DETACHED EDDY SIMULATION OF UNSTEADY CAVITATION AND PRESSURE FLUCTUATION AROUND 3-D NACA66 HYDROFOIL

by

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The unsteady cavitating flow and pressure fluctuation around the 3-D NACA66 hydrofoil were simulated and validated based on detached eddy simulation turbulence model and a homogeneous cavitation model. Numerical results show that detached eddy simulation can predict the evolution of cavity inception, sheet cavitation growth, cloud cavitation shedding, and breakup, as well as the pressure fluctuation on the surface of hydrofoil. The sheet cavitation growth, detachment, cloud cavitation shedding are responsible for the features of the pressure fluctuation.

Key words: *hydrofoil, cavitation, detached eddy simulation, reentrant jet*

Introduction

The unsteady oscillation of cavitation is responsible for the erosion, noise, and vibration in hydraulic machinery, so cavitation remains a challenge for the better understanding the cavitation dynamics. The extensive experimental and numerical studies conducted by Leroux, *et al.* [1] suggest that the cavity instability is triggered by the interaction between re-entrant jet and the cavity interface, as well as a shock wave induced by the collapse of cavitation cloud.

Inspired by their work [2-5], the objective of this paper is to investigate an economical and accurate simulation method to analyze the cavitation shedding flow around a 3-D NACA66 hydrofoil by using detached eddy simulation (DES) and homogeneous cavitation models. The unsteady features of the cavitation shedding flow and pressure fluctuation were analyzed by both numerical and experimental results.

Numerical method description and set-up

Detached eddy simulation and cavitation model

The DES [6] is a hybrid turbulence model of large eddy simulation (LES) and Reynolds-averaged Navier-Stokes (RANS). DES based on shear stress transport (SST) k-ω turbulence model [7] was employed in this paper, which can switch from the SST-RANS mode in wall boundary to LES mode in regions. When LES mode is activated in turbulence fully developed region, the local grid spacing Δ is used for the calculation of the dissipation rate in the k-equation.

The SST k-ω model is modified in the DES as:

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$$\varepsilon=\beta^{*}kF_{\mathrm{DES}}, \qquad F_{\mathrm{DES}}=\max\left(\frac{L_t}{C_{\mathrm{DES}}\Delta},1\right)$$

where ε is the dissipation rate, Δ – the maximum local grid spacing (Δ = max (Δ_i), $L_t = k^{1/2}/\beta^{*}\omega$ – the turbulent length scale, and C_{DES} – the calibration constant in the DES formulation, which is set to be 0.61.

Zwart *et al.* cavitation model [8], a Rayleigh-Plesset based homogenous cavitation model, was employed to simulate the unsteady cavitating flow in this paper.

Boundary conditions and mesh

The simulation was conducted using the CFD code ANSYS CFX14.5. The hydrofoil NACA66 was used in this paper. The computational domain is illustrated in figs. 1 and 2. The geometry and boundary conditions were set exactly the same as the experiment conducted by Leroux *et al.* [1], *e. g.* angle of attack α = 6°, inlet velocity v_{ref} = 5.33 m/s, and outlet absolute pressure p_{o} = 17636.4 Pa.

Corresponding to Reynolds number based on the hydrofoil chord length c, Re = $V_{\mathrm{ref}}\ c/\nu$ = 0.8·10^6, cavitation number $\sigma=(p_o-p_{\mathrm{vap}})/(0.5\rho V_{ref}^2)=0.99$. Time gap between two consecutive images is Δt = 0.02 s, and cycle time of one period is 0.28 s, corresponding Strouhal number $\mathrm{S_{tc}}$ = 0.10.

