy Model

CV-2

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ELECTROCHEMICAL POTENTIAL DIFFERENCE GENERATED BY CAVITATION

Many years of study on the phenomenon of cavitation erosion, lead the researchers to the conclusion that it is a consequence of two different mechanisms. These consist in the effect of the microjets formed during the collapse of the cavitation bubbles when they loose the spherical symmetry and the effect of the shock waves radiated during the rebound phase.

Erosion is thus connected to thermomechanical effects.

On the other hand, corrosion is often related to the appearance of electrochemical potential differences generated by the inhomogeneity of the material, i.e. to the so called galvanic currents.

Now, it appears that there is some experimental evidence [1.2] that, in presence of cavitation, both can be effective as inhomogeneous cavitation near the surface of a metal originates electrochemical potential differences in the metal itself.

The experiments were conducted irradiating with ultrasound a specimen of different metals immersed in distilled water, contained in a cell, whereas another specimen of the same metal was placed in the same cell, but sonically isolated. Ultrasounds of frequency of 20 kHz were employed. The potential difference $\Delta\phi$ between the two specimen, that was found to be absent in absence of irradiation, was measured and revealed a complex dependence on the ultrasound intensity, proportional to the square of the transducer vibration amplitude A, as indicated in figure.

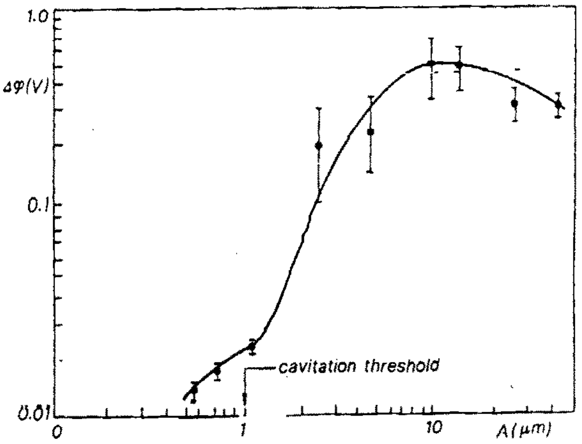

Fig. 1. Electrical potencial difference $\Delta\phi$ versus transducer vibration amplitude A for Aluminium in distilled water. Continuous irradiation at 20 kHz was used

A little potential difference was found to be present also at sonic intensities below cavitation threshold (measured through the noise emission intensity), but increased sharply by about one order of magnitude when transient cavitation was present.

This potential difference was formerly attributed to the effect of the microstreaming flows, generated by ultrasound and strongly enhanced by cavitation, on the part of the electric double layer lying on the liquid. Actually, it seems that part of it could be attributed to the generation of REDOX partners induced by cavitation [2].

It was found that the effect of salt is to decrease $\Delta\phi$ of about one order of magnitude passing from distilled water to saturated solution at room temperature, whereas similar experiments conducted at higher frequency indicated a somewhat lower value of $\Delta\phi$.

References

[1] Johri, G.K., Dezkhunov, N.V., Iernetti, G., Ciuti, P., Francescutto, A.: "Electro-Chemical Potential Difference Variation by Pulsed Ultrasound", Proc. Ultrasonics International '87, London, 1987, pp. 589-593.

[2] Dezkhnunov, N.V., Iernetti, G., Ciuti, P., Francescutto, A.: "The ultrasound Effect on the Electrode Potential", Contribution to Working Party on Electrochemistry, ICTP, Trieste, September, 1990.

CV-3

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COMMENTS ON THE REPORT

A. ON THE NEW VENTURI METER (with centerbody) (Section 1.3)

In Grenoble we used the new venturi meter intensively along the years 1986–87. Our experience leads us to express some remarks:

a. The sampled water volume used for the nuclei counting can be large enough since the flow rate can reach 1 liter/s, on condition that the time for the measurements is sufficient, for example 50 or 100 seconds.

b. The measured nuclei spectrum compares well enough to the number of bubbles which are activated on a cavitating foil as counted on rapid films.

c. At the time of the tests, the minimum cavitation number of the new venturi meter was about 0.7. Below this value, an attached cavity could be seen on the ogive nose. It resulted in a limitation of the nuclei measuring range, which was then connected to the operating conditions upstream of the venturi.

d. On a practical ground, there is some interest in building nuclei spectra versus the critical pressure: firstly this parameter characterizes each nucleus, if gas diffusion is negligible, and does not depend on the ambient conditions; secondly, it compares easily to the minimum pressure in the flow field.

Reference

[1] Briançon–Marjollet, L., Michel, J.M.: "The Hydrodynamic Tunnel of I.M.G.: former and recent equipments". Int. Symp. on Cavitation Research Facilities and Techniques, Boston, Nov. 1987 (published in the J. of Fluids Eng., Sept 1990).

B. ON THE λ^{-3} SIMILARITY RULE (Section 1.5)

1. Primarily, the λ^{-3} rule means that in homologous volumes (model and prototype), the number of active nuclei is the same. Thus, if liquid volumes suffer pressure reductions, as in similar venturi throats for example, the non-dimensional interactions between the growing bubbles will be the same in the mean. That conclusion lies on two main assumptions: only the inertial forces play an appreciable role during the bubble growth; the bubble size is almost independent from its initial value (this is found to be correct for the low values of σ_v).

2. In the case of transient bubbles along a curved wall with an appreciable transverse pressure gradient (as a 2–D foil), the situation may be different:

a. Experience shows that nuclei which actually grow and become macroscopic bubbles originally pass through a layer with thickness δ, situated in the region of minimum Cp. In general, δ is smaller than the thickness we can deduce by potential calculations.

b. Assume the bubbles grow in such a way they cover the dowsntream part of the foil beyond an abscissa x_s where the bubble radius is $R(x_s)$. This region is said

$$n \simeq \frac{1}{4\delta R^2(x_s)}$$

Formally, this expression leads to the λ^{-3} rule, by the dimension of the concentration itself.

However, the transverse direction probably plays a role different from the wall surface coordinates as the thickness δ may be controlled by viscous effects. Then we can expect a different power law, such as $\lambda^{-(2+\eta)}$, with η between 0 and 1.

c. Practically, if we take in account the nuclei concentration available, we can estimate both values of x_S and n. The result is that x_S decreases and tends to a limit when n increases. Then the foil can be said *fully saturated*. In such a circumstance the power law on λ has no more interest since a considerable increase in the amount of nuclei has no practical effect, neither on x_S nor on the forces coefficients.

3. In the case of incipient cavitation, water susceptibility is the most important parameter. The power law is useful only for similarity on the number of critical events. Here also the exponent could be $-(2+\eta)$ instead of -3.

References

[1] Briançon-Marjollet, L.: "Couches limites, germes et cavités en interaction: étude physique" Thesis, Grenoble, October 1987.

[2] Briançon-Marjollet, L., Franc, J.P., Michel, J.M.: "Transient bubbles interacting with an attached cavity and the boundary layer" J. of Fluid Mech., 218 (Sept. 1990) pp.355-376.

C. ON EXPERIMENTATION IN UNSTEADY CAVITATION (Section 4.3)

Laboratory experiments with oscillating hydrofoils probably do not fully represent the unsteady sheet cavitation on propeller blades, as is said in the Report. However, from a physical viewpoint they are useful for several purposes:

- the delays between the static case and the dynamic one, which seem to be due to the inertial forces for their most part, should prevent us from using quasi-static models when representing the cavitating flow;
- convective effects on special points as boundary layer separation (laminar or turbulent) and cavity detachment seem to be dominant;
- the link between the laminar separation and the cavity detachment is unaffected by the unsteadiness of the flow, at least for the temporal rates which can be produced in experimental situations. On the contrary, turbulent spots destroy cavity detachment in a very short time, probably smaller than 10^{-4}s;
- large modifications of the forces coefficients can be seen, if not exactly measured; they are due to the implosion of vortical cavitating structures which degenerate into cloudy cavitation;
- endly, cavitation erosion can be seen on oscillating hydrofoils at flow speeds lower than usual in steady conditions.

