Cavitation Committee

Committee Chair: Dr. M. Billet
Session Chair: Dr. D. Husson

I DISCUSSIONS

To the Cavitation Committee,
On High-Speed Cavitation Performance

by Kudo, T. and Ukon, Y.
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We would like to say some words opposing the conclusion in chapter 9 of the cavitation committee report. The work in the field of propellers for high speed ships should be encouraged. A fair review is requested by the ITTC community.

The Ship Research Institute has developed a theoretical design method [1] for a new generation of super-cavitating propellers and an analytical method, SC-VLM [2] for SC propeller performance in the cooperative research project SR214 (The Ship Research Panel No.214). These works solved long-pending questions on SC propellers. Although two relevant papers were presented at the international symposium Cav. 94 in Tokyo, a review on them was omitted.

Later the SRI improved this design method more rigorously, so that a three-dimensional cambered surface of a SC propeller for the lifting surface correction can be computed including the effect of three dimensional cavities and vortex systems as in the SC-VLM algorithm [3]. This paper was presented at the international symposium on PROPCAV 95 in Newcastle. These outstanding works are neglected not only in the review of chapter 9 but even in the references in the present cavitation committee report. Both design methods can offer us higher efficiency SC propellers than the empirical ones using the trailing edge cup or erroneous SC blade section, because they are based on a non-linear cavity flow theory without any empirical tuning [1,4].

Using the new SRI design method, high performance racing boat propellers were designed successfully [5]. The performance of these propellers was evaluated not only in the SRI large cavitation tunnel but also in the racing site together with other practical propellers. As shown in Fig. 1, a propeller designed using the SRI method, SC-3, ran at the highest speed of about 97 km/h (=26.8m/sec.).

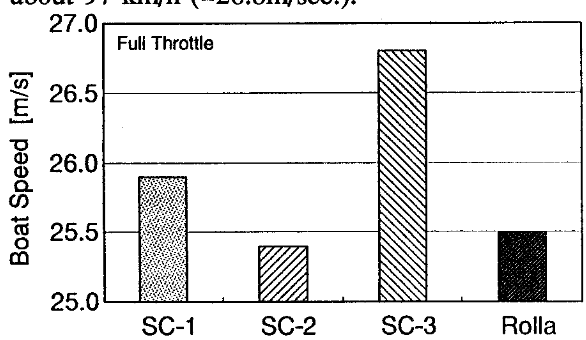

Fig. 1 Result of Speed Running Test

Fig. 2 shows that the racing boat with the SC-3 propeller completed a lap around two turning buoys 300 meters apart within 33.8 seconds which was 1.4 seconds faster than that with a famous commercial propeller, the "Rolla Propeller". Two tests were performed with boats of different weight. The propellers seem to operate in a semi-submerged condition in the racing site.

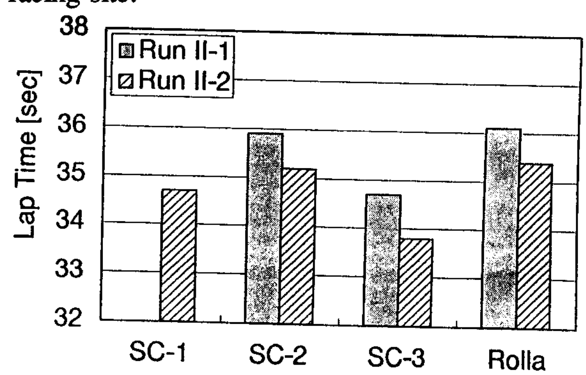

Fig. 2 Result of Racetrack Running Test

These SC propellers were designed based on a different concept of Trans-Cavitating propellers to that given by Yim and reviewed in the committee report. The propeller blade shape of SC-3 is shown in Fig. 3. The other Trans-Cavitating propeller is more practical, because the blade sections in the intermediate zone are designed by the interpolation from SC blades near the tip to sub-cavitating ones near the root along the radial direction.

