SESSION ON PROPULSION
PROPELLER

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Discussion of the Report and the draft Recommendations of the PROPELLER COMMITTEE

I. DISCUSSIONS

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In the first place I want to compliment the members of the committee with their report. Many of the problems encountered in testing the propeller performance are dealt with, and the report can be seen as a state of the art for advanced propeller experiments. As a consequence, however, the report presents an atmosphere of question signs, uncertainties and difficulties, and a towing tank superintendent, after having read the report, must become afraid to carry out experiments for his customers. Nevertheless, I still want to express my appreciation for the report. Further I should like to make a few remarks:

a. Concerning practical criteria for allowable stern pressures, surface forces and shaft forces (Page 243, right handed column).
   In the introduction of this paragraph of the report it is stated correctly that little or nothing can be said about allowable excitation levels without the knowledge of the structural response of the ship.
   The rules and formulae, as given in the following pages, will never be an assurance for the shipbuilder that the vibratory operation of the ship will

be acceptable. From these criteria can only be concluded that, from a point of view of hydrodynamic propeller excitation, the ship design is good or bad, and no conclusions whatsoever can be drawn in connection with vibratory ship operation. The danger exists that shipbuilders, anxious to go ahead with the work on the yard, make a misinterpretation of the mentioned criteria.

b. Concerning experimental procedures for the measurement of induced hull pressures.
It is correctly stated that pressure transducers, amplifiers and other electronic equipment are capable of sensing the frequencies involved in fluctuating hull pressures (page 235). It is, however, dangerous to state that the effect of the vibration of the model on the recorded pressure can be taken care of by calculated corrections (page 239).
In fact the whole model and the inserted instruments must be seen as a pick-up with a certain band width and natural frequency.
Not only the vibration pattern of the pick-up but also the spatial distribution of the amplitudes of the vibrating hull surface (plating) and shape of the hull are essential parameters. Also the flexibility of the shaft of the propeller model and the dynamic characteristics of propeller and shaft will play a role in the pressure measurements.
Similarly, a comparison of the model measured pressure fluctuations and the fluctuations measured on a full-size ship can not simply be made, because model and ship have different dynamic characteristics, resulting in different recordings.

c. Concerning the integration area to convert to total surface force.
The very aim of the pressure measurements is to generate an input for the vibration analyst. If the pressure fluctuations are restricted to a small area of the hull, an integration to a simple single force can be accepted, because the effect of a small variation in the point of application of the force of say 2 propeller diameters, will not much influence its effect on the vibration output.
When, however, integration has to take place over 25% of the hull (page 240) to obtain the surface force, it is erroneous to take this force as an input for the vibration calculation and as a consequence, the considerable contribution from this large area of integration to the total force is misleading. In fact, for the vibration calculation, a pressure at a certain location has to be multiplied with a positieve or negative weighting factor (participation factor), and cancellations are very well possible, which means that in the case of large area integrations a more sophisticated integration procedure is necessary.

d. Concerning highly skewed propellers and elastic deformation (page 280, in my copy of the proceedings printed as page 281).
In order to take care of the elastic deformation of highly skewed propellers it is suggested to build distorted models of propellers having deflected full scale geometry. It is stated (as a certain "escape possibility") that it is also possible to build a structural model.
My point is that it should be tried in the first place to build a model having also *elastic similarity*, before thinking about the other solutions. This can be done according to additional scaling factors, determining the ratio of full scale and model bending- and torsion

stiffness without affecting the geometric similarity /1/.

In my opinion this is necessary, because the elastic deflection is variable during tests with variable parameters, such as K_Q, K_T and number of revs, so that in the case of the distorted stiff model only one test condition is correct, if the finite element calculations, based on calculated blade pressure distributions suffering from a fairly wide scatter (page 233) give a reliable answer for the deformation.

REFERENCES

1. Wereldsma, R.: "Fundamentals of experiments on models of elastic seaborne structures, a tankery problem" Group discussions, 14th ITTC, Ottawa, 1975

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The present committee is to be congratulated for its excellent work. The Propeller Committee of the 14th ITTC recommended that methods should be developed for the accurate and reliable prediction of propeller induced fluctuating pressure forces for full-scale ships based on model meaurements and theoretical techniques. The present committee further pointed out that in carrying out the measurements of fluctuating pressure on board ships, the record may be in error due to fluctuating pressure produced by the vibrating hull plating. I would like to mention some of our measured results to support the above finding. It is considered that before any model-ship correlation could be established, a method of separation of the induced pressure by the vibrating plating from the total measured pressure is of great importance. We have tried to extend the concept of Dr. Huse's work /1/ with an aim of searching a theoretical basis for the experimental approach in predicting the pressure induced by vibrating plating. It has been found that for a given mode of vibration, the amplitude of fluctuating pressure induced by the vibrating plate at a point on the plate is primarily dependent upon the amplitude of linear acceleration normal to the plate at the same point, while the influence of ship speed and frequency may be considered as factors of minor importance.

As a first attempt, we have carried out and analysed our experiment as follows:

1. Over the top of the propeller disc, an acceleration transducer was mounted adjacent to a pressure transducer on the stern plate near a stiffening member. An exciter with frequencies up to 68 Hz was used to set the plating into vibration while the ship was mooring, both acceleration and pressure signals were recorded. A diagram of acceleration-amplitude versus pressure-amplitude was plotted. The same measurements were taken while the ship was underway with propeller running at a range of rpm corresponding to blade frequencies 12 to 27.5 Hz.
2. The pressure amplitude (at blade frequency) induced by the vibrating plating, while the ship was underway, was estimated with the measured amplitude of acceleration (at blade frequency) by means of the previous diagram. An example of the analysed results is given in the following table:

Total double amplitude of fluctuating pressure measured under blade frequency (kp/cm^2)	0.0074	0.0396	0.054
Corresponding amp.of acceleration (g)	0.0056	0.022	0.05
Estimated double ampl. of fluctuating pressure induced by plating (kp/cm^2	0.0012	0.0047	0.0109
Percentage of total	16.2	11.9	20.2

It shows that the influence of the pressure due to vibrating plating is rather significant.

Two aspects remain to be investigated:

1. If the frequencies of the exciter-test and the blade frequencies of ship trial were within a certain range, such as below the natural frequency of plating at stern, then what would be the degrees of similarity between these corresponding modes of vibration?
2. To arrive at a quantitative separation of the two kinds of pressure, it is necessary to determine the phase relationship between the propeller-excited acceleration and pressure. Such a separation is rather complicated since the signals, recorded while the ship is underway, are random to a certain degree.

REFERENCES

1. Huse, J.E.: "Hull, vibration and measurements of propeller-induced pressure fluctuations" I.S.P., Vol. 17, No. 187, March 1970

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This report surely reflects intensive work for which the Propeller Committee deserves high commendation from the Conference. I wish only to make a few suggestions and some commentary which are germane to the report. The referred-to sections of the report are identified by the indicated headings taken verbatim from the report.

Additional Factors Influencing Pressure Measurements and Integrated forces (pp. 239-240).

The most probable reason that measurements of propeller-generated pressures made on model hulls in the SSPA tunnel and the NSMB Vacuum Tank show close agreement in spite of the presence of a rigid wall at the waterplane in the SSPA facility as contrasted to the presence of the water surface at NSMB is due to the large submergence of the propeller below the waterplane which means that the *positive* image of the propeller at SSPA and the negative image at NSMB are distant from the measurement points. For points close to the waterplane, the pressure from the propeller and its image in either case is exceedingly small. In principle, right at the waterplane the induced pressures at SSPA should be twice that of the propeller alone (plus a reflection effect from the hull), whereas at NSMB the pressure should be zero. One suspects that the difference in pressure in the two facilities at near waterplane locations is within the experimental accuracy and, in any event, should not pose a question which warrants further investigation.

I am gratified that others are realizing that, due to the slow decay of certain components of blade-frequency pressures from non-cavitating and intermittently cavitating propellers, the force density along the hull diminishes slowly so the total force requires an axial integration over many diameters. This characteristic of the pressure fields of non-cavitating propellers has been elucidated in Ref.30 where the total vertical hull force on a flat-bottomed ship arising from the *blade frequency* loading is achieved only after integrating over 15 diameters when the presence of the free surface is neglected and over 7 diameters when the alleviating effect of the free surface is taken. Moreover, the b.f.blade loading is *1/40th* that of the mean (or zero frequency) loading which, although it induces much stronger pressures near the propeller, these decay extremely rapidly longitudinally and, when integrated transversely, are self-annulling, yielding a force which is only 1/65th of that due to the b.f. blade loadings. Those results are shown on Figure 1 taken from Ref. 30.

