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Control Strategy for a Ventilated Supercavitating Vehicle in Initial Phase

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Supercavitation reduces the resistance of an underwater vehicle by enveloping it in a bubble. When the velocity of the vehicle is low and the depth is significant, natural supercavitation is inhibited. Consequently, an artificial cavity to which gas is supplied, called a ventilated cavity, is used to maintain the supercavitating condition. This study models ventilated supercavity according to the cavity closure type and the design depth and proposes a ventilation control strategy that swiftly changes the closure type from the toroidal vortex regime to the twin vortex regime in the initial phase of flight. Numerical simulations verify the efficacy of the proposed strategy.

INTRODUCTION

Objects moving in fluid media, such as water, are slowed down by fluid forces collectively called drag. Drag forces increase quadradically with the object's speed, and hence the thrust force also increases. Consequently, underwater vehicles have a velocity limit due to the limit of the thrust force. Much research has been conducted with the aim of reducing the drag and increasing the speed of underwater vehicles. In the 1970s, Russian scientists proposed a hitherto radically different approach to solve this problem; they proposed reductions in the surface area of the body in contact with water to eliminate one type of drag, the skin-friction drag. When an object moves rapidly in water, an air bubble called a cavity is formed. The supercavitating technology proposed by the Russians is based on the idea that skin-friction drag can be reduced significantly when a vehicle is encompassed by large gas bubbles. Consequently, the performance of the supercavitating vehicle depends on how quickly it generates cavitation bubbles. The ideal conditions for developing supercavitation are high speed and shallow depth. However, in general, conditions are non-ideal in the initial phase of flight. Therefore, ventilation is used to easily achieve the supercavitating condition.

Basic research on cavity length and shape was conducted in the mid-to-late 1900s (Garabedian, 1956; Logvinovich and Serebryakov, 1975; May, 1975). Varghese et al. (2005) studied the characteristics of a partial cavity in the transition phase. Gas leakage from ventilated cavities in the twin vortex regime and in the toroidal vortex regime was studied by Campbell and Hilborne (1958) and Spurk (2002), respectively. Semenenko (2001) described in detail the physical characteristics and modeled ventilated cavities. Kinzel et al. (2009) proposed modeling of ventilated cavities considering all types of cavity closure modes. Recently, Zou et al. (2010) studied the gas leakage rate of unsteady ventilated supercavities and established a gas leakage formula.

In this study, we model ventilated supercavity considering cavity closure types and design controllers for the rapid change of the cavity closure type from the toroidal vortex to the twin vortex. Two types of controllers are designed: a ventilation rate controller and a depth controller. The results of the simulations conducted to analyze the characteristics of the system and to validate the modeling and performance of the designed controllers are presented.

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KEY WORDS: Ventilated cavity, supercavitating vehicle, ventilation control, depth control, artificial cavity, cavity closure.

MODELING OF VENTILATED SUPERCAVITY

Axisymmetric Supercavity

The cavity is a major component of the supercavitating system. The behavior of the cavity bubble around the vehicle affects the fins and body immersion. The cavitator continuously maintains the cavity while the vehicle is moving. The cavity axis, which integrates each cavity section center, is equal to the trajectory of the cavitator if there is no gravity effect and the cavitator angle of attack is zero; in other words, the cavity is axisymmetric. The plane that is perpendicular to the trajectory of the cavitator is called the cavity section, and the cavity contour is obtained by the integration of all the cavity sections along the trajectory of the cavitator. The cavity changes with time, independent of the vehicle dynamics. Each cavity section first expands until it reaches its maximum radius and then starts to contract and disappear (see Fig. 1).

The important parameter that represents the cavity characteristics is the cavitation number σ:

$$\sigma = \frac{p_\infty - p_c}{0.5\rho V^2} \tag{1}$$

where p_∞ is the ambient pressure, p_c is the pressure inside the cavity measured in pascal (Pa), and V is the vehicle velocity. The cavitation number σ is used to characterize the potential of the flow to cavitate. When σ is low, which means the velocity of the vehicle or the cavity pressure is high, large and wide cavities tend to occur. Several researchers have investigated cavity shape models. For example, Logvinovich (1972) studied the cavity radius and cavity contraction rate for the disk-type cavitator in steady flow. Garabedian (1956) derived formulas that are useful for predicting the cavity length L_c and the maximum cavity radius. The cavity