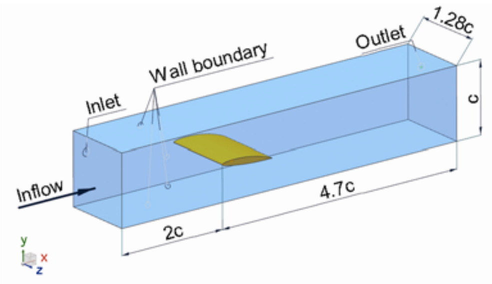

Figure1. Computational domain

Figure 2. Mesh near the hydrofoil

Results and discussion

The numerical time evolution of cloud cavitation shedding is illustrated in fig. 3, in which one typical period is divided into 14 instants. Iso-surface with vapor volume fraction 0.1 stands for the boundary of the vapor bubble. The predicted one typical cycle time is 0.22 s, and Strouhal number is $\mathrm{S_{tc}}$ = 0.128. Time gap between two consecutive images is Δt = 0.0157 s. Compared with the experiment visualizations [1], the predicted unsteady cavitation features shows a good agreement with the experimental results in the non-dimensional time scale. However, the predicted cycle time is larger than the experimental data. As shown in fig. 3, the cavity grows slowly from fig. 3(a) to (e). Cavity is cut by the upstream flowing re-entrant jet and continues to roll up into vapor cloud in fig. 3(h) and (i). Main cloud detaches in fig. 3(j) and breaks down in fig. 3(k). Regeneration of sheet cavity at the head of hydrofoil when vapor cloud collapses in fig. 3(l) to start a new cycle.

The time domains of pressure fluctuation are presented in fig. 4. Numerical results also agree fairly well with the experimental results, although some discrepancies exist, *e. g.* the amplitude and the order of sequence. From the pressure fluctuation of cavitating flow, one typical period can be divided into 4 phases by 5 dashed lines: I~II, stable sheet cavity generation; II~III, cavity detachment and primary shedding; III, main cloud cavity collapse; III~IV, oscillation of residual cavity; IV, free of cavity on suction side of hydrofoil; V, sheet cavity starts to grow again in another cycle.

