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Shedding frequency of sheet cavitation around axisymmetric body at small angles of attack*

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Abstract: Cavity shedding of cavitating flows around an axisymmetric body belongs to the unsteady cavitating flows in the condition of steady incoming current. The periodic characteristics of unsteady cavitating flows around an axisymmetric body at small angles of attack are investigated experimentally and numerically. The evolution and shedding process of the three-dimensional sheet cavitation are computed numerically by the Reynolds averaged Navier-Stokes equations and the RNG k-ε model. The modification approach for eddy viscosity coefficient in the transition area of the two-phase flow is adopted to reproduce the shedding process of cavitating flows. The computed frequency of the cavity shedding coincides with the experimental data for the cases of unsteady cavitating flows around axisymmetric bodies with four headforms. Given the cavitation number, the shedding process of the cavitating flow depends heavily on the headform of the axisymmetric body. If the angle of attack of the axisymmetric body is greater than a critical value, the violent shedding of the sheet cavitation seems to be depressed.

Key words: Cavitating flow, shedding, fluctuation, axisymmetric headform

Unsteady behavior of cavitation on two-dimensional hydrofoils in the case of steady incoming flows has been the subject of intensive investigations. The Strouhal number for the lift and the drag fluctuation, defined by the chord length, was obtained experimentally as 0.14 for an Eppler foil[1]. Using the high speed photography, the evolution and abrupt cavity separation of unsteady cavitation on a hydrofoil NACA4412 were analyzed and the Strouhal number, corresponding to the violent deformation of the cavity, was proposed as 0.158[2]. Through numerical simulation, it was found that, for the unsteady cavitating flow on two-dimensional hydrofoils NACA0015, the computed value of the Strouhal number is equal to 0.1[3].

Regarding the cavitation pattern on an axisymmetric body with different headforms, it can be divided into cavitation inception, developed cavitation and supercavitaion. There are several experimental investigations on the mechanism of unsteady cavitating flows through analyzing the cavity profile measured by high speed photography. It turns out that the reentrant jet moving through the cavity would be the major factor causing the cavity to detach from the front near the cavitator leading edge[4]. Such periodic fluctuation of the cavity profile affects hydrodynamic lift and drag on the headform[5]. In order to model the fluctuating hydrodynamic loads, it is essential to establish an empirical formula to calculate the frequency of unsteady cavitating flows.

An experimental investigation on unsteady cavitating flows on an axisymmetric headform was carried out at SSRI K15 Cavitation Tunnel[6]. The characteristics of the frequency of cavity evolution and hydrodynamic loads were discussed based on the high speed movies and the wavelet analysis of the measured time series of forces. The length of the test section is 2.6 m,

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its cross section is a square of 0.6 m by 0.6 m. The maximum flow speed reaches 12 m/s and the minimum static pressure can be controlled from near vacuum to 200 kPa. A de-aeration system was used to control the dissolved air content of the water. The relative dissolved air content is around 0.3 in the experiments measured by a Van Slyke equipment. The cavity profiles were recorded by the high speed photograph HIGHSPEED10-16. The recording rate was 6 000 frame per second. A three component balance was adopted to measure the lift, drag and moment acting on a slender model with different headforms. We selected four headforms in the experiment, including an elliptic headform, a 1/4-caliber give headform, a 600-conical headform and a hemispheric headform, shown in Fig.1. The heaform diameter is 62.9 mm. The axisymmetric model consisted of a headform and a parallel cylinder with the length of 657 mm. The strut-mounted slender model was attached to the wall of the test section of the cavitation tunnel.

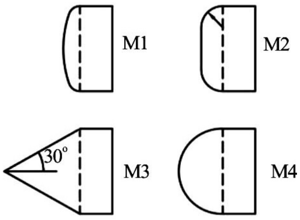

Fig.1 Four headforms used in experiments

The cavitation number σ is defined as

$$\sigma = \frac{p_\infty - p_0}{0.5\rho V_\infty^2} \tag{1}$$

where p_∞ and V_∞ are the pressure and reference velocity, respectively, p_0 is the vapor pressure at the bulk temperature of the water, and ρ is the water density.

The Strouhal number St is defined as

$$St = \frac{fD}{V_\infty} \tag{2}$$

where f stands for the fluctuating frequency of unsteady cavitating flows and D represents the diameter of the headform.

Analyzing the time series of the drag acting on the headforms by FFT and the images of cavity by digitalizing high speed records, the measured frequencies of the cavity evolution are shown in Table 1. The averaged value of the Strouhal number obtained by analyzing the measured drag on the models is equal to 0.107. Here, we might propose an empirical formula $St = 0.107 \pm 0.014$ of the periodic shedding of the cavitation flows around an axisymmetric body with different headforms and small angle of attack.

Table1 Measured frequency of cavity shedding

	Model	AOA	V_∞	σ	f /Hz	St
Drag	M1	4	8.478	0.371	12.4	0.092
		0	8.468	0.329	13.4	0.099
	M2	4	8.459	0.367	12.4	0.092
	M3	4	6.993	0.768	12.4	0.111
		0	6.984	0.562	13.4	0.120
	M4	4	6.985	0.499	12.4	0.112
		0	6.981	0.477	13.4	0.121
Image	M2	0	7.560	0.380	14.9	0.118

We carried out numerical simulations of unsteady cavitating flows around the axisymmetric body with four headforms. The RANS equations and the RNG k-ε model are used to simulate the cavitating turbulent flows[7,8]. The cavitation model developed by Single et al. was adopted in the present study[9]. The grid convergence was checked carefully in terms of the pressure distribution on the axisymmetric body. The grid number of the meshes for the numerical simulations is 1.67M and the corresponding $y^+ = 30$-60. In order to reproduce the shedding process of the cavitating flow around an axisymmetric body at small angles of attack, the modification approach of decreasing the vortex viscosity of two phase flow inside the cavitation region is implemented in numerical simulations[10].

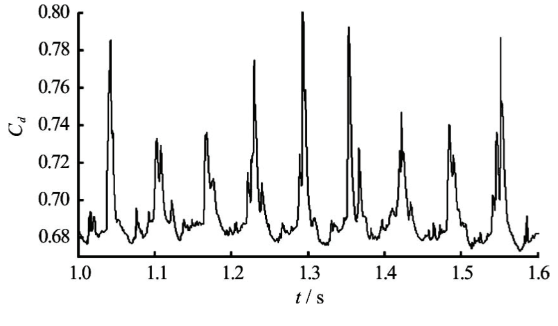

Fig.2 Time series of drag force on cavitating model M2

For the model M2, the computed time series of the drag acting on the axisymmetric body is plotted in Fig.2 for the case of $\sigma = 0.38$ and zero angle of attack. Analyzing the drag by FFT, the peak frequency of the spectra is equal to 15.6 Hz and the corresponding Strouhal number is 0.124. It is confirmed by the experimental data as shown in Table 1. The snapshots of