An Experimental Investigation of Artificial Supercavitation with Variation of the Body Shape

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Abstract

In this study, artificial super-cavitating flow around a three-dimensional body has been investigated. Experiments were conducted in a cavitation tunnel of the Chungnam National University that has a special equipment to remove injected air for carrying out ventilation tests. Behaviors and dimensions of the artificial supercavity depending on the shape configuration of the body were examined. Pressures inside the supercavity were measured by using an absolute pressure transducer and the cavity formation was observed by using high-speed visualizations. The results show that several parameters defining the body geometry and the combination of the cavitator have a significant influence on the development of the supercavity.

Keywords: cavitation tunnel experiment; cavitator; natural supercavitation; artificial supercavitation

Introduction

In recent years, supercavitation has again attracted interest and attention for practical advantages in drag reduction of underwater vehicles. As a submerged object travels at very high speeds and a vaporous cavity naturally grows to cover the entire body. Supercavitation can also be formed by injecting gas into the low pressure regions behind the front part of a body, cavitator, which is termed as a ventilated or an artificial supercavity. Both types of supercavities appear to be alike at the same cavitation number conditions. However, the main difference between the two is the effect of gravity. Artificial supercavitation can be generated at relatively lower speeds than the natural case for given conditions, thereby making Froude number effects significant. Most previous experimental researches on artificial supercavitating flows were performed for the case of cavitators alone [1, 2, 3, 4, 5]. In this work, we investigated the effects of the combination of body and cavitator on the supercavity dimension and development. Here, three different cavitators including disk, cone and ellipsoidal shape and also three different fore body angles were considered.

Experimental apparatus and test models

A vaporous cavity is naturally formed on the body by increasing the flow speed, or by decreasing the ambient pressure. Natural cavitation is governed by the parameter referred to as the cavitation number, $\sigma_n = (P_\infty - P_v)/(\frac{1}{2}\rho U_\infty^2)$. As the cavitation number is gradually decreased, a partial cavity grows longer and transitions into a supercavity. Based on the same principle, a supercavity can also be attained by injecting gas into the low pressure regions and making cavities to envelope the body. Artificially created supercavities mainly depend on the amount of injected air and the pressure inside the cavity. Especially, the influence of gravity causes the cavity to deform and its tail to go up. The phenomenon of artificial supercavitation is characterized by the artificial cavitation number, $\sigma_c = (P_\infty - P_c)/(\frac{1}{2}\rho U_\infty^2)$, and other parameters such as air entrainment coefficient, $C_q = \dot{Q}/(U_\infty d_c^2)$, and Froude number, $F_n = U_\infty / \sqrt{g d_c}$. The key parameter of artificial supercavitation is pressure inside the cavity, which is determined by injected gas rate. Contrary to the case of unbounded flow, when the supercavity is generated in a flow confined by the walls in tunnel experiments, blockage effects should be considered. Figure 1 shows the CNU cavitation tunnel employed in this experimental work. The test section is 100 mm square and 1,400 mm long and maximum flow speed is 20 m/s. Cavitators and the overall shape of the test model are also shown in Figure 1. Disk type including two different shapes, cone and ellipsoidal type cavitators can be combined with different fore body parts. Dimensions of the test models

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named M-I, M-II and M-II are shown in Table 1. Here, d_c, S_L, B_D, B_L are cavitator diameter, fore body (shoulder) length, body diameter and body length respectively.

The air is supplied through a pipe inside the body from the outside of the tunnel, and it is injected through 1.5 mm four holes behind the cavitator. Using an absolute pressure sensor, we measured the pressure inside the cavity at 30mm apart from the cavitator. We also recorded the growth process of the supercavity by using a high-speed camera placed at the side of the test section.