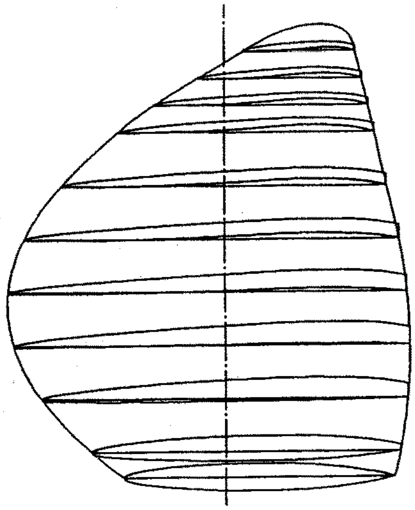

Fig. 3
Propeller Blade Shape of SC-3 Propeller

This idea can be applicable to more practical and lower speed propellers, such as propellers for a patrol boat, a pleasure boat and car ferries. The SRI and other organizations are currently working to extend this idea and to develop new high performance propellers. A "Cavitation Controlled Propeller Designed by Theory with a High Level of Performance" will be developed and applied for more general and practical use in the next three years.

References

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2. Kudo, T., Ukon, Y., 1994, "Calculation of Supercavitating Propeller Performance Using a Vortex Lattice Method", The Second International Symposium on Cavitation, Tokyo.
3. Ukon, Y., Kudo, T., Kurobe, Y., Matsuda, N., 1995, "Design of High Performance Supercavitating Propellers Based on a Vortex Lattice Method", PROPCAV'95, Newcastle upon Tyne.
4. Kudo, T., Ukon, Y., 1993, "Computation on a Two-Dimensional Supercavitating Hydrofoil Using the Linear Vortex Panel Method," Trans. of the West-Japan Society of Naval Architects, No.86.
5. Ukon, Y., Kudo, T., Kurobe, Y., Matsuda, N., Kato, H., Sasaki, T., 1995, "Design of Supercavitating Propeller for Racing Boat", J.SNAJ, Vol. 178.

Contribution to the discussion of the report of the Cavitation Committee

by G. Kuiper
MARIN, Wageningen, The Netherlands

This committee has delivered a very interesting and important report with broad reviews and new ideas. Especially the review on tip vortex cavitation is very clear and complete and can serve as a reference of available knowledge. In the field of nuclei effects the committee has further evaluated the results of the tests in the GTH, and the concept of extrapolation to "zero tensile strength" seems very promising, especially for bubble cavitation. The recommendation to the conference in this respect is very general, however, and is still far away from a standard procedure which can be used to satisfy e.g. ISO 9000.

The procedure for extrapolating inception to zero tensile strength requires knowledge of the nuclei density distribution in the test section in the same test conditions as the cavitation tests. In the report the results of the centerbody venturi are used for that purpose. The main barrier for a further application of an extrapolation technique as proposed is that not many towing tanks have such a venturi and to use it on a regular basis increases the amount of work for inception tests considerably. It is therefore not yet feasible to recommend the measurement of the full nuclei density distribution in inception tests.

The results of the committee do illustrate, however, that with weak water the inception index approaches that of water with "zero tensile strength". That is especially true for bubble cavitation.

The current practice to have a high gas content in the tunnel during those measurements is therefore correct. The main problem is to determine if the water is weak enough to be close to zero tensile strength. A simple method to determine that deviation would be practical and is suggested below.

In fact such a method has been pursued by the ITTC for a long time by searching for a "standard cavitator". The venturi basically is a standard cavitator with a known minimum pressure and pressure distribution. A propeller such as propeller B can also serve as a standard cavitator for bubble cavitation. Based on the pressure and the velocity in the test section such a standard propeller can be set at a fixed loading coefficient by adjusting the rotation rate. The number of cavities on the blades of the standard propeller in that condition gives an indication of the nuclei density by the number of bubble cavities on the blade, as illustrated in Figure 4. When the bubble cavities are sufficiently far apart the size of the bubble cavities indicates the distance in pressure to inception at zero tensile strength.

What is required is a calibration of the picture of the cavitating standard propeller with nuclei density distributions as given in the report. Inversely, when a towing tank has a picture of the standard propeller in a certain condition of the tunnel, a simple comparison can reveal if the situation is close to zero tensile strength.

