Experiment on the cloud 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 used. The features of cavities are obtained in conditions with different submerged depth. Development of the cavity length and effect of free surface are discussed. The free surface can delay the shed process of the cavity on the upper side, which causes the length difference between the upper and down side. With the decrement of submerged depth, the cavity length difference increases.

Keywords

Launching experiment – Free surface – Cloud cavitating flow

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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 [2–6]. Other works involving influence of the free surface are about the supercavitating flow in shallow water [7]. However, experimental researches about cloud cavitation near the free surface are still not seen in literature. This is mainly because the free surface can hardly be produced in cavitation water tunnels.

In the present paper, typical experiments are performed in a scaled underwater launch system based on an SHPB device, and an axisymmetric projectle is used as the testing model. The unsteady non-axisymmetrical characteristics of cavities evolution are obtained. The effect of the free surface on reentry jets and cavities shedding are studied, while influence of the free surface on cavities is also investigated.

1. EXPERIMENTAL SETUP AND MODEL

The typical experiment is carried out in a Split-Hopkinson pressure bar (SHPB) launching system(as shown in Figure 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 signal of the stress wave propagating in the transmission bar and the projectile can be obtained by using the strain sampling system. The high-speed camera is used to capture the trajectory and cavities features. The tank dimensions are C×B×H=2000mm×1000mm×800mm, and the top of the tank is directly exposed to the open air (as shown in Figure 2). More details about the system can be refer to [8].

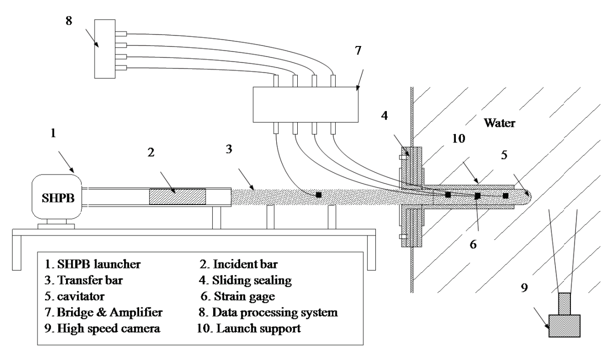

Figure 1. Underwater launch system

An axisymmetric projectile with flat head is used in this article (as shown in Figure 3). The length of the projectile is 150 mm, and the diameter is 37mm. Lengths of the cavity can represent the transient behavior of cavitating flows. The red line in Figure 3 marks for the cavity length on the lower side (L_{down}) and the black line is the cavity length on the upper side (L_{up}). H is the distance from the free surface and the

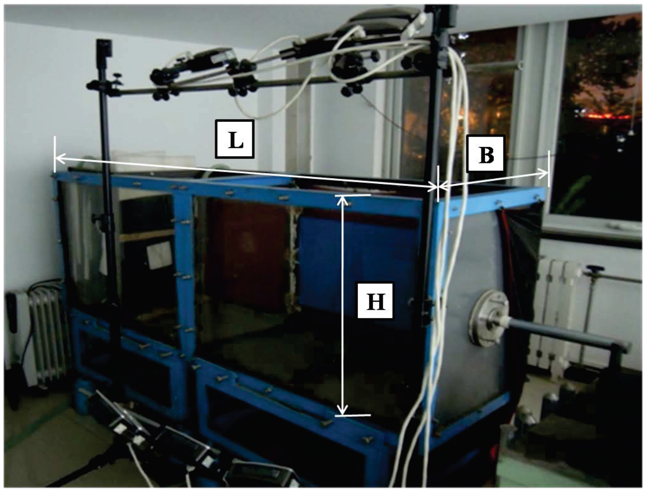

Figure 2. A picture of water tank

projectile. Lengths of cavities are gotten through pixel analysis on pictures. For example, the projectile with the length of 150mm shows about 488 pixels. Then, 1 pixel stands for 0.31mm, and the deviation is 0.31mm. The development of the cavity length will be discussed in the following.