References

[1] Franc, J.P., Michel, J.M.: "Experimental investigation of unsteady effects in cavity detachment on an oscillating cavitating hydrofoil" Int. Symp. on Propeller and Cavitation, Wuxi, April 1986.

[2] Franc, J.P., Michel, J.M.: "Unsteady attached cavitation on an oscillating hydrofoil", J. of Fluid Mech., 193 (Aug. 1988), pp. 171–189.

D. ON CAVITATION EROSION (Section 6.2, 6.3)

1. Cloudy cavitation seems to be associated to the shedding of vortical cavitating structures, either in unsteady flow around oscillating hydrofoil or as a result of the partial cavity closure unsteadiness. In the last case it was experimentally proved that rentrant jet plays an important role in that process, as it contributes to the shedding of new vorticity into the flow.

2. The flow aggressivity, or damage potential, is an important point in erosion studies since, independently from the detailed mechanisms of energy concentration, it gives the actual boundary conditions which are imposed to the solid walls (at least if in a first step we neglect the liquid–solid interactions). The main problems we have to consider are: the pressure peaks measurements, the establishment of peak histograms and the similarity laws on these histograms. There is a need for new knowledge in this field in order to base erosion prediction methods on a firm ground.

References

[1] Le Q.: "Etude physique du comportement des poches de cavitation partielle", Thesis, Grenoble, Sept. 1989.

CV-4

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ON CAVITATION TUNNEL WALL EFFECT ON WAKE DISTRIBUTION

The BSHC cavitation tunnel was recently equipped with an additional large measuring section [1] for performing cavitation experiments with a complete ship model.

The present contribution is intended to give some additional arguments to Appendix 2 of the 19th ITTC Cavitation Committee Report [2] with regard to the flow liners employed in order to overcome the tunnel wall effect and to simulate estimated full scale wake.

In the experimental practice of BSHC cavitation laboratory, flow liners were also introduced. Employing a complete ship model of the famous "Sydney Express" incorporated with flow liners [3], the estimated full scale wake distribution was simulated with the same accuracy as that, presented in [1,4]. The agreement was also quite good for the transverse velocity components of the wake. However, "Sydney Express" is comparatively thin ship (c_B = 0.60) and in case of full ships, as it is wellknown, the wake distribution and thus the cavitation patterns are significantly more affected by the wall effects.

As an example, some results from wake simulation of comparatively full (c_B = 0.78) products carrier are

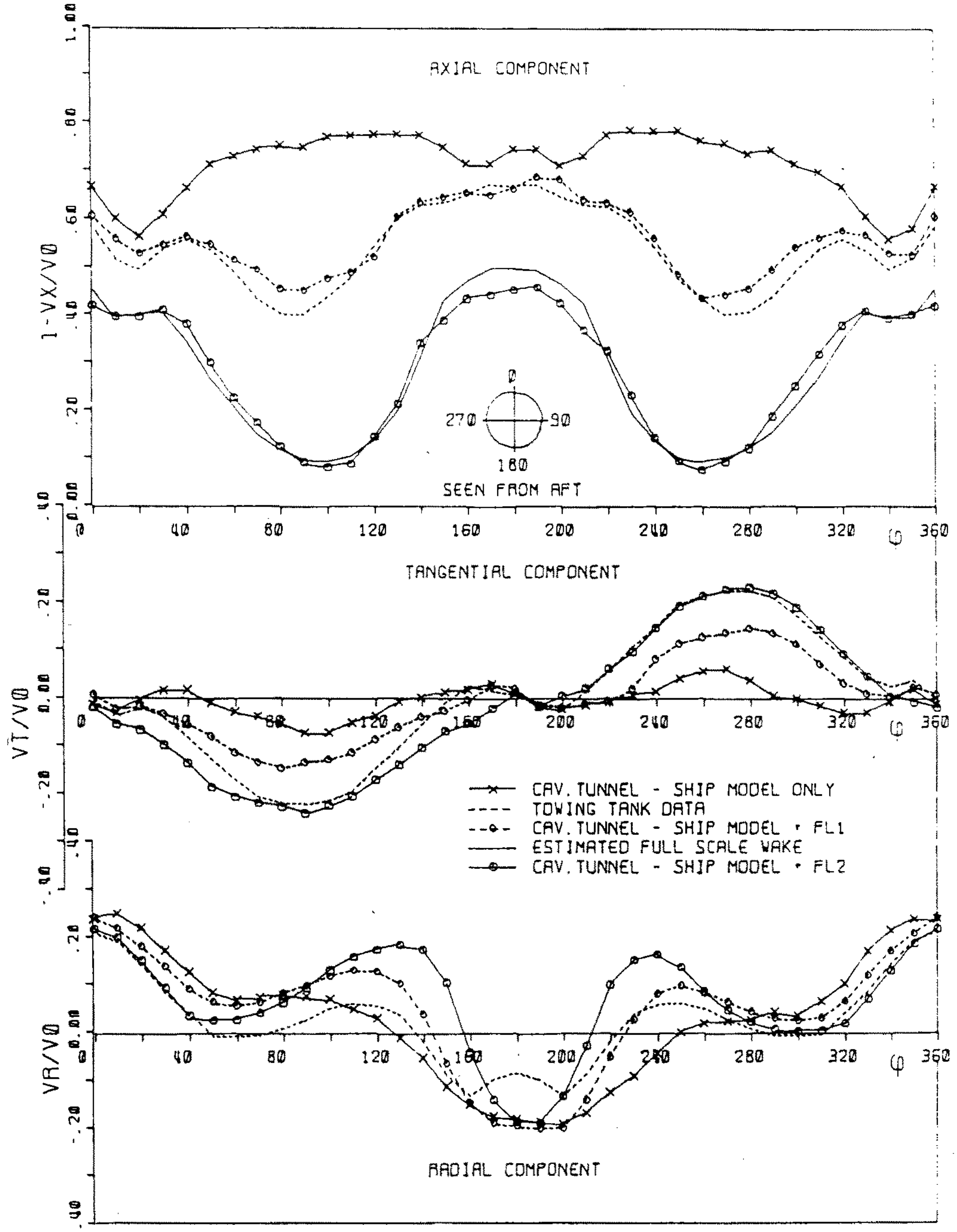

Fig. 1. Circumferential Wake Distribution at r/R = 0.8

presented here. Circumferential distribution of axial, tangential and radial components of the wake is shown in Fig. 1 for one typical radius. It is well seen from the diagrams, that the distribution of all three velocity components differ very much from the towing tank data (and much more from the estimated full scale wake), when there are not any flow liners. Then, when we are employing particular flow liners (designated here as FL1) a wake field distribution similar to the measured in the towing tank is obtained (see Figs. 1 and 2). Thereafter, incorporating flow liners of another design (FL2), the estimated axial wake distribution (by Sasajima and Tanaka's method) is simulated (Fig. 3). Besides, the simulation of the transverse wake components with flow liners FL2 is quite acceptable (Fig. 4).