The standard propeller to be used should have a low minimum pressure to ensure that it is cavitating earlier than inception of bubble cavitation for most commercial propellers in the same conditions. So it should have thick blade sections and a simple geometry. It is possible to use propeller B for that purpose, but an even more simple geometry is feasible. Inception conditions of tip vortex cavitation may be such that the "standard propeller" does not cavitate in those conditions. At model scale, inception of tip vortex cavitation is delayed with respect to full scale and the conditions of interest are generally in the lowest part of the cavitation bucket, and the standard propeller can generally give information in those conditions.

If propeller B is used the committee should publish available observations of the cavitation pattern in the various conditions used in the report and make the propeller (geometry) available for other towing tanks for further correlation. When sufficient practical experience has been obtained this might lead to the simple recommendation that every inception test should be accompanied by a series of observations of the standard propeller in the relevant inception conditions.

Comments to the Cavitation Committee on Comparative Measurement of Hull Pressure Fluctuations with an Easily Reproducible Wake

Ukon, Y., Kurobe, Y. and Kudo, T
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The SRI performed a comparative measurement of hull pressure fluctuations in an easily reproducible wake, made by the MHI. The test results from SRI are not included in the present committee report.

The simulated wake measured in the SRI large cavitation tunnel is shown in Fig. 5. The measurements were performed at three velocities. The width and the peak of the wake measured at the higher velocity are narrower and lower, respectively. The SRI simulated wake is somewhat similar to the MHI wake, as shown in Fig. 4 of the committee report.

Even using the same wake generator, remarkable differences were found concerning the peak of the wake and the effect of velocity on the wake distribution.

The maximum extents of cavitation patterns observed in the SRI wake were almost the same as others, while frequent intermittency was observed due to insufficient number of nuclei. The air content ratio was kept at about 36~38%.

Eighteen measurements of pressure fluctuations were performed to evaluate the accuracy of the present measurements, while changing parameters which might affect the measured results.

Our measurements varied with the propeller revolution rates as was found by other investigations. In our measurements, 30~50% higher pressure fluctuations were obtained at the beginning of the test series and immediately after the dry out period in the test section. At the end of the test series, the measurements were consistent. In Fig. 6, the measured results in the SRI wake are compared with the MHI and SRC data. At more than 30rps, all of the data became similar.

Our questions to the committee report are:

1. Are the data sets above 30rps (which are consistent) valid results? Without comparative measurements or full scale measurements, how can we determine the correct values?

2. In our opinion, the most serious problem is how we can remove the influence of propeller revolution rate. The committee should offer us consistent procedures to determine correct measurements.

3. Since the quality of water affects the occurrence of cavitation and the measured results, how can we control the nuclei distribution during the test to get reasonable measurements?