This says two things: firstly, if one wants the total vibratory hull forces on a ship, they will not be secured by measuring a few points *near* the propeller and integrating these in phase as is now done in towing tanks; secondly, since the force density is significant over a large axial extent, *it is not the total force which should be the objective, but the integral of the pressures weighted by the elastic model influence functions of the hull as has been ably demonstrated in a paper by Carlsen /1/.* Using a FEM program, he gave comparative evaluations of ship vibratory response using concentrated forces and distributed b.f. pressures which showed widely differing responses.

To obtain in a rational fashion the b.f. pressures on a hull and the hull "reflection" contribution, one must solve the hull-propeller diffraction problem as first advanced by Breslin in 1965. This vastly improved and extended procedure is described in Ref. 30. The Vorus procedure (see pp. 240-1) does not give any information about the pressures; both methods compared very well with force measurements (Ref. 30). If one wishes all the forces and moments arising from hull-induced pressures, the Vorus method requires one to solve *six* boundary-value problems; in contrast, the method developed at DL requires only a *single solution* from which all forces and moments are calculated from one pressure distribution. Once the DL program is checked against extensive hull pressure measurements made by Huse /2/, it would seem reasonable to use this theory together with FEM or modified beam theory to estimate ship vibration with the remaining uncertainty of the harmonic content of the ship wake as compared to that deduced from models. This check against Huse's data will be made at DL in the latter part of this year.

The field around an intermittently cavitating propeller generated by the time varying surely has a dominant component which decays slower than the slowest of those from the loadings. However, the approximation p = const:R alluded to on page 239, cannot be correct at large distances because the "infinite" frequency image of the propeller in the free surface (or, equivalently, the relieving effect of the water surface) must be accounted for which gives $p \to \rho \ddot{V}/R^3$ where $\ddot{V}$ is the second time derivative of the *blade frequency content* of the cavity volume (see Ref. 51)*. To understand this, let us consider the pressure field generated by a time- or blade-position-varying cavity and its negative image in the water surface, i.e.

$$p = \frac{\rho}{4\pi}\frac{\partial}{\partial t}\iint_{S_c} m(s,\theta(t)+\theta')\ \{\frac{1}{R} - \frac{1}{R_i}\}s\,ds\,d\theta' \qquad (1)$$

where R is the distance from any dummy point $(\xi,s,\theta+\theta')$ in the cavity to the field point (x,r,ϕ) and R_i is the distance from the image of the cavity above the waterplane which is a distance d above the shaft axis. Specially

$$R^2 = [(x-\xi)^2 + s^2 + r^2 - 2rs\cos(\phi-\theta-\theta')]$$

and

$$R_i^2 = [(x-\xi)^2 + s^2 + r^2 + 4d(d-z) -$$

$$- 2s\sqrt{r^2+4d(d-z)}\cos(\phi_i-\theta-\theta')]$$

$$\phi_i = \cos^{-1}\{\frac{2d - z}{\sqrt{r^2+4d(d-z)}}\};\ \phi_i = \phi = \cos^{-1}(\frac{d}{r})\ \text{for } z \equiv d$$

$$m = (\frac{\partial}{\partial t} - \frac{\sqrt{U^2 + (\omega s)^2}}{s}\frac{\partial}{\partial\theta'})\ \zeta(s,\theta+\theta')$$

ζ is the cavity ordinate distribution.

As the x-wise extent of the cavity is very small, we may suppress the dummy variable ξ and make use of the expansion

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* *Propeller Committee Report*

$$\frac{1}{[x^2+r^2+s^2-2rs\cos(\phi-\theta-\theta')]^{1/2}} =$$

$$= \frac{1}{\pi\sqrt{rs}} \sum_{n=o}^{\infty} \varepsilon_n Q_{n-1/2}(Z) \cos n(\phi-\theta-\theta'); \; \varepsilon_n \begin{matrix} =1, n=0 \\ =2, n>0 \end{matrix} \qquad (2)$$

which puts the harmonic content in evidence; here $Z = (x^2+r^2+s^2)/2rs$. As we are interested here in only that harmonic contribution which comes from the time-dependent source strength m, we need keep only the first term which is then expanded for $Z >> 1$ to give

$$\frac{1}{\pi\sqrt{rs}} Q_{-1/2}\left(\frac{x^2+r^2+s^2}{2rs}\right) = \frac{1}{[x^2+(r+s)^2]^{1/2}} +$$

$$+ \frac{rs}{[x^2+(r+s)^2]^{3/2}} + \ldots \qquad (3)$$

Using (2) and (3) in (1) and replacing r by $\sqrt{r^2+4d(d-z)}$ when using (3) for the second term in (1), we obtain

$$p \rightarrow \frac{\rho}{4\pi} \left\{ \frac{1}{[x^2+(s+r)^2]^{1/2}} - \frac{1}{[x^2+(s+\sqrt{r^2+4d(d-z)})^2]^{1/2}} \right. \qquad (4)$$

$$+ \frac{rs}{[x^2+(s+r)^2]^{3/2}} -$$

$$\left. - \frac{s\sqrt{r^2+4d(d-z)}}{[x^2+(s+\sqrt{r^2+4d(d-z)})^2]^{3/2}} + \ldots \right\} \frac{\partial}{\partial t} \iint\limits_{s_c} m\, s\, ds\, d\theta'$$

(taking s as the effective radial location of the cavity). Now clearly if x and s are small compared to the submergence d, then we can see that

$$p \rightarrow \frac{\rho}{4\pi} \frac{1}{(x^2+(s+r)^2)^{1/2}} \frac{\partial}{\partial t} \iint\limits_{s_c} m\, s ds\, d\theta' \qquad (5)$$

and, if we can then concider $x >> s+r$ *without* violating the above stipulation that $x << d$, then we see that $p \sim \frac{1}{|x|}$. Ultimately for $x >> s + \sqrt{r^2+4d(d-z)}$, we obtain

$$p \rightarrow \frac{\rho}{4\pi} \frac{2s(\sqrt{r^2+4d(d-z)} - r) + 4d(d-z)}{|x|^3} +$$

$$+ \ldots\} \frac{\partial}{\partial t} \iint m\, s\, ds\, d\theta' \qquad (6)$$

which passes to zero as the point of interest is taken to the free surface, i.e., $z \rightarrow d$ as required. Thus, the effect of the free surface is to increase the rate of decay of the pressures with axial distance x. As

$$m = \left(\frac{\partial}{\partial t} - \frac{V}{s}\frac{\partial}{\partial \theta'}\right) \zeta(s, \theta(t) + \theta')$$

ζ being the cavity ordinate, we see that the integral is simply the time rate of change of cavity volume and the pressure is proportional to the acceleration of the cavity volume, in a sense to first order, although neglected terms involving weighted integrals of the cavity ordinates may contribute the order of one-third of the cavity-generated pressure for points near the propeller.

Comparative calculation of Propeller-Blade Pressure Distributions

The distributions calculated by 16 establishments as shown in Figures 20a through 22c surely display a large spread. In Figure 2 of this discussion, I have identified our contribution from Davidson Laboratory; it is clear that it departs considerably from the rest of the "crowd". Now there are four *necessary* conditions which a correct distribution should meet, viz.,

1. *The sectional loadings should agree well with the load distribution adopted in the design of the propeller.*
2. *The values of thrust and torque coefficients should compare well with the design and measured values.*
3. *The contribution due to thickness on either side should give a minimum pressure coefficient which is close to, but less negative than, that for the same two-dimensional thickness distribution incorporated in the design.*
4. *The predicted critical cavitation index should compare favorably with those observed from experiment, albeit that such comparisons are fraught with the influences of parameters such as nuclei size and population, air content and surface finish.*

The load distribution (given by the chord-wise integrals of the *difference* in pressure from the pressure and suction sides) to which the propeller was designed (published in Reference 3) is shown on Figure 3 of this discussion together with that obtained from the Davidson Laboratory lifting surface program. Here we see that close agreement is secured.

Figure 4 shows a comparison of the DL thrust and torque coefficients with the DTNSRDC measured values as a function of J. Here the agreement is good, but not perfect. We now have much better agreement at design J.

In Table I, a comparison of the three-dimensional thickness-induced minimum pressure coefficient as calculated is provided with the two-dimensional minimum value for the NACA 66 series at each radius. In the fifth column I give a corrected two-dimensional value to account (in an approximate way to be sure!) for the three-dimensional effect since the blade sections are imbedded in a three-dimensional blade. Column six is the ratio of the DL value to the corrected 2-D value and we see that the DL results meet the third necessary condition as well.