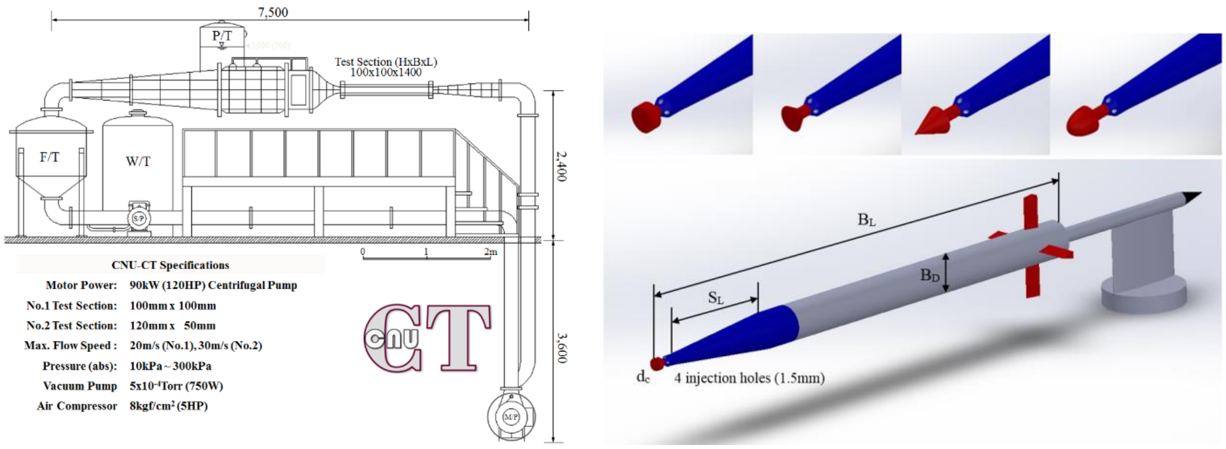

Figure 1. CNU cavitation tunnel (left) and test model and cavitators (right)

Table 1. Specifications of the test models

Model name	d_c [mm]	S_L [mm] (angle)	B_D [mm]	B_L [mm]	B_D /d_c	S_L /d_c
M-I	8.6	82.5 (6.1°)	25	326	2.9	9.5
M-II	9.4	160 (3.1°)	25	326	2.7	17.0
M-III	10.5	180 (2.9°)	25	326	2.4	17.1

Results and discussions

Figure 2 shows a typical formation of the artificial supercavity occurring from the test model, M-I and M-II, with respect to different air entrainment coefficients, C_q. Initially a short foamy cavity appears and grows as injected air increases. This foamy cavity is closed by an unstable wake flow of the cavitator and the rear part of the cavity is re-entrained by the outer flow. At a critical value for the air entrainment coefficient, the cavity varies rapidly from a foamy cavity to a clear cavity. As the injection rate increases, the cavitation number reaches to a minimum value the clear supercavity occurs and maintains the shape even if the injection rate decreased. This mechanism of the hysteresis effect has been reviewed by many experts [3, 6, 7]. Figure 3 shows gravitational effects on M-III model according to the Froude number. The supercavity is more straightforward as the Froude number increases by an increase in velocity. It is easy to figure out this effect by observing the location of the closure of the supercavity. Figure 4 shows the dimension of the supercavity generated in each model. Comparing with the case without body, it shows that the cavity length is greatly influenced by the presence of the body, and the smaller the angle of the fore body the larger cavity. In Figure 5 (left), cavitation numbers are plotted against Froude numbers for each model. As the Froude number increases the cavitation number continually decreases until it reaches the minimum value dictated by blockage. Figure 5 (right) shows non-dimensional cavity length according to the fore-body angle, which is corresponding to the results of Figure 4. Figure 6 shows high-speed images of the development of the supercavity from the disk and cone type cavitator for 0.08 second. Supercavity grows faster in cone type cavitator rather than that of the disk type cavitator, but the cavity dimension is larger in the disk type cavitator.