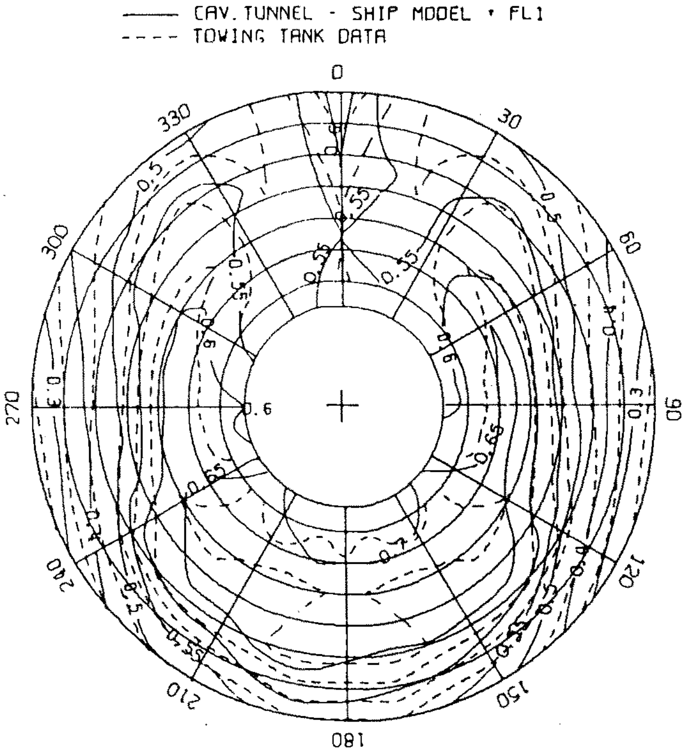

Fig. 2. Simulated Model Wake Distribution

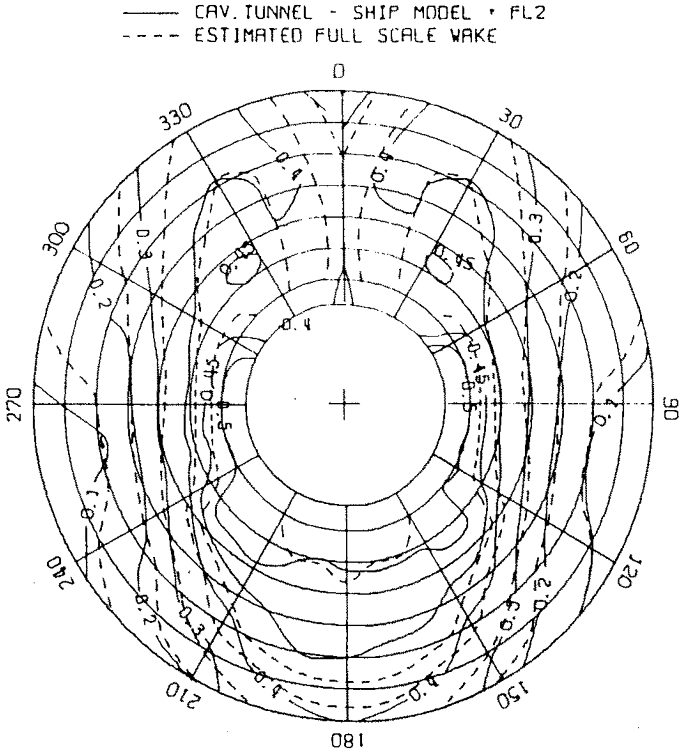

Fig. 3. Simulated Estimated Wake Distribution

Furthermore, in contradistinction to the "Sydney Express" model propeller, on which the cavitation development is quite similar irrespective of its operation behind either wire mean screen or a ship model [2], in the present case the cavitation pattern differ remarkably depending on the method of wake simulation: wire mesh or ship model (Fig. 5). Moreover, the distribution of axial velocity component simulated by wire mesh screen appears to be similar to the one behind a ship model (both fields simulate the estimated full scale wake in this case). It is necessary to mention, that for the presented ship, the

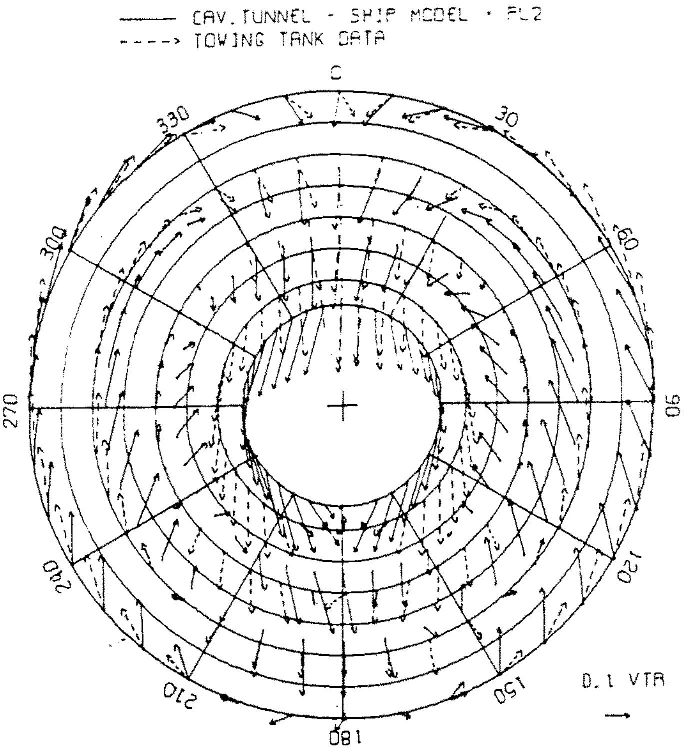

Fig. 4. Transverse Velocity Field

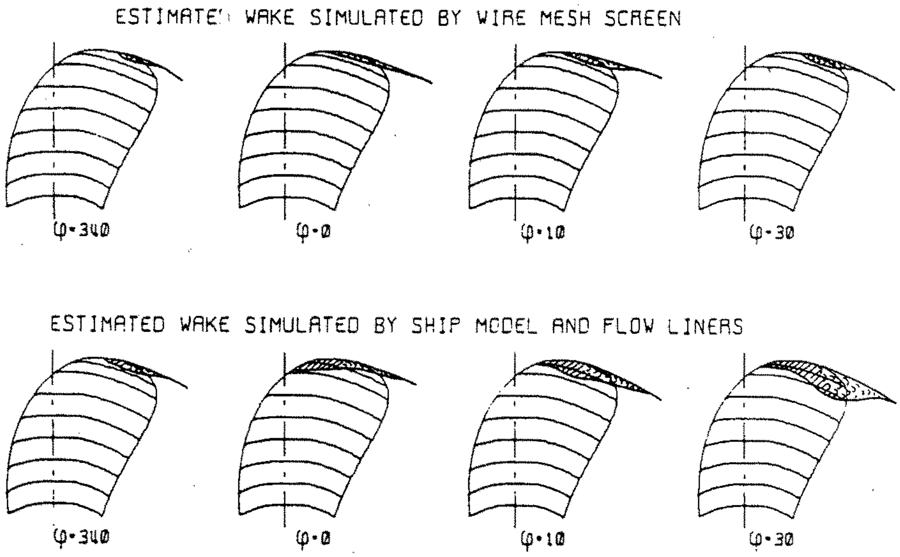

Fig. 5. Comparison of Cavitation Pattern at Different Methods of Wake Simulation

transverse velocity components are significantly greater than those for a thin ship like "Sidney Express". The phenomenon, described here was also observed for other full ships.

All this proves once more the necessity of wake simulation by complete ship model incorporated with properly designed flow liners for conducting of unsteady cavitation experiments.

References

[1] Yosifov, K. and Kalchev, R.: "Additional Test Section for BSHC Cavitation Tunnel Proc. of 17th ITTC, Vol. 2, Goteborg, 1984.

[2] Report of Cavitation Committee, Proc. of 19th ITTC, Vol. 1, Madrid, 1990.

[3] Gerchev, G. and Kalchev, R.: "Investigations on: Nominal Wake Field, Propeller Cavitation and Propeller-Excited Pressure Fluctuations on Ship Model of "Sydney Express" in the No. 2 Working Section of BSHC Cavitation Tunnel", BSHC Rep. No. TP-85-01. 12/25, Varna, May, 1990 (in Bulgarian).

