EXPERIMENT ON CAVITATING FLOW AROUND AN AXISYMMETRIC PROJECTILE NEAR THE FREE SURFACE

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ABSTRACT: The typical experiment on the cloud cavitating flow around an axisymmetric projectile near the free surface is carried out in a Split-Hopkinson pressure bar (SHPB) launching system in this paper. An axisymmetric projectile with flat head is tested. The trajectory and cavitations' features are obtained with different distances from the free surface and the projectile. The development of the cavity length and the effect of free surface are discussed. The free surface can delay the shed process of the cavity on the upper side, which will cause the length differce between the upper and down side. With the decrement of distance from the free surface and the projectile, the cavity length on the upper side increase.

INTRODUCTION

Cavitation, as a critical phenomenon, has been attractive in the past decades. Especially when the interaction between free surface and cloud cavitating flow is involved, the problem becomes more complex. Relevant studies in literature are very limited. An understanding of the interactions is still inadequate [1].There are a few theoretical and numerical approaches established [2-5]. Other works involving influence of the free surface are about the supercavitating flow in shallow water [6]. However, experimental researches about cloud cavitation near the free surface are still not seen in literature.
In the present paper, a scaled underwater launch system and an axisymmetric vehicle are adopted. The unsteady non-axisymmetrical characteristics of cavities evolution are obtained. The effects of the free surface on re-entry jets and cavities shedding are studied, while the influence of free surface on the cavities is also investigated.

EXPERIMENTAL SETUP AND MODEL

The typical experiment is carried out in a Split-Hopkinson pressure bar (SHPB) launching system(as shown in Fig. 1). The scaled underwater launch system mainly consists of four parts: the launching system (1, 2, 3, and 5), the water tank (4 and 10), the stain-sampling system (6, 7, and 8), and the high-speed camera (9). The projectile is transiently accelerated by the launching system with slight disturbance on the water. The stress-wave signal traveling in the transmission bar and projectile can be obtained from the strain sampling system. The high-speed camera is used to capture the trajectory and cavitations' features. More detail about the system can be refer to [7].

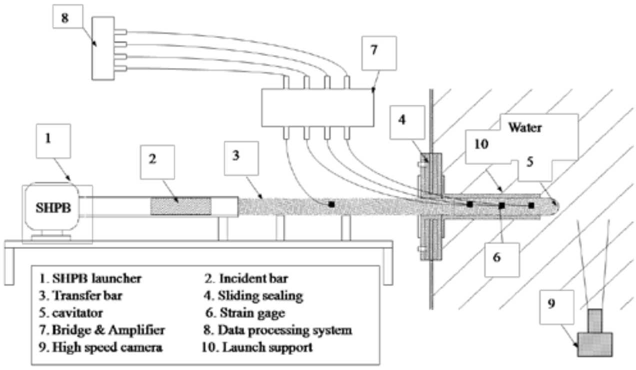

Figure 1. Underwater launch system

An axisymmetric projectile with flat head is tested in this article (as shown in Fig. 2). The length of the projectile is 150 mm, and the diameter is 37mm. The length of the cavity represents the transient behavior of cavitating flows. The red line in Fig. 2 marks for the cavity length down sides (L_{down}) and the black line is the cavity length up sides (L_{up}). H is the distance from the free surface and the projectile. The lengths of cavities are gotten through measuring the pixels in pictures. For example, the projectile in which the length is 150 mm is about 488 pixels in pictures in experimental results. Then, 1 pixel stands for 0.31 mm, and the deviation is 0.31 mm. The development of the cavity length will be discussed in the following.