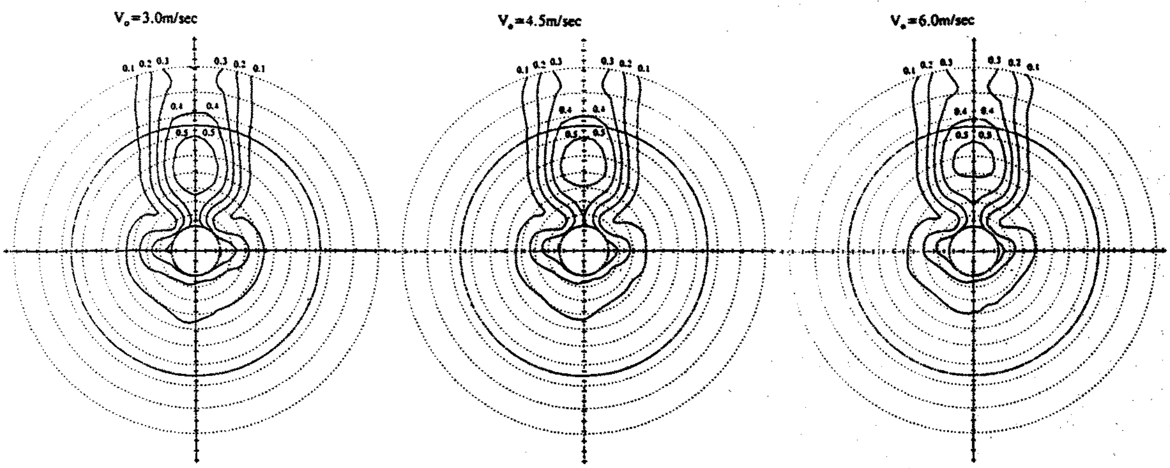

Fig. 5 Wake Patterns at Three Velocities

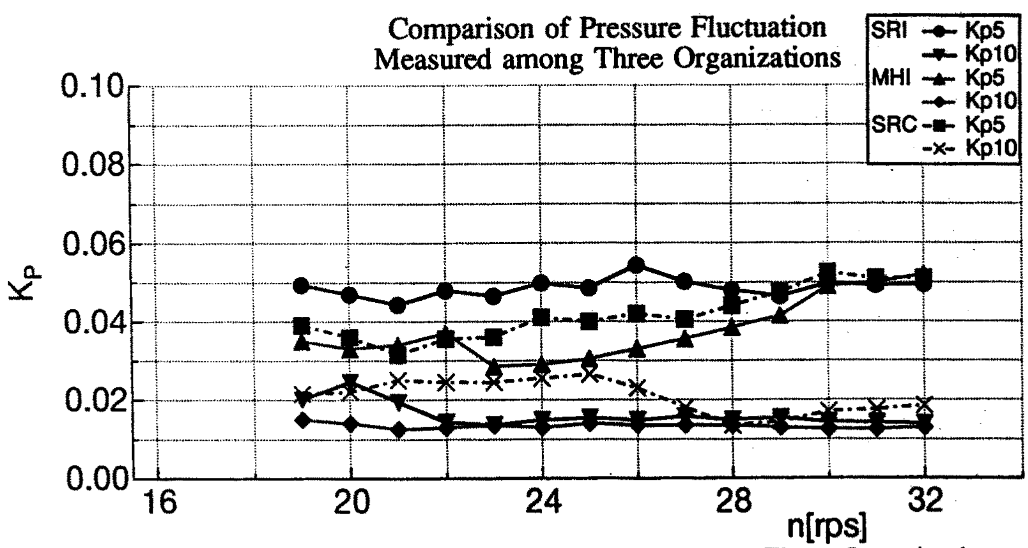

Fig. 6 Comparison of Pressure Fluctuation Measured among Three Organizations

Contribution to the discussion of the report of the Cavitation Committee

by H.C.J. van Wijngaarden
MARIN, Wageningen, The Netherlands

The Cavitation Committee has produced an interesting report in which I found the clear explanation of the nuclei effects on cavitation inception especially useful.

As for the measurements of hull pressure fluctuations it was encouraging to see the decrease in variability in test results between the various facilities, once the wake field was made sufficiently similar. Nevertheless, the spread in the results is still large according to the (very small) figures 7, 8 and 9. It would be interesting to see the effect of other major parameters on the variability when treated in a similar way. I would recommend that more facilities across the world would participate in studies like this one (and the one concerning nuclei spectra of GTH and CEIMM). It is only then that one can arrive at a "highest common factor" in the way in which model testing is (or rather should be) performed. The latter being a prerequisite for any ISO-9000 standard procedure.

Apart from experimental studies on the prediction of hull pressure distributions, a lot of work is going on concerning the numerical modelling of the same distributions. In the report the Committee mentions the reasonable accuracy that is obtained for the first harmonic. The higher harmonics are usually underpredicted by state-of-the-art methods. This is exactly MARIN's experience. In practice the role of the higher harmonics is becoming increasingly important, hence the need for improvement in the numerical modelling to allow for their prediction.

Considering the great amount of work that is put into this extensive report, I tend to agree with my colleague Prof. Kuiper, that the recommendations are not very specific.

II REPLIES

Reply of ITTC Cavitation Committee to Dr. Kudo, T and Dr. Ukon, Y.