TABLE I

Comparison of Three-Dimensional Minimum Pressure Coefficients Due to Thickness on DTNSRDC on Propeller Model 4118 with Compensated Linearized, Two-Dimensional Minima for NACA 66 Series

1 Radial Location r/r_o	2 Thickness Chord Ratio, τ/c	3 DL 3-D'm'l Calc.	4 2-D'm'l Value*	5 Compensated 2-D Value	6 Ratio Col 2 to Col 5
0.50	0.045	-0.065	-0.110	-0.077	0.84
0.70	0.027	-0.041	-0.065	-.046	0.89
0.90	0.017	-0.026	-0.041	-0.029	0.90

Note NACA 66-Series linearized $C_{p_{min}} = -2.42\ \tau/c$ (see Breslin, J.P. and Landweber, L., "A Manual for Cavitation of Inception of Cavitation on Two- and Three-Dimensional Forms", SNAME Tech. and Res. Bulletin No. 1-21, October 1961.)

A short explanation of the method of estimating the three-dimensional effect on the pressures due to thickness is in order. Calculations of the pressure distribution on the blades of the propeller model 4118 were made for lenticular thickness distribution. When the minimum of these at various radii were compared to the two-dimensional value given by $8/\pi$ times thickness-chord ratio, it was found that the three-dimensional minima were about 0.7 of the two-dimensional values and this compared favorably with an unpublished calculation made by the discusser. Thus, Column 5 in Table I is obtained from Column 4 by multiplying by 0.70, which may be regarded as only a rough rule to compensate for the three-dimensional effect. To be sure, the factor should vary with radial location of the section. For a disc having a lenticular section, the minimum pressure at the center is 78% of the two-dimensional value and at the "shoulders" of the disk the pressure minimum is 42% of that at the center (as found by the discusser by applying the usual thin body theory).

To check the *total* pressure minima on the suction side, we have compared the minimum pressure coefficients with the observed cavitation inception σ in Figure 5, the DTNSRDC curves having been obtained as a cross plot from Figure 19 of the Committee report. Here we see good correlation, not perfect, but perhaps as good as can be expected for such comparisons because of the vagaries attending cavitation inception.

Pressure and Surface Force Criteria

I believe that any formulation of pressure or force criteria should be framed from at least a rudimentary theory which reflects the physics of the phenomenon. From the foregoing Part 1, we see that the most rudimentary approximation for the pressure due to the intermittent cavitation alone is

$$p \sim \frac{\rho \ddot{V}}{(x^2 + (r+s)^2)^{1/2}}$$

The second derivative of the blade frequency part of the cavity volume is dependent on the mean loading and the variation of the geometric angle of attack seen by the blade and this is some function of the afterbody shape. If the pressure control point is directly above a propeller of radius r_o and $r = r_o + a_z$ (if indeed a_z is the tip clearance), then if we take the effective radial location of the cavity as $s = r_o$, we have $p \sim 1/(2r_o + a_z)$ and this is surely not inversely proportional to the tip clearance as proposed by the SSPA criterion on pag. 244. I cannot understand how the pressure can *increase* when the axial clearance a_x increases! I think the correlation formula is highly misleading and can readily give naval architects a belief in the mystical powers of tip clearance and the detrimental effect of axial clearance! The SSPA correlation says that if one increases the tip clearance from 10 to 20% of diameter, the pressures will reduce by a factor of 2! By my *rudimentary* calculations, the pressure is reduced in the ratio 1.10/1.20 = 0.92-- quite a difference!!

The Takahashi surface force criterion is flawed with respect to *non-cavitating* propellers because the integration region is taken symmetrically above the propeller. Thus, the "thrust-associated" pressure component (as identified by the discusser years ago) integrates precisely to zero because it is an odd function of fore-aft distance x, leaving only the contribution of the very small "torque-generated" pressures which are even functions of x. But, the forward integration of the thrust-generated pressures from a forward station whose distance is equal to that if the stern from the propeller, yields large forces arising from the N-1, N, N+1-th blade loading frequencies. I think that Reference (30) may be of help in that matter and, moreover, a calculation of the pressures and forces induced by a pulsating point source on a semi-submerged spheroid would produce a more rational framework for correlation of ship data when propellers cavitate intermittently (surely the non-cavitating contributions need a different model and should be looked after). In this way, one can find how ship size, propeller diameter, clearances, etc., enter the solution.

Recommendations

I would like to urge the Conference to direct the Propeller Committee to:

1. Request these contributors to the comparative blade pressure calculations to compare their results with the above specified necessary conditions.
2. Compare propeller-induced hull pressures with theory which accounts for the shape of the hull.
3. Urge the development of pressure and hull force criteria which are founded on the basic physics involved.
4. Select an able applied mathematician interested in three-dimensional hydrodynamics to serve as a member of the committee.

REFERENCES

1. Carlsen, C.A.: "A Parametric Study on Global Hull and Superstructure Vibration Analysis by Means of the Finite Element Method". Presented at the Spring Meeting of the Royal Institution of Naval Architects, 1977
2. Huse, E.: "The Magnitude and Distribution of Propeller-Induced Surface Forces on a Single-Screw Ship Model" Norwegian Ship Model Experiment Tank Publication No. 100, December 1968
3. Denny, S.B.: "Comparison of Experimentally Determined and Theoretically Predicted Pressures in the Vicinity of a Marine Propeller" NSRDC Report 2349, May 1967

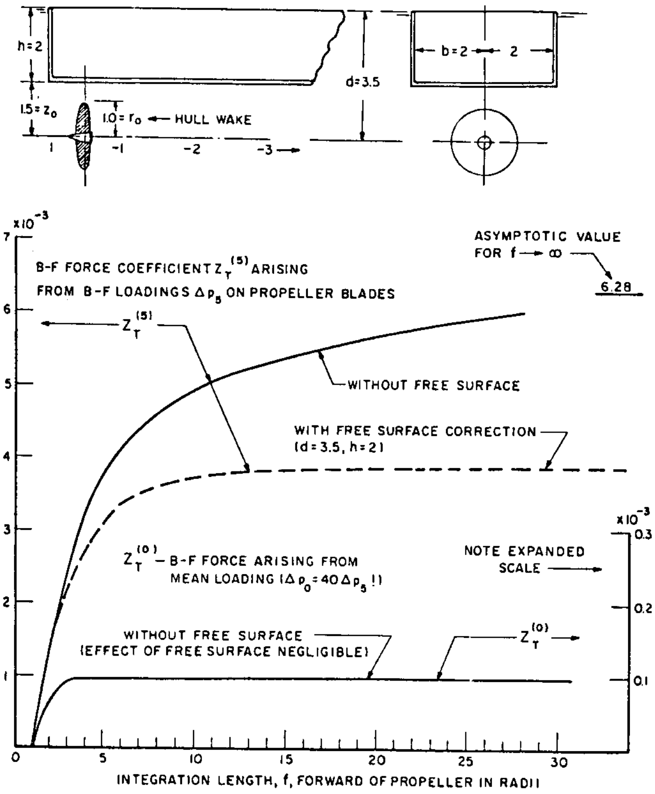

FIG. I APPROXIMATE MODULI OF B-F FORCES ON BARGE-LIKE SHIP FROM PRESSURES EMANATING FROM MEAN AND B-F LOADINGS ON A 5 BLADED PROPELLER (IN A SINGLE SCREW SHIP WAKE) AS A FUNCTION OF INTEGRATION LENGTH FORWARD OF PROPELLER