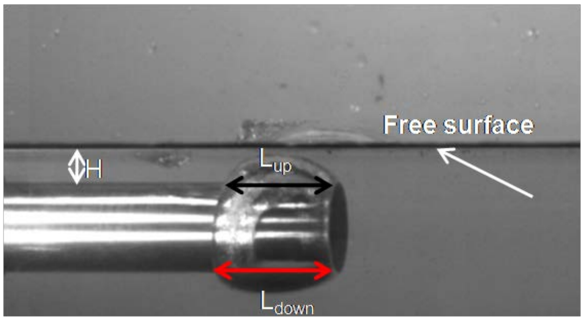

Figure 2. The test model

The cavitation number is defined as

$$\sigma = \frac{p_{out} - p_v}{0.5\rho_l V_\infty^2} \tag{1}$$

Where p_{out} is the static pressure of outlet, 101 kPa. p_v is the vapour pressure, 2.97 kPa. ρ_l is the water density, 998.0 kg/m^3. V_∞ is the inflow velocity, 18 m/ s, thus the cavitation number is $\sigma = 0.6$.
The Reynolds number is defined as

$$\mathrm{Re} = \frac{\rho_l \mathrm{V}_\infty l}{\mu} \tag{2}$$

Where l is the length of the projectile, 0.15m, which is treated as the characteristic length. μ is the water dynamic viscosity, 0.001003kg/ms. Thus the Reynolds number is $\mathrm{Re} = 2.7 \times 10^6$.

RESULTS AND DISCUSSION

Cavity evolution in a shedding cycle

The quasi-periodic development of cavity shape is obtained from the experimental results. Photographs at different moments are shown in Fig. 3. In this case, the distance from the free surface and the projectile is H=15mm. The variation of cavity length is shown in Fig. 4.
The cavity evolution in every cycle can be divided into two stages. Firstly, the bubble is in the growth stage (as shown in Fig. 3 (a) and in Fig. 4 (Stage 1-1)). Then the re-entry jet is generated and developed (as shown in Fig. 3 (b-c) and in Fig. 4 (Stage 1-2)). The cavity sheds in stage 2-1 and collapses in the stage 2-2 (as shown in Fig. 4), in which the re-entry jet is also generated for the second time. In the stages of 1-2, 2-1 and 2-2 (as shown in Fig. 4), there are a significant difference between the lengths of in the up and down sides of the projectile. Longer cavities appear alternately.

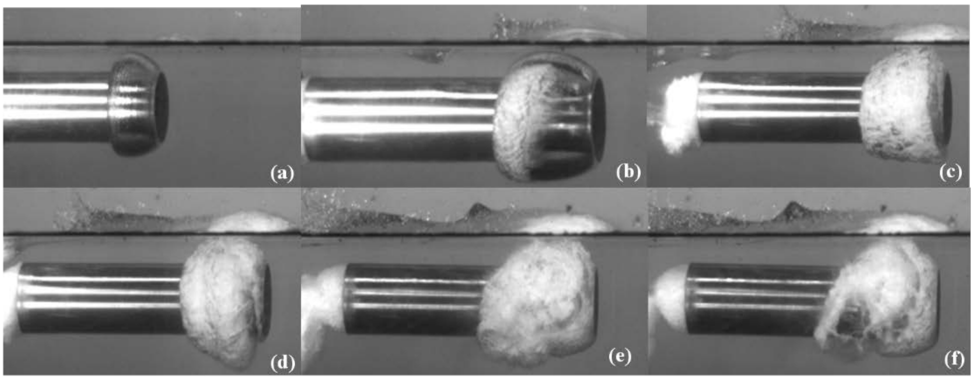

Figure 3. Time evolution of cavity patterns(H=15mm)

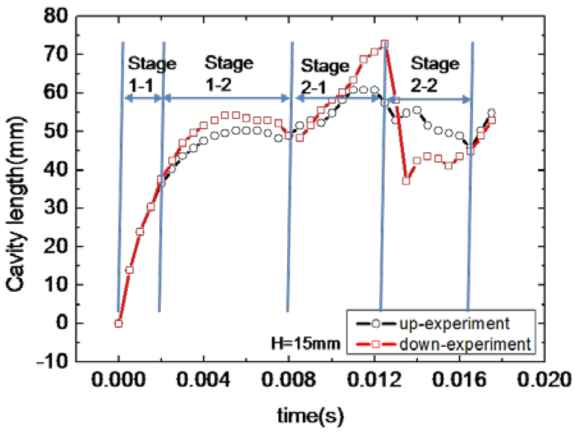

Figure 4. The comparison of the variation of cavity length between up and down sides (H=15mm)