[4] Ukon, Y., Kurobe, Y. and Saito, I.: "Comparative Experiment on Hull Pressure Fluctuations and Cavitation with the "Sidney Express" Propeller" Proc. of 18th ITTC, Vol. 2, Kobe, 1987.

CV-5

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PROPELLER NOISE

The Committee has made some efforts to clarify the scale effects on noise emitted by cavitating propellers. In a questionnaire the Committee has asked us to give our views on a formula reproduced on page 197, or more specifically on the exponent y of that formula.

In our answer we made some remarks, a few of which I repeat now:

1. The value y = 2 proposed by the Committee gives, according to our experience, good correlation model - full scale. This is not astonishing, as this value corresponds to what we call "Kp-scaling", i.e. the formula collapses to

$$Kp = \frac{p}{\rho D^2 n^2}$$

which is used when scaling low frequency, near field pressure fluctuations. Bad correlation occurring when using this formula should, in our opinion, not be improved by changing the exponent but rather by looking for the influence of other phenomena.

2. This leads us over to an item which we think is more important, i.e. to investigate the region of cavitation number (i.e. limited cavitation)

within which the cavitation number has to be different in the model and full scale cases. Because of this a term of the type

$$(\frac{\sigma_S}{\sigma_M})^n$$

has to be included in the equation for determining the scale effect. This problem is discussed in detail in Ref. [31] and elsewhere. If cooperation within this area is not made impossible by the fact that a lot of the results available are classified, I would suggest that this item is recommended for further work of the Committee.

CV-6

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REMARKS AND QUESTIONS TO THE 19TH ITTC CAVITATION COMMITTEE REPORT

By reading the comprehensive Cavitation Committee Report with particular interest a number of remarks and questions arose to me. However, I would like to put forward only the following ones:

1. CAVITATION NUCLEI

In this somewhat unreflected section on cavitation nuclei a comparison of results between different methods is presented. In part 1.2.2.1 it is explained that the white light scattering system detects spheres in a smaller size band than holography, because the reflection coefficientes of plastic are different from those for air. This is not understandable, since the PDA system measures the spheres in the correct size band, in spite of mainly utilizing the reflecting behaviour of the spheres. A comment on this point would be appreciated.

The statement in section 1.3.2 that any optical technique cannot accurately measure nuclei diameters less than 10 μm may be correct for holography but for the PDA system this limitation does not apply for the following reasons:

a) For the PDA system a certain light intensity, depending on the test conditions and amplification is well necessary, but once a bubble detection occurred, the proportionality between light intensity and diameter squared, being valid for amplitude dependent systems, is no longer relevant for the PDA as frequency based system. For this system linear proportionality between the measured phase from two detectors and the nuclei diameter is applied for the evaluation. Therefore, the PDA-method can measure down to extremely small diameters, theoretically down to zero.

b) But also practically, diameters less than 10 μm have been shown to be detectable with the PDA. Results down to around 7 μm for the PDA System in comparison to the evaluation of bubbles from simultaneously taken photographs are shown in Fig. 1 for a laboratory measurement.

This, we believe, supports the reliability of the PDA results in the bubble range even below 10 μm in

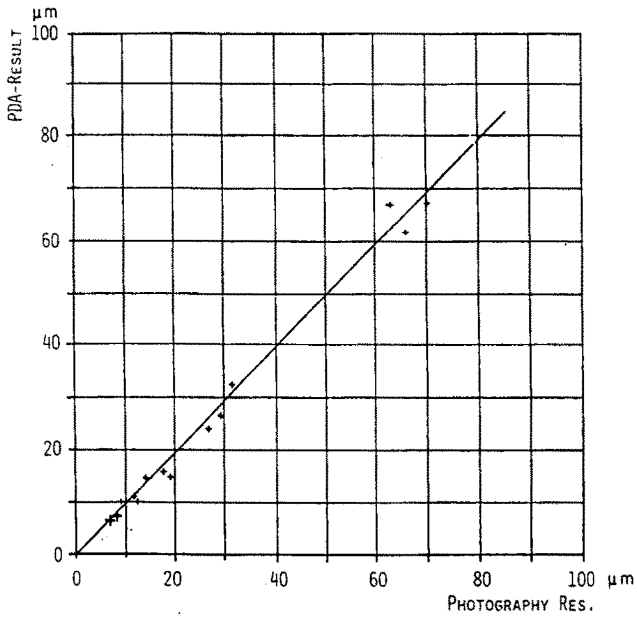

Fig. 1. Comparison Photography Results – PDA Results

contrast to the dropping sensitivity of the holography as shown in Fig. 1.7 of the report. This difference is important, as it is well known that the smaller diameter nuclei participate in the cavitation process especially on propeller profiles.

Furthermore, I miss a remark in the report regarding the on-line evaluation capability of the PDA system in contrast to the time consuming evaluation process required for hologrphy.

I also miss the treatment of the influence of micro bubbles in comparison to solid particles and pore nuclei on the cavitation process, as well as of pore nuclei or of organic skins on the stabilization of the gas nuclei.

2. LEADING EDGE TRIPPING

The 18th ITTC Cavitation Committee Report recommended leading edge roughness for further exploration and stated a lack of upper roughness Reynolds numbers to prevent premature and unrealistic types of cavitation. Also, the 17th ITTC CC Report stated the danger of premature cavitation on roughness elements as well as the fact that the effect of roughness effects on propeller tip vortex cavitation and lift characteristics was not fully understood.

Are these problems solved to day so far that a recommendation of roughness application can be made without any caution?

3. PROPELLER-INDUCED HULL PRESSURES

The better agreement between different (Japanese) facilities for the comparative pressure fluctuation measurement of the "Sydney Express" is appreciated. However, this improvement could also be reached just by increasing the thrust coefficient for the model from $K_T = 0.175$ to $K_T = 0.184$; the first value is the correct full scale one. Due to this increase the scale effects involved could be partly compensated.

4. CAVITATING TIP AND HUB VORTEX

Chapter 7 of the CC report is an excellent summary on vortex cavitation. Regarding the application of the tip vortex scaling in sections 7.3.1 and 8.6 it should, however, be mentioned that the hydrodynamic background of HSU's work [119] is improbable, since Hsu applies Kirde's theory [331]. This is an unsteady viscous similarity solution for *laminar* vortex flows, whereas *turbulent* ones should be used here. In our current HSVA work on tip vortex scaling we are trying to extend the theoretical work on tip vortices in this regard.

Concerning the efficiency gain due to the applications of vanes, cited in references [326 to 329] of the report, the propeller community is not yet convinced how relevant and reliable such an increase in efficiency for propellers in full scale really would be.

CV-7

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REDUCTION OF TIP VORTEX CAVITATION ON A PROPELLER BY ARTIFICIALLY ROUNGHENED SURFACES ON BLADE TIPS

This contribution is a topic of an experimental investigation which aims to reduce tip vortex cavitation on a propeller by the artificially roughened tip. The flow visualization on propeller blades by the oil-film method and measurement of static-pressure for the inception of tip vortex cavitation are conducted in I.H.I. cavitation tunnel.

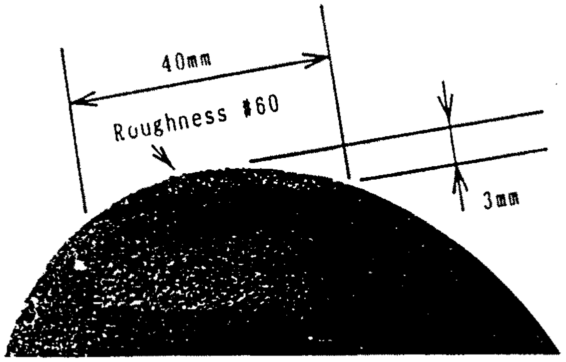

Fig. 1. Close-up View of Applied Roughness. (Pressure Side, Suction Side is same.)