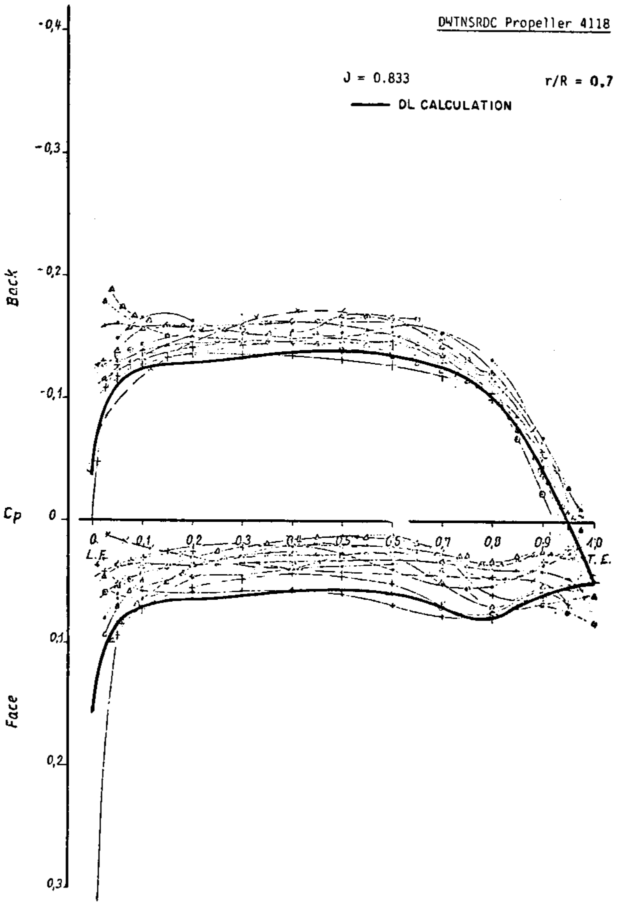

FIG. 2. Results of Propeller Blade Pressure Distribution Calculations

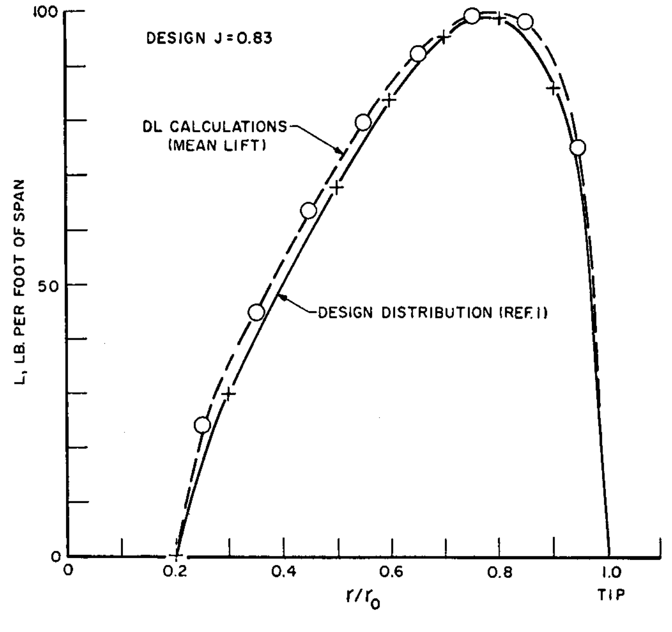

FIG. 3. SPANWISE DISTRIBUTION OF LIFT FOR 3-BLADED PROPELLER 4118 (EAR=0.6) AT DESIGN J=0.83

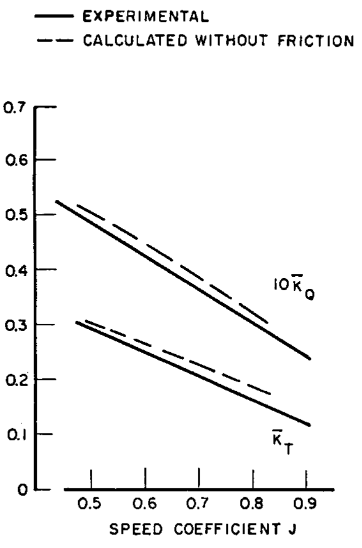

FIG. 4. OPEN-WATER PERFORMANCE CURVES FOR DWT NSRDC PROPELLER 4118

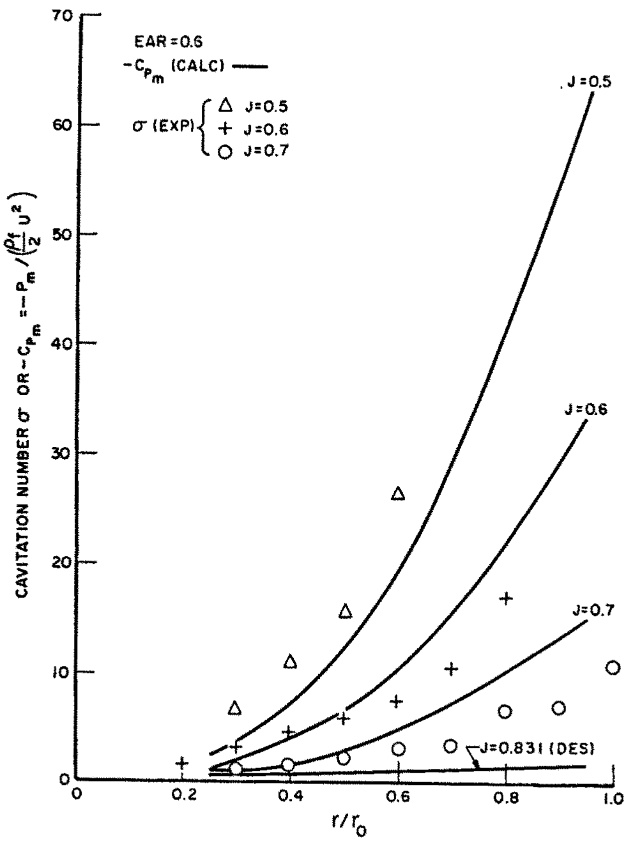

FIG. 5. COMPARISON OF CALCULATED $-C_{P_{min}}$ AND EXPERIMENTAL CAVITATION NUMBER σ, PROPELLER 4118 (EAR=0.6)

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In the report the committee pays some attention to calculation procedures for the cavitation-induced pressure fluctuations on the ship's hull. I like to make some remarks with respect to this section. Quite rightly Huse /45/ is given the honour for showing first the effect of volume variations of the cavity on the pressure fluctuations. Huse stated that the volume variations (growth and collapse) of the cavity has to be described by a source distribution. In the theoretical model of Huse an expression for the cavity volume was lacking. The cavity volume can be approximated either by using experimental results, making the model semi-empirical, or by using a theory, making the model a mathematical-physical one (analytical). The experimental results can be obtained by a stereo-photogrammetrical technique (see Ref. 1) or the procedure as described in /46/. The analytical method is the free streamline theory as described in /9/ and /47/. Based on the results in /47/ the committee concludes that the correlation with experiments is poor. However, to prevent some misunderstanding with respect to the free streamline theory, I like to draw the attention to /9/ where an improved theoretical model is given. In /9/ it is shown that the poor correlation in /47/ is connected with the simplified description of the growing and collapsing cavity. This is illustrated in Figure 1.

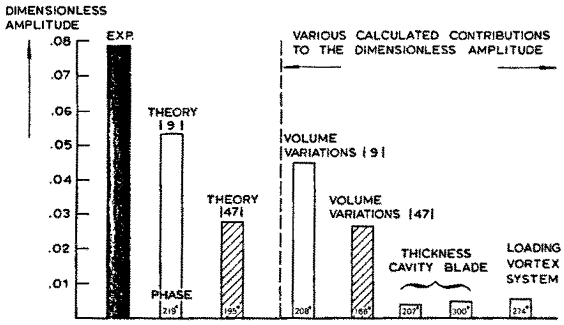

Fig. 1. Comparison between the measured and calculated pressure amplitude.

In this Figure a comparison is made between the calculated and measured first harmonic of the periodical fluctuation of the hull pressure. This is given in the left-hand side of the Figure. The calculated amplitude is obtained by a simplified (shaded column) and an improved theoretical model for the volume variations (growth and collapse) of the cavity. The differences between both approximations are shown in the right-hand side of the Figure. The simplified description comprises an approximation of the volume variations by a single line sourse /47/. The improved description comprises a distribution of line sources in chord-wise direction /191/. The improvement obtained by using a more detailed description of the volume variations is clearly illustrated. For a detailed discussion the reader is referred to Ref. 2.

Further I like to make some remarks with respect to /7/ and /8/. In contrast with what the committee reports, in /7/ no theoretical considerations are made with respect to cavity geometry. In /8/ a correlation between full-scale hull pressure measurement and corresponding measurements in the SSPA-large cavitation tunnel is given. The committee mentions that the pressure fluctuations agreed well. The full-scale cavitation pattern does not correlate with the model cavitation pattern. Looking at the model cavitation pattern one might expect higher dimensionless harmonic components of the pressure fluctuations at model-scale than at full-scale. However, the pressure signal obtained at model scale is quite irregular (due to irregular cavitation) leading to a reduction of the expected higher level of the harmonic components. The final result is a good correlation, at least for the first harmonic, but it is clear that such a correlation is a happy coincidence. Only those correlations with respect to pressure fluctuations are meaningful when at least also a good correlation of cavitation patterns occur.

Finally in order to penetrate further in the complex field of hydrodynamic excitation and quoting /46/ "to decrease the risk for a happy coincidence to occur" it is suggested

- to evaluate the various calculation procedures for hull excitation including the assumptions made;
- to determine the cavity geometry accurately;
- to perform a comparative study with excisting calculation procedures;
- to conduct properly defined experiments.

REFERENCES

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2. Noordzij, L.: "Considerations on the hull excitation force induced by a cavitating propeller", International Shipbuilding Progress, Vol. 25, No.288, August 1978

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In its report the Propeller Committee discusses the problem of wake scaling. Today only the nominal velocity behind model hull is measured and wholly satisfactory prediction procedure of ship wake requires a "Herculean effort" (Committee dixit).

To have some light on the scale effect on effective wake pattern it is necessary to carry out velocity measurements in the propeller plane in behind conditions. Such measurements are very difficult to carry out and to analyse.
Nevertheless it is possible to have an idea of the influence of the propeller suction and scale effect on wake pattern by measuring the radial stress near the blade root of a propeller and making harmonic analysis of these measurements. Theoretically the various harmonics of

the stress fluctuations vary as the product N x V x wake harmonic amplitude.
So the curve harmonic stress amplitude verses N.V can indicate how modifications occur in the wake patters when the propeller operates from zero thrust to propulsion point thrust and beyond.

