SESSION ON PROPULSION, CAVITATION

Chairman: Prof.Dr.J.D.van Manen

Presidium of the Session

Discussion of the Report and the Draft Recommendations of the Cavitation Committee

I. DISCUSSIONS

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SOME COMMENTS ON THE PROPULSION PROBLEMS FOR HIGH SPEED CRAFT USING WATER PROPELLERS ON INCLINED SHAFTS

These questions have also been discussed by the Performance Committee and the High Speed Marine Vessels Panel.

At model tests with this kind of ships some difficulties appear which are not present when testing ordinary ships.

- At the self-propulsion test of a high speed ship the trim by stern is usually considerably larger than at the towing test. This increase in trim is caused mainly be the decrease in pressure at the stern induced by the propellers and not by the fact that the thrust is transferred through the inclined shaft. The widely used method to tow the model in the direction of the propeller shafts will therefore not correct for this discrepancy. Because of this the resistance measured at the towing test is not very representative for the self-propelled model. The thrust deduction factor obtained in the traditional way is therefore an expression more of the resistance change with trim than the resistance increment caused by the horizontal component of the propeller "suction".

- As it is known that the propeller open water characteristics are changed in oblique flow, it is tempting to assume that these characteristics are valid also in behind condition. Using this assumption the effective wake should then be based on the oblique flow characteristics.

- It is also tempting to use current information about the lift force, normal to the thrust and produced by the propeller in oblique flow, to introduce a propeller efficiency valid for the horizontal direction.

- Finally, cavitation (not present at the towing or self-propulsion tests) can make considerable modifications of the discussed parameters.

To meet these difficulties a number of corrections are discussed in the 16th ITTC reports. For example it is suggested in the Cavitation Committee Report to split the thrust deduction factor into five different fractions taking account of the effects of shaft inclination and cavitation and the resistance increments due to horizontal pressure force, change of trim, change of loading and appendages.

Further, it is suggested that effective wake should be based on open water characteristics measured in oblique flow. The total propulsion efficiency is then finally defined using these corrected values of thrust deduction and wake and a propeller efficiency measured in oblique flow and corrected to be valid in the horizontal direction. Thus, this traditional method to evaluate the propulsion problems ends ups with a rather complex procedure where the actually measured values of thrust and efficiency are very far away.

At SSPA it has been discussed to introduce a more direct method where the prediction is based on the thrust measured at the self-propulsion test and the efficiency measured at the cavitation test, thus, omitting the towing test as the basis for power predictions. The main features of this method should be:

- As the thrust deduction factor is assumed to be the same in model and full scale, it is not necessary to determine its value explicitly. The thrust can therefore be measured directly at the self-propulsion test.

- The towing tests will be used only to determine the appendage drag.

- When running the self-propulsion tests, efforts should be made to achieve trim and propeller loading representative of the full scale ship. This means that the calculation of the so called Ra-force will involve not only the traditional correction for viscous resistance, but also correction for appendage drag and an empirically derived model - full scale correlation factor for the thrust.

  It also means that estimated cavitation influence on the lift force on the aftbody (through pressure changes in the water transferred to the hull bottom and through the brackets) should be considered by changing the ballasting of the model.

- The thrust is then directly measured in the shaft direction and used to define the propeller loading for the ship

$$K_T/J^2 = \frac{T}{\rho D^2 V^2 (1-W)^2}$$

- Propeller characteristics in behind cavitation conditions are finally measured in the cavitation tunnel with the propeller working behind the complete ship model mounted in the tunnel. The propeller thrust and efficiency will then be automatically corrected for the influence of shaft inclination, clearances to bottom and rudders, cavitation, lift forces through brackets and trim changes due to the work of the cavitating propeller.

- Input values to the cavitation tests are propeller loading and cavitation number. Output values will be the number of revolutions and power demands for the tested ship speeds.

Although this method also has some weak points it is felt that we could gain a simpler correlation with full scale, as directly measured values of trim, thrust, number of revolutions and power could be compared between model and full scale.

I would also like to comment on the very recent investigation of of propeller-wall clearance on the propeller characterictics carried out by Suhrbier, Kruppa and Brandt [226]*. As mentioned in the Cavitation Committee Report, this investigation showed very little influence which is contradictory to measurments carried out at SSPA [92]*. The reason for this is probably that different arrangements were used.

At SSPA the propeller was tested downstream of the dynamometer. Thus, to some extent simulating the condition where the propeller is working behind a hull (especially at the oblique flow tests). In the investigation carried out by Suhrbier et al. the propeller-wall effect is tested in a more strict way as the propeller was mounted upstream of the dynamometer.

The physical explanation for the differences between the tests is not very clear. Possibly some kind of amplification of the shaft wake could be caused by the plate. However, the agreement between the simple plate tests at SSPA, tests with the complete ship model and full scale tests is remarkably good [80] . Thus, it is tempting to assume that the effect of the plate-dynamometer is similar to that of the hull-shaft.

As it is rather difficult to evaluate whether a simplification of a test arrangement is justified or not, we highly recommend cavitation tests with the complete ship model. In my opinion, this attitude is further stressed by these new test results presented by Suhrbier et al.

The method of using the complete ship model has now been used for a number of high speed projects. The results and the comparison with full scale are so far very satisfying.

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With view on an improved power prediction of high speed vessels that part of the report, concerning the propeller hull interactions of high speed craft with inclined shaft propellers is very useful. The effects of oblique propeller inflow on the propulsive coefficient and its three elements are shown very clearly. In the case of semi-displacement round-bilge hulls and of planing hulls

wake fraction
thrust deduction fraction and
propeller efficiency

are affected not only by shaft inclination but also by considerable angles of running trim.

Different propulsive parameters of similar hull designs and errors in the power prediction of these both vessel types can often be explained by the oblique propeller inflow condition.

For a more realistic estimation of hull efficiency and propeller efficiency of high speed vessels more attention should be given to all the described effects. Instead of the axial open water test results, diagrams which are corrected by the method of Gutsche should be used. For calculating the thrust deduction fraction the axial thrust should be replaced by the horizontal thrust component reduced by the horizontal propeller normal force.

In the report of the High Speed Marine Vehicle Panel these procedures are used for a reliable power calculation of semi-displacement round bilge hulls.

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CAVITATION NOISE FROM SYDNEY EXPRESS PROPELLER MODEL. MODEL TESTS IN SSPA CAVITATION TUNNEL NO 2.

On request of the ITTC Cavitation Committee measurements of cavitation noise have been carried out in SSPA cavitation tunnel No 2 with Sydney Express propeller model (HSVA propeller model No 2024). The propeller was operated in homogeneous flow and noise measurements were performed by 4 hydrophones (Brüel & Kjaer Type 8103) in different arrangements.

Measurements were carried out at

$$J = \frac{V_A}{n\,D} = 0{,}6;\ 0{,}7 \text{ and } 0{,}9$$

at the following cavitation numbers:

$$\sigma_n = \frac{p - p_V}{\frac{\rho}{2}(\pi n D)^2} = 0{,}185;\ 0{,}193;\ 0{,}202 \text{ and } 0{,}211$$

where D = propeller diameter = 0.375 m
n = rate of propeller revolutions

Measurements were carried out at $n = 32.67$ r/s for $J = 0.7$ and at $n = 30.0$ r/s for $J = 0.6$; 0.7 and 0.9. The background levels shown by the filled dots in the enclosed figures are obtained with a rotating noncavitating propeller (Exception: At $J = 0.9$ some pressure side cavitation is present also at the highest pressure shown by the filled dots). In this preliminary note results are only shown from the hydrophones H2 and H3. H2 was positioned approximately at the recommended position and H3 somewhat closer to the propeller (Fig.1).

In Figs. 7-9 both measured levels $L(1\text{ Hz}, r_2)$ and $L(1\text{ Hz}, r_3)$ at the actual hydrophone positions r_2 and r_3 are shown and on request also the levels reuced to 1 m distance from the propeller hub centre, $L(1\text{ Hz}, 1\text{ m})$. The signals were analyzed in 1/3-octave bands and the levels were then transformed to levels in 1-Hz bands as requested. This transformation is simplified so far as it is carried out for all bands. If, however, the levels in some bands are dominated by spectral lines, this simplified procedure is not very satisfactory.

To perform a more correct calculation of levels in 1-Hz bands, it must be known to what extent measured broad band levels are dominated by spectral lines. Such problems often occur in the important region between low and high frequencies, and if the knowledge about the line spectrum in this region is limited, it seems better to show the original data (often 1/3-octave band spectra in this type of measurements). This seems especially convenient if it is not clear how the spectrum will be used later on. If for example the scaling law applicable at low frequencies is used also at higher frequencies, it is suitable to use band spectra of constant percentage bandwidth for scaling of spectra composed of both lines and continuous parts. Another way out of these problems is of course to consider only rather high frequencies where the influence of spectral lines often vanishes.

Also the reduction of levels to a 1 m distance by supposing 1/r-variation of pressure is boubtful as the hydrophones were positioned in domains where reflections and structure-borne noise are of great importance, and as no transfer functions for obtaining free field levels were known. (An old transfer function of this kind was not usable because of changed equipment.) This problem is illustrated by the fact that L(1 Hz, 1 m) obtained from H2 and H3 is different.