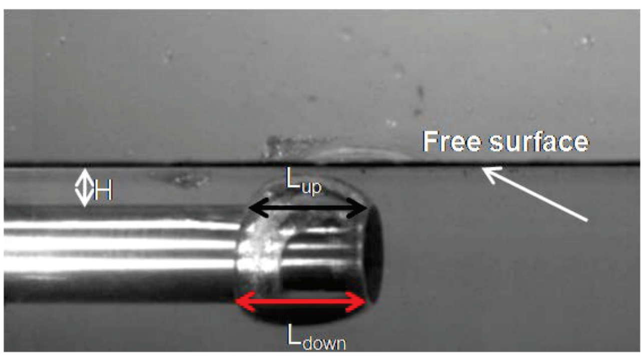

Figure 3. The test model

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, 1 atm. p_v is the vapour pressure, 2.97 kPa. ρ_l is the water density, 998.2 kg/m3. V_∞ is the inflow velocity, 18.5 m/ s, thus the cavitation number is $\sigma = 0.58$. The value of V_∞ is also gotten through pixel analysis on pictures. With the same method, we can find how the head position of the projectile varies with time and calculate the velocity of the projectile. The Reynolds number is defined as

$$\text{Re}=\frac{\rho_l V_\infty l}{\mu} \tag{2}$$

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 $\text{Re} = 2.7\times10^6$. Experiments of five working conditions are performed with various water depths from 5mm to 40mm.

2. RESULTS AND DISCUSSION

2.1 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 Figure 4. The value of H is gotten through measuring the distance from the free surface and the projectile by experiment. For the first shedding cycle of cavity evolution, the time is short so the difference of H can be neglected with the length L. In this case, the distance from the free surface and the projectile is considered as a constant value as H=15mm. The variation of cavity length is shown in Figure 5.

The cavity evolution in every cycle can be divided into two stages. Firstly, the bubble is in the growth stage (as shown in Figure 4 (a) and in Figure 5 (Stage 1-1)). Then the re-entry jet is generated and developed (as shown in Figure 4 (b-c) and in Figure 5 (Stage 1-2)). The cavity sheds in stage 2-1 and collapses in the stage 2-2 (as shown in Figure 5), 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 Figure 5), there are a significant difference between the lengths of in the up and down sides of the projectile. Longer cavities appear alternately.

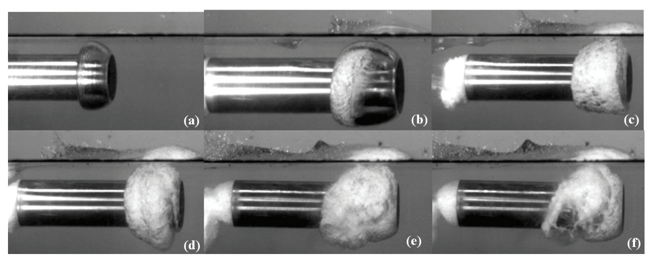

Figure 4. Time evolution of cavity patterns(H=15mm)

2.2 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 Figure 6). In the picture, the t represents the time of the development of the cavity. 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.

Re-entry jet is the key factor on the shedding of cavity and vortex, which has been widely studied. Re-entry jet is a 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

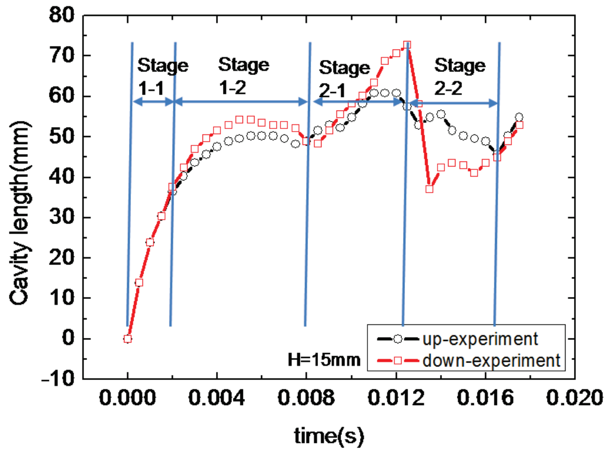

Figure 5. The comparison of the variation of cavity length between up and down sides (H=15mm))

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. In the present condition under the effect of the free surface, the re-entry jet on the upper side is generated earlier and faster than that on the lower side. Consequently the frontier of the re-entry jet on the surface is oblique and the re-entry jet on the upper side reaches the shoulder of the projectile firstly. The shedding of the cavity on each side is also not synchronous, which induces the differences of lengths and shapes between cavities on the upper and lower side.

