Proceedings of the 7th International Symposium on Cavitation
CAV2009
August 17-22, 2009, Ann Arbor, Michigan, USA

CAV2009 – Paper No.

Numerical Prediction of Cavitation and Pressure Fluctuation around Marine Propeller

Kei Sato
Ship & Ocean Engineering Lab.
Mitsubishi Heavy Industries, Ltd.
Nagasaki-city, Nagasaki, Japan

Akira Oshima
Ship & Ocean Engineering Lab.
Mitsubishi Heavy Industries, Ltd.
Nagasaki-city, Nagasaki, Japan

Hisayuki Egashira
Ship & Ocean Engineering Lab.
Mitsubishi Heavy Industries, Ltd.
Nagasaki-city, Nagasaki, Japan

Shinichi Takano
Ship & Ocean Engineering Lab.
Mitsubishi Heavy Industries, Ltd.
Nagasaki-city, Nagasaki, Japan

ABSTRACT

The applicability of numerical prediction method for cavitation around marine propeller was studied. A commercial CFD code was applied for computation of 10 different propellers. The computed cavitation patterns and pressure fluctuations were compared with model test. As the result, it's shown that this method can be used for the prediction of the behavior of sheet cavitation and the pressure fluctuation of the 1st order of blade frequency component.

INTRODUCTION

It has been well known that unsteady cavitation occurring on marine propellers operating behind ship accounts for major part of propeller-induced hull vibratory forces. To prevent or control this harmful effect, prediction methods for unsteady cavitation and pressure fluctuation has been studied. But it's still difficult to achieve sufficient accuracy because of the complexity of cavitation phenomena. In these days, some results have indicated that numerical simulation using commercial CFD code provides reasonable cavitation pattern, and some of them have shown the possibility to predict pressure fluctuation [1, 2, 3, 4, 5]. However there have been few comparisons between CFD simulations and experiments, so it's still difficult to evaluate the applicability for actual design work. Therefore, in this study, 10 propellers which designed for actual commercial ships were calculated using commercial CFD in similar methodology, and compared with corresponding model tests to discus its applicability.

NOMENCLATURE

Ae/Ad	expanded area ratio
Dp	diameter of propeller
Kt	thrust coefficient $Kt=T/\rho N^2 Dp^4$
N	shaft rotating speed
P/D	pitch ratio at 70% radius section
Po	ambient pressure
Pv	vapor pressure
T	propeller thrust
Z	number of blade
ρ	density of fluid
σn	cavitation number $\sigma n=(Po-Pv)/(0.5\rho\ N^2 Dp^2)$
θ	blade angler position $\theta=0$ shows the blade position at vertical upward, and increase in rotational direction.
θs	skew angle

COMPUTATIONAL METHOD

ANSYS CFX® is applied for computational simulation of cavitation and pressure fluctuation. This software solves RaNS (Reynolds averaged Navier-Stokes) equation using finite volume method, and can deal with cavitation phenomenon using VOF (Volume of Fluid) method. In this study, SST k-omega model was adopted for turbulence model.

The overview of computational domain and computational grid on propeller surface are shown in Figure 1. Propeller is set in cylinder with free-slip wall, and only small cylindrical domain around propeller is rotating with transient rotor-stator connection. The topology of computational grid near propeller is almost similar to Kawamura et al. [2]. The y-plus values of the grids on blade surface are about 1 to 3, depending on local flow pattern. The number of grid is about 1.8 million, and required CPU time for each computation is about 24 hours using 6 CPU parallel computing in PC-cluster.

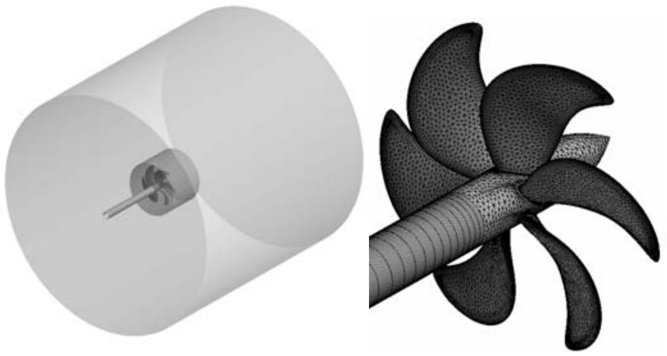

Figure 1: Computational domain and grid
(Left : overview of domain, Right : grid on propeller surface)

As inflow boundary condition, wake distribution is given. The wake distribution is the flow field at the propeller plane behind ship, and it's obtained in the absence of propeller. An example of wake distribution is shown in Figure 2, and this pattern is changed corresponding to each ship and its loading condition.

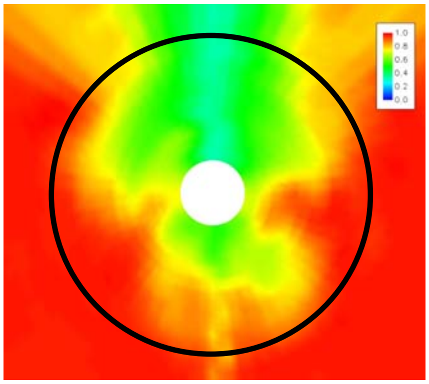

Figure 2: An example of wake distribution
(The contour shows velocity in axial direction, which normalized by ship's speed. The black circle shows the diameter of propeller disk.)

For unsteady computation, the revolution angle in 1 time step was set to 6 deg. i.e. 1 revolution consists from 60 steps. This time stepping is thought too coarse to express detailed phenomena of cavitation, but it was chosen to predict low frequency approximate phenomena in reasonable computation time for actual design work. Also the low frequency components of pressure fluctuation are highly important because they cause whole hull vibration, which is difficult to reduce by small modification of hull structure.

OVERVIEW OF MODEL TEST

To compare and validate computational results, model tests were done. These model tests were carried out in cavitation tunnel as shown in Figure 3 and Figure 4. This cavitation tunnel is closed jet type. The measurement section's shape is 710 mm square. The propeller is set in the center of measurement section and driven by the dynamometer set at upstream position. In the cavitation tunnel, the wake distribution was simulated with wire-mesh set at upstream position of propeller. The thrust coefficient Kt and cavitation number σn are adjusted to each ship's operating condition by controlling flow speed and pressure in tunnel.

In the tests, cavitation patterns were observed and sketched through window beside propeller, and pressure fluctuations were measured with pressure transducers on flat plate set above propeller. These pressure fluctuations were analyzed by FFT to obtain the amplitudes of the blade frequency components [6].

In this study, typical Dp of model propeller is 250 mm, and N is 25 rps.

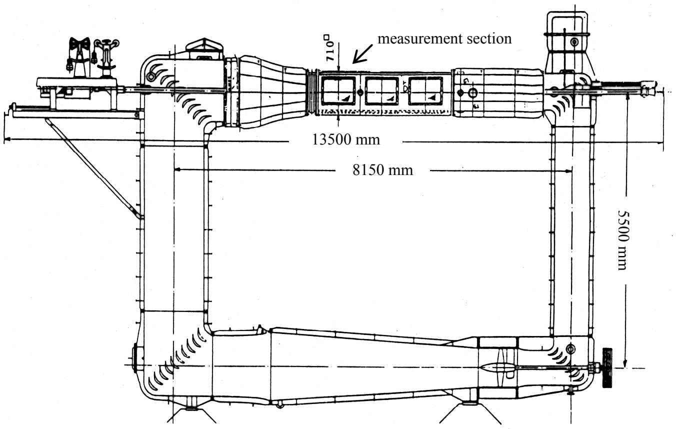

Figure 3: General arrangement of cavitation tunnel

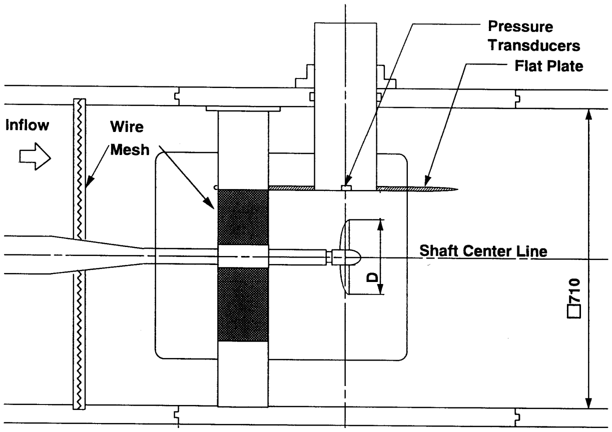

Figure 4: Test arrangement in cavitation tunnel

APPLIED PROPELLERS

The principal particulars of applied propellers are shown in Table 1. These propellers were chosen from different ships and types.

Table 1: Principal particulars of applied propellers

index	type of ship	type	Z	P/D	Ae/Ad	θs (deg,)
prop.A	A	FPP	6	Abt.1.0	Abt.0.8	Abt.30
prop.B	B	CPP	4	Abt.1.4	Abt.0.7	Abt.40
prop.C1	C	CPP	4	Abt.1.1	Abt.0.6	Abt.40
prop.C2	C	FPP	5	Abt.1.0	Abt.0.8	Abt.30
prop.C3	C	FPP	5	Abt.1.0	Abt.0.8	Abt.30
prop.C4	C	FPP	6	Abt.1.0	Abt.0.7	Abt.30
prop.C5	C	FPP	6	Abt.0.9	Abt.0.7	Abt.30
prop.D1	D	FPP	5	Abt.0.9	Abt.0.6	Abt.20
prop.D2	D	FPP	5	Abt.0.9	Abt.0.7	Abt.20
prop.D3	D	FPP	6	Abt.0.9	Abt.0.7	Abt.30

*FPP: Fixed Pitch Propeller
*CPP: Controllable Pitch Propeller

COMPUTATIONAL RESULTS AND DISCUSSION

COMPUTATIONAL CONDITIONS

All computations were carried out in model scale. The loading and pressure conditions were adjusted to each ship's operating condition by same way of model tests.

CAVITATION PATTERNS

Here computed cavitations are visualized using iso-surface of void fraction, and compared with cavitation patterns observed in model tests. In this study, 20% is adopted for the void fraction value corresponds to cavity surface.

Comparison of cavitation patterns of prop.A are shown in Figure 5. In computation, thin sheet cavitation appears at early phase (θ=0deg.) although there is slight and unstable bubble cavitation in model test. As blade rotates, computed cavitation area shifts to trailing edge and the shape becomes similar to model test result, and finally computed cavitation disappears at tip of blade similarly to model test. On the other hand tip-vortex cavitation isn't shown clearly in computation.

In the case of other propellers, this tendency of difference and similarity between computation and model test was almost same with prop.A. From these results, it can be said that the fundamental behavior of sheet cavitation seems to be well predicted by computation, although there is some difference at early phase.

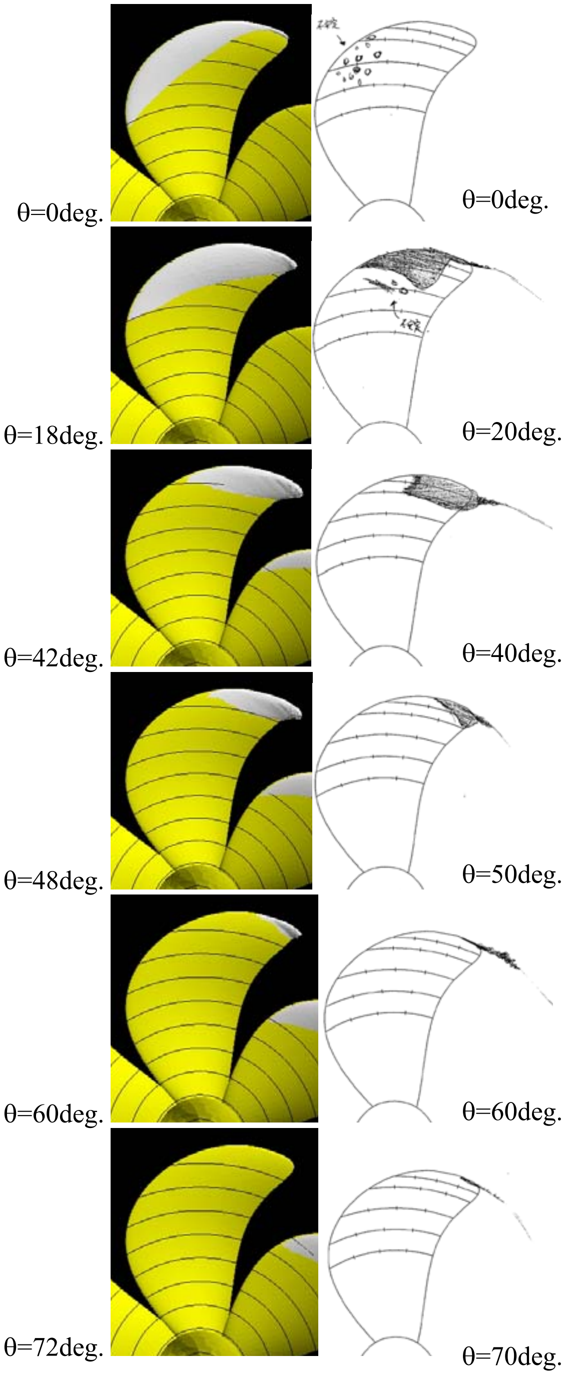

Figure 5: Comparison of cavitation patterns (prop. A)
(Left : computed, Right : model test)

Figure 6 shows the comparison of cavitation pattern in 10 propellers. Computed results seem to be able to predict the difference of sheet cavitation area between 10 propellers. So it can be expected to select better propeller by using this computation.

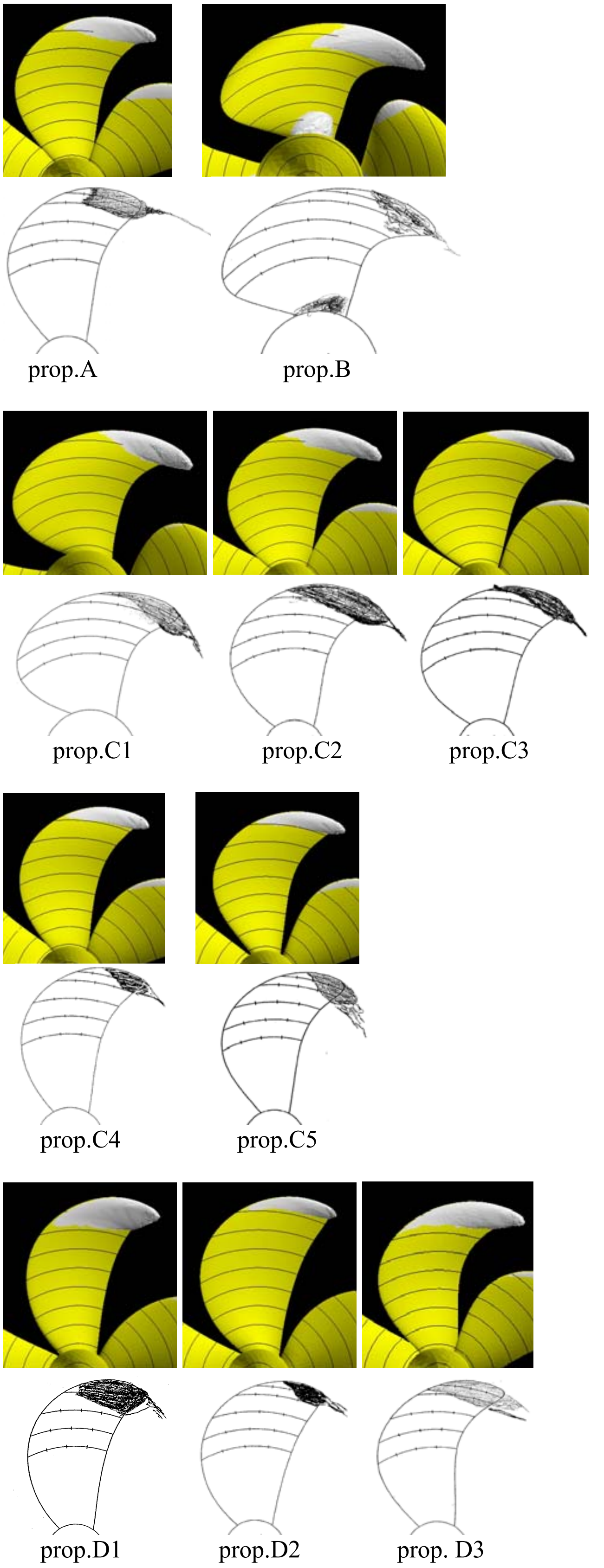

Figure 6: Comparison of cavitation patterns in 10 propellers (Upper: computed, θ=42deg., Lower: model test, θ=40deg.)

PRESSURE FLUCTUATIONS

Pressure fluctuation induced by propeller is one of important performance factors for propeller design, because it is major source of hull vibration. In computation, time history of pressure was sampled at the point in open space just above propeller. After that, the computed pressure was multiplied by solid boundary factor, to compare with those of model tests which measured on solid plate. Here solid boundary factor expresses the image effect [7], and the value was assumed as 2.0 in this study.

A comparison of typical time history of pressure is shown in Figure 7. In the computation, the pressure fluctuation looks like some kind of sine curve. In the model test, the rough shape of signal still looks different from the simple curve of computation.. And also there are some high frequency pressure pulses.

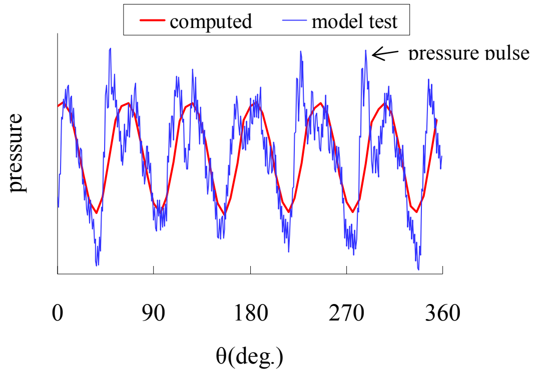

Figure 7: Comparison of time history of pressure above propeller (prop.D3)

To obtain amplitudes of blade frequency components, Fourier Transformation was applied to time history of pressure, which was multiplied by solid boundary factor.

Comparison of blade frequency components of pressure fluctuations between computations and model tests are shown in Figure 8 and Figure 9. As for 1st order components, the agreement between computation and model test is fairly good. Also the tendency in similar ship's propellers is predicted fairly well by computation. On the other hand, the 2nd order components are quite underestimated in computation. It can be expected from the difference of time history of pressure, shown in Figure 7.

To predict this 2nd or higher order components, higher accuracy of computation is required, especially in prediction of the changing rate of cavitation volume. Also it's important to simulate bursting of tip vortex cavitation, which has strong relation with pressure pulse as shown in Figure 7 [8]. For such computation, higher resolution both in time and space is necessary. And also some modification of cavitation model, including collapse of cavity bubbles may be necessary.

In this study, time stepping of computation was set coarse (6 deg./step) and 2nd order components of pressure fluctuation were not predicted well as mentioned above. Therefore, an computation with finer time stepping (1deg./step) is carried out for prop.D3 as trial. Computed time history of pressure is shown in Figure 10. With change of time stepping, the pressure fluctuation changes from simple curve as shown in previous computation (Figure 7), and some higher frequency fluctuation appears.

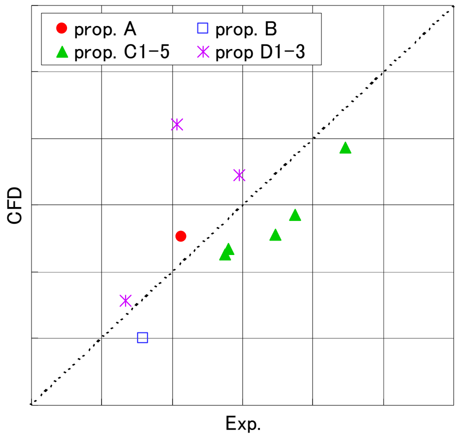

Figure 8: Comparison of the amplitude of pressure fluctuation (1st order components)
(Horizontal axis: model test, Vertical axis: computed, Dotted line indicate equal line with solid boundary factor = 2.0)

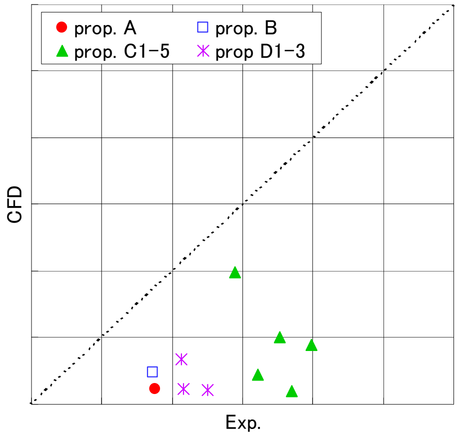

Figure 9: Comparison of the amplitude of pressure fluctuation (2nd order components)
(Horizontal axis: model test, Vertical axis: computed, Dotted line indicate equal line with solid boundary factor = 2.0)

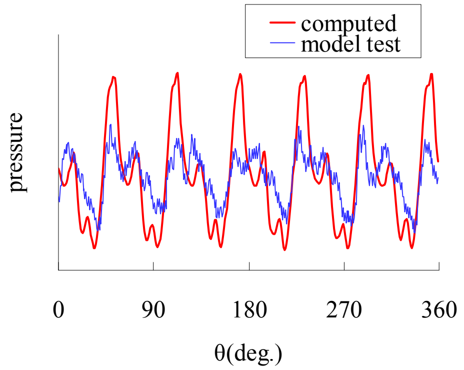

Figure 10: Time history of pressure computed with finer time stepping (revolution angle in 1 time step = 1 deg.)

CONCLUSION

The applicability of CFD for marine propeller cavitation was studied using 10 propellers for commercial ships. Computed cavitation patterns and pressure fluctuations were compared with those of model test. The results are summarized as follows.

(1) Computation predicted the fundamental behavior and area of sheet cavitation fairly well.
(2) There was some difference of sheet cavitation when the blade comes top position (θ=0deg.). Also tip-vortex cavitation wasn't shown clearly.
(3) As for 1st order blade frequency components of pressure fluctuation, the tendency in similar ship's propellers was predicted fairly well.
(4) The 2nd order components are quite underestimated in computation. It can also be expected from the difference of time history of pressure fluctuation.
(5) By a test computation with finer time stepping, some higher frequency fluctuation appeared in time history of pressure.

Thus, it can be said that CFD computation can predict the behavior of sheet cavitation and the 1st order component of pressure fluctuation. On the other hand, it's still difficult to predict detailed cavitation and higher order components of pressure fluctuations.

To improve the accuracy and applicability of computation, more study for computational resolution both in time and space is necessary. And also some modification of cavitation model, including collapse of cavity bubbles may be necessary.

REFERENCES

[1] Watanabe, T. et al., 2003, "Simulation of Steady and Unsteady Cavitation on a Marine Propeller using a RANS CFD code", Proceedings of 5th Int. Symp. on Cavitation (CAV2003), Osaka, GS-12-004
[2] Kawamura, T. and Kiyokawa, T., 2008, "Numerical Prediction of Hull Surface Pressure Fluctuation due to Propeller Cavitation", Conference Proceedings of the

Japan Society of Naval Architects and Ocean Engineers, Nagasaki, Japan, No. 6, pp.213-216

[3] Hasuike N., Yamasaki S. and Ando J., 2009, “Prediction of Cavitation on Marine Propeller Using Generally Applicable Computation Fluid Dynamics (2nd Report)” , Proceedings of 14th Symposium on Cavitation, Sendai

[4] Huang Z., Kawamura T. and Omori T., 2009 “Numerical Prediction of Pressure Fluctuation Induced by Propeller Cavitation”, Proceedings of 14th Symposium on Cavitation, Sendai

[5] Specialist Committee on Cavitation, 25th ITTC, 2008, “Final Report and Recommendations to the 25th ITTC”, Proceedings of 25th ITTC, Volume 2, pp.473-512

[6] Hoshino T., 1982, “A Method to Predict Fluctuating Pressures Induced by a Cavitating Propeller”, Mitsubishi Technical Bulletin 150.

[7] Huse E., 1968, “The Magnitude and Distribution of Propeller-Induced Surface Forces on a Single-Screw Ship Model”, Norwegian Ship Model Experiment Tank, Publication No. 100 (1968)

[8] Oshima, A., Sasajima, T. and Chiba, N., 1986, “Study on Tip Vortex Cavitation Bursting and Its Effect on Pressure Fluctuation on Ship Hull”, Proceedings of 1st Int. Symp. on Cavitation, Sendai, Japan, pp.227-232