No hydrodynamic-acoustic scaling is applied to the spectra shown in this report. It may perhaps be of some interest to directly compare such non-scaled spectra obtained at different rates of revolutions and from different facilities. However, the most interesting thing seems to be comparisons between such spectra after application of hydrodynamic-acoustic scaling. While waiting for the "final" scaling formulas, the scaling normally applied at low frequencies may be tried. For the "final" scaling formulas, the scaling normally applied at low frequencies may be tried. For the corresponding spectral lines this scaling is:

$$\frac{p^2_{rms,1}}{p^2_{rms,2}} = \left(\frac{r_2 D_1}{r_1 D_2}\right)^2 \left(\frac{\rho_1}{\rho_2}\right)^2 \left(\frac{n_1 D_1}{n_2 D_2}\right)^4 \qquad (1)$$

where indexes 1 and 2 refer to systems 1 and 2 (geometrical similarity is supposed)

p_{rms} = sound pressure, rms value
r = distance noise source - hydrophone
D = propeller diameter
ρ = density of water
n = rate of propeller axis revolution

For the continuous part of the band spectrum the corresponding formula is:

$$\frac{p^2_{rms,1}}{p^2_{rms,2}} = \left(\frac{r_2 D_1}{r_1 D_2}\right)^2 \left(\frac{\rho_1}{\rho_2}\right)^2 \left(\frac{n_1 D_1}{n_2 D_2}\right)^4 \frac{n_2}{n_1} \frac{\Delta f_1}{\Delta f_2} \qquad (2)$$

where Δf is the bandwidth.

If constant percentage bandwidth is used, (1) and (2) become identical which simplifies the application. The corresponding frequencies f_1 and f_2 at which these scalings shall be used are related as:

$$\frac{f_1}{f_2} = \frac{n_1}{n_2} \qquad (3)$$

To obtain a dimensionless spectrum according to these scaling formulas the frequencies can, if simplifying assumptions are accepted, be normalized by some fundamental frequency f_0. (For a propeller operating in a wake the blade frequency is suitable for normalizing at least the lower frequencies while there are indications that blade frequency is not significant for normalizing very high frequencies).

A suitable amplitude measure $L(K_p)$ for use in a scaled and dimensionless spectrum can be based on the dimensionless coefficient K_p normally used at very low frequencies:

$$L(K_p) = 20 \log 10^6 \cdot K_p \qquad (4)$$

where K_p in principle is defined as:

$$K_p = \frac{p_{rms}}{\rho\, n^2 D^2} \qquad (5)$$

K_p can be defined in slightly different ways, but also (5) is generally usable and is equivalent with (1) and (2) if the possible corrections due to bandwidth are included in the p_{rms} inserted in (5).

From (4) and (5) one obtains:

Hydrophone positions View from above

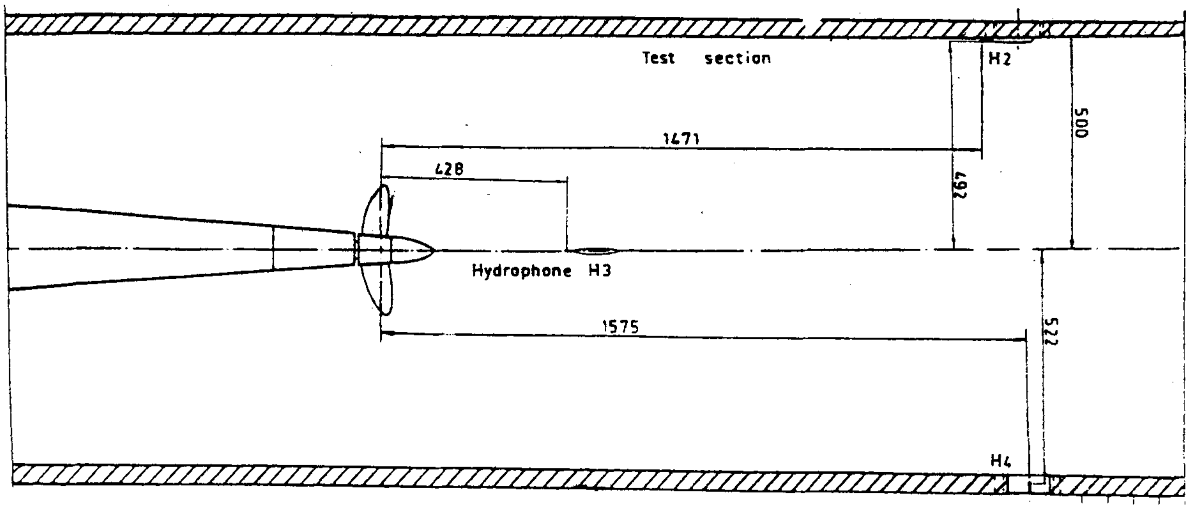


Fig 1

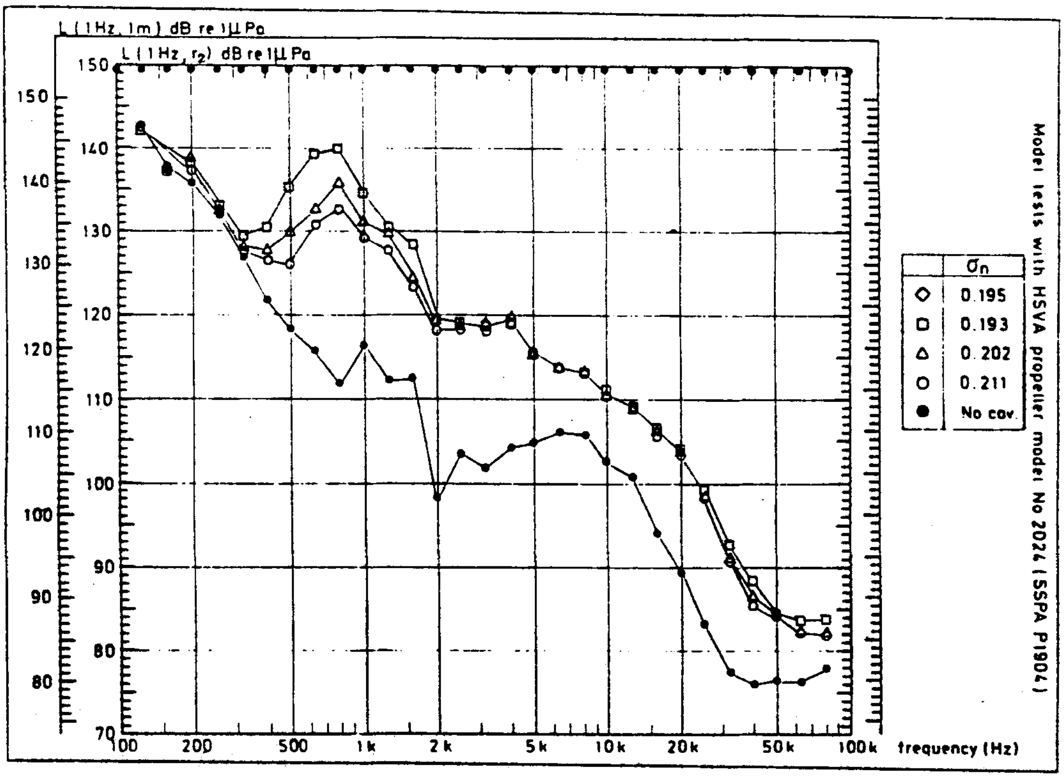


Fig. 2

Noise results.
J = 0.6 n = 30 r/s
Hydrophone No H2

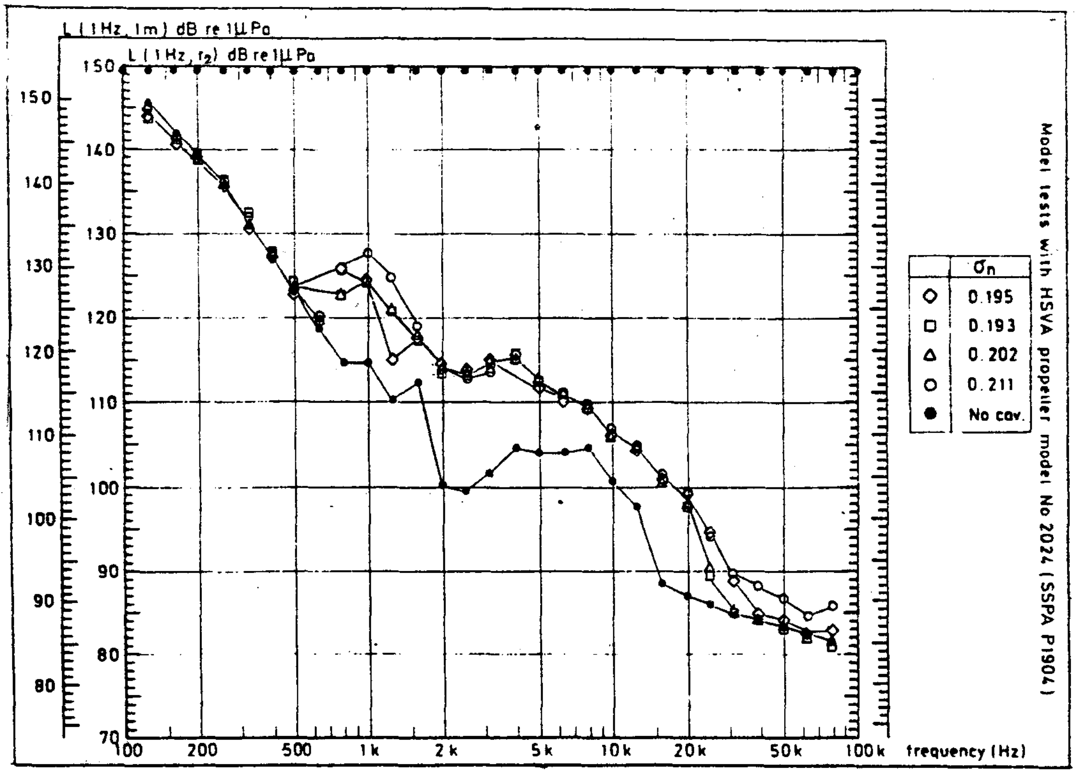


Fig. 3

Noise results.
J = 0.7 n = 30 r/s
Hydrophone No H2

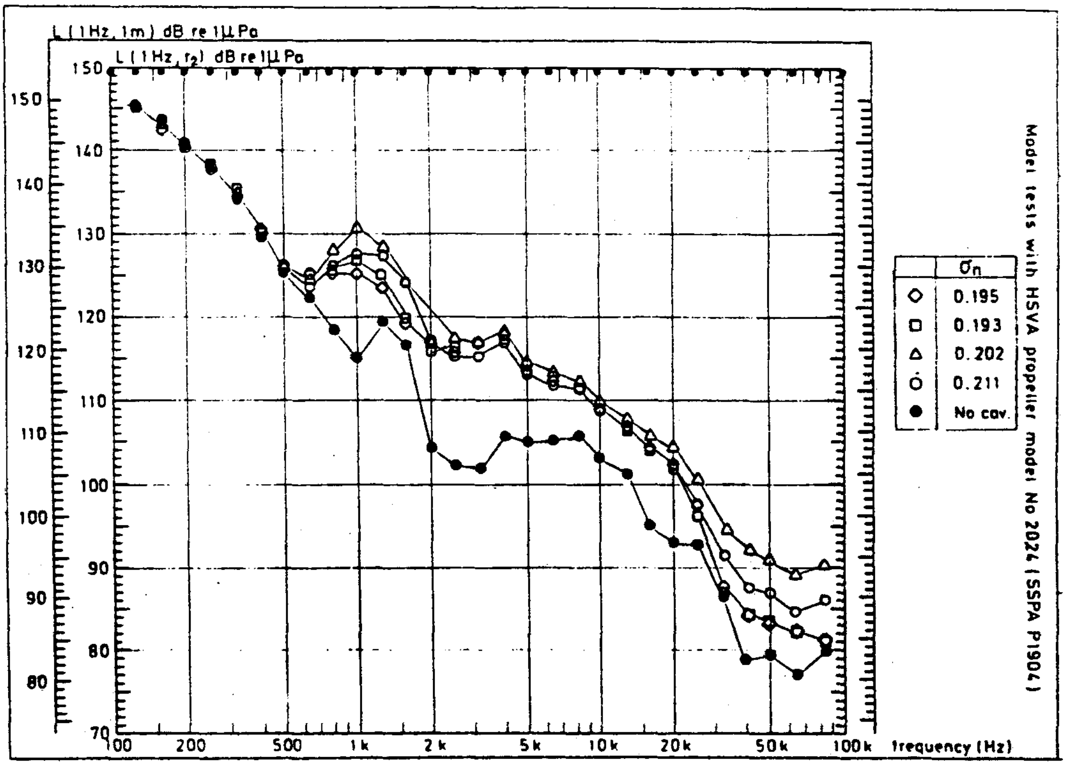


Fig. 4

Noise results.
J = 0.7 n = 32.67 r/s
Hydrophone No H2

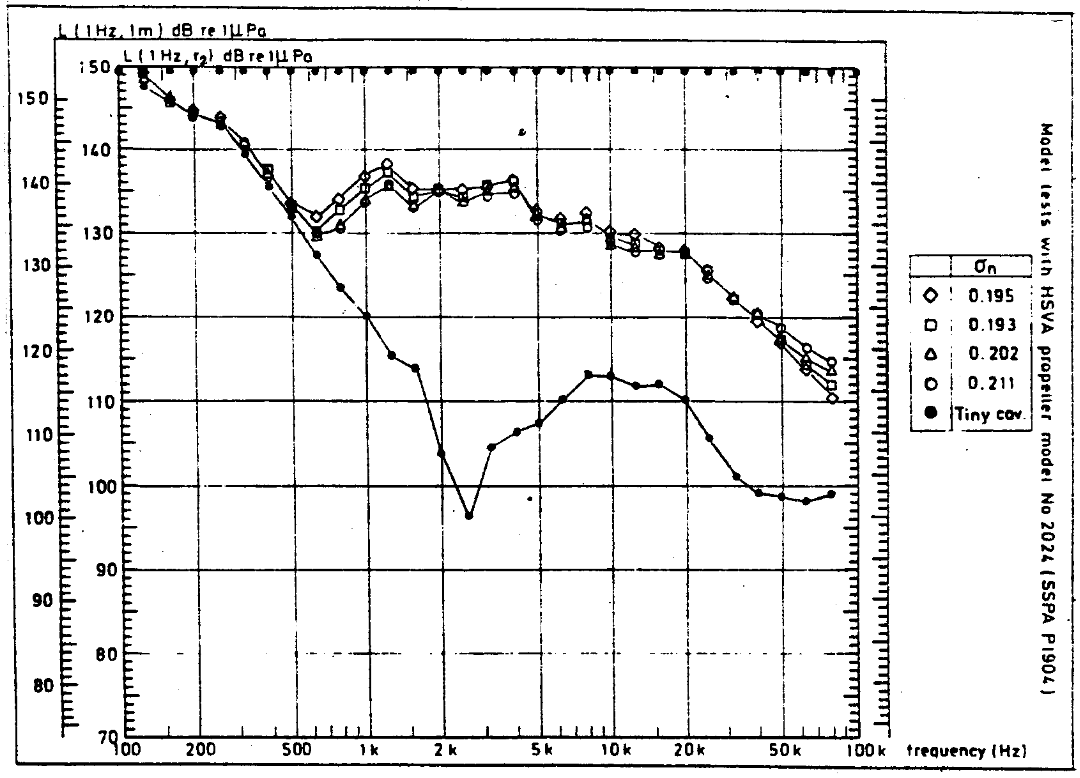


Fig. 5

Noise results.
J = 0.9 n = 30 r/s
Hydrophone No H2

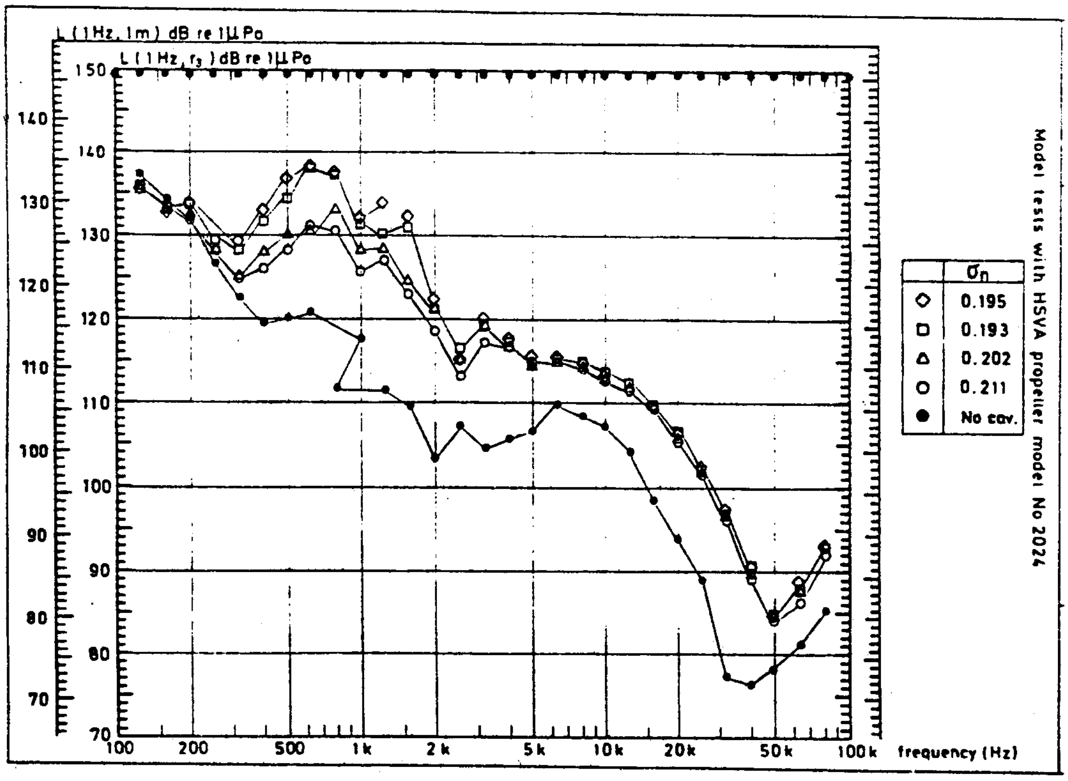


Fig. 6

Noise results.
J = 0.6 n = 30 r/s
Hydrophone No H3

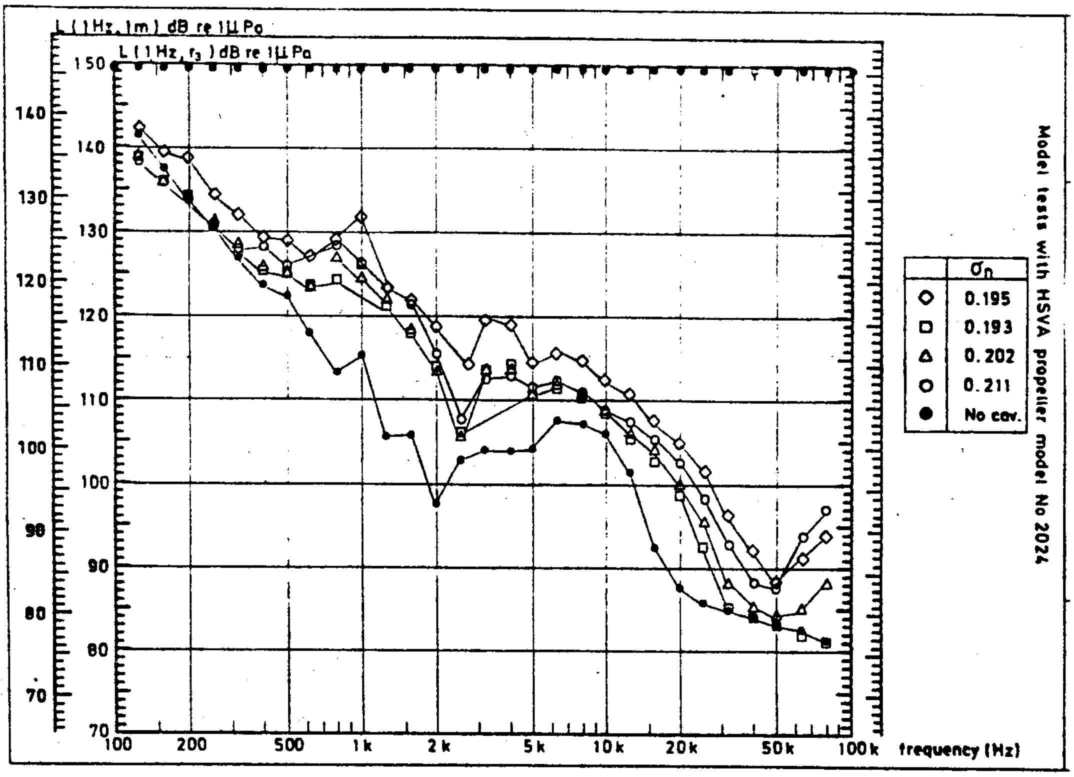


Fig. 7