In the same way the comparison of the various stress harmonics of the model and the ship propellers can indicate how the scale effect acts on the various harmonics of the wake.
Note, approximate values of the bearing forces can be deducted from the amplitude of suitable harmonics of stress fluctuations.

Experiments carried out in France have shown:

- first that the propeller suction or the scale effect acts differently on the various wake harmonics. In some cases we observed that some harmonics of large amplitude of the nominal wake disappeared in the effective wake at the operating propeller thrust.
- secondly, that the bearing forces deducted from stress fluctuation measurements on a ship propeller were in good agreement with those that can be expected from model bearing forces measurements.

R.E.A. ARNDT - Saint Anthony Falls Hydraulics Laboratory, University of Minnesota, Minneapolis, USA

The Committee must be congratulated on a most creditable piece of work. I would like to limit my remarks to some of the suggestions for cavitation testing, especially those incorporated in recommendation 2. In my opinion the investigation of viscous effects on cavitation should be extended to include the effects of boundary layer flow on the development of the tip vortex and subsequent cavitation in that region.
During the investigation reported in Reference 34, one blade of a five bladed model propeller was coated on the *suction* side only with a uniform sand grain roughness. This blade experienced almost no tip vortex cavitation at the same time that the other four blades were experiencing fully developed vortex cavitation. Upon removal of the sand, this blade also experienced the same level of tip vortex cavitation as the other four blades. This observation is completely contrary to observations with non-rotating lifting surfaces where it is observed that the boundary layer on the *pressure* side of the blade supplies the viscous fluid to the core of the tip vortex. Obviously, centrifugal pumping effects in the boundary layer play an important role in tip vortex development.
Secondly, I am sure that the committee has been overwhelmed by the explosion of knowledge in the past few years on environmental factors that are relevant for proper simulation of cavitation patters on marine propellers. Although the current focus of attention is on viscous effects and free gas content, I must say that proper attention must also be paid to the level of dissolved gas content. This is especially true for the evaluation of forces where developed cavitation occurs, either in the form of sheet cavitation or vortex cavitation. Matching of relative saturation levels is not enough. It must be emphasized that the diffusion of gas across a cavity wall must be properly accounted for in order to insure complete success in modelling certain phenomena. I am somewhat hesitant to make a specific suggestion at this point, but consideration should be given to the ratio of partial pressure due to dissolved gas and a reference dynamic pressure viz.

$$\text{Gas parameter} = \frac{\alpha\beta}{\frac{1}{2}\rho V_o^2}$$

wherein α = level of dissolved gas
β = Henry's constant
$\frac{1}{2}\rho V_o^2$ = dynamic pressure

W. VAN GENT and M. HOEKSTRA - Netherlands Ship Model Basin, Wageningen, The Netherlands

The propeller action in the wake is a complex aspect of ship propulsion. Although this is confirmed by the committee, a loose description is given, being a mixture of experimentally observed effects and theoretical models for certain flow types. For instance, it is inconsistent and not explanatory to say that the change in pressure on the stern affects to some extent the potential velocity field (page 247).

The following is meant to improve the description of the effective wake concept and to clarify the discussion about this subject as well as about the methods trying to derive the effective wake distribution.

The design of a propeller or the analysis of a propeller with a given geometry is based on some propeller theory. Existing propeller theories are founded on the supposition that the flow in which the propeller operates is inviscid. Moreover the assumption is made that the wake field in which the propeller operates is unbounded and irrotational. Thus the vorticity in the flow is taken to be confined to the bound and trailing vorticity of the propeller, and it follows that the upstream propeller-induced velocity field is an irrotational flow field.

When the assumption of the wake being an unbounded, irrotational and inviscid flow is fulfilled (closely resembled by a propeller in open water), the flow field ahead of the propeller plane in presence of the operating propeller is obtained by a superposition of the flow without propeller (nominal flow field) and the propeller-induced flow. In that particular case the inflow of the propeller, which is the base for the application of existing propeller theories, is equal to the nominal wake. Then we say that the effective wake is identical with the nominal wake. A ship's propeller, however, does not operate in an unbounded irrotational flow. The ship's hull is present in close proximity of the propeller and the no-slip condition to be satisfied at the hull surface leads to a steady production of vorticity which is subsequently diffused and convected so that the nominal wake is highly rotational.

The description of the wake always consists in a superposition of a potential flow field and a flow field induced by the vorticity. The total flow field satisfies the no-slip condition as well as the condition of zero normal velocity at the hull. When the operating propeller is introduced in this flow the vorticity production and transport are affected and the flow patterns of the forementioned types change. It will be clear that these changes are not fully incorporated in the propeller-induced velocity field as defined by the existing propeller theories. Therefore these changes are interpreted as an interaction effect between the propeller-induced flow and the hull-induced flow. The apparent inflow of the propeller is a modified nominal wake field due to the interaction and that is what is called the effective wake. It has to be noticed that:

i) As the interaction depends on type and loading of the propeller, the effective wake cannot be seen as a property of the hull alone;

ii) The effective wake field cannot be measured as it is not a real flow or a flow that can be simulated. Only indirect methods for determination can be used and it is loose to remark "Improv-

> ed methods of measuring effective wake distribution should be developed" (page 282).

Turning now to the methods for determination of the effective wake it is recalled that this wake can be seen as the total flow field of the propeller-hull combination minus the propeller-induced field. The total flow field can be determined by measurement only. For the propeller-induced field an unambigious definition is: the flow induced by the propeller, bound and trailing, vortex system and by the source-sink system describing its body in the actual situation. For the determination of the propeller-induced field it has to be realized that the location and strength of the vortices, sources and sinks is only approximately known or simulated and consequently the result will depend on the method which is used. This fact also requires that the propeller model used to determine the effective wake should be consistent with the propeller theory used for the design of a propeller in that wake.

Comparing finally the applied methods to derive the effective wake distribution, we consider first the work by Titoff and Otlesnov. They have obtained the propeller induction from measurements ahead of the propeller in open water. This is possible because the propeller then operates in irrotational flow. However, the actual propeller induction is only approximated. Circumferential loading variations for example, are neglected. On the other hand the location of the trailing vortices is probably more realistic than in a propeller theory.

In the method of Hoekstra, where a diffuser is used, a vortex system corresponding to the mean loading of the propeller is simulated. This vortex system deviates also considerably of the actual vortex system but the advantage of the method is that the measurements can be carried out in the propeller plane.

With Huang's method a theoretical propeller model is used and it is possible to incorporate part of the interaction effects in the propeller theory. With improvement of this method one can come closer to the above definition of propeller-induced field.

In the proposal of the committee to determine the propeller induction from measurements ahead of the propeller operating in a screen wake an important effect is overlooked. Apart from the enormous difficulties associated with a proper simulation of a ship wake by screens, the wake of the screen is not irrotational. Consequently there is interaction between the propeller-induced field and the vorticity in the wake, being mainly an effect on the vorticity transport. First the report has mentioned this effect on page 247, but in the suggested procedure on page 249 it is inadmissibly disregarded.

K. TAMURA and H. KASAI - Mitsubishi Heavy Industries Ltd., Nagasaki Technical Institute, Nagasaki, Japan

In the report of the Propeller Committee the effects of rounded inlets on tunnel thrusters and of the presence of thruster support struts downstream of C.P. rotors are discussed and their advantages are explained quantitatively (page 262).
It is doubtless that these explanations will give a good guidance for the persons concerned. However, as the effects stated above are rather popular and several studies have been made up to now, careful assessment over these studies would be necessary. From this viewpoint, the writers feel that the values quoted in the report seem to be too precise and to be in lack of explanations for general use. For reference, the writers would explain the studies made by Taniguchi et al /1/

and compare them with the present report. According to their studies power increased by 50-60% with square inlets compared with rounded inlets, when the dimensions of impeller and its revolutions are the same. It must be referred to also that the impeller thrust increased also by 30-40%, while the total thrust including impeller and duct was almost unchanged. The power increase is considerably higher than the present report.

In contrast to the present report, the power and the thrusts of impeller and duct changed very little with number of struts (0-3) and number of blades (3 and 4). This difference might come from the different shape and arrangement of struts. Finally the writers should like to add that not only the thrust increase, but also the change of power should be stated in the present report, if there is any.

