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The inception cavitating flows over an axisymmetric body with a blunt head-form*

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Abstract: The inception cavitating flows around a blunt body are studied based on flow visualizations and velocity field measurements. The main purpose of the present work is to study the incipient cavity evolution and the interplay between the inception cavitation and the local turbulent flows. A high-speed video camera is used to visualize the cavitating flow structures, and the particle image velocimetry (PIV) technique is used to measure the velocity field, the vorticity, and the Reynolds stresses under non-cavitating and inception cavitating flow conditions. It is found that the appearance of visible cavities is preceded by the formation of a cluster of micro-bubbles not attached to the body surface and in a hairpin-shaped vortex structure. During its evolution, the cavity moves downstream with a lower speed. The effect of the incipient cavity is significant on the local vortical structures but slight on the time-averaged velocity distribution. The mean Reynolds stress distributions in the turbulent shear flow can be substantially altered by the incipient cavities. The presence of the incipient cavities can lead to the production of turbulent fluctuations.

Key words: inception cavitation, PIV, turbulent fluctuations, vortex, axisymmetric body

Introduction

Cavitation is the formation of vapor or gas filled cavities in a liquid by the explosive growth of small bubbles or nuclei due to instability caused by a low instantaneous local pressure[1]. From the engineering viewpoint, cavitation is undesirable in general as it can bring about associated problems of noise and vibration as well as material damages through the cavitation erosion. For example, cavitation can reduce the efficiency of pumps and ship propellers, and affect the hydrodynamics and the manipulation of naval underwater bodies. Thus, cavitation is a vital topic of the fluid machinery and in the naval hydrodynamics fields.

Since the late 19th century, the cavitation inception has attracted considerable research interest. Chau et al.[2] studied the viscous effects in the inception cavitating flow. Wienken et al.[3] conducted a computational study of inception cavitating flows past a square cylinder, and evaluated the LES method. O'Hern[1] made an investigation of the cavitation inception in the turbulent shear flow and the relation between the Reynolds number scales and the inception indices. Ling et al.[4] conducted a systematic investigation of the formation of microscale vortex cavitations on a blunt axisymmetric headform and found that the initial inception was in the form of a thin cavity line like hairs. Wang et al.[5] studied the inception cavitation on the hydrofoil by an experimental method and obtained time-evolutions of incept travelling bubbles. As the turbulence has a significant effect on cavitating flows, many studies focused on the complex relations between the cavitation and the vortex structures[6-9]. Chang et al.[10] studied the counter-rotating vortex interaction in the flow to reveal the form of the vortex cavitation inception and its bubble dynamics. The influence of cavitation on the turbulent flow structure is also an interesting topics. The collapse of cavitation bubbles leads to the production of turbulence within the flow[11]. Singhal et al. used a probability density function (PDF) approach for accounting the effects of

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turbulent pressure fluctuations on cavitation, and proposed that the phase-change threshold pressure value should be raised[12]. Iyer and Ceccio[13] used the PIV technology to measure the velocity field and Reynolds stresses of the flow and analyzed the influence of cavitation on the flow of a turbulent shear layer.

In view of above studies, the present paper studies the inception cavitating flows over a cylinder with blunt headform using a high-speed video camera together with a PIV system. The purpose is to provide further insight into the characteristics of the inception cavitating flow and the interplay between the turbulence fluctuations and the inception cavitation.

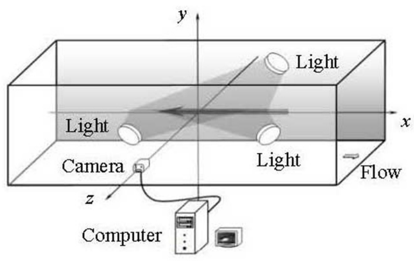

Fig.1 Layout of high-speed video camera system

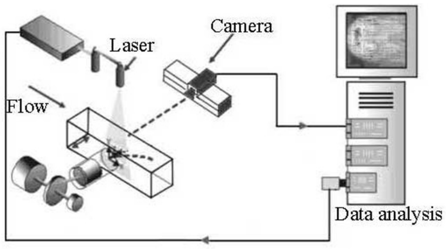

Fig.2 Arrangement of the PIV system

1. Experiment approach and setup

The experiments are carried out in a closed-loop cavitation tunnel, and its schematic description is given in Ref.[14]. Figure 1 shows the layout of the visualization system. A high-speed video camera (HG-LE, by Redlake) system, with a rate of up to 10^5 frames per second (fps), is used to take pictures of the inception cavitating flows, with a frequency of 5 000 fps with various qualities of images and other requirements. During the experiment, three high-energy lamps are applied to scan the flow field, and the high-speed video camera takes pictures from the side of the test window. Figure 2 shows the PIV system, which is used to measure the velocity fields of both non-cavitating and inception cavitating flows. During the PIV experiment, a double-pulsed light sheet of about 0.001 m thick created by Nd: YAG lasers scans the test section parallel to the main flow. The lasers emit light pulses with a duration of 10ns, a wavelength of 532 nm, and an energy of 50 mJ/pulse at a repetition rate of 30 Hz. The CCD camera is used to acquire images with a resolution of 1 024×1 024 pixels. The double-pulsed images are processed using the commercial post-processing software. Here, the interrogation region of 32×32 pixels is used typically with an overlap of 50%. The hollow glass beads with the density of 1.03×10^3 kg/m^3 are chosen as tracer particles.

The data acquisition and analysis procedures of the PIV technology were developed in our laboratory[14,15]. With numerous vapor bubbles in the cavitating flows, the velocity inside the cavity can be determined by using the vapor bubbles as "tracer particles"[14,16,17]. In the non-cavitating regions, the tracer particles are used to measure the local velocity. The strong reflection and refraction of the light sheet by the vapor-liquid interface is an issue not yet resolved[18]. Here, in order to reduce the effect of the reflection on the PIV measurement, firstly the energy per pulse of the lasers is lowered, giving a modest light budget. Moreover, the axisymmetric body is painted black and the images are pre-processed by subtracting the mean image, reducing the reflection of the wall surface and the cavity interface. Then, during the post-processing, multiple filters are employed to remove the erroneous vectors by specifying the relative tolerance.

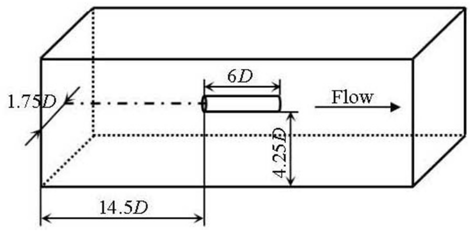

Fig.3 Sketch of the axisymmetric body position in the test section

Figure 3 shows the sketch of the experimental model location in the test section. The axisymmetric body is $6D$ in length, located at the middle of the test section. Here, D is the diameter of the axisymmetric body. During testing, the free-stream velocity is U_0 = 8.8 m/s, giving a Reynolds number of $Re = 1.76\times10^5$ based on $D = 0.02$ m, and the environmental temperature is 20°C. In this study, the inception cavitation number is 1.2 based on the upstream pressure as well as the free-stream velocity. Li et al.[14] and Huang et al.[17] reported that the experimental conditions are maintained to within 1% uncertainty on the angle of incidence and 2% uncertainty on both the flow velocity and the upstream pressure. In general, the cavitation number can be controlled to within 5% uncertainty. The turbulent intensity is less than 2%, further details can be found in the Refs.[14] and [17].