Fig. 1. shows an example of a propeller blade with artificially roughened tip. Carborundum(=60) was put on the blade tip of a conventional propeller (5 blades, 250 mm in diameter). The roughness was fitted on both pressure and suction sides of all the blades. Position and area of the roughness were decided from the oil-film pattern showing the roll-up process of tip vortex on the blade without roughness.

Fig. 2 shows comparisons of tip vortex cavitation on the propeller between with and without roughness at the same cavitation numbers. The propeller was tested at 23 r.p.s. in the uniform flow of 4.3 m/s, and the static-pressure was varied from 1.1 kgf/cm^2 to 0.4 Kgf/cm^2. The results depict apparent effect of the roughness on reduction of tip vortex cavitation.

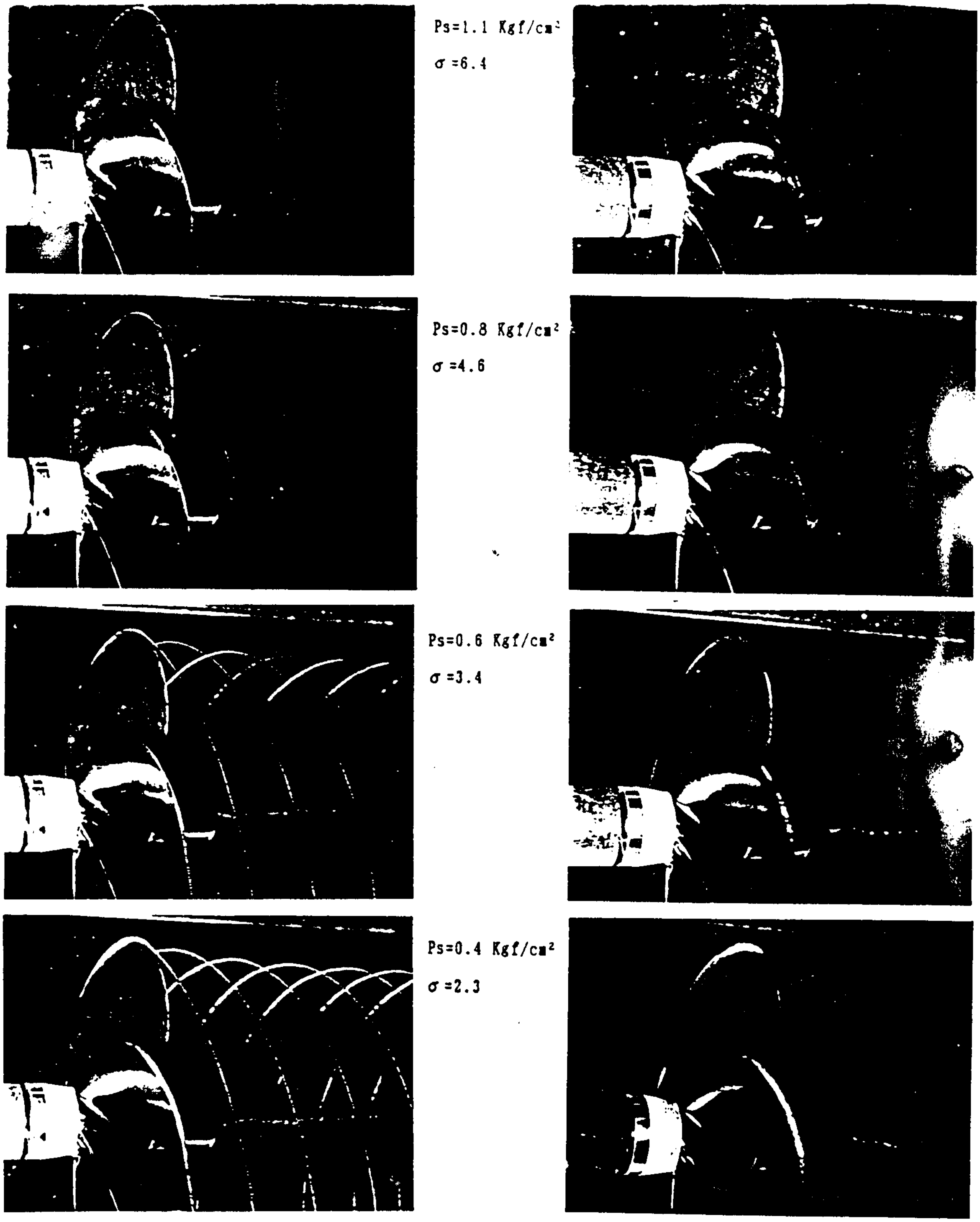

Fig. 2. Comparison of Tip Vortex Cavitation between with and without Roughness at Various Static-pressure.

Ps: Static-pressure, σ: Cavitation Number $= \dfrac{Ps - Pv}{1/2 * \rho * N^2 * D^2}$

CV-8

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CAVITATION NUCLEI MEASUREMENT

One of the devices reviewed by the Committee is the cavitation Susceptibility Meter, based on a Venturi meter system. Some of the drawbacks with the existing systems are discussed and it is said that further research is required in this area.

Having read this chaper I find that the Committee holds a somewhat ambiguous view on this device. Thus, on page 169, it is said: "The CSM is a convenient cavitation reference device but it is not likely to become a general standard cavitator". On the bottom of page 171, on the other hand, a more promising future is indicated for this device. I quote: "The Committee recommends the use of the CSM as only a cavitation reference device for continuous monitoring of water cavitation susceptibility during routine tests, but **not yet** as a nuclei distribution measuring device".

With these statements in mind I would like to ask the Committte about two things:

1. Which is the exact meaning of the concept standard cavitator?

2. Would the Committee advice us to invest **now** in the Venturi set up which is commercially available, or is it too early?

CV-9

B.R. PARKIN

Arl., Pen State University, U.S.A.

SOME QUESTIONS FOR THE CAVITATION COMMITTEE

Three members of the conference wish to thank the committee for preparing a comprehensive revision of developments in cavitation research since the 18th ITTC. There are some points of confusion on my part which I hope the members of the committee can clarify for me.

1. What are the axis labels for Fig. 2.5 on p. 182?

2. In par. 2.8.1: How are the Boundary layer nuclei generated when leading edge blade roughness is present? Some specific questions are:

   a) Is bubble collapse always involved?
   b) Where are the nuclei found?
   c) Do free-stream nuclei play any role in the development of micro-cavitation?
   d) What is meant by "micro-cavitation" and "cavitation inception" in the context of the report?

CV-10

K.R. SUHRBIER
Vosper Thornycroft (UK) Limited, U.K.

ON PROPELLER-INDUCED PRESSURES

I would like to thank the Committee for a most interesting report. It covers a wide range of topics and gives a great deal of useful information.

I noted with interest the comments on propeller-induced pressures and the influence of the frequency ratio (stiffness) on the transmissibility. It is said (in 3.3.6) that "in order to improve the vibratory response of the flat plate system, its natural frequency should be made sufficiently lower than the resonance frequency as in the case of the ship model". I presume the purpose of this proposal is to match the model natural frequency by that of the plate arrangement in order to investigate (on the plate) more easily the influence of stiffness on the measured signals and possibly determine corrections - since the elastic properties of the hull model cannot (easily) be properly scaled.

As stated in the report (and also referred to in that of the 18th ITTC), a good check on the influence of the stiffness of the test arrangement on the recorded pressure pulses may be obtained by measuring p over a range of rpm at constant J and see whether the non-dimensional K_p values are reasonably constant, within 5% or so. I can confirm that we found this simple approach most useful.