- First of all we would like to thank Dr. Kudo and Dr. Ukon (a distinguished former Cavitation Committee member) for their attention and careful reading of our report.

- The content of the task under which we have this contribution is partly overlapping with a similar recommendation to the Propulsor and the High Speed Marine Vehicle Committees.

- The papers, and what is more important, the subject are reviewed and addressed in the Propulsion Committee report, in line with constant and careful cooperation among the committees. Thus, the SRI new SC propellers are not only not neglected, but are recognised as a significant contribution, as higher efficiency SC propellers can now be designed based on non-linear cavity flow theories without any empirical tuning.

- In conclusion, we totally endorse and sincerely stress the authors' suggestion for the need for increasing model and full scale experiments. We appreciate and encourage their efforts in this direction.

Reply of the Cavitation Committee to G. Kuiper.

We thank Gert Kuiper for his discussion. This reply is focused on four major points:

1. Gert Kuiper agrees on the importance of reaching the so-called "zero tension" cavitation characteristics.
2. The use of a Centerbody Venturi seems to him to be a source of considerable increase of work during a model test.
3. Gert Kuiper suggests the use of a so-called "standard propeller" to evaluate the nuclei distribution of a model test facility. More precisely, he suggests another procedure: that every inception test should be accompanied by a series of observations of the standard propeller in the relevant inception conditions.
4. He suggests the conduct of comparative tests on such a "standard propeller" in several water tunnels.

Concerning the fourth point, several ITTCs ago, there were suggestions for the conduct of comparative tests on a "standard cavitator". There was a famous headform cavitation comparative test program carried out. The results obtained from the various facilities were so different that it was impossible to conclude anything about a possible qualification of a tunnel facility by the use of such a standard cavitator. Then in 1992, the ITTC Cavitation Committee, chaired by Gert Kuiper, conducted a large test program in the French large cavitation tunnel, the GTH, in order to try to relate nuclei distribution with propeller cavitation inception. These tests and some of the results have already been reported on by the previous Cavitation Committee.

With regard to the third point - evaluation of the nuclei tension from a "standard propeller" - we repeat the conclusion made after the 1992 tests: "both water tension and nuclei content have to be quantified precisely to relate water quality (nuclei) with cavitation inception".

Another conclusion of the ITTC Cavitation Committee is that the correlation between cavitation inception and nuclei characteristics must be related to the fluid dynamics associated with the cavitating volumes on the propeller blades, which are specific to each propeller geometry.

A large test program was conducted in the Italian Navy cavitation tunnel, with nuclei measurements made for each cavitation inception point. The results show the direct influence of the tunnel hydrodynamic conditions on the nuclei distribution; that means the effects of factors such as pressure, flow rate, dissolved gas content, geometry of the facility, etc. In fact, even a slight change of sigma value will modify the whole time history of the water inside the flow loop, and the nuclei characteristics will be different. By measuring precisely the nuclei distribution, and evaluating the volume of the blade flow susceptible to cavitation, we were able to quantify the relationship between nuclei and cavitation inception. However, this was only through measurements of complete nuclei distributions. The whole flow circuit time history will be different in each facility, which means that the evolution of the nuclei distribution with the test operating conditions will be specific to each facility. Using a standard propeller that will give only one point of the nuclei distribution, and that with a rather large uncertainty, will not be sufficient to extrapolate to the evolution of nuclei within the whole operating domain of the facility. When testing the subject model propeller, characterized by its own geometry and hydrodynamic performance, we will not be able to evaluate the nuclei tension leading to cavitation inception, just from the data obtained from the standard propeller measurement.

The second point of the Kuiper discussion is that he considers that the use of the Centerbody Venturi adds a considerable amount of work to an inception test. From experience with conducting tests in facilities other than the GTH, it can be said that the use of a Centerbody Venturi is relatively easy and quick. A complete measurement of the whole nuclei distribution could take about five minutes. It is noted that this does require very specialized equipment and thoroughly experienced personnel to accomplish.

Our role with regard to the influence of nuclei was to try to relate precisely nuclei characteristics with cavitation inception on a marine propeller. The so-called "zero tension" characteristic inception curve should allow the direct comparison of the results from different facilities and the prediction of the full scale characteristics.