REFERENCE

1. Taniguchi, K., Wanatabe, K. and Kasai, H.:"Investigations into the Fundamental Characteristics and Operating Performances of Side Thruster", Mitsubishi Technical Bulletin No. 35, May 1966

H. TAKAHASHI - Ship Research Institute, Tokyo, Japan

Comparative Calculations of Propeller Blade Pressure Distributions

1. It is interesting that the results of the comparative calculations represent the present state of the arts on propeller theories. We think it would be more useful if the relationship between the calculation method and the result was presented, which might suggest reasons for the differences.

2. We agree with the plan of analysis of the lift distribution along radius. Furthermore, it is necessary to present the calculated values of K_T, K_Q, especially for institutes which adopt the theoretical method such as ours /1/.

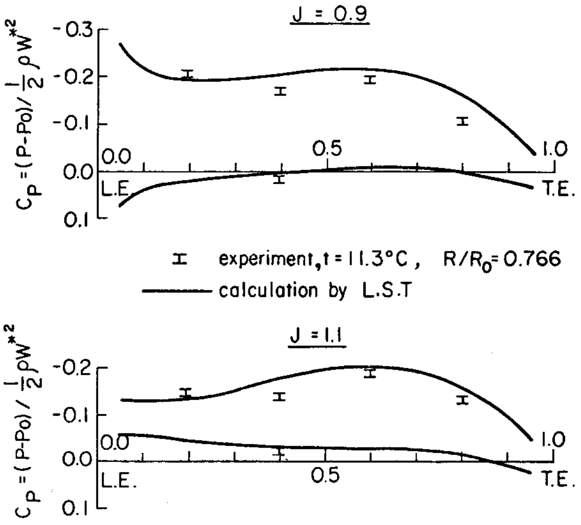
3. I would like to present the comparison between results of calculation and experiments of pressure distribution on one blade (this model propeller is not proposed by Propeller Committee). (Refer to reference No. 85 in the Report of Cavitation Committee).

		J		
		0.700	0.833	1.000
K_T	Exp.	0.203	0.150	0.077
	Cal.	0.198	0.148	0.083
K_Q x 10	Exp.	0.365	0.285	0.175
	Cal.	0.325	0.260	0.162

Particulars of the propeller model

MODEL PROPELLER NO.	0 123
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°
NUMBR OF BLADES	6
BLADE SECTION	SRI · a

DESIGN POINT J = 0.92



Pressure Distribution (uniform flow)

Reduction of Cavitation

Reduction of unsteady cavitation is very useful from the point of view of vibratory forces.
The satisfing result was obtained in reducing circulation distribution near the tip /2/.

REFERENCES

1. Schwanecke, H.: "Comparative Calculation on Unsteady Propeller Blade Forces", Appendix 4, Propeller Committee Report, Vol. 3, Proceedings of 14th ITTC (1975)
2. Ienaga, I, et al, "An Experimental Study on the Wake Adapted Propeller", presented to the Spring Meeting of the Society of Naval Architects of West-Japan (1978)

K. TAMURA - Mitsubishi Heavy Industries Ltd., Nagasaki Technical Institute, Nagasaki, Japan

In the report of the Propeller Committee it is assumed that in the behind condition there is enough initial turbulence to ensure fully turbulent flow on the blades of the propeller model (page 276). This assumption, however, seems to be unrealistic. As stated in the report of the Performance Committee (page 370), a considerably wide range of laminar flow still remains on the blades of a propeller model which is usually used for the self-propulsion tests of 6 - 7 meter ship model, although the extent of turbulent flow is somewhat larger in the behind condition than in the open-water condition.

It is highly desirable, therefore, to find a method to evaluate a Reynolds number for propeller open-water tests such that the extent of turbulent flow on the blades is the same as in the behind condition, in order to obtain correct self-propulsion factors.

One of the practical solutions for the above question may be the adoption of an artificial turbulence stimulator on the blades or the adoption of artificially roughened blades of propeller model.

The writer should appreciate it very much, if the Propeller Committee would pay its attention to the importance of these items and include them in the recommendations for the next committee.

S.T. TUNG - China Ship Scientific Research Center (ESSRC), Shanghai, People's Republic of China

We endorse the opinions on testing techniques for ducted propeller, put forward by the present Propeller Committee. It is our opinion that further research should be done on the method of analysis for ducted propellers tested in cavitation tunnels and a method of standardization for such analysis should be one scope of work for the future committee. This situation arises from the fact that only few member organizations enjoy the benefit of a depressurized towing tank and most of them may have to carry out cavitation tests of ducted propellers in a cavitation tunnel.

My colleagues, Mr. Y.P. Yeh and Y.M.Cheng have conducted both series tests on ducted propellers in cavitation tunnel and open-water tests in towing tank for the last few years. Details of their report are to be published. From the limited experience gained by their experiment, it was found that the correction for tunnel-wall effect in the case of ducted propellers is even more pronounced than conventional propellers. The basic principle of correction adopted by Yeh and Cheng were in accordance with them employed by NSMB for their B-series tests in cavitation tunnel, but the velocity correction was based on C_{TP}. They tried several different approaches including the C_{TT}-identity and K_{TP}-identity methods. On comparison, it was found that much larger correction for J and σ values were involved for the K_{TP}-identity method, whilst lesser corrections were concerned with the C_{TP}-identity method. Hence, the latter is more acceptable. As an example, calculations of the same ducted propeller but based on two different methods of correction are listed here for comparison:

Table I

Uncorrected $\delta_{v_t} = 4.50$

J	K_{TP}	K_{TD}	$10K_Q$
0.43	0.216	0.0509	0.374
0.47	0.221	0.0526	0.387
0.51	0.213	0.0503	0.379
0.55	0.203	0.0446	0.369
0.59	0.188	0.0357	0.344

Corrected with K_{TP}-identity method

σ_y.	J	K_{TP}	K_{TD}	$10K_Q$
14.6	0.256	0.216	0.1090	0.396
12.2	0.303	0.221	0.1100	0.411
10.1	0.360	0.213	0.1000	0.404
8.62	0.416	0.203	0.0859	0.393
7.54	0.474	0.188	0.0680	0.366

Corrected with C_{TP}-identify method

σ_v.	J	K_{TP}	K_{TD}	$10K_Q$
5.28	0.403	0.189	0.0680	0.355
5.30	0.440	0.193	0.0688	0.368
5.30	0.477	0.186	0.0648	0.362
5.29	0.515	0.177	0.0572	0.353
5.25	0.554	0.165	0.0465	0.331

Another aspect is that the corrected values based on C_{TP}-identity and C_Q-identity methods are closer together than that based on C_{TT} and C_Q-identity. So, finally they based their corresponding corrections on the C_{TP}-identity method, using the open-water test curves as the basis of reference. Concerning the correction of propeller efficiency for cavitation effects, they derived their corrected efficiency values from the open-water efficiency values by maintaining the ratio of cavitation-influenced and non-influenced efficiency (both obtained from tunnel tests) to be the same. Thus from the K_{TT} and π values, one may obtain the K_Q values. The total thrust was corrected in the same manner as the efficiency curve. However, this is only an attempt to approach a rational method for correcting tunnel-wall effects of ducted propeller tests.

K. TAMURA and N. CHIBA - Mitsubishi Heavy Industries Ltd., Nagasaki Technical Institute, Nagasaki, Japan

On looking at Figure 3 and the statement thereof on page 240, we wonder if the integration of the pressure could be made so simply and should be made over such a wide range as exceeding 25% of the ship length. The Committee may be right in stating that the pressure amplitude is in proportion to 1/R and therefore will not decrease so rapidly with distance from the propeller.

In evaluating the vibratory response from the pressure distribution, however, ship's hull should be treated as an elastic structure. According to Ohtaka /1/, the response of a linear vibratory system to a sinusoidal force F is given by the following formula

$$\frac{\alpha(x)}{F(x')} = \sum_{n=1}^{\infty} \frac{\omega^2 \phi_n(x) \phi_n(x')}{M_{en}\sqrt{(\omega_n{}^2 - \omega^2)^2 + (\frac{\delta_n}{x}\omega)^2}} \quad (1)$$

where α = vibratory acceleration at location x

F = exciting force applied at location x'
ω = natural circular frequency of exciting force
ϕ_n = n-th normal mode of vibration
ω_n = natural circular frequency of n-th mode
δ_n = logarithmic decrement of n-th mode
M_{en} = effective mass of n-th mode

For distribution of vertical forces as shown in Figure 3, therefore, vibratory response should be calculated by

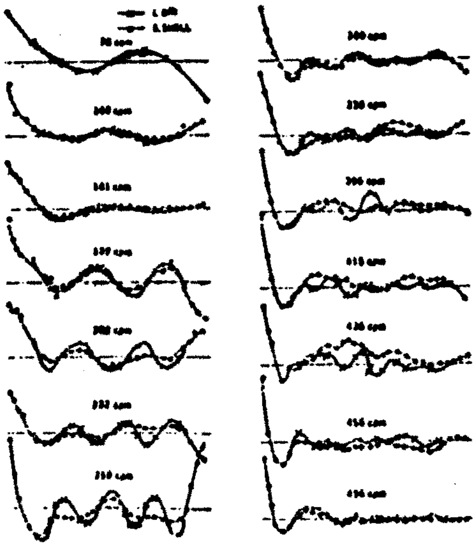
$$\alpha \propto \int f(x')\phi_n(x')dx' \qquad (2)$$

instead of

$$\alpha \propto \int f(x')dx' \qquad (3)$$

Such consideration is especially important for higher mode vibrations usually with modes of about 10 or more corresponding to blade frequency and its harmonics. As an example, the mode curves of a 130 KDWT tanker are given below. Judging from this Figure, the structural response for such high frequencies as above 400 cpm may be approximated by integration of formula (2) over 10-15% ship length from the aft end.