Effect of free surface

The difference of cavity lengths between up and down sides is obtained to analyze the relationship between the up and down sides (as shown in Fig. 5). In the picture, the t represents the time of the development of the cavity. $L_{down} - L_{up}$ is the difference of cavity lengths between up and down sides. It can be seen that the difference of lengths stays approximately stable at growth stage (Stage1-1), and its length varies in a very small range at Stage1-2. There is a significant difference between the lengths of in the up and down sides of the projectile at Stage2-1, 2-2. The cavity length difference reach a maximum when the down side cavity sheds. That may be caused by the re-entry jet. Re-entry jet is the key factor on the shedding of cavity and vortex, which has been widely studied. Re-entry jet is a transparent liquid stream, which is opposite to the direction of the main flow in the cavity. Re-entry jet is produced by the adverse pressure gradient near the closure the cavities. It indicates that the formation of a re-entrant jet is the main reason for the unsteadiness. The cavity will be cut off by the re-entry jet. Then the shedding cavity collapses which leads to a high pressure in local domain. Another re-entry jet will be induced accordingly. Thus the re-entry jet plays a significant function in the vapor cloud shedding process.

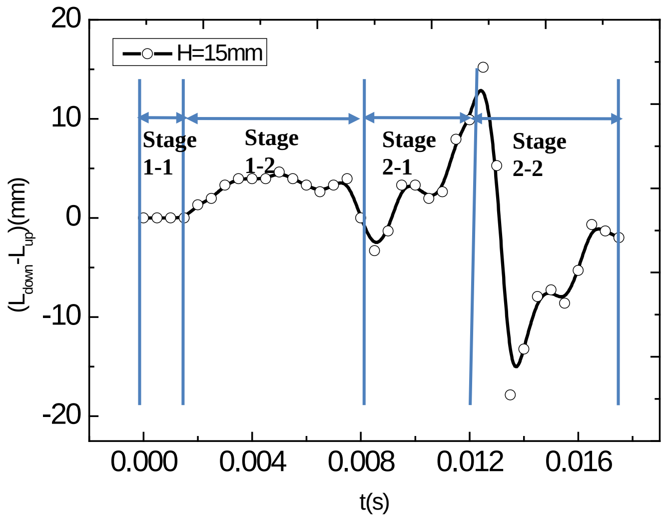

Figure 5. The difference of lengths between up and down sides (H=15mm)

Cavity evolution varied with different depth

In order to investigate the relationship between the cavity length and the distance from the free surface and the projectile, another two conditions are investigated with different H. The values of H are 10mm (as shown in Fig. 6 and Fig. 7) and 5mm (as shown in Fig.8 and Fig. 9), respectively. Refer to the evolutions aforementioned, we can see the cavity on the upper side stays approximately stable, and its length varies in a very small range after the growth stage. The free surface can delay the shed process of the cavity on the upper side. With the decrement of distance from the free surface and the projectile, the cavity length on the upper side increase. For example, the cavity length on the upper side keep around 50mm at H=10mm, and the length is about 80mm at H=5mm.

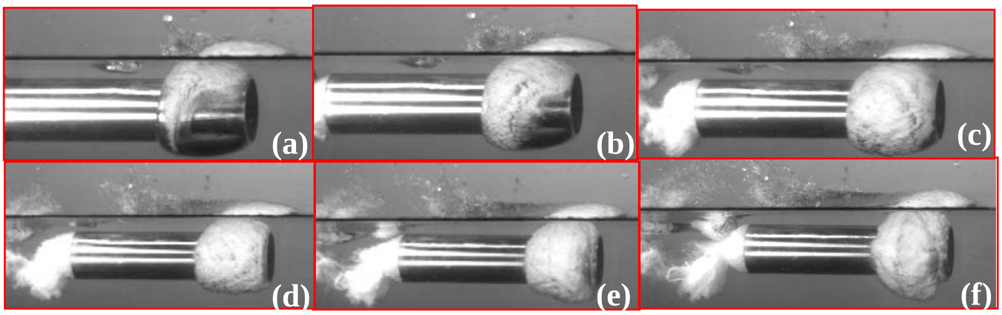

Figure 6. Time evolution of cavity patterns (H=10mm)

