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Numerical investigation of tip vortex cavitation inception and noise around NACA16-020 using bubble dynamics

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ABSTRACT

Hybrid numerical methodology is developed for the efficient and accurate prediction of wing tip vortex cavitation and its noise. The proposed method consists of four sequential steps: prediction of flow field using CFD techniques, reconstruction of tip vortex using vortex models, simulation of tip vortex cavitation formation using bubble dynamics model, and prediction of flow noise due to vapour bubble using spherical monopole source model. The tip vortex cavitation formed in the water flow passing by the wing consisting of NACA16-020 is investigated. First, entire flow field is predicted by solving the RANS equations with finite volume based CFD techniques. However, it is well known that the numerical RANS solution has difficulty in predicting the tip vortex accurately due to its excessive numerical damping. The more resolved tip vortex is synthesized by using the vortex model of which parameters are computed using the RANS solutions. Then initial nuclei were distributed upstream and their development during their journey through the synthesized vortex flow field are simulated using the spherical bubble dynamics model. It is shown that the predicted tip vortex cavitation phenomena match the experimentally observed one. Finally, flow noise due to tip vortex cavitation is predicted by using the bubble noise model which is basically equivalent to monopole source. There are good agreements between the predicted and measured ones. These results highlight the applicability of the current numerical methodology to the prediction of CIS as well as cavitation noise of a wing-shaped body

Keywords: Flow noise, Cavitation inception, Bubble dynamics, Vortex model
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1. INTRODUCTION

The physical mechanism of non-cavitation flow noise generated by the propeller in water is basically the same as that of aerodynamic noise of rotating machine in air such as fans. Therefore, dipole source due to unsteady pressure fluctuation on the rotating blade surface dominantly contribute to overall noise of such machine. However, once the cavitation is formed in the flow field driven by the propeller, the flow noise due to cavitation overwhelms the non-cavitation noise due to the cavitation bubbles act like monopole source of which the efficiency is much higher than the dipole source. Especially, it can be seen that the noise spectrum levels are increased in the broad high frequency range when cavitation occurs. Among various kinds of cavitation in the flow driven by the propeller, tip vortex cavitation occurs first. That is why the tip vortex cavitation phenomena restricts the maximum operation speed of ships and submarines. Therefore, it is essential to understand the onset condition of cavitation in order to design the propeller so that cavitation does not occur even at high speed operation. For the understanding of tip vortex cavitation, development of reliable numerical methodology for the accurate prediction of the occurrence of tip vortex cavitation is a prior key technology[1,2].

In this study, hybrid numerical methodology is developed for the efficient and accurate prediction of wing tip vortex cavitation and its noise. The proposed method consists of four sequential steps: prediction of flow field using CFD techniques, reconstruction of tip vortex using vortex models, simulation of tip vortex cavitation formation using bubble dynamics model, and prediction of flow noise due to vapor bubble using spherical monopole source model. we propose a methodology for predicting wing tip vortex cavitation of NACA 16-020 and its noise using bubble dynamics. The tip vortex cavitation formed in the water flow passing by the wing consisting of NACA16-020 is investigated by applying the proposed numerical method. To confirm the validity of numerical method, the predicted results are compared with the measured ones in terms of shape of tip vortex cavitation.

2. NUMERICAL METHOD

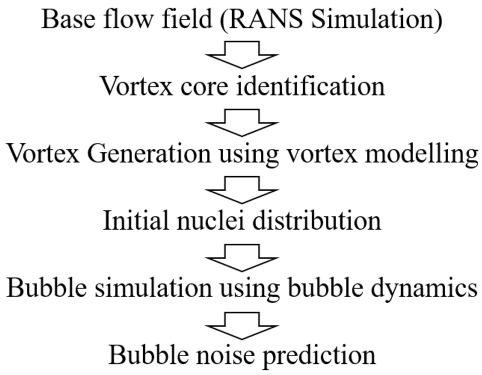

Figure 1.Bubble simulation diagram

The detailed procedure in the proposed numerical methodology can be divided into four stages with two initial conditions, as shown in Figure 1. First, the flow field around the wing is predicted using the single-phase RANS simulation which is performed by using the ANSYS Fluent (version 19.3). From the RANS results, the positions of the wing tip vortex core are identified by using the minimum pressure point, maximum λ_2, and the maximum vorticity in each plane normal to the inflow direction. It is found that all of the three values predict the similar locations. Then, tip vortex flow field is synthesized by using Scully vortex modelling whose core centers are located at the same positions identified in the above described stage. Scully vortex model is written in the form,

$$V_\theta(r) = \frac{\Gamma}{2\pi}\left(\frac{r}{a_c^2+r^2}\right) \tag{1}$$

Here, the circulation Γ and the vortex radius a_c are determined by using the RANS result. Then, initial nuclei are distributed in the flow region upstream of the wing. Its number concentration density is determined by following that of O' Hern et al. who measured the number concentration density distribution of nuclei in pacific waters[3]. The movement trajectory and radius variation of each nuclei are computed by using the bubble dynamics theory. The time-variation of bubble radius is predicted by solving the Rayleigh-Plesset equation[4]:

$$R\ddot{R} + \frac{3}{2}\dot{R}^2 = \frac{1}{\rho}\left[p_v + p_{g0}\left(\frac{R_0}{R}\right)^{3k} - p - \frac{2\gamma}{R} - \frac{4\mu}{R}\dot{R}\right] + \frac{(\bar{U}-\bar{U}_b)^2}{4} \tag{2}$$

The bubble trajectory is computed by solving the following equation,

$$\rho_b V_b \frac{d\bar{U}_b}{dt} = V_b(\rho_b - \rho)\bar{g} + V_b \nabla p + \frac{1}{2}\rho A_b C_D(\bar{U} - \bar{U}_b)|\bar{U} - \bar{U}_b|$$
$$+\frac{1}{2}\rho V_b\left(\frac{d\bar{U}}{dt} - \frac{d\bar{U}_b}{dt}\right) + 6A_b\sqrt{\frac{\rho\mu}{\pi}}\int_0^t \frac{\left(\frac{d\bar{U}}{d\tau} - \frac{d\bar{U}_b}{d\tau}\right)}{\sqrt{t-\tau}}d\tau \tag{3}$$

Finally, cavitation noise is predicted by modelling each spherical bubble as point monopole source in the form[5],

$$p_a(t') = \frac{R\rho}{l}\left[R\ddot{R}(t') + 2\dot{R}^2(t')\right] t' = t - \frac{l-R}{c} \tag{4}$$

3. NUMERICAL RESULT

Water flow of NACA 16-020 wing[6] was investigated with emphasis on tip vortex cavitation. The NACA 16-020 wing and the entire computational domain with boundary conditions applied are presented in Figure 2.

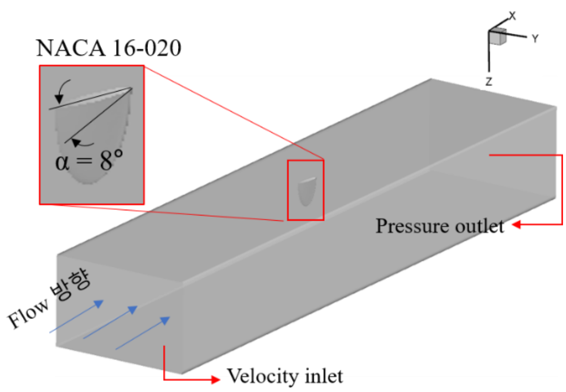

Figure 2. Computational domain and boundary conditions

The distributions of turbulent kinetic energy and vorticity magnitude obtained from the RANS simulation are shown in Figure 3. It is seen that the wing vortex dissipates while flowing in the downstream direction.

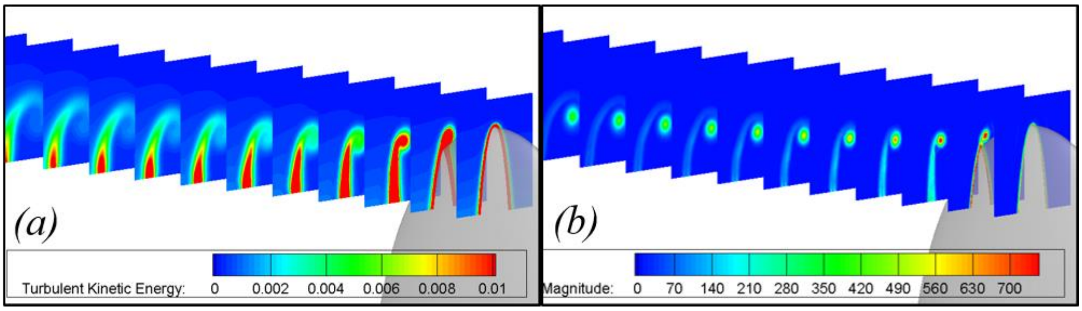

Figure 3. RANS result : (a) Turbulent kinetic energy, (b)Vorticity magnitude

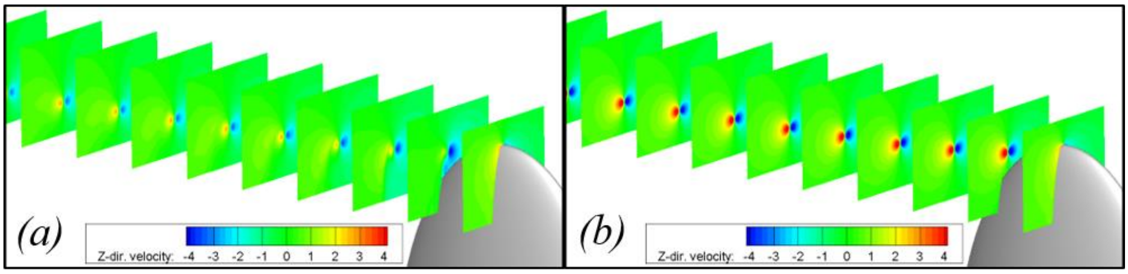

Figure 4. Comparision of z-dir. velocity : (a) RANS result, (b) Vortex modelling result

Reconstruction of tip vortex is performed by combining the Scully vortex model with the RANS simulation results. Figure 4 compares the tip vortex structures between the RANS result and the reconstructed one from the Scully vortex model in terms of the z-directional component of fluid velocity. It can be seen that the strength of synthesized tip vortex is higher than the RANS results and is kept along the downstream direction.

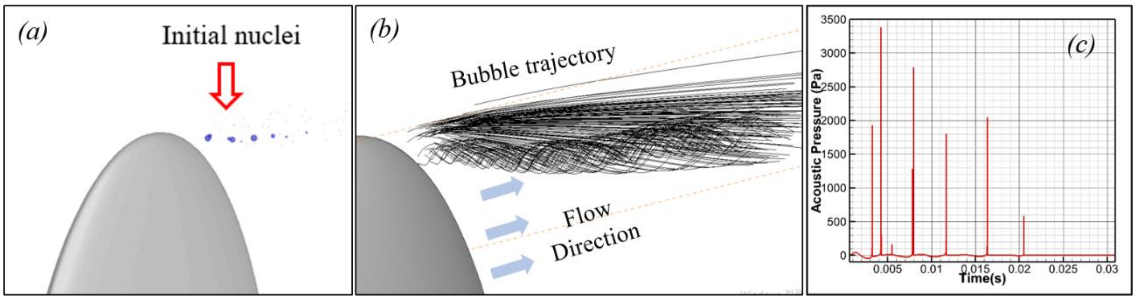

Figure 5. Bubble simulation result : (a) bubble flow field, (b) bubble trajectory, (c) Acoustic pressure (Pa)

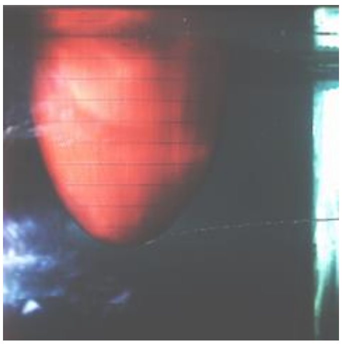

Figure 6. Tip vortex cavitation experimental result (σ=1.2)

The formation of tip vortex cavitation is simulated by using the spherical bubble dynamics model. The initial nuclei are distributed in the inflow just upstream of wing tip. Then the radius and movement of each nuclei are computed by solving Equation 2 and 3, respectively. Figure 5(a) shows the formation of cavitation bubble in the tip vortex core region. The predicted tip vortex cavitation shows good agreement with the measured one in Figure 6. Figure 5(b) shows the trajectory of all the nuclei, most of which are formed around the tip vortex region. Figure 5(c) presents the predicted time signal of sound pressure predicted by using Equation 4.

4. CONCLUSION

In this study. a numerical methodology is presented for simulating wing tip vortex cavitation and its noise. First, the RANS simulation was performed to obtain the initial background flow field information around the NACA 16-020 and then more resolved tip vortex is synthesized by combining the Scully vortex model with the background RANS results. It is found that the strength of regenerated tip vortex is higher than that obtained from the RANS solution and is kept along the more downstream distance. The synthesized tip vortex is more consistent with the observed one. Then, wing tip vortex cavitation is predicted by combining the bubble dynamics model based on the Rayleigh-Plesset equation with the tip vortex flow. The predicted tip vortex cavitation shows good agreement with the measured one. Finally, flow noise due to tip vortex cavitation is predicted by using the monopole source model whose input data is obtained from the predicted location and radius variation of the cavitation bubbles. The predicted magnitude of sound pressure level seems to be greater than the measure one, although the comparison is not shown in this paper due to the restricted page number. The reason for this difference may be due to the propagation effects neglected in the current noise model. This will be more investigated in a future study.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

1. H. Seol, S.-Y.Kim, *“Study on the analysis of model propeller tip vortex cavitation inception”*, Journal of the Acoustical Society of Korea Vol.37, pp.387~395(2018)
2. J. Kye, *“A study on improvement of core technologies for the propeller noise reduction of naval warships”*, Korea Association of Defense Industry Studies, Vol.13, No.2(2006)
3. T. J. O’Hern, L. d’Agostino and A. J. Acosta, *“Comparison of holographic and coulter counter measurements of cavitation nuclei in the ocean”*, Journal of Fluids Engineering, Vol.110, pp.200-207(1988)
4. C. T. Hsiao, G. L. Chahine and H. L. Liu, *“Scaling effect on prediction of cavitation inception in a line vortex flow”*, Journal of Fluids Engineering, Vol.125, pp.53-60(2003)
5. H. M. Fitzpatrick and M. Strasberg, *“Hydrodynamic sources of sound”*, Proceedings of the First ONR Symposium. On Naval Hydrodynamics. (1956)
6. M. Dreyer, *“Mind the gap:Tip leakage vortex dynamics and cavitation in axial turbines”*, Dissertation, PhD thesis, EPFL, Lausanne, Switzerland, (2015)