In this connection it will not be appropriate to discuss on a criterion of fluctuating pressure without due consideration regarding the response characteristics of a hull.



REFERENCE

1. Ohtaka, K.: Practical Approach for Estimation of Hull Vibration, PRADS 1977 (Tokyo)

J. VAN DER KOOIJ and S. HYLARIDES - Netherlands Ship Model basin, Wageningen, The Netherlands

For a first, rough qualification of predicted pressure fluctuations or hull pressure forces, simple criteria are required. In our opinion the mentioned formula

$$2p_{allowed} \qquad 6.25\,\frac{\nabla}{D^2}\,\frac{a_x}{a_z}\left(0.75+\frac{75}{L}\right)$$

(developed by Johnsson of SSPA) has a realistic basis. However, it is susceptible to improvements:

1. The factor $\frac{a_x}{a_z}$, which accounts for differences between relation of the pressure fluctuation on the hull above the propeller and the resulting hull pressure force (starting from a certain propeller diameter D), is too restrictive. This is immediately clear if an open-stern arrangement is considered, but also for other cases the use of this criterion can lead to erroneous decisions.

Another aspect is the shape of the ship above the propeller as mentioned by Ward et.al. in 1975/1/, see Figure 1, recognized by Johnsson and originating from DnV, which has to be included in the criterion.

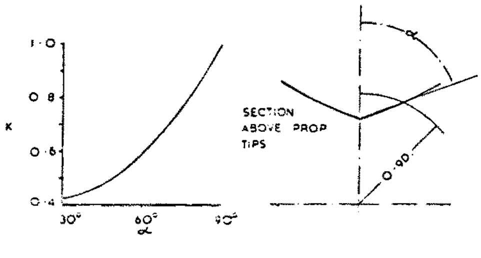


Figure 1. Factor K to estimate effect of section shape on hull pressure forces.

Further, the phase differences of the pressure fluctuations at different places on the hull are very important in the relation between hull pressure force and the pressure fluctuation above the propeller. This information can only be obtained when pressure fluctuations are measured (or calculated) at various locations on the afterbody. In this way a more accurate criterion is obtained. If the number of locations, in which pressures are measured (or calculated), is taken large enough, the total hull pressure forces can be estimated by integration of the local pressure fluctuations. This results in an expression for the allowed force, instead of the allowed pressure:

$F_{allowed} < \text{const.}\ \nabla\ (0.75 + \frac{75}{L})$ which can be considered more accurate than the previous criteria.

2. From fundamental considerations the term $(0.75 + \frac{75}{L})$ could represent the excitation frequency (At the NSMB a similar expression for the relation between propeller rate of revolutions and ship length L was found, although with different constants). Therefore it is more accurate to replace the above term by the actual excitation frequency, i.e. the blade frequency or its multiples.

3. Also the way how to evaluate the measurement signals: peak-peak, harmonics sole or combined has to be worked out.

It should be stressed, however, that the suggested extension still gives only a first idea of the risk of vibration hindrance. The expression is still based on a certain level of hull girder vibrations. The step to deckhouse vibrations should also be taken into account. Some suggestions in this respect have been given already by Ward et.al. in the mentioned paper. Further, also the risk of noise should be estimated, because the combined effect of noise and vibration is experienced by the crew and determines the rate of hindrance, as has been shown by Janssen /2/.
In conclusion, it is considered necessary to extend the formulation of criteria for the allowed pressures or pressure fluctuations, and to add a recommendation in the report accordingly.

REFERENCES

1. Ward, G. and G.T. Willshare: Propeller-excited vibration with particular reference to full-scale measurements. R.I.N.A. Spring meeting 1975, paper no. 4
2. Janssen, J.H.: A proposal for standardized measurements and annoyance rating of simultaneous noise and vibration in ships. Netherlands Ship Research Centre T.N.O., report 126S, June 1969

II. REPLY OF THE PROPELLER COMMITTEE

The Propeller Committee would like to express its thanks to all those who have taken part in the discussion of this report.

The section of the report dealing with criteria for surface pressures and forces and shaft forces and moments, attracted discussion with regard to the derivation of these criteria. The Committee would like to point out, however, that it has restricted its role to collecting and reporting the criteria only. In view of the simple nature and obvious limitations of such criteria it was considered premature to comment critically on them. The Committee is pleased, however, that it has attracted interest and this gives encouragement to continue and extend its work in the future. The concern expressed by *Prof. Wereldsma* that such data might be used irresponsibly by members of the profession is not shared by the Committee. Sufficient comment regarding their limitations have been given in the report. Prof. Wereldsma discussed the difficulties of measuring the pressure fluctuations on flexible hull surfaces and he criticized the Committee for having stated that it was possible to make theoretical corrections. In fact it was stated that it was possible to make theoretical corrections if the hull vibration patterns were known. However, these calculations can never be more accurate than the accuracy of the input values.

Another very interesting investigation of this problem was presented by *Mr. Tung* who reported on full scale measurement of pressure fluctuations. The relationship between the plate accelerations and the special test where the plates were vibrated by an excitor. The fact that Mr. Tung found a large influence of the local hull plating flexibility on the pressure amplitudes shows how dangerous it is to make model scale comparisons without considering the flexibility of the plating.

The Committee agrees with *Dr. Breslin* that, from available theoretical considerations, the propeller induced pressure amplitude must tend to zero when approaching the water surface. We do not agree with him, however, when he suggests that the reason for the good agreement between results from the SSPA large cavitation tunnel and NSMB depressurized towing tank should be the large submergence of the propeller under the waterplane. As a matter of fact this comparison was made both in full load and ballast conditions. In ballast condition the water surface was at the top of the aperture and the distance between the water surface and the propeller tips was small. The pressure transducer above the propeller was just a few mm below the free water surface. In the worst cavitating condition tested the pressure fluctuations were larger in ballast than in full load. They were also larger for the pressure transducer closer to the water surface than for another transducer located at a deeper position.

Additionally, there is some full scale information which indicates that the pressure fluctuations on the hull, quite close to the free water surface, can be very high. The good correlation between these measurements and corresponding model tests in the SSPA large cavitation tunnel was discussed by *Dr. Noordzij* who claimed that this agreement was a happy coincidence. We suggest that Dr. Noordzij should discuss these matters directly with Mr. Johnsson of SSPA.

Obviously a discrepency exists between theory and experiment and, therefore, it is the opinion of the Committee that the influence of the free water surface on the pressure fluctuations should be investigated further. The distinguished discussers are welcome to help us clarify the problem.

The Committee thanks *Dr. Noordzij* for presenting his new data on pressure fluctuations. Unfortunately his most recent paper on this subject was published after completion of the Committee report. As Dr. Noordzij has shown in reference /10/ one of the difficulties in making comparison between calculated and experimentally measured pressure fluctuations is that measured values can vary depending upon the nuclei content.

A number of discussers have touched upon the subject of integrating hull pressures to obtain excitation force. In our report we have not gone much further than stating the problem, that a single point force can hardly be sufficient in representing surface excitation.

Dr. Breslin's theoretical work, dealing with the free surface effect upon the rate of decay of the pressure amplitudes as one moves away from the propeller, is indeed very interesting. The reason why it was not included in the main part of our report is simply that it was not published until after the Committee had completed its report. The Committee appreciates Dr. Breslin's theory as useful in providing an understanding of the phenomena in question. However, it considers that his theory overestimates the effect of the free surface. In reality, there is no free surface of infinite extent to justify a complete negative image of the propeller above the surface. A large solid body, the hull, comes between.

When attempting to integrate pressures to obtain surface force, one should, of course, as stated in our report, take phase angles into account. In fact, the Committee is rather surprised to hear Dr. Breslin claim that there are some establishments that do this integration without taking phase angles into account. Firstly the phase angle differences arise from the fact that the propeller-induced pressure field is partly a rotating dipole type pressure field and partly an oscillatory monopole field. This effect should follow from carefully conducted model tests as well as calculations with correct theoretical modelling of the propeller and cavities, and the reflexion properties of the hull. Secondly, there is a phase shift due to the finite velocity of propagation of the pressure waves in water. There are certain possibilities of estimating this effect by theoretical calculations. Thirdly, to account for the modal influence of the elastic hull. one may have to apply a "weighting function" to the pressure amplitude as correctly indicated by Dr. Wereldsma in his discussion. A negative weighting function is the equivalent to a phase shift of 180 degrees.

It is only very recently, that some suggestions have been put forward on how to deal with this third item in practical applications. *Dr. Tamura* and *Mr. Chiba* in their very constructive contribution to the discussion, drew attention to such a practical method. Talking of present and future development, another method is being developed at the Norwegian Ship Model Tank. Their approach is to measure pressures at a few positions on the hull model as before. From the pressure measurements one calculates an equivalent singularity distribution to represent the propeller. Then combined with an extension of Vorus's method, this gives the excitation force corresponding to any given mode of vibration.

To *Ing.Gen. Aucher*'s comment on the term amplitude, the Committee recommends that it should be used to represent half the peak-to-peak value of a sinusoidal function. If the function is periodic but not sinusoidal, the term amplitude should only be used in connection with each of the harmonics (see ITTC Dictionary of Ship Hydrodynamics, Seakeeping Section, and Propeller Committee Report, Nomenclature relating to Unsteady Propeller Forces, 14th ITTC).

In his discussion *Prof. Arndt* points to the explosion of knowledge on the subject of marine propeller cavitation testing over the past few years. The Committee acknowledges this fact and is pleased to acknowledge also Prof. Arndt's contribution in the subject of basic cavitation. Perhaps his discussion could have been addressed to either the Cavitation or Propeller Committee, however, the Propeller Committee is pleased to answer it and perhaps the Cavitation Committee might comment on it later.

Prof. Arndt touches on an interesting aspect of propeller performance regarding the formation of propeller tip vortices and the Committee agrees that this topic deserves deeper consideration. Undoubtedly the inadequacies in the theoretical calculation of propeller tip cavitation are associated with our lack of knowledge in this matter and although a specific recommendation is not devoted to it, recommendation 6 for the next Committee is pertinent.

Prof. Arndt's comments regarding free and dissolved gas are also noted with interest, however, the Committee questions the importance of the precise level of dissolved gas in experiments where periodic cavitation is involved. Typically in model propeller cavitation experiments where the growth and collapse of the blade cavity and its associated tip vortex takes place about 1/100th to 1/200th of a second, it seems doubtful if diffusion, which is a relatively slow process, can assume a role of high importance. This does not apply to steady cavitation, of course, and may not apply to full scale propeller periodic cavitation where the times corresponding to those quoted above will be much longer.

Ing.Gen.Aucher has presented us with some very interesting information on wake scaling. However, we are not convinced that comparison of the various stress harmonics at the blade root between model and full scale would really tell much about the details of wake scaling for general ship forms. In the first place, it is not proper to scale the wake harmonics for general ship forms because reducing the wake into its harmonic components is an artifice. In the second place, the harmonic content of the unsteady stress in the blade root may not represent the harmonic content of the wake since both the spanwise amplitude and phase of the wake controls the unsteady stress. However, where the wake is coherent, such as for a ship with a very open stern and high shaft angle, then it may be possible for the harmonic content of the root stress to be an indication of the harmonic content of the wake.

Dr. Van Gent and *Mr. Hoekstra* discussed the section of the report on "Determination and Scaling of Wake". We wish to thank them for pointing out the misprint on page 280. The ninth line from the top in the left hand column should have the word "measuring" changed to "assessing". Since the effective wake distribution does not really exist in a physical sence, but must be derived, lengthy and pedantic discussions can arise in connection with it. Dr. van Gent and Mr. Hoekstra have interpreted our mention of propeller theory in discussing propeller induction on the wake as if we were considering some particular existing theory, but we are using the term "propeller theory" in a general sense in an attempt to describe the problem of determining, or even defining the effective wake distribution. Most of their remarks seem to be in context of the adequacies or inadequacies of the existing theories rather than in context of the principles involved. We agree that use of different propeller theories will give rise to different effective wakes. With regard to their comments on procedures for evaluating the propeller induction on the wake, the Committee's comment was not really a proposal but a suggestion that the use of a screen might offer some improvement over the method of Titoff and Otlesnov. One should not take this suggestion out of context in the whole discussion, especially when the present techniques are so crude. Even if the Committee was not completely clear on the interaction of the vortex systems, it is very doubtful if this interaction is important relative to the other assumptions.

The Propeller Committee is grateful to *Dr. Tamura* and *Mr. Kasai* for pointing out the omission of the reference by Taniguchi, et al, on thrusters. Much useful information is given in that report. As regards the power increase and the redistribution of thrust when changing from rounded inlets to square inlets, as quoted in the Committee Report, these refer to constant thrust being developed by both arrangements, i.e. with rounded and square inlets. Therefore, the power increase of 26% and 50-60% quoted in the Committee Report and by Tamura and Kasai, respectively, have the same basis. The large difference in power increase presumably arises from the particular arrangements tested and possibly the scale of the tests also. However, this contribution emphasizes the importance of fitting adequate intake roundings on dynamically positioned vessels where tunnel thrusters may be in use for very considerable periods of time. That the static thrust factor of merit is improved by struts downstream of the propeller has been found on several occasions unlike the case quoted by Tamura and Kasai where no change was found. Again this points to the need for obtaining test results for specific arrangements when considering the design of new vessels.

The Committee thanks *Dr. Breslin* for listing the four necessary conditions which a correct pressure distribution should meet. We assumed these conditions to be so self evident that it might embarrass some participants taking part in the comparative calculations if they were told how to check their results. However, the Committee is very grateful to Dr. Breslin for identifying his results. Unfortunately the Committee is not in a position to present the measured pressure distributions because there are no experimental data. It is understood, however, that useful experimental information may be forthcoming from several institutions in the foreseeable future and we can ensure him that the Committee is intent on pursuing this matter.

In reply to *Dr. Takahashi*'s contribution concerning the propeller blade pressure distribution calculations, it should be stated that the Committee had good reasons for not disclosing the calculation method used to obtain a particular result. One of the reasons was that there was no desire to discourage participants just entering this field of work by identifying their results. Another reason was that there were no experimental results for comparison when the exercise commenced. To all those participants who wish to compare their results with those from a specific establishment, it is suggested that they contact them directly and ask if they are prepared to identify their results. The Committee is grateful to Dr. Takahashi for the comparison of the results of pressure distribution experiments and calculations on his propeller model No. 123. This appears to be very encouraging. Dr. Takahashi's remarks on the reduction of unsteady cavitation by unloading the propeller blade tips are also noted with much interest.

In reply to *Dr. Tamura*'s contribution, it should be stressed that the Committee did not intend to imply that in the behind condition there is always enough initial turbulence to ensure fully turbulent, flow on the blades of model propellers. In fact the intention was to point out that the procedure which appears to be suitable for correcting open water results prior to using them for determining the hull factors from self-propulsion tests is based on the assumption of fully turbulent flow on the model propellers. Owing to the instability of transient phenomena, like partial laminar flow, it is doubtful, if it is possible to define a Reynolds number for propeller open-water tests so that the extent of turbulent flow on the blades is the same as in the behind condition. It is also doubted if it would be advisable to adopt turbulence stimulators on propeller blades because they could affect lift as well as drag, thus eliminating one uncertainty by introducing another one. In cases where laminar flow effects become apparent from the analysis of the open water results (using the equivalent blade section method) corrections can be made as in the Committee report.
The Committee agrees with Dr. Tamura that these problems are of such importance that they deserve the attention of the 16th ITTC Propeller and Performance Committees.

MR. TUNG discussed a testing problem for ducted propellers not considered by the Committee. The wall effects connected with testing in closed cavitation and wind tunnels can be quite important and Mr. Tung presented some alternative correction procedures. He found that the C_{TP}-identity method gave more reliable results than the K_{TP}-identity method. We agree with him, but would recommend that he uses the C_{TT}-identity method in the future since this method follows the Committee recommendation that the duct plus the propeller should be treated as a unit.

Prof. Wereldsma in his comments on the section on highly skewed propellers stated that the model propeller should be built to have elastic similarity with the full scale propeller. At a superficial glance this appears very appealling. However, one must not underestimate the practical problems, such as building the model and carrying out the normal set of tests without overloading it. The Committee did not state in the report that it was possible to build a structural model. What was stated was "in principle a structural model could be used".

In his recommendations, *Dr. Breslin* urged the Conference to direct the Propeller Committee to select an able applied mathematician interested in three-dimensional hydrodynamics to serve as a member of the Committee. Dr. Breslin should take note that the Propeller Committee does not select its members. However, the Committee did have considerable debate on what, or who, was an "able applied mathematician".