Noise results.
J = 0.7 n = 30 r/s
Hydrophone No H3

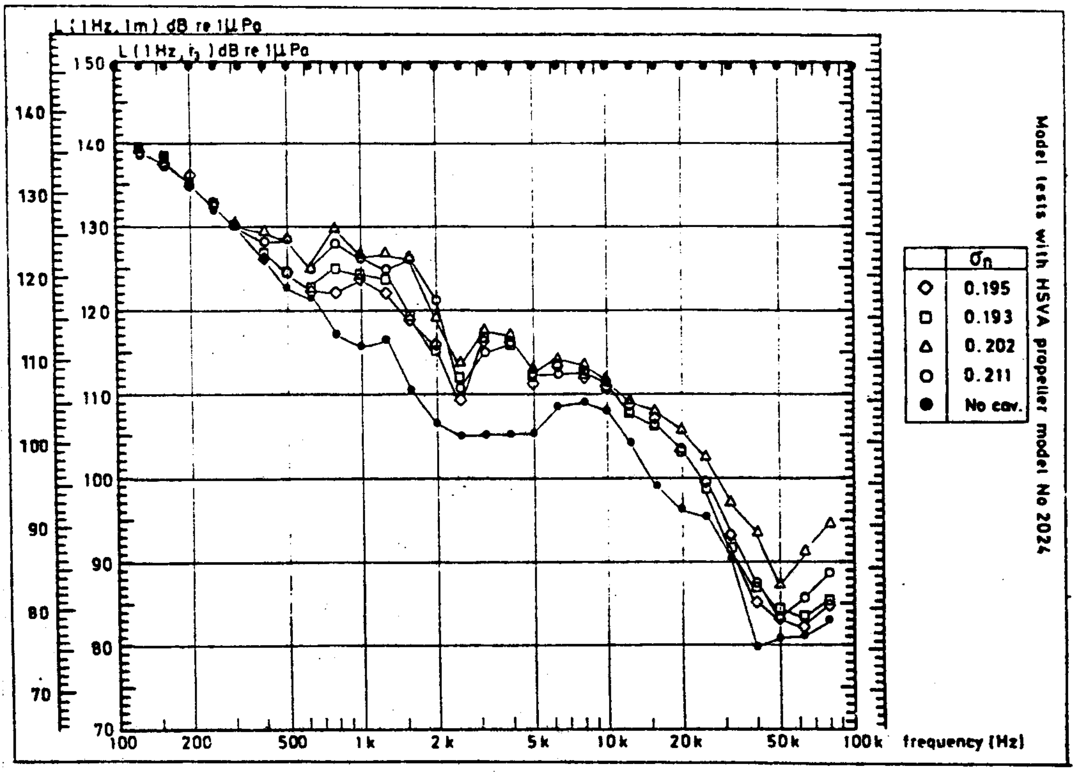


Fig. 8

Noise results.
J = 0.7 n = 32.67 r/s
Hydrophone No H3

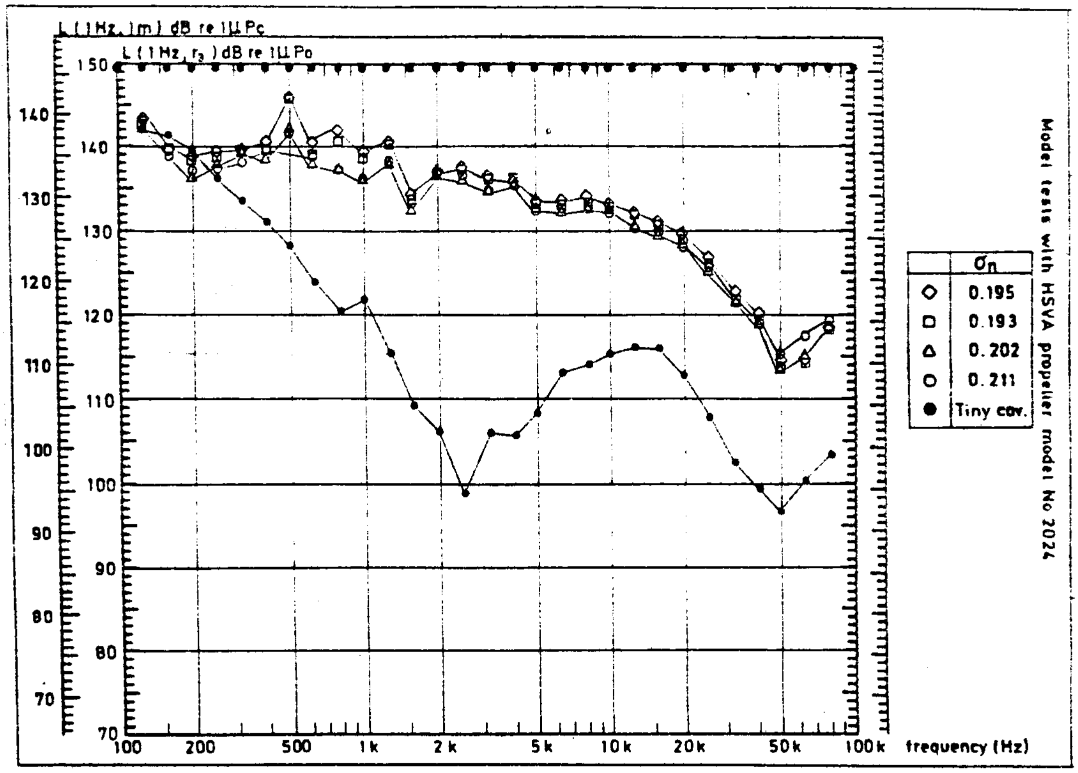
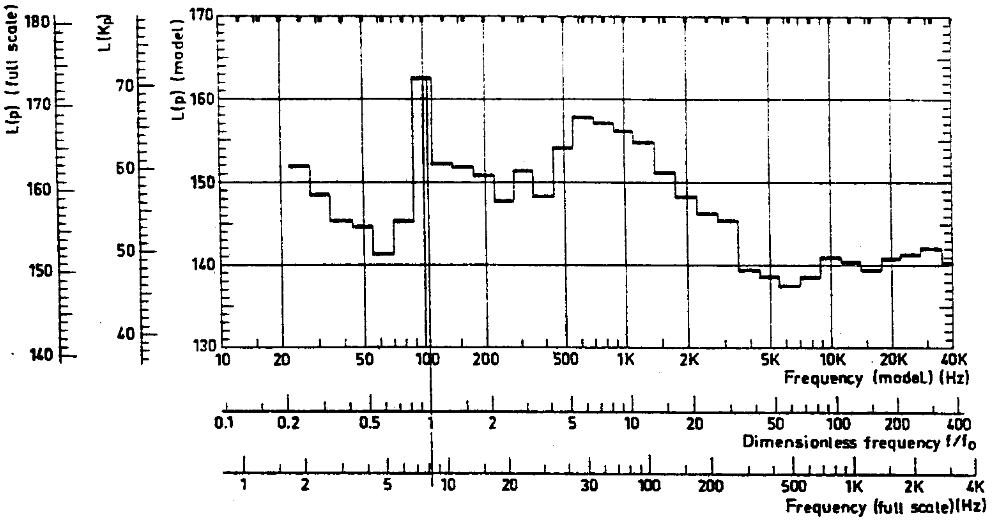


Fig. 9

Noise results
J = 0.9 n = 30 r/s
Hydrophone No H3



$L(p) = 20 \log \frac{p_{rms}}{10^{-6}}$ dB re 10^{-6} Pa (1/3 oct. band) $L(K_p) = 20 \log 10^6 K_p = 20 \log \frac{p_{rms}}{10^{-6} \rho n^2 D^2}$ (1/3 oct. band)

Fig 10. Example of scaling a 1/3 octave spectrum

$$L(K_p) = 20\log\frac{p_{rms}}{10^{-6}} - 20\log\rho n^2 D^2 \qquad (6)$$

and it is observed that the first term is the usual sound pressure level.

