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Prediction of Performance of a Cavitating Propeller in Oblique Inflow

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Abstract. A cavitating propeller subject to an oblique inflow in a cavitating tunnel is simulated using potential flow methods coupled with a Reynolds-averaged Navier-Stokes (RANS) solver. The propeller is mainly modelled using a panel method, while the inflow to the propeller is evaluated by coupling a Vortex-Lattice Method (VLM) with the RANS solver. The effects of the tunnel wall are incorporated into the calculated effective inflow to the propeller. The predicted propeller forces and cavity pattern are correlated with experiment. The fully wetted open water characteristics of the propeller predicted by the panel method are presented as well.

1. Introduction

Potential flow methods are intensively used in the design stage of marine propellers. In general the methods are sufficiently accurate for axisymmetric inflows. In the real design practice, the methods are commonly used with a measured wake behind a hull. Nonetheless the methods have not been carefully validated in the cases of non-axisymmetric inflows.

In order to provide computational fluid dynamics (CFD) groups with experimental data of a propeller in non-axisymmetric inflow with clearly defined boundary conditions, a series of experiments on a propeller in oblique inflow was conducted by SVA Potsdam GmbH in the workshop of the fourth international symposium on Marine Propulsors 2015 (SMP' 15) [1]. The test case is referred to the acronym PPTC'15 (Potsdam Propeller Test Case 2015)[1].

In this paper PPTC'15 will be simulated using mainly a panel method with effective wake calculated by coupling a Vortex-Lattice Method (VLM) with a RANS solver. The results will be correlated with experimental data.

2. Methodology

2.1. The panel method and the cavity model

A panel method code, PROPCAV is adopted to predict propeller performance. Details of PROPCAV can be found in [2]. A potential flow model which combines a constant pressure condition with a tangency condition to determine the cavity extent and shape is used to simulate the cavity. This cavitation model was proposed by Fine and Kinnas [3]

2.2. Effective wake calculation

In PPTC'15, the cavitating test was conducted in a cavitation tunnel. In order to consider the effects of the tunnel wall but without model it in the panel method, the effective wake concept is adopted to prepare the inflow to the propeller. The effective wake is defined as the time averaged difference between the total velocity and the propeller induced velocity, thus contains the information of the surrounding boundaries and the ambient flow of the propeller. The effective wake can be determined by coupling a potential flow solver with a RANS solver. The effective wake approach was proposed by Kerwin et al. [4] as an intuitive extension of the actuator disk concept to model ducted propellers. The approach was later improved by the Ocean Engineering Group (OEG) at the University of Texas at Austin and has been successfully applied in the case of a ducted propeller in axisymmetric inflow [5] and hull/thruster interaction [6]. In this paper, a VLM code, MPUF-3A is coupled with ANSYS Fluent to determine the effective wake.

3. Experimental Setup

In the experiment, the propeller is operating in a pull configuration with the hub cap pointing upstream. The propeller axis is inclined by 12°. More details of the experiment can be found on the website of SMP'15 [1]. The same propeller in axisymmetric uniform inflow was tested in the workshop of the second international symposium on marine propulsors 2011 (SMP'11) [7].

4. Numerical implementation and results

4.1. Wetted open water characteristics in axisymmetric uniform inflow

Before simulating the propeller in oblique inflow, the results from the panel method are first validated against experiments in the case of axisymmetric uniform inflow. The propeller is simulated using 80×30 (chordwise × spanwise) panels. Two trailing edge wake models of the propeller are adopted: the full wake alignment (FWA) model proposed by Tian and Kinnas [8] and a simplified wake model, namely PSF-2 type alignment [9]. Figure 1 shows the discretization of the blades and the trailing edge wake from FWA at J=0.8. Figure 2 correlates the predicted open water characteristics with experiments. Clearly the FWA model significantly improves the results at low advance ratios.