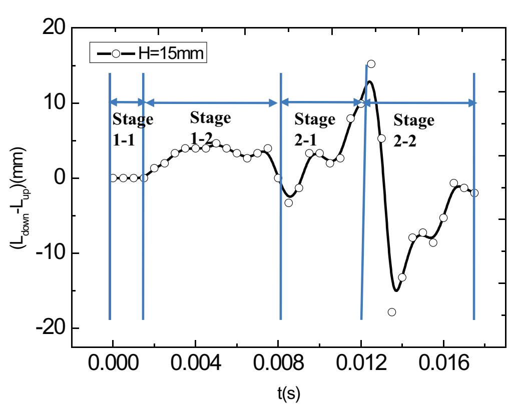

Figure 6. Time evolution of cavity patterns(H=15mm)

2.3 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, the other condition is investigated with different H. The value of H is 10mm (as shown in figure 7 and figure 8). Refer to the evolutions aforementioned and in contrast with the condition of 15mm depth, we can see the cavity on the upper side stays approximately more 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 also increases. For example, the cavity length on the upper side keeps around 50mm at H=10mm.

The maximum length difference between cavities on the upper and lower side are shown in the curve in Figure 9. The difference increases when the depth decreases. And the values are similar in the conditions with the depths of 25mm and 40mm, which is because the effect of the free surface is negligible in these conditions. The differences are induced by the randomness of cavity fluctuation.

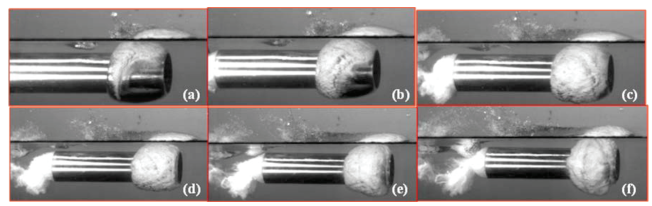

Figure 7. Time evolution of cavity patterns(H=10mm)

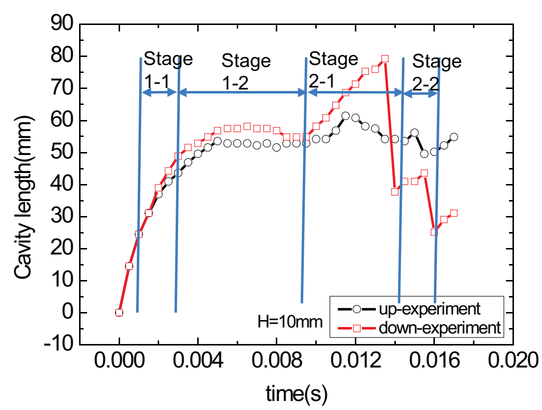

Figure 8. The comparison of the variation of cavity length between up and down sides (H=10mm))

3. CONCLUSIONS

Experiments on the cloud cavitating flow around an axisymmetric projectile near the free surface have 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 cav-

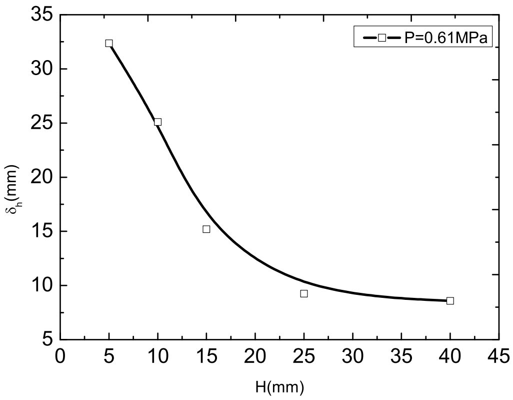

Figure 9. The variation of maximum cavity length difference with depth

ity, the generation and development of re-entry jet and the collapses of the cavity. The lengths of cavities on the upper and lower sides are different under the effect of the free surface.

The difference is larger and the cavity is more stable on the upper side when the free surfaces is closer to the free surface.

The mechanism of the free surface effect is worthy of further analysis. And in the condition that the depth is 5mm, ventilation phenomenon occurs that the air above the free surface is injected into the cavity, which is also need to be investigated in the future.

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