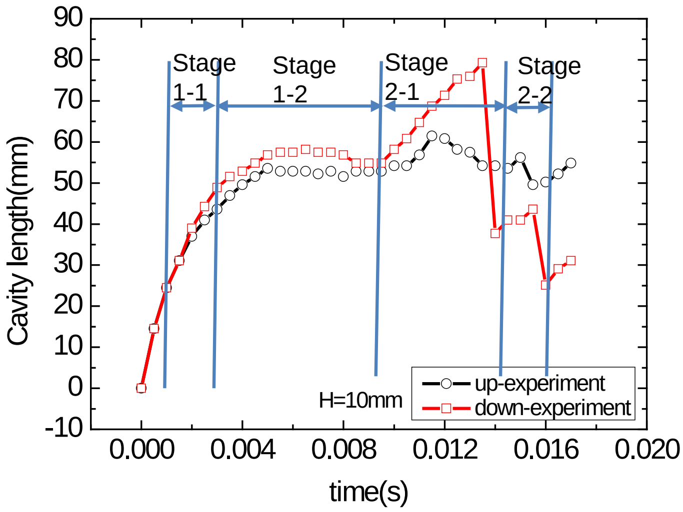

Figure 7. The comparison of the variation of cavity length between up and down sides (H=10mm)

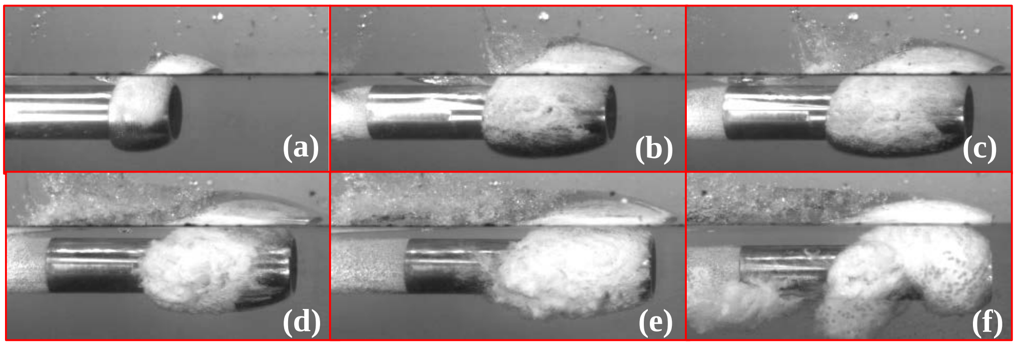

Figure 8. Time evolution of cavity patterns (H=5mm)

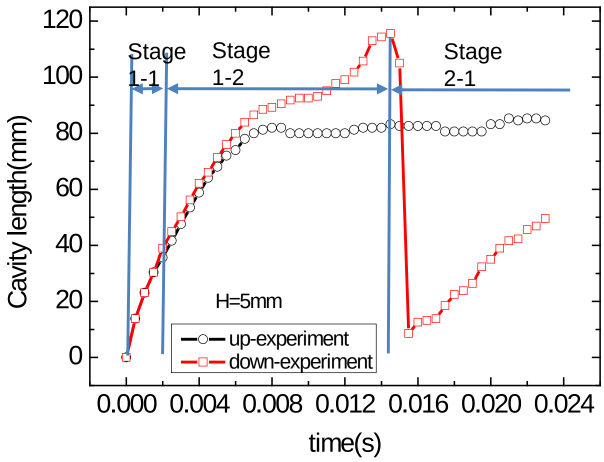

Figure 9. The comparison of the variation of cavity length between up and down sides (H=5mm)

CONCLUSIONS

An experiment on the cloud cavitating flow around an axisymmetric projectile near the free surface has been presented in this paper. Cavity evolution in a shedding cycle, effect of free surface on the cavity lengths and the cavity lengths varied with different distance from the free surface and the projectile are discussed.

The results show that:

The development of cavity shape is quasi-periodic. The cavity evolution in every cycle contains the growth of the cavity, the generation and development of re-entry jet and the collapses of the cavity.

The free surface can delay the shed process of the cavity on the upper side. With the decrement of distance from the free surface and the projectile, the cavity length on the upper side increase.

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