If, as is proposed above, constant percentage bandwidth is used and p_{rms} in (5) is the pressure measured at a distance r_2, then the following simple scaling from system 2 to system 1 is obtained:

$$L_1 = 20\log\frac{p_{rms,1}}{10^{-6}} - 20\log 10^6 K_p + 20\log\left(\rho_1 n_1^2 D_1^2 \frac{r_2 D_1}{r_1 D_2}\right) \qquad (7)$$

In Fig. 10 one such example is shown (with $r_2D_1/r_1D_2 = 1$) for a 1/3-octave spectrum.

It is stressed that the method of scaling and presentation that is briefly outlined above is simplified, but to our experience it works as a first approximation.

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CAVITATION NOISE

The discussors think it important and necessary to keep background noise in the cavitation tunnel as low as possible to increase S/N ratio of measurements, since the background noise sometimes exceeds the propeller noise at some frequency ranges, as shown in Fig.1, where no information about propeller noise is obtainable. Exchange of experiences and techniques to silence cavitation tunnels organized by the Committee is considered to be useful.

At the same time, since the correction method of the background noise to the measured propeller noise is not included in the standard procedure to estimate free-field noise proposed by the 15th ITTC Cavitation Committee, the discussors think it useful for the Committee to include it in the proposal.

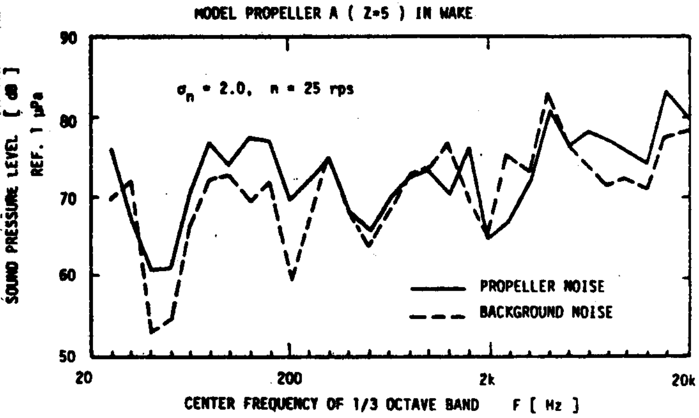

Fig. 1 Example of comparison between propeller noise and background noise

WU-HUA ZHU, HONG-ZHEN WANG and WE-CHUN YE - Shanghai Chiao-Tung University, China

MEASUREMENT OF TUNNEL WALL EFFECT IN THE CAVITATION NOISE TESTS

According to the proposed procedures for documenting cavitation noise tests of the 15th ITTC, two sets of measurement are made, one in the low acoustic frequency range and the other in the high acoustic frequency range.

(1) The facilities used in the measurement

In Fig.1 is shown the water tunnel used for model experiments in Shanghai Chiao-Tung University.

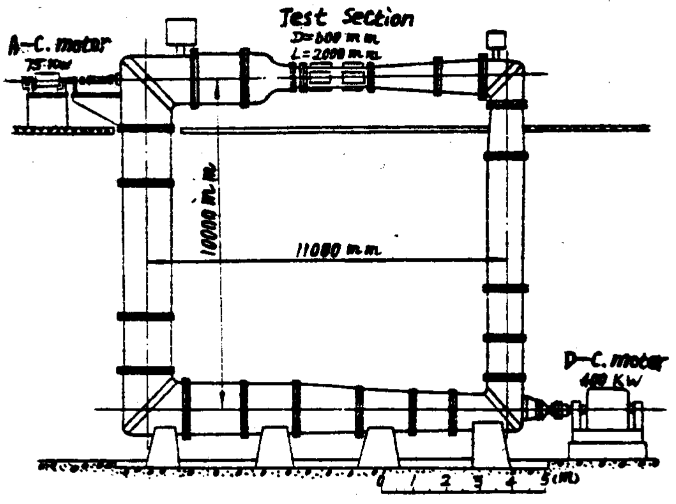

Fig.1. The diagram of the cavitation tunnel of The Shanghai Chiao-Tung University

Two type SMH-101 hydrophones with continuous frequency range 5HZ-100KHZ are used to receive the acoustic signals from the propeller. They are placed at locations no.1 and no.2. in Fig. 2 at distances 0.35 meter and 1.05 meters from the plane of propeller respectively, and the transducer (projector) is located in the middle part of the test section near the center of this plane.

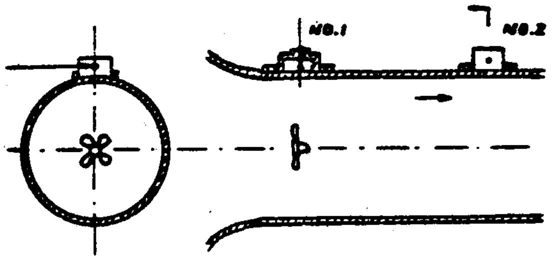

Fig. 2. Arrangement of the hydrophones

Due to the frequency constraints of the directivety and voltage response characteristics of the transducer, two different transducers A1 and A2 are used. Transducer A1 shown in Fig. 3 vibrating in a flexural mode, is omnidirectional up to 6.3KHZ, its directivity and voltage response characteristics are shown in Fig.4 (a) and 4 (b), in which only a part of performance within the frequency range 1 KHZ-5KHZ (the frequency range I) is used in this measurement.

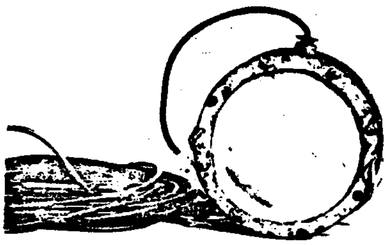

Fig. 3. Transducer A_1 used as a projector

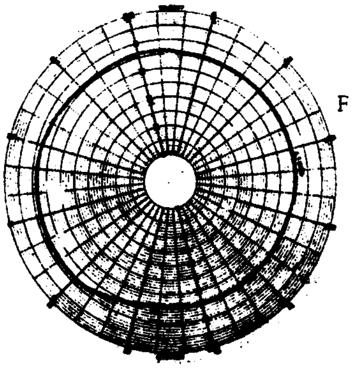

Fig. 4(a). Typical directivety patterns of the hydrophone Type A_1 transducer At 6.3KHZ

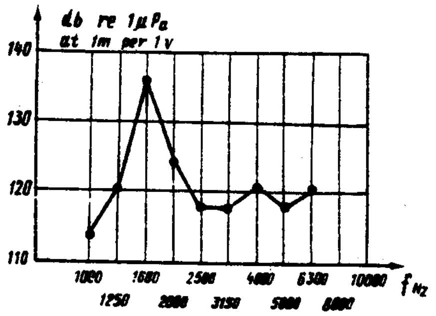

Fig. 4 (b). Typical transmitting response to voltage of Type A1 transducer

Transducer A2 is of the B&K8100 type, and within the frequency range 5KHZ - 40KHZ (the frequency range II) used in this measurement, it is omnidirectional, its directivity and voltage response characteristics are shown in Fig. 5 (a) and 5 (b).

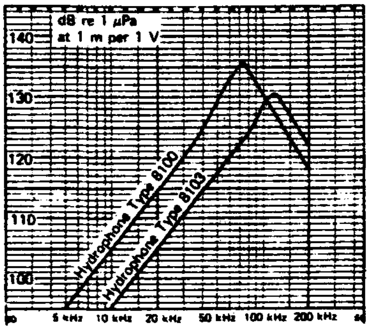

Fig. 5.(a).Typical transmitting response to voltage of Type A2 transducer

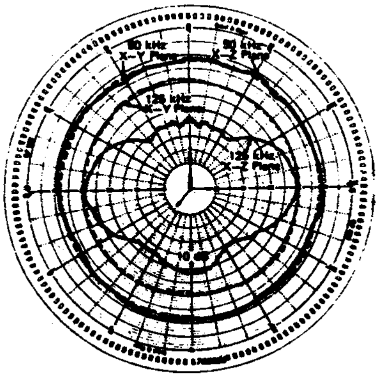

Fig. 5(b).Typical directivity patterns of the hydrophone Type A2 transducer

(2) Measurement of tunnel wall effect and the definition of tunnel wall reflection coefficient:

(a) In these measurements, cavitation propeller in the tunnel is substituted by a transducer whose performance is known, and the free-field measurement (without reflection) is performed in a reservoir. In Fig. 6 and Fig. 7 are shown facilities used in these measurements in cavitation tunnel and in the reservoir respectively.