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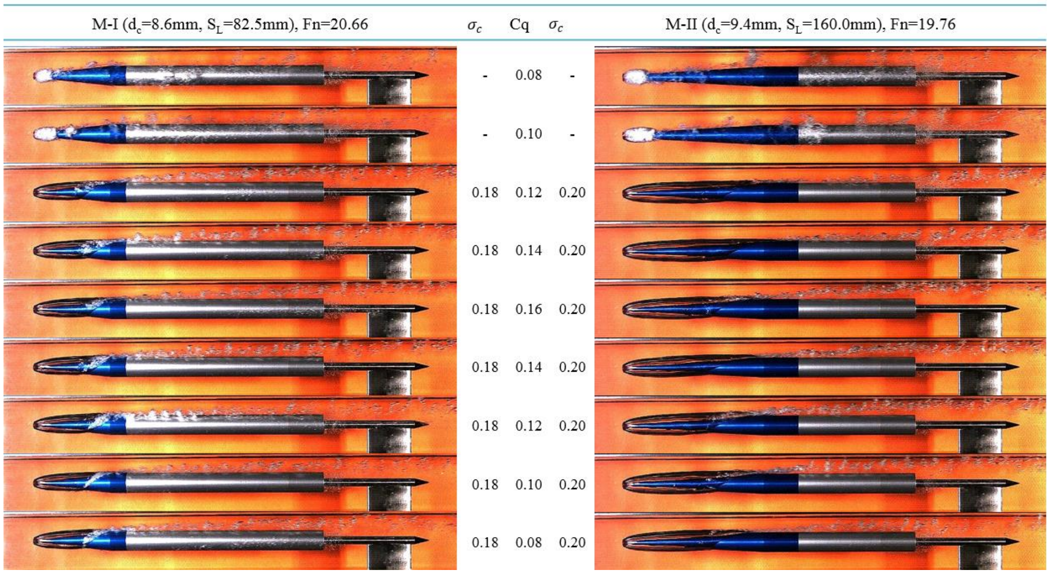

Figure 2. Supercavity formation corresponding to M-I model (left) and M-II model (right)

