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Eddy vorticity in cavitating tip vortices modelled by different turbulence models using the RANS approach

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VTT Technical Research Centre of Finland and Aalto University have investigated the hydrodynamics of cavitating propeller flows by the Reynolds-Averaged-Navier-Stokes (RANS) method. The cavitation model utilized in the simulations is based on Merkle's mass transfer model [1]. In the present study, special emphasis is given to investigating the effect of different turbulence models on the eddy viscosity and the velocity distributions inside cavitating tip vortices. Chien's $k-\varepsilon$, Menter's SST $k-\omega$, and EARSM turbulence models are studied.

The propeller investigated in this study is the model-size PPTC propeller of SVA Potsdam [2]. Previously, VTT and Aalto University have studied the cavitation extent on that same propeller for different loading and ambient pressure conditions, and the effect of the empirical coefficients in Merkle's mass-transfer model on the cavitation on propellers [2, 3].

Cavitation is a common phenomenon in ship propellers which causes several detrimental effects to the ship and the environment, such as vibrations at the stern of the ship, erosion, and noise to the interior of the vessel and the underwater environment. Improvements to the propeller or ship wake are difficult and expensive to perform after the ship is built. Complex hydrodynamic phenomena are involved with cavitation. The viscous effects play an important role in the shedding mechanism of sheet cavitation. The eddy viscosity produced by the turbulence models also damps the strength of the tip vortices.

The RANS equations are solved with FINFLO, a general-purpose Computational Fluid Dynamics (CFD) code [2,3,4]. The RANS equations are discretized by applying a finite-volume approach. In the present incompressible case, a third-order upwind-biased scheme is utilized for the convective fluxes. The pressure gradient is centrally differenced and a second-order central-differencing is used for the discretization of the diffusion terms.

Two-phase flow is solved using the pressure correction method based on the assumption of an incompressible flow. Consequently, the cavitation model is based on the continuity and momentum equations of the mixture rather than directly coupling the energy equation to the pressure correction method. The solution of the pressure-correction equation is based on an algebraic multigrid (AMG) method with line Gauss-Seidel smoothing. The Antoine equation is implemented for the $p-T$ saturation line fit, while the model proposed by Merkle is utilized for the mass transfer.

The global performance characteristics for the propeller thrust, torque, and efficiency are well predicted at various advance ratios, as shown in Figure 1. The circumferential distributions of the velocity components in the slipstream of the propeller in the tip vortex region were also close to the LDV measurements. The exact location of the tip vortex is not known *a priori* in the simulations. To have a high concentration of cells in the tip vortex region but to keep the total number of cells in the domain reasonable, the grid in the slipstream is created iteratively.

Figure 2 shows the circumferential distribution of eddy viscosity and vapour volume fraction at the vortex core radius at an axial plane located at x/D = 0.2 behind the propeller plane. It is seen that the $k-\varepsilon$ model produces significantly more eddy viscosity to the tip vortex core in wetted and cavitating conditions than the other two turbulence models. The SST $k-\omega$ and EARSM models give low eddy viscosity levels at the outer core of the cavitating vortex. In the vaporous vortex core, the eddy viscosity is practically zero in both models. It is seen that the core of the vortex is filled with almost pure vapour in all the simulations.

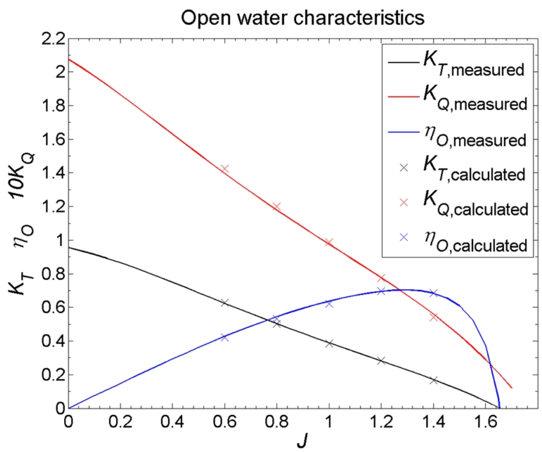

Figure 1. Polynomial fits of the measured open water curves and the calculated figures in non-cavitating conditions. Measured data provided by SVA Potsdam.

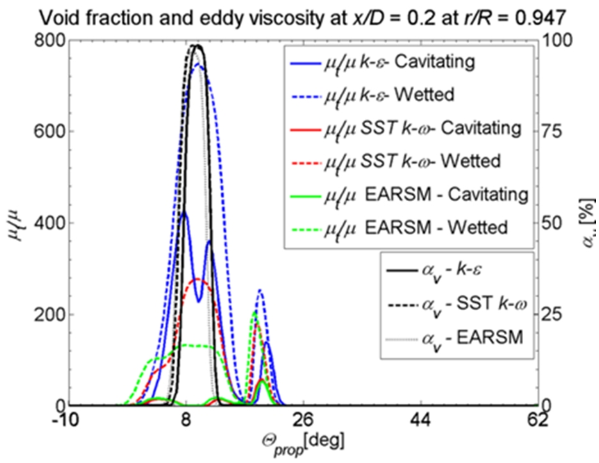

Figure 2. Circumferential distributions of eddy viscosity and void fraction at x/D = 0.2 behind the propeller at the vortex core radius. The results are shown for the wetted and cavitating conditions calculated with different turbulence models.

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