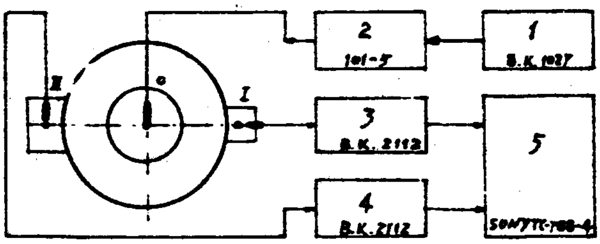

Fig. 6. Measurement in the cavitation tunnel

1. Signal generator
2. Power amplifier
3.4. Audio-frequency spectrometer
5. Magnetic tape recorder

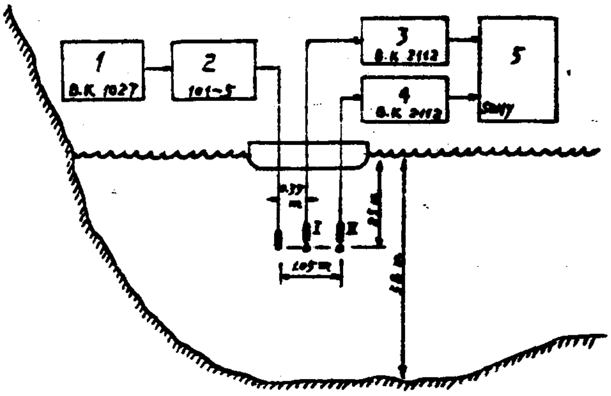

Fig. 7. Measurement in the reservoir
1. Signal generator
2. Power amplifier
3.4. Audio-frequency spectrometer
5. Magnetic tape recorder

In these measurements, the following requirements are observed:

1. Same transducer and same hydrophones must be used in the cavitation tunnel and in the reservoir.
2. The transducers must be excited by the same signal generator.
3. The hydrophones must be placed at the same distance from the transducer both in the cavitation tunnel and in the reservoir.
4. The frequency spectra obtained in the measurement must be analysed by the same spectrometer.

(b) Let Fourier Ttansforms $P_d(f)$ and $P_t(f)$ be made on the direct wave signal $P_d(t)$ in the reservoir and on the signal $P_t(t)$ (with wall reflections) in the cavitation tunnel. These are used to define tunnel wall reflection coefficient K(f) as follows:

$$K(f) = 20\log(|P_t(f)| / |P_d(f)|)$$

From the data obtained in the measurements, these coefficients are calculated.

(3) Results and proposals

In Figs. 8 and 9 are shown the tunnel wall reflection coefficients in the frequency ranges I and II, calculated from the data obtained in several measurements.

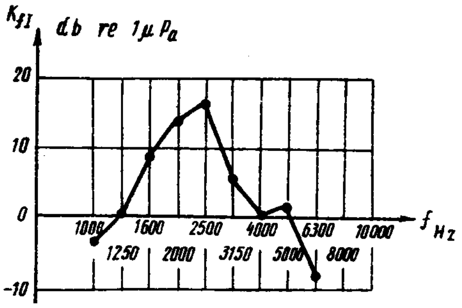

Fig. 8(a) The tunnel wall reflection coefficients in IKHZ-5KHZ frequency range of hydrophone No. 1

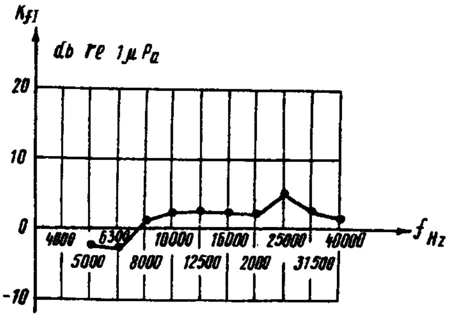

Fig. 8(b) The tunnel wall reflection coefficients in 5KHZ-40KHZ frequency range of hydrophone No.1.

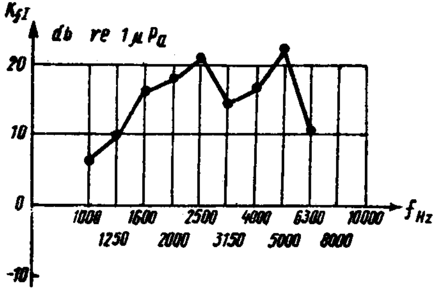

Fig. 9(a) The tunnel wall reflection coefficients in IKHZ-5KHZ frequency range of hydrophone No.2.

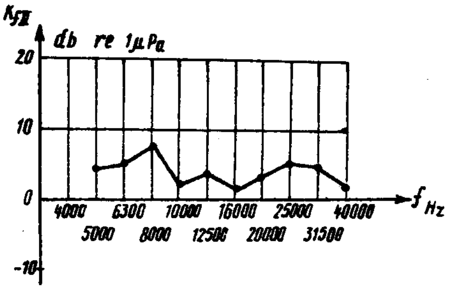

Fig. 9(b) The tunnel wall reflection coefficients in 5KHZ-40KHZ frequency range of hydrophone No.2.

From these experimental results, the following proposals are suggested:
Since different tunnel wall reflection coefficient characteristics are obtained with different types of transducers, it is proposed that in a cavitation tunnel, repeated measurements should be done with several omnidirectional transducers of the same type in different acoustic frequency ranges.

To compare the performance of each cavitation tunnel with a proposed common measurement procedure, a transducer suitable for measurement in each frequency range should be recommended by ITTC.

Since it is very difficult to determine accurately the locations where cavitation is likely to occur within the test section, the transducer is placed at the center of the propeller plane in each acoustic measurement.

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MEASUREMENT OF CAVITY THICKNESS DISTRIBUTION ON MARINE PROPELLERS BY LASER SCATTERING TECHNIQUE

Several methods have been proposed for predicting hull pressure fluctuations induced by unsteady cavitation on marine propellers theoretically [1] . It is well known that the surface forces exerted on ship hull can be simply expressed as a function of the cavitation volume variation [2] . However, no suitable analytical cavity models exist for the theoretical prediction. Only a few data on the time-varing cavity volumes have been published [3,4] , mainly because of the difficulty in measuring them on a propeller working in non-uniform flow. Cavity volumes on marine propellers have been measured by stereo photogrammetrical method [3,5] and the pin method [4] . The calculated results of pressure amplitudes performed with the measured cavity volumes agree well with the corresponding experiments [5] . Therefore, it is indispensable to develop more feasible and inexpensive measurement technique for the cavity volumes on unsteady propellers, in order to predict accurately the pressure fluctuation amplified by unsteady cavitation.

In the Ship Research Institute, we have developed a new method for measuring the cavity thickness distribution on model propellers operating in non-uniform flow by using laser. The present technique is based on the detection of the position of the laser beam scattered by cavity surface and propeller blade. The arrangement of the measurement system is provided in Fig.1. The laser beam is synchronized with the position pulse of the propeller dynamometer, diffracted by the acousto-optic light modulator, and radiated like stroboscope. Among the pulsated and diffracted laser beams, the 1st order diffracted laser beam is isolated by the pin hole aperture and applied to a model propeller blade.

Fig. 2 shows coordinate system of the propeller and a schematic drawing of the principle of the measurement of cavity thickness. First, the laser beam is aimed at a given position P on the propeller blade in non-cavitating condition. Next, under the cavitating condition, the laser beam is scattered by the cavity surface and shifted to another position Q. As the laser system traverses along the normal line, the spot Q where the laser beam is scattered moves on cavity surface. When the spot coincides with the point R on the normal line to the propeller pitch surface, the moved distance in the x-axis Δx is read from the scale attached to the traversing system. At the present experiment, the judgements of coincidence were made by visual inspection through the sight device which can make the vertical plane including the normal line. Cavity thickness τ is given by the following simple formula;

$$\tau = \Delta x \sqrt{1 + \tan^2 \varepsilon + \tan^2 \phi}$$

where ε : geometrical pitch angle of a propeller blade
ϕ : rake angle

Measurements of cavity thickness distribution were made in the No.1 working section of the Large Cavitation Tunnel located at the Ship Research Institute. Table 1 demonstrates the particulars of the model propeller which is utilized in several experiments [6,7] . The experiments were conducted in the wake of a large tanker under the condition given in Table 2. In the present measurements of cavity thickness, the pin method was also used to compare with the measured value obtained by the laser scattering technique.

Photo 1 demonstrates cavitation patterns on the model propeller under the condition 3. Fig.3 shows the measured cavity thickness distribution at the angular position of 17^o under three experimental conditions. The curves are the result obtained by the laser scattering technique. The symbols represent the result of measurements by the pins. The cavity profile is similar to the one obtained by stereo photogrammetrical method [4] . It can be seen that the cavity profiles at 0.95 and 0.9R are affected by the developed tip vortex cavitation. It is found that the pin method gives significant values near the tip region. The present thickness distribution is referred to the propeller blade surface. In Fig.4 the cavity volume obtained by double integral of cavity thickness distribution is plotted against the angular position of the generator line of the model propeller. The cavity volume becomes maximum nearly at the angular position of 17 degree.

From the experimental results described above it can be said that the measurements of cavity thickness distribution by the laser scattering technique give significant measured values. The present method has excellent several merits that the analysis of measured data is not only very easy but also precise comparing with other methods. The following defects are pointed out although these can be overcome by the artificial methods, such as stimulation of cavitation by roughness. Firstly, it is very difficult to measure cavity thickness distribution when cavitation is very intermittent and the surface of cavity is not so frothy that the laser beam is not scattered on it. Secondly, the measurement time becomes lengthy because of the frequent change of the pressure in the cavitation tunnel. The uncertainty of the laser scattering technique is estimated to be ± 5 percent except behind the trailing edge of propeller blades while the inaccuracy of the stereodiagrams for model propellers ranges from 30% to 100% [3] .