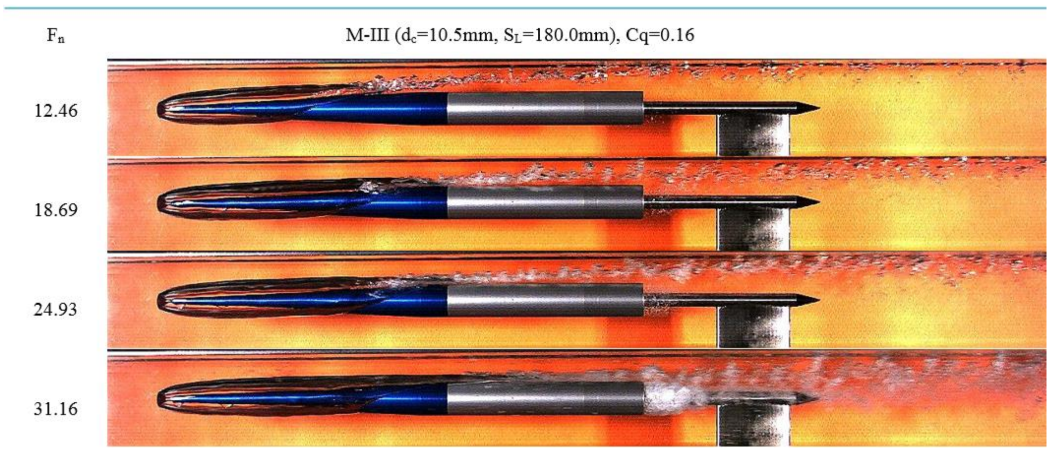

Figure 3. Gravity effects of M-III model

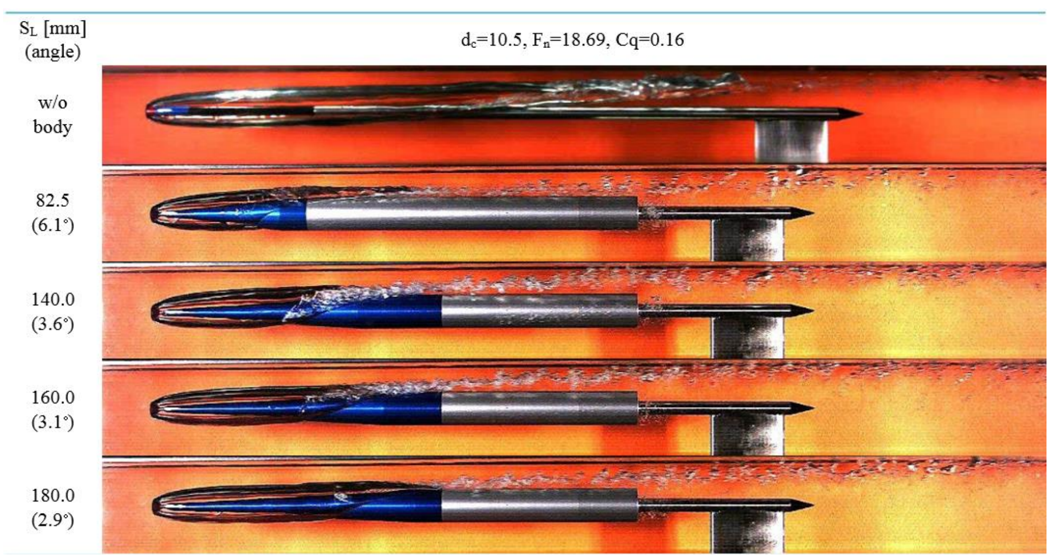

Figure 4. Cavity dimensions according to the fore body angle

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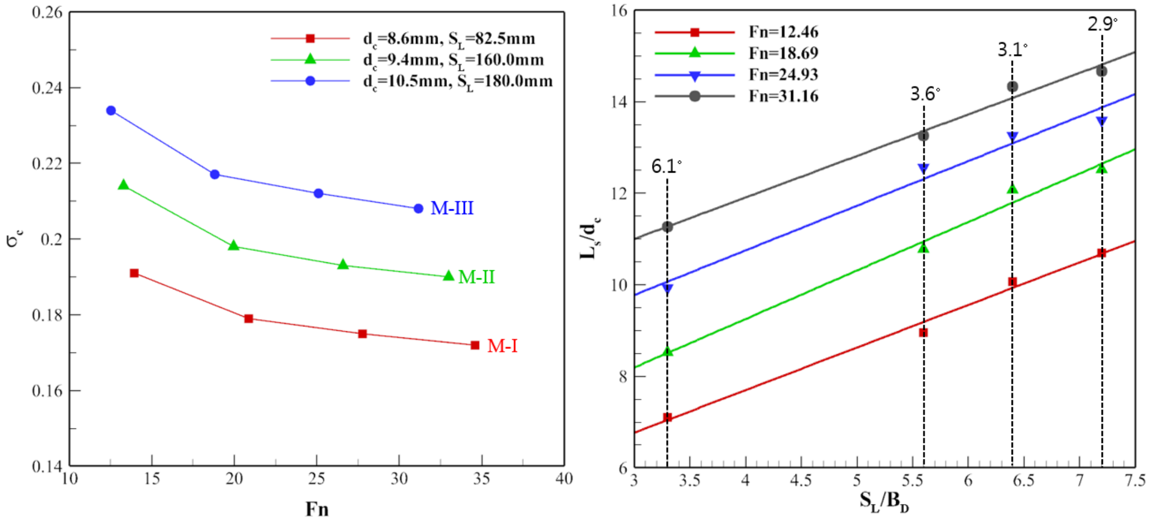

Figure 5. Cavitation number against Froude number for each model (left) and non-dimensional supercavity length according to the fore body angle (right)

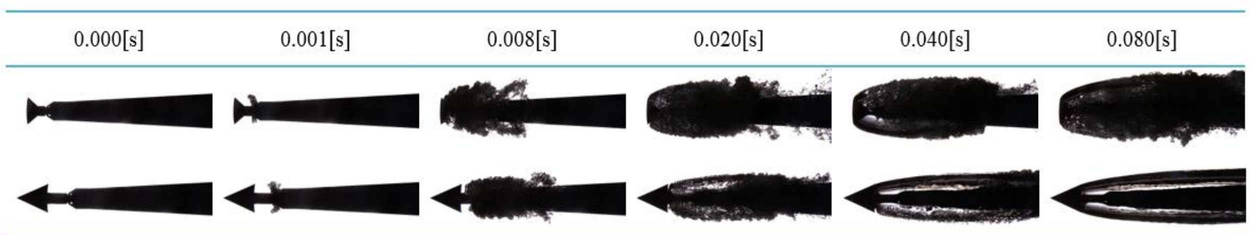

Figure 6. Comparison of the supercavity formation of the disk type (top) and cone type cavitator (bottom) for 0.08 second

Concluding remarks

On the basis of the previous experiment of artificial supercavitation in a disk type cavitator without the body, in this study we investigated the effects of the body behind the cavitator on the supercavity dimension. Three models with different body shape combinations were tested in a cavitation tunnel. Typical characteristics of the artificial supercavity such as the gravity effect and hysteresis effect were observed for each model. Using high-speed visualizations, supercavity dimensions were measured according to the fore body angle, and also the formation process of the supercavity in different cavitators was examined. In conclusion, it was found that the combination of the fore body shape greatly affects the development of the supercavity.

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