Finally, I would like to add that I am very pleased to see that the Committee continued the discussion on 'Practical Aspects of Cavitation Testing' and I hope that the next Committee will be able to do likewise.

CV-11

Y. SHEN
China Ship Scientific Research Center, China

DISCUSSION ON THE REPORT OF THE CAVITATION COMMITTEE

The report of the Cavitation Committee gives a wonderful review of cavitation research and some very useful conclusions which can be considered as the guides to continue both theoretical and experimental research.

Some important parameters to influence the model test results of propeller-induced fluctuating pressure are reviewed in this report. They are simulation of full-scale wake, sufficient active nuclei, use of leading edge roughness and so on. However, the effect of stern appendages on the fluctuating pressure is not concerned in the report of the Cavitation Committee.

As seen in the report of the Propulsor Committee, "the influence of rudder on the propeller forces fluctuation is not as negligible as considered hitherto". A comparative test to show the effects of rudder on propeller-induced fluctuating pressure was carried out in the large cavitation tunnel of CSSRC for a twin-screw ship with a plat bottom above the propeller. The difference between with and without rudder of the fluctuating pressure is significant for the transducers located behind the propeller plane, especially in case of the presence of vortex cavitation. The observation of cavitation pattern shows that there is a strong deformation of helical vortex cavitation in the case of presence of rudder. The helical tip vortex cavitation is no longer located on the surface of a cylinder of constant diameter as seen in the case of absence of rudder, and it pass round the top of the rudder. The amplification of hull fluctuating pressure is attributed to the reduction of the distance from the cavitation to the transducer. So it is our experience that the dummy model for the fluctuating pressure test should be fitted with rudder, at least for twin-screw ships. Could the Cavitation Committee say a few words on the effect of appendages as a comment?

I noticed that the "Sydney Express" model propeller was employed with leading edge roughness on both sides of the propeller leading edge. I wonder whether this consideration is aimed at keeping the camber line unchanging or at avoiding a laminar boundary layer? In most cases, however, there is no face cavitation in the range of advance ratio adjacent to the design point. I guess that maybe the use of roughness only on the suction side is better than on both sides, because the latter can keep lift unchanging but increase drag.

CV-12

J.H.J. van der MEULEN
MARIN, The Netherlands

DISCUSSION ON REPORT OF CAVITATION COMMITTEE

The Cavitation Committee has to be commended on presenting a detailed review on a number of topics of importance to the ITTC community. The analysis has led to a number of conclusions which have or did not have become recommendations to the Conference.

In dealing with tripping devices at the leading edge of propeller models the Committee has stated that the effectiveness of tripping devices in eliminating scale effects on cavitation inception has to be attributed to nuclei generation due to micro-cavitation and not to turbulence stimulation.

I fully agree with this statement. I was rather disappointed, however, to find out that this statement has not led to a clear and general recommendation to the Conference. On page 212 of the report of the Committee stated: "The use of leading edge roughness on propeller blades is encouraged for small cavitation facilities with limited nuclei population and speed capacity".

In my opinion this encouragement, or rather recommendation, should also include high-speed facilities and even facilities with nuclei seeding, unless it can be proven that sufficient nuclei are already present near the blade surface.

In the section on erosion the Committee briefly touched upon the subject of correlating noise and erosion. In this regard it might be useful to introduce the concept of cavitation intensity. In dealing with acoustic cavitation Flynn [1] has demonstrated the usefulness of this concept. Bul also for hydrodynamic cavitation the concept of cavitation intensity may prove its usefulness. Noise, erosion and even luminescence can all be regarded as a measure of hydrodynamic cavitation intensity [2]. In a recent study on sheet cavitation [3] the intensity of the cavitation was based on measuring the intensity of luminescence. Due to this approach it could be argued that isolated sheet cavitation will lead to full scale propeller erosion.

References

[1] Flynn, H.G.: "Physics of Acoustic Cavitation in Liquids", Physical Acoustics, Vol. 1B, Academic Press, New York, 1964, pp. 57–172.

[2] Van der Meulen, J.H.J.: "Some Physical Phenomena Associated with Cavitation", Proceedings 17th International Congress of Theoretical and Applied Mechanics, Grenoble, August 1988, pp. 369–386.

[3] Van der Meulen, J.H.J. and Wijnent, I.L.: "On the Structure and Intensity of Sheet Cavitation", ASME Cavitation and Multiphase Flow Forum, Toronto, June 1990, pp. 101–105.

CV-13

J.W. ENGLISH
British Maritime Technology Ltd., Teddington, U.K.

DISCUSSION TO CAVITATION COMMITTEE REPORT

Referring to air injection into cavities for the purpose of reducing fluctuating pressures on nearby surfaces, reference 293 indicates that no significant effect was found, although the noise was reduced by 20dB. I find this curious and strange. My experience with injecting air into cavitating tip vortices on noisy model marine propellers is such that radiated fluctuating pressures and noise were invariably reduced together. This I suggest is to be expected and is probably associated with damping of the cavity collapse both on and of the propeller blade surfaces.

Regarding the stimulation of turbulent flow on model propellers and the use of leading edge roughness we should not overlook the usefullness of turbulence in the onset flow for this purpose. This turbulence can be increased with upstream gauze screens or counterflowing jets, for example, and this avoids the possibility of introducing unwanted parasitic cavitation effects due to blade roughness.

In the commercial testing of model propellers in cavitation tunnels the use of optical methods for bubble counting is not tenable due to cost. In the past I used a simple acoustic monitor that told me that the conditions on a second or subsequent run were similar to the first one. I suggest that the Committee should investigate this alternative approach in future because of its simplicity, utility and low initial and operating costs.

CV-14

J.P. BRESLIN
Professor Emeritus, U.S.A.

TUNNEL BOUNDARY EFFECTS

The members of the Cavitation Committee have done splendid work in rendering this extensive report. I wish to raise an issue which was not addressed in regard to tunnel boundary effects.

Measurements were made of the pressures induced by an intermittently cavitation proper on the stern of a model in the SSPA Cavitation Tunnel. There, as you know, the model is surrounded by plywood which extends to the steel work of the tunnel. This is secured from above and has water above, and of course, below. Our calculations (1) were done for two extreme of this lateral surface around the hull; one considering the plywood to be rigid, i.e., on which the vertical component of velocity is zero, the other for a free water surface on which the induced pressure and potential vanish (high frequency limit). Comparison of computed and measured pressures showed better agreement with the first boundary condition, viz., the fully reflecting rigid "wall". However an eminent acoustic later told me that because the plywood is thin relative to the acoustic wave length at the test frequency and because it is soaked with water (ρC = that of water) the propeller induced pressures would not be reflected but would pass through as though the plywood was absent.

I find this difficult to believe since the potential of an acoustic source is $i2\pi R/\lambda$
where

$$R=M(T)\frac{e}{R}$$

where
R is the distance from source to any point and
λ the wave length.

In the very near field (where the pressure picks up were located) $R/\lambda << 1$ because λ = 8 to /16 meters, so the fluid acts as if it were incompressible in the near field at low frequencies of the order of 100–200 Hertz.

As this artificial "water plane" around the model must be a feature or other large water tunnels, I suggest that this problem be addressed by the Cavitation Committee. Very recent and interesting work by Dr van Gent at MARIN might be extended to this boundary effect.

II. REPLIES BY THE CAVITATION COMMITTEE

Reply to Dr. HO-SHUNG LEE

The Committee would agree that a good dummy model provides the best wake simulation in a cavitation tunnel. We would like to emphasize that it is important when simulating a ship wake to represent the crossflow as well as the axial flow produced by the hull at the propeller position. The tangential velocity component of the crossflow is of particular importance. It may, therefore, be expected that representation of the wake by a wire grid alone would not create the flow for a realistic variation in cavitation pattern during the rotation of a propeller blade.