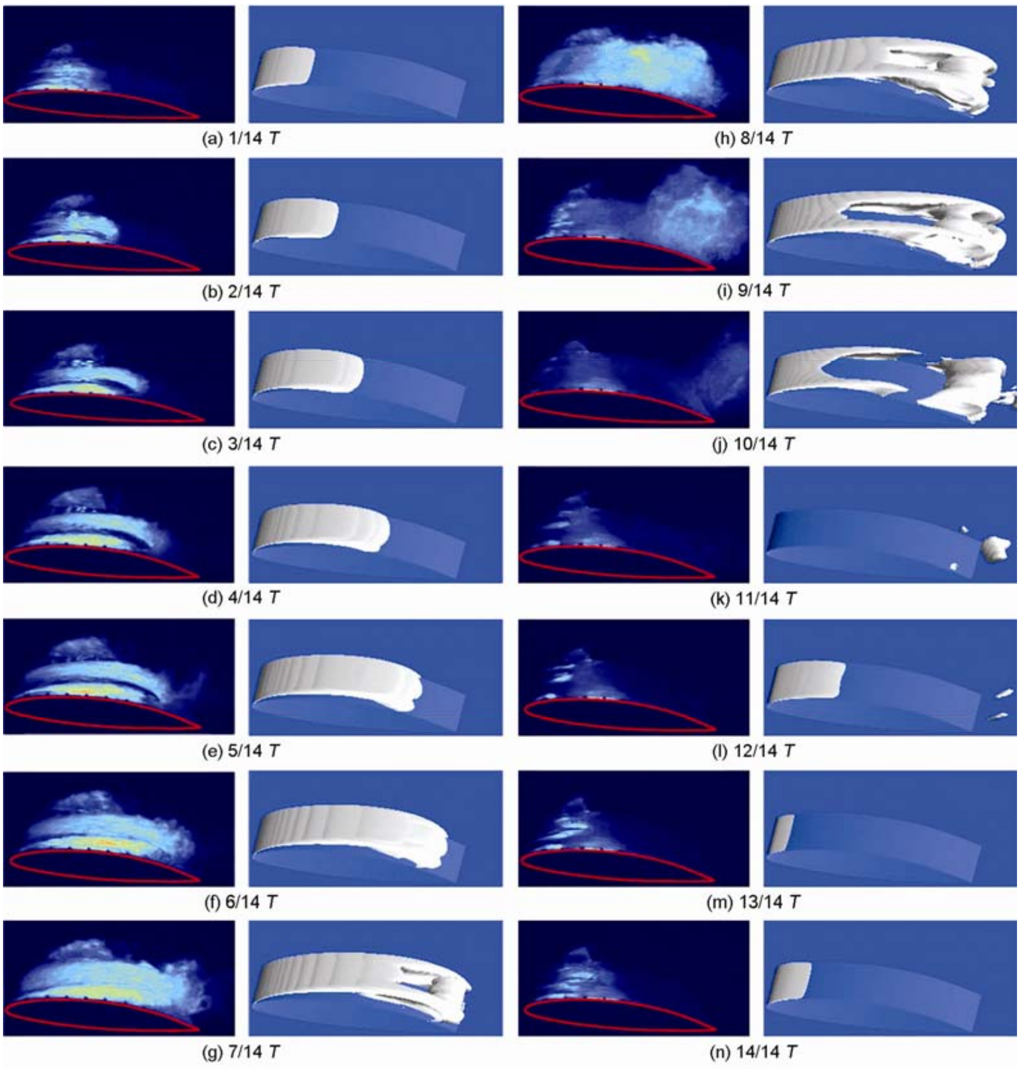

Figure 3. Comparison of experimental and numerical results of cavitation cloud cavitation

Conclusions

The cavitating flow and evolution around NACA66 hydrofoil were well-predicted by DES and Zwart cavitation model. The correlation of the time domains of pressure fluctuations and the instant cavities at different time steps all show that the one typical period can be divided into 4 phases: (1) steady cavity generation; (2) cavity detachment, primary shedding, and main cloud collapses; (3) oscillation of residual cavity; (4) free of cavity on suction side of hydrofoil.

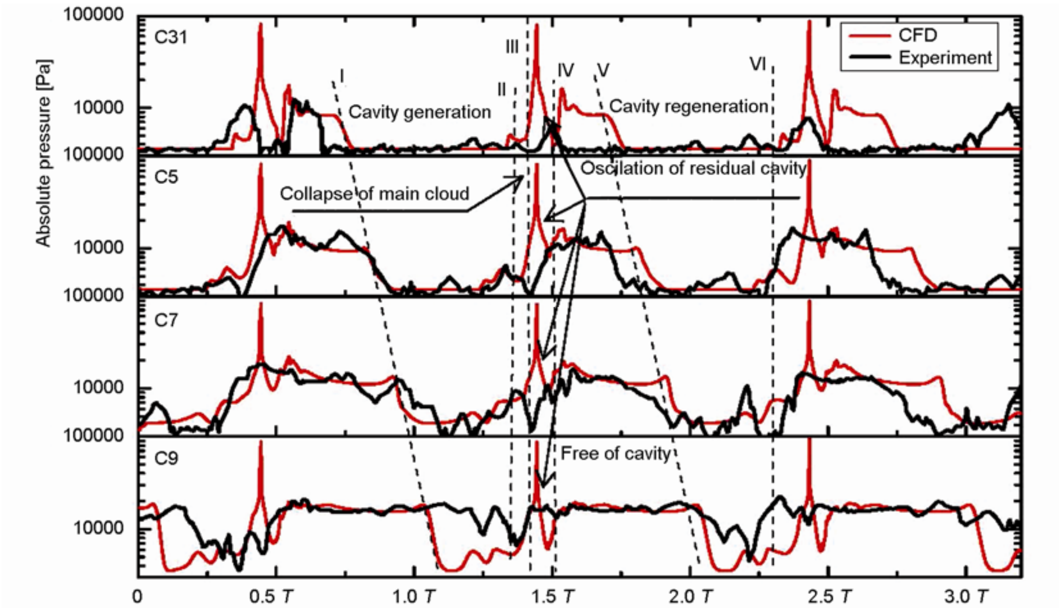

Figure 4. Experimental and numerical comparison of pressure fluctuation on points C31, C5, C7, and C9

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