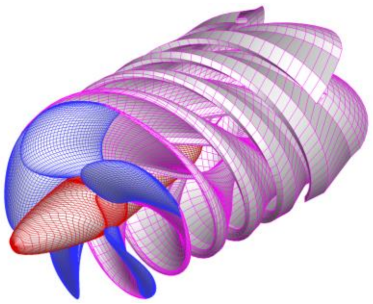

Figure 1. Surface panels of Propeller VP 1304 in axisymmetric uniform inflow with FWA, $J = 0.8$

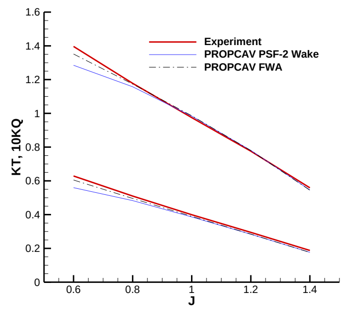

Figure 2. Predicted performance of Propeller VP 1304 in axisymmetric uniform inflow, comparing with experiment.

4.2. Wetted open water characteristics in oblique uniform inflow

The wetted open water characteristics of the propeller in oblique uniform inflow are then investigated. The propeller is simulated using 60×20 (chordwise × spanwise) panels and 80×30 panels. Unfortunately the FWA has not been extended into non-axisymmetric cases yet. Only the PSF-2 type alignment is adopted in the following simulations. The numerical solutions are convergent, as shown in figure 3. Figure 4 compares the predicted mean performance of the propeller against the experiment. Reasonable correlations can be observed, whereas the KT and KQ at low advance ratios are under-estimated. The FWA model should improve the low J results as what has already been observed in the axisymmetric inflow case.

4.3. Cavitating propeller in oblique inflow

In order to take account of the effects of the tunnel wall, the effective wake is calculated by coupling MPUF-3A with ANSYS Fluent. The RANS grid has about 1.3 million cells, as shown in figure 5. Standard k-ϵ turbulence model is applied, along with QUICK scheme for spatial discretization. The total velocity field from RANS is shown in figure 6.

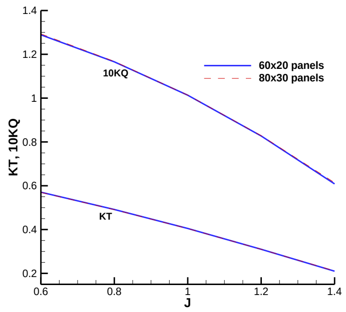

Figure 3. Predicted mean performance of Propeller VP 1304 in oblique uniform inflow from different spatial resolution.

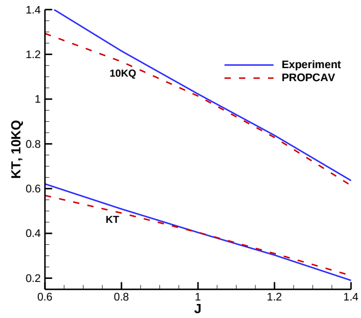

Figure 4. Predicted mean performance of Propeller VP 1304 in oblique uniform inflow, comparing with experiment.

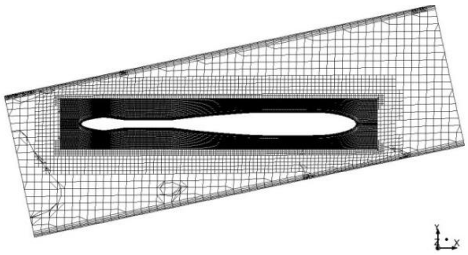

Figure 5. The RANS grid for the effective calculation

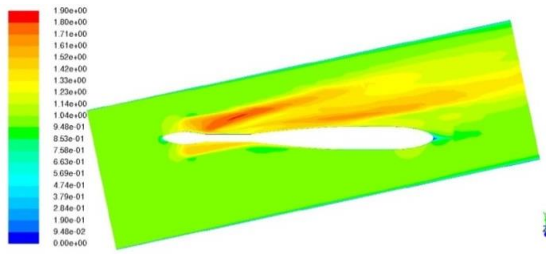

Figure 6. Total velocity field predicted by RANS/VLM coupling.