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Table 1. Particulars of Model Propeller

MODEL PROPELLER NO.	0123
DIAMETER (m)	0.250
BOSS RATIO	0.180
PITCH RATIO	1.264 (0.7r)
EXPANDED AREA RATIO	0.800
BLADE THICKNESS RATIO	0.050
ANGLE OF RAKE	7.5°
NUMBER OF BLADES	6
BLADE SECTION	SRI-a

Table 2. Experimental Condition

Experimental Condition	1	2	3
n (rps)	15.0		
K_t	0.357		
σ_n	4.81	4.08	3.34
α/α_s	0.6		
θ_w (°c)	27		

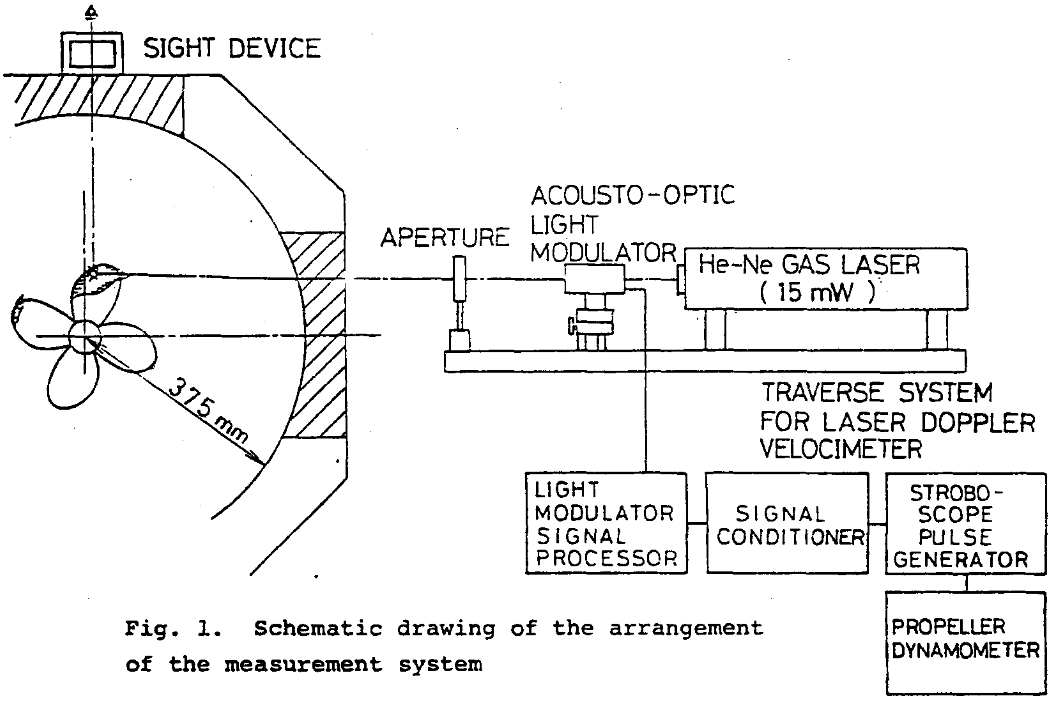


Fig. 1. Schematic drawing of the arrangement of the measurement system

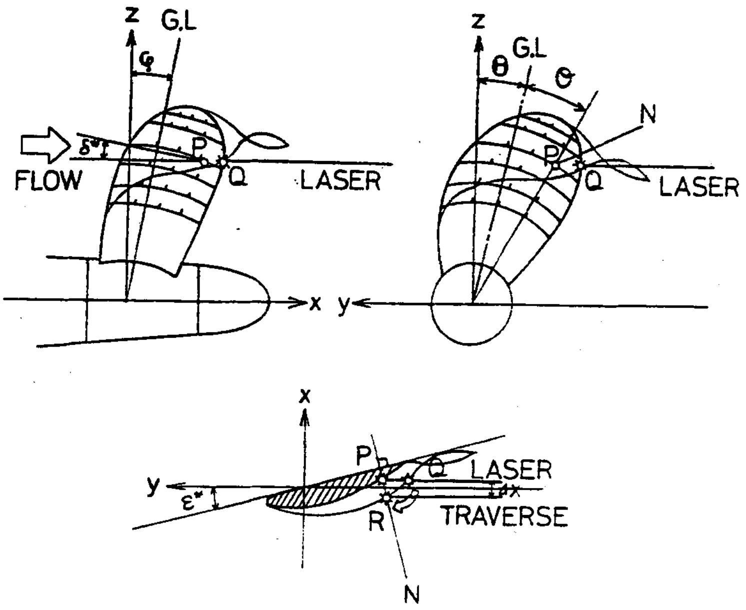
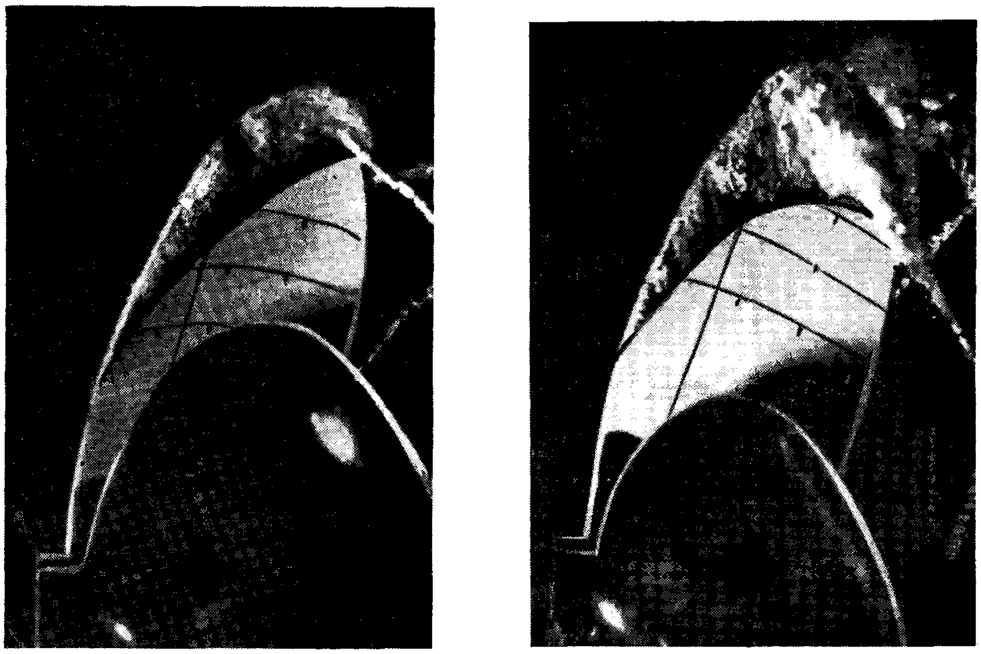


Fig. 2. Coordinate system of propeller



θ = 357°

θ = 17°

Photo 1. Cavitation Patterns on Model Propeller

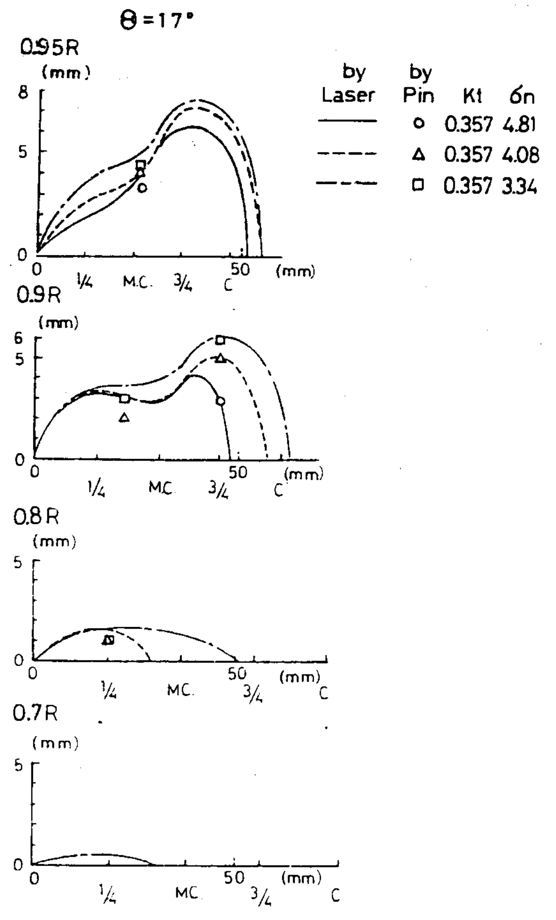


Fig. 3. Chordwise Cavity Thickness Distribution

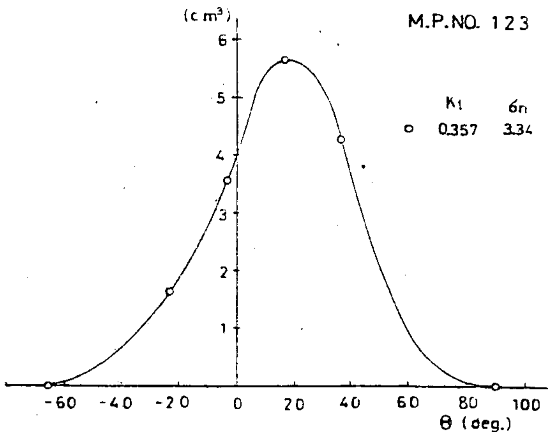


Fig. 4. Variation of Cavity Volume

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I would like to state some considerations, concerning the Report of the Cavitation Committee.