A dummy model simulates the wake better than does the wire grid provided the model is long enough.

At the Reynolds numbers usually possible in a Cavitation Tunnel, a smooth dummy model will not produce the necessary turbulent layer so that wires attached to the hull surface, are required. If tunnel wall blockage effects are significant then a flow liner may improve the situation.

Reply to Drs. DEZKHUMOV, FRANCESCUTTO and IERNETTI

In the report a "DECER" erosion detector was discussed. The kind of detector, based on electrochemical phenomena, looks promising for the quantitative evaluation of pressure pulses or cavitation intensity. Measurement of the potential difference, as shown by Dr. Dezkhumov et al, will be one of these methods. Further studies will be necessary for practical application in model propeller tests in a cavitation tunnel, but the Cavitation Committee appreciates additional information from the discussors.

Reply to Dr. MICHEL

The 'Institute de Méchanique de Grenoble' has been one of the leaders in basic cavitation research and I would like to thank Dr. Michel for his comments that clarify some issues on the venturimeter and support conclusions on unsteady cavitation and erosion. The Committee agrees that the new center-body venturi meter has better stability than the previous system. The interest in obtaining the nuclei spectrum from the venturi data is due to the need to quantify and scale cavitation inception on a test body. The venturi gives a value for liquid tension in its pressure field and has been shown to be sensitive to nuclei distribution. However, the solution does not appear to be unique. Different body pressure distributions in general are sensitive to different nuclei distributions at inception. The comments of Dr. Michel on the $\lambda 3$ similarity rule are important to the inception problem. In the case of cavitation inception, this rule may not be useful and more research is required before a recommendation can be given as to the distribution and number required for modeling.

As to the comments on cavitation erosion, the Cavitation Committee agrees with Dr. Michel's comments. Development of small-riged pressure sensors, such as one developed by Prof. Kimota, is to be encouraged.

Reply to Dr. KALCHEV

The Committee would like to express their appreciation of his valuable contribution on the reduction of wall effects and the simulation of estimated full scale wake by the flow liners. The case of the "Sydney Express" is one of the good examples where the flow liners work well in simulating the estimated wake. In the case of full ships, the wake distribution behind a complete ship model without the flow liners suffers from strong wall effects. In the extreme case, the wake distribution becomes unsymmetric. The use of the flow liners can solve this problem, as discussed by the SRI and the discussers. The combination of a complete ship model and the flow liners works most effectively in the case of a full ship. The influence of the tangential component of wake on the pressure distribution, that is on the cavitation extent, is remarkable, as will be indicated in the Group discussion No. 2 on the full scale measurement of the pressure distribution.

The flow liners can control the overall wake behind a ship, but it is difficult to manage the wake simulation in the vicinity of propeller boss and to simulate high wake peak. The Committee would like to ask the discussers to publish the work on the design of flow liners.

Reply to Dr. JOHNSSON
Subject: Propeller Noise

We appreciate the comments by Dr. Johnsson and agree that the power j = 2 for the velocity dependence may give good correlation for some types of cavitation noise. But for other types a much higher volume may be required as discussed in our report and in the previous report. Dr. Johnsson proposes that bad correlations should be improved by looking for the influence of phenomena not considered up to now. That is also one of our main conclusions. Further improvements will require more complete physical models for description of the noise generation and adequate stochastic models for cavitation noise. Here we once more would like to refer to vortex by Bark [31], Baiter [25], and to ref. [1]. The normal procedure in cavitation testing is to apply the same cavitation number as in full scale. Dr. Johnsson mentions the possibility to set the cavitation number in model scale lower than in full scale in order to obtain identical cavitation patterns and to apply the ratio between the cavitation number in the scaling laws. To operate with different cavitation numbers in full scale and model scale and to apply different reductions depending upon whether we have incipient cavitation or well developed cavitation may be one solution. An alternative is to apply identical cavitation numbers and to manipulate the power for velocity dependence, what it all boils down to is the need for better control over Rn effects and nuclei effects on cavitation both at model and full scale. Some of those aspects have been discussed in our report. We share Johnsson's view that Bark's proposal [3] is an interesting approach.

Reference

[1] Baiter, Gruneis and Tilmonn: "An Extended Base for the Statistical Description of Cavitation Noise", Internal Symposium on Cavitation Noise (Book No. H.00231) ASME.

Reply to Dr. E.A. WEITENDORF

1. Cavitation Nuclei

First of all, we would like to acknowledge the support of HSVA in providing the PDA system and engineering staff during the experiments. HSVA has continued to develop the system in order to define the importance of nuclei distributions on cavitation inception. Both the PDA and light scattering systems depend on Mie scattering theory and hence the relative index of refraction is variable. The relative refractions of the polystyrene spheres was entered into the on-line PDA analysis procedure and the PDA correctly sized the 144 μm spheres. The white light scattering system was calibrated for bubbles and the analysis procedure was not changed during the experiments. Hence, this system would incorrectly size the polystyrene spheres as bubbles. Subsequent calculations clearly show that the 44 μm bubble in Fig. 1.5 would correspond to the 14 μm sphere using the correct relative index of refraction.

I agree completely with Dr. Weitendorf's comments that the PDA system can measure accurately bubbles below 10 μm in diameter. The problem that I am referring to is due to the water tunnel environment. As an example, I would like to discuss why holography can not detect small bubbles. In air holography can easily detect solid particles as small as several microns. However, in water the scattering of small bubble is combined with the scattering of similar size solid particles and the phase information is lost in the background speckle. The PDA has a similar background level problem. Removing the solid particles will improve the resolution; however, the numbers of the particles is several orders of magnitude larger than the bubbles.

The importance of nuclei type on cavitation inception has been discussed by many investigators and a conclusion can not be easily made. However, micro bubble nuclei are weak in tension when compared to solid particles or pore nuclei. Therefore, as pressure is lowered and the liquid tension on the body is increased, the microbubbles will cavitate first if present.

2. Leading Edge Tripping

The Committee report discussed the cavitation inception process with rouhgness elements and attempts to clarify the physics. The Committee agrees with Dr. Weitendorf that the effect of leading edge roughness on lift characteristics and tip vortex cavitation requires further investigation. The Committee does not recommend the application of roughness as a general testing procedure but relies on the experience of the members regarding application.

3. Propeller-Induced Hull Pressures

The 18th ITTC comparative measurements on pressure fluctuations for the "Sydney Express" were performed under the condition of slightly higher thrust coefficient than that of HSVA. The higher thrust coefficient gives a more stable cavitation occurrence and higher pressure amplitude qualitatively discussed by Dr. Weitendorf. The present improvement can be obtained not by performing the measurements under the higher thrust coefficient, but only by quantifying the experimental conditions with the artificial nuclei seeding, employment of the estimated wake and a detailed check of the tunnel effects on the measurements. The scatter of data in the previous comparative measurements were given by the lack of a defined procedure. For the present comparative measurements, the simulation discussed gave satisfactory agreement on cavitation extent and pressure fluctuations for the "Sydney Express" propeller.

4. Cavitation Tip and Hub Vortex

We would like to thank Dr. Weitendorf for his comment on vortex cavitation. We agree that the model of HSVA only applies in the roll-up region of a laminar vortex. However, cavitation has been observed to initiate in this region and the power dependency is determined from the propeller database. We would like to encourage HSVA to continue to develop on turbulent model and present their results at the next ITTC meeting.

The results presented in Ref. 326 and 329 are supported by additional data in the Propulsor Committee report. A strong hub vortex is an energy loss and the purpose of the vanes is the recovery of this rotational energy.

