UNDERWATER ACOUSTICS AND CAVITATING FLOW OF WATER ENTRY*

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ABSTRACT: The fluid mechanics of water entry is studied through investigating the underwater acoustics and the supercavitation. Underwater acoustic signals in water entry are extensively measured at about 30 different positions by using a PVDF needle hydrophone. From the measurements we obtain (1) the primary shock wave caused by the impact of the blunt body on free surface; (2) the vapor pressure inside the cavity; (3) the secondary shock wave caused by pulling away of the cavity from free surface; and so on. The supercavitation induced by the blunt body is observed by using a digital high-speed video camera as well as the single shot photography. The periodic and 3 dimensional motion of the supercavitation is revealed. The experiment is carried out at room temperature.

KEY WORDS: water entry, underwater acoustics, supercavitation, PVDF hydrophone, high-speed photography

1 INTRODUCTION

This paper is a follow-up after a series of work on the water entry problem [1~6]. The water entry is an old problem, but it has not been paid enough attention for a quite long time. However, recently Hrubes [7] reported an US Navy research program in high-speed underwater munitions whose velocities exceed the speed of sound in water. These munitions are candidates for use in submarine and surface ship terminal torpedo defense. On the other hand, from the accident of the Russian Navy submarine “Kursk” in 2000, it is known that the high-speed supercavitation torpedo has been deployed. This new type of torpedo is designed to move in a supercavity, which greatly reduces the drag in water so that the velocity of the torpedo can reach 230 knots (~ 120 m/s). The existing cavitation theory cannot answer the question of how to verify that the supercavity is stable in such a projectile speed or whether there exists a speed limit of the underwater projectile to keep the supercavity stable. In fact, from Hrubes’s work [7], it can be found that when the velocity of the underwater projectile is around 1500 m/s, the unsteadiness of the supercavity may be a serious problem to the projectile trajectory. In this paper, the initial velocity of the underwater projectile is 352 m/s. We will first show the experimental results of underwater acoustics measurements. These results are an addition to those in the previous work [3,6]. Then we will introduce the results of an optical observation of supercavitation, which will show that the supercavity is often unstable if the trajectory of the underwater projectile is three dimensional.

2 EXPERIMENTS

Figure 1 shows the schematic view of the measuring system of underwater acoustics in water entry.

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A 352 m/s projectile of 5.7 mm in diameter, 12.3 mm in total length and 2.67 g in mass moves downward to enter into a water tank. A PVDF (polyvinylidene-fluoride) needle hydrophone is submerged in water by a special designed support, by which the probe can be moved in vertical and radial directions and it can also be rotated. As shown in Fig.1(b), the hydrophone is placed at a position where it has a radial distance \( H \) from the impact center and a water depth \( D \) from the free surface. The axis of the hydrophone is aligned to the impact point so that it is inclined an angle \( \theta \) to the free surface. The hydrophone is Mueller Ingenierotechnik 100/100/1, with a 0.5 mm diameter sensitive element, a measurement range of \((-10 \sim 200)\) MPa, rising time 50 ns, and sensitivity 3.35 pC/MPa. It has the following advantages: (1) since the diameter of the probe head is only 1.5 mm, a point-to-point measurement is possible; (2) because the rising time is very short, the underwater shock waves can be measured; (3) it does not need a charge amplifier as in the case of a Kistler pressure transducer. In Fig.1(a), the laser beam above a distance on the water surface is for determining the beginning time of water entry since the projectile velocity and the distance are known already.

Figure 2 shows the schematic view of the high-speed photographic system for observing the supercavitation in water entry. A digital high-speed video camera (Memrecam ci-4, Nac Co., Ltd.) is used, which can operate at 500, 1000 and 2000 fps framing speeds, respectively. The camera is triggered when the projectile breaks up a thin carbon rod above the water surface. The image signals taken by the camera are sent to a personal computer for processing. The optical system of the single shot photography using an open shutter camera was given in Ref.[2].

(a) Measurement system  
(b) Position and direction of pressure transducer

Fig.1 System for measuring the underwater acoustics in water entry

Fig.2 High-speed photographic system for observing the supercavitation