One of the important research fields in cavitation is the study of its initial stages, namely, of the physics and mechanism of its inception. Theoretical investigation of these phenomena is inconceivable without reliable physical models, based on the results of extensive labotatory experiments and full-scale trials. One of the most difficult questions is the physics of birth of the cavitation bubbles, their reciprocal location, their interaction both in free stream and on the surface of bodies (propeller blades, hydrofoils) made of different material, their dynamic action on a ship structure.

In this connection the general direction of research of scientists from many countries, as the organizing and coordinating activity of the Cavitation Committee of the ITTC can be surely approved of.

The Report of the Cavitation Committee indicates a considerable technical and scientific progress in the field of research of cavitation physics. To be mentioned, in particular, is the implementation of the new experimental equipment and instrumentation, enabling, for example, the measurement of the nuclei dimensions with the help of holography, laser technique, etcetera.

Equally meets approval the development of research on the influence of the surface quality and viscous effects on the cavitation inception. A set of systematic model tests of spherical heads and hydrofoils in six laboratories permitted to carry out certain comparisons.

Important exploratory effort is given to the research on cavitation erosion which enabled to understand better its mechanism (behaviour of the bubbles near a rigid boundary, pressure measurements near the point of bubble collapse, propagation of the pressure waves along a surface of different material).

Some of the experimental results are compared with theory (for example, a theoretical solution of the problem of the bubble motion near a wall was obtained by finite element method).

In conclusion I would like to make some observations which in no way affect my appreciation of the performed research.

1. It is necessary to widen the range of experiments on different aspects of the physics of cavitation on the basis of standard programs, aiming at obtaining more reliable data for comparisons.
   Such a necessity becomes evident after the analysis of the experimental data, presented in the Appendix to the Proceedings. This data show considerable discrepancy of the experimental results, obtained in different laboratories.

2. Some investigations have accidental character from the point of view of choice of laboratory equipment, instrumentation and accuracy of the measurements. The requirements to the parameters of the cavitation are not at all common.

3. To date the mathematical theory of the planning of an experiment is fairly well developed. Its application would facilitate rational choice of parameters of the experiment in different labotarories.

4. The majority of physical experiments were performed in laboratories and the processing of the data carried out with no account of the scaling effect. In this connection it seems necessary to broaden research on the physics of cavitation under full-scale sea conditions.

For the purpose of comparison of the laboratory data with full-scale trials different identification methods can be used which are well developed at present.

REPLY OF THE CAVITATION COMMITTEE

We thank *Mr. Rutgersson* for his contribution on high speed propulsion. We agree, of course, largely with his comments on the complexity of the test procedures and interpretation of the interaction effects. The thrust deduction fraction obtained for these craft in the traditional way is only a kind of adaption factor. As also pointed out in the report its meaning is not necessarily compatible with the original definition. The resistance change due to trim has, of course, an important influence. The other effects do, however, also exist. The thrust difference contribution $5t_T$ may even be the most significant one, if conventional procedures are used.

Furthermore, we would like to emphasize that we did not recommend any particular approach. It was merely intended to explain and highlight the effects of cavitation on the various parameters.

It would certainly be interesting to look at another procedure, such as suggested by Mr. Rutgersson. Some fundamental questions may arise and this would obviously require closer examination - not only by the next Cavitation Committee but also by other Committees concerned with high-speed performance.

As far as the propeller/hull-clearence effects are concerned, different conclusions are at present drawn from different - but principally similar - experiments. Further effort is obviously required to explain the discrepancies.

Mr. Müller-Graf's comments are greatly appreciated. We agree that the analysis based on horizontal thrust is more realistic. It is, however, also more involved and is therefore not normally carried out. It seems that the Berlin tank is perhaps the only facility which uses such a more advanced approach for their model test analyses. It should, however, also be borne in mind that for prediction purposes cavitation effects ought to be allowed for if appropriate.

The Committee appreciates receiving the preliminary data from SSPA on noise measurements of the "Sydney Express" propeller. This should provide a very fruitful basis for further discussion with the 17th Committee. As a general procedure, we agree with SSPA that 1/3 Octave bands are most appropriate for presenting the noise data. In the recommended procedures of the 15th Committee, 1/3 octave band presentation was proposed. Only in the interest of making preliminary comparisons in the 16th Committee was 1 Hz band requested. For a more detailed presentation of the 17th Committee, most likely the 1/3 octave bands will be used. It was anticipated by this Committee that each member organization would apply their appropriate transfer function obtained by a facility calibration based on the hydrophone free field calibration. Therefore, reference to one meter distance was only to be a means of standardizing the data. The question of scaling the data to full scale is a subject to be dealt with by the 17th Committee. The procedure, of course, will differ depending on whether it is low frequency near field or far field information that is desired.

Noise measurements down to 100 Hz in the water tunnel are quite difficult since as mentioned by *Dr. Bark,* the modal character and structureborne noise are very important. The 15th Committee report suggests a means of determining the low frequency limit. The comments from SSPA on this suggestion would be welcomed.

In order to compare the SSPA noise data with that taken in other facilities, the following information would be useful to the 17th Committee:

1. Method of facility noise calibration
2. Description of cavitation present
3. Determination of the extent of sound absorption by free gas bubbles, and
4. Influence of air content on the results.

Thank you *Dr. Tamura* for presenting these comments on the noise measurement difficulties at Nagasaki Technical Institute (NTI). The general problem of low signal to noise ratio is, as we are sure you will acknowledge, very complex. If the basic tunnel design is such that the water tunnel impeller produces much noise and if high velocities occur outside of the test section, then one can expect high background noise levels. Some structural changes in the water tunnel to reduce flow noise & unwanted cavition may be possible. Other efforts to increase the signal to noise ratio may be possible, such as locating a reflector behind the hydrophone which in turn is located in a water filled box attached to the water tunnel. Another problem may also be present in the NTI water tunnel and that is the presence of many free gas bubbles which may attenuate the cavitation noise. The cavitation committee recommends that NTI correspond with the 17th committee on the details of how the facility is calibrated and how noise measurements are made.

The contribution of *Wu-Hua Zhu, Hong-Zhen Wang & We-Chun Ye* from Shanghai University is very mush appreciated. It is encouraging to hear that your facility is actively involved with evaluating the proposed noise measurement procedures recommended by the 15th Cavitation Committee. From figure 2 of the contribution it appears that the hydrophone was placed in a water filled box attached to the water tunnel. This is a commonly used approach that has been found to be useful, however it also has limitations with respect to measurements over a broad frequency range. It is a difficult problem to have many transducers evaluated in a tunnel in order for the cavitation committee to recommend a specific type of transducer for various frequency ranges. Each tunnel configuration and each method of mounting the hydrophone presents a unique configuration for measurement purposes. We suggest that the University correspond with the 17th Committee to discuss this topic further.

The Committee wants to express its thanks to *Dr. Ukon* and his colleagues for this very interesting possibility of measuring the cavity thickness, which is a necessity when evaluating the cavity volume.

This new method may detect more details about the structure of sheet cavities and the method could become a useful tool in cavitation research. A similar use of the method emerges for comparisons of different cavitating model propellers, e.g. skewed and non-skewed propellers.

As mentioned in the contribution, the measuring time is long, but getting the stereometrical thickness results referred to in ref.5 of the contribution lasted almost two years. By the way, the accuracy of this ref.5 was much better than those 30-100% of Ref.3. So the ±5% uncertainty of the new method looks excellent.

The Committee encourages SRI to continue the development of the novel device and we look forward to receive information about your progress. Concluding, if this new method would turn out to be practical and the efforts to realize this equipment are not too high, it means that a step forward in instrumentation both for cavitation research and routine work could be achieved.

The Cavitation Committee appreciates the remarks from *Prof. Rozhdestvensky*. While the Committee is pleased to acknowledge its interest in learning about new results in cavitation research we hasten to note that the Committee does not do research nor does it coordinate research. These activities are carried out by ITTC member organizations. Similarly, the Cavitation Committee does not run full scale trials. The Committee is a focus for the receipt of information on the above subjects from ITTC members. It tries to put the information it receives in perspective for the benefit of the ITTC as a whole. The Committee also *expects scatter in data from different* facilities and the purpose of the Committee's work is to show these difference as clearly as possible. Without full scale data, the Committee cannot state which scaling methods are useful and we encourage members to make such data available to the Cavitation Committee.

Referring to the technique of nuclei measurements the present results are not quite as satisfactory as Prof. Rozhdestvensky may think. However, it is believed that reliable results will be available within three or four years.

Referring to point number one, the Committee agrees with Dr. Rozhdestvensky that cavitation inception requires further study in order to relate the basic physics of the process to observation. We note in this context that a recent review prepared for the 19th American Towing Tank Conference (1980) (Proceedings available from the University of Michigan, Department of Naval Architecture, Ann Arbor, Mich.) compares the different scaling laws for inception as they are presently understood. The important point for our discussion is that various forms of cavitation inception will have different scaling laws. Therefore it is most important that scale effect experiments include complete documentation of the cavitation inception forms observed.

The point 4 of this contribution, namely that no account of scale effects was given, the Cavitation Committee does not understand. At least two kinds of scale effects are mentioned in Committee's Chapter A on fundamentals of cavitation, namely the inception scale effect due to different pressures on model and full scale propellers and furthermore due to the hull wake.

Regarding the identification methods which seem to be developed in the Soviet Union the Committee would like to have some more information and references.

Concluding, the Cavitation Committee again would like to express its thanks for this interesting contribution.