Reply to Drs. AKIYAMA and SATO

The work of Akiyama and Sato clearly show the influence of tip vortex inception of propeller blade roughness. This supports the previous research of McCormick [202] and Souders and Platzer [261] and the results shown in Fig. 2.5 of the Committee Report. Many issues remain in the understanding of the physic and more research is required before roughness can be used as a general tip vortex cavitation delay device. One important issue is the cavitation performance of the roughened tip at high full scale Reynolds numbers.

Reply to Dr. JOHNSSON

Subject: Cavitation Nuclei Measurement

We would like to thank Dr. Johnsson for noting an apparent inconsistency in the report. A standard cavitator is a body and/or device whose cavitation characteristics are well defined. This device can be utilized in parallel with a reference body in a cavitation test to predict scaling effects. Liquid tension is determined by the venturi and this is a measure of water quality. The venturi details a specified dynamic behaviour in a specific pressure field. This information is not enough to address the scaling issues of a different pressure field; however, it is more information than before but not as much as the bubble distributions. One important step in solving the scaling effects problem is to conduct experiments with consistent values of liquid tension. Therefore, if the organization wants to utilize a liquid tension measurement as a part of the cavitation experiments, the Committee recommends the use of the venturi systems.

Reply to Prof. PARKIN

Prof. Parkin correctly points to an ommission in Fig. 2.5 on page 182. The vertical axis is the cavitation index, the horizontal axis is the thrust coefficient.

Prof. Parkin also asks for details of the nuclei generation in regions where the local mean pressure is above the vapor pressure. As mentioned in the report little is known in this regard. The phenomena have to be related with experiments on a larger scale. When roughness is present, the flow separates from the roughness elements. A short separation bubble is known to cavitate nearly independent of the nuclei content of the fluid. Since nuclei are necessary to break the fluid bond it can be assumed that the nuclei required to generate inception in a reattachment region are either generated in that region or that only very small flow nuclei are required for inception in the reattachment region due to the local low pressures or due to diffusive growth in sheltered regions. Prof. Parkin has done detailed work in this field himself. So if any free-stream nuclei play a role in the development of micro cavitation their size is very small and practically inception is independent of the nuclei distribution in the size range above a few microns.

When the local mean pressure above the boundary layer is higher than the vapor pressure, cavitation can still occur on the roughness elements due to the locally lower pressures. This generates larger nuclei, mainly by gas diffusion into initiating very small flow nuclei, as mentioned before. Such a process may occur also without cavitation, but due to the growth of nuclei in low pressure regions alone. However, when the local mean pressure becomes too high the nuclei generation from the roughness elements stops. So it is probable that bubble collapse is always involved.

The nuclei generated on the roughness elements express themselves downstream in low pressure regions as bubble cavities.

As stated in the report micro cavitation and its inception have to be distinguished from cavitation on a macro-scale, which occurs when the pressure outside the boundary layer is lower than the vapor pressure. The latter cavitation is what matters and cavitation inception in practice therefore has to be defined as inception of this scale of cavitation.

Reply to Mr. SUHRBIER

The discussion in par. 3.3.6. where Mr. Suhrbier refers to is not meant as a proposal for tunnel testing. It is a possible method to quantify the influence of plate vibrations on hull pressures to arrive at extrapolations from model scale results. The elastic properties of ship models cannot be influenced very much indeed and the aim should be that the model should be as stiff as possible. In that case the pressure coefficients will be independent of the rpm and the method of rpm variations is a good check indeed.

Reply to Dr. SHEN

The effect of a rudder at zero degrees angle on the propeller performance is not negligible indeed. Not only the flow downstream of the propeller is influenced, the interaction with the propeller itself is also large and the propeller loading is affected. When hull pressure measurements are done it is therefore important to fit all appendices which affect the propeller performance.

For stimulation of cavitation inception leading edge roughness is only required at the side of the propeller where cavitation occurs. For stimulation of a turbulent boundary layer application at both suction and pressure side may be required, since the boundary layer at the pressure side may also be laminar over some distance. As mentioned in the report the effects of roughness on sectional lift are still unclear, but when the roughness is applied at the suction side only the effect on the lift will be unrealistically large. So when roughness is applied it is better to apply it at both sides of the blades.

Reply to Dr. van der MEULEN

Dr. van der Meulen correctly observes that the recommendation of the Committee on application of roughness is still careful. This is because much of the described mechanisms are found from reasoning rather than from direct experimental results. This does not mean that in large facilities scale effects do not exist. Especially on propellers with a constant pressure distribution at the suction side or with thick leading edges, laminar flow may exist up to very high Reynolds numbers. The size of roughness to be applied, however, will decrease with increasing Reynolds number, and it will be more difficult to apply properly. For the generation of nuclei, leading edge roughness can indeed be useful in any facility, since it is nearly impossible to scale the number of nuclei in bubble cavitation properly by controlling free stream nuclei. This is especially important when radiated noise is measured.

The concept of cavitation intensity can indeed be useful. It is the intensity of the collapse of cavitation bubbles or vortices and as such directly related with radiated noise and with erosion. However, intensity has to be measurable and quantifyable in order to be useful. Dr. van der Meulen use of luminescence as a measure for cavitation intensity is therefore important.

Reply to Dr. ENGLISH

For air injection to be effective on fluctuating pressures the dynamic behaviour of the cavity has to be influenced. This means that the gas pressure has to become effective when the volumen change of the cavity is still appreciable. The effect of gas injection on noise generation is due to the gas pressure at the very end of the implosion of cavities. The amount, necessary for the latter will in general be smaller. It seems therefore possible that the amount of gas is such that noise is damped by air injection, while no effect on radiated pressure fluctuations is found. The actual effect will depend very much on the type of cavitation and the dynamics of it. The experience of Dr. English is apparently focussed on cavitating tip vortices. These are not always the main source of fluctuating pressures, so that a general statement of the effects of air injection will be very difficult.

Dr. English point to the effects of flow turbulence on the propeller boundary layer. There certainly may be an effect of it on the transition of the propeller boundary layer. The effect depends very much on the turbulence scale in combination with the critical frequence in the boundary layer. The latter is very much dependent on the pressure distribution on the blades. So the effect of flow turbulence may differ. If sufficient turbulence can be generated to trip the propeller boundary layer without other unwanted effects should be investigated. In "normal" cavitation tunnels, even at higher velocities, the turbulence level is of the order of 2 percent and this is certainly not sufficient. In towing tanks in behind condition the turbulence in the wake is also high but not sufficient. Of course the lower Reynolds number makes it ever more difficult there.

The use of acoustic methods to ensure constancy of test conditions is an alternative for the well known van Slijke apparatus in that it gives an indication. For inception, however, the largest nuclei are important and these may be only a fraction of the total amount of nuclei. It is very difficult to measure that aspect acoustically. The venturi systems do so more directly and are not very costly either. Optical methods are indeed still expensive and difficult to work out.

Before dwelling further into the measuring of nuclei distributions it was the opinion of the present Committee that in the near future the emphasis had to be on criteria to be maintained for nuclei size and number distributions to avoid scale effects. This in order to use the present possibilities properly.

Reply to Dr. BRESLIN

We thank Dr. Breslin for his comments. The response of any walls in the vicinity of cavitation induced pressures is an important question. Until now it has been assumed implicitly that both at model and ship the walls were completely stiff in the frequency range involved, so the normal velocity would be zero. That this is an improbable assumption at full scale is being realised recently, but to account for hull vibrations is still difficult. This problem is certainly worthwhile to be addressed by the new Cavitation Committee.

With regard to the problem of the soaked plywood it seems that it is possible that completely soaked and flexible plywood is acoustically transparent. It will be very difficult to establish this with the calculations as done by Prof. Breslin, because the inaccuracies in the calculated radiated pressures may be larger than the variation caused by compliance of the wall.