Reply of the Cavitation Committee to Y. Ukon, Y. Kurobe and T. Kudo

Thanks to Dr. Ukon, Mr. Kurobe, and Dr. Kudo for the additional comparative measurement of hull pressure fluctuations. The results from SRI show the smallest effect of the propeller revolution rate on the pressure fluctuations.

The main purpose of the present series of comparative measurements was to minimize the error associated with the wake simulation among different facilities. The differences between pressure amplitudes obtained by various organizations come from differences in water quality, the measurement devices, size of the measurement test section, and so forth. Nevertheless, the measured data above 30 rps show fairly good correspondence among the contributors. Therefore, the data sets obtained at rotational speeds above 30 rps would be consistent as pointed out by the discussers. Further research with an appropriate wake would be necessary to get a better correlation with full scale measurements.

The influence of propeller revolution rate on pressure fluctuations is divided into three parts. The first is the resolution capability of the measurement system; second could be due to the presence of the boundaries of the test section; and third could be the effect of Reynolds number on cavitation patterns. The first could be improved by making the resonance frequency of the measurement system as low as possible, compared with the boundary effects. Thus, the influence of Reynolds number on cavitation patterns would be the remaining effect.

The third point involves two different issues: the water quality conditions for making consistent measurements, and how the nuclei distribution can be controlled. The water quality, i.e. the nuclei content, has a major role in cavitation phenomena. Thus it is essential to conduct tests with an appropriate nuclei content. The appropriate content is recognized by the committee as corresponding to a large amount of reasonably large nuclei. That is, they should be large enough to be activated by a pressure just below the vapour pressure, but not so large that absorption of pressure pulses will affect the measurements. Otherwise, transfer functions must be determined. Typically, tests carried out at a high flow velocity will minimize the absorption effect, since the equilibrium size of the nuclei will be smaller due to the higher pressure level used in the test section. Moreover, the activated nuclei will have a higher dynamic behaviour at high flow velocity.

With regard to the control of nuclei distribution, when a facility is not designed to fully control both dissolved gas and free nuclei, it is not really possible to control the nuclei distribution. A workable practical procedure is to maintain relatively high dissolved gas content and to test at a high flow velocity.

Concerning the change of data just after the system stabilizing procedure ("dry out period"), we can say that the nuclei content in a cavitation tunnel can change with time since the time history of the flow through the circuit will affect its characteristics. Typically, after a stabilizing period, the water quality will evolve to a certain equilibrium condition that strongly depends on the facility arrangement and the hydrodynamic operating conditions. Thus, the nuclei distribution can in fact change. This will affect the cavitation development and the pressure signal absorption.

Reply of ITTC Cavitation Committee to H.C.J. van Wijngaarden

The committee would like to answer the comment of Mr. van Wijngaarden concerning the measurements of hull pressure fluctuations as follows:

• We fully agree that more facilities should participate in comparative tests. We feel that other parameters - which are mentioned in the report - should also be treated as major factors in the experimental program. In fact, this committee planned to have more tests carried out, but this was not possible within the time frame involved.

• We have not yet arrived at a complete, "common factor" outline on how to perform our tests. But within the different parts of this report, recommendations have been made that will lead to practical solutions. The main points, which are in accordance with many recommendations made in the past, will be repeated here:

- Tests should be done in a realistic wake, if possible in a three-dimensional one.
- The Reynolds number should be as high as possible to assure turbulent flow on the blades, and this means large models and high rotational speeds.
- The nuclei content of the water in the facility should be as high as possible without influencing the possibilities to characterize the cavitation. Concerning the higher harmonics of the pressure fluctuations, sometimes the damping effect of the bubbles in the liquid cannot be neglected. In this case, transfer functions for the specific facility and the specific test conditions should be performed.
- Each facility should check its procedures by comparing results with full-scale data.

• We would like to close our comment with the remark that the conduct of parameter studies in different facilities and the development of a "highest common factor" for pressure fluctuation measurement should probably be the main task of a specialist committee.