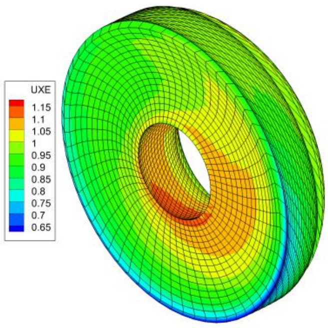

Figure 7. Predicted axial effective wake, normalized by U_∞

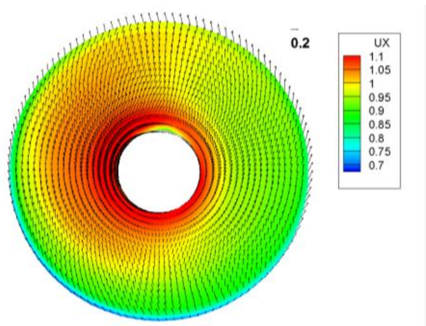

Figure 8. Predicted effective wake on the blade mid-chord surface, normalized by U_∞

Figure 7 and 8 plot the effective wake. The transverse components of the velocity due to the inclination of the shaft are largely retained. In the meantime, the upper half of the blade zone is subject to higher axial velocity than the lower half, because of the presence of the upper tunnel wall.

Figure 9 and 10 show the cavity pattern from both the numerical simulation and the experiment. The predicted cavity appears largely at correct blade angles. However, the tip vortex at blade angle 216^{o} is missing from the numerical results and thus needs further investigation.

Figure 11 plots the KT from PROPCAV on top of the experimental measurement. Clearly thrust breakdown is well predicted.

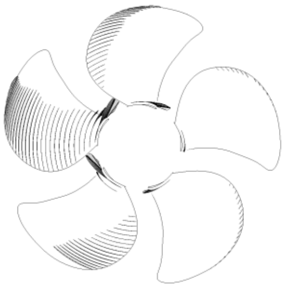

Figure 9. Predicted cavity pattern from the numerical simulation.

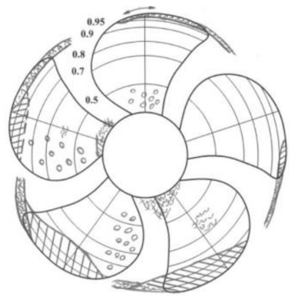

Figure 10. Observed cavity pattern in the experiment.

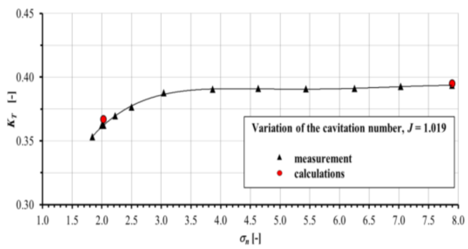

Figure 11. Predicted KT vs. experiment.

5. Conclusions and future work

The wetted and cavitating performance of a propeller in oblique inflows are simulated using a panel method code, PROPCAV. The numerical results are validated against the experimental data in PPTC'15. For the wetted performance of the propeller in oblique inflow, the predicted performance recovers the experimental measurement at the design advance ratio, but slightly deviates from the experimental data at low advance ratios. The discrepancy could be reduced if the FWA model was used. For the cavitating performance of the propeller in the tunnel, a coupled VLM-RANS method is adopted to calculate the effective wake to the propeller. Reasonable cavity pattern and good KT value are predicted by the panel method. Nonetheless the tip vortex at certain blade angles is missing.

In the future, the FWA model will be extended in the case of non-axisymmetric inflow. Other J and σ_n combinations tested in PPTC'15 will be simulated as well. The time history of the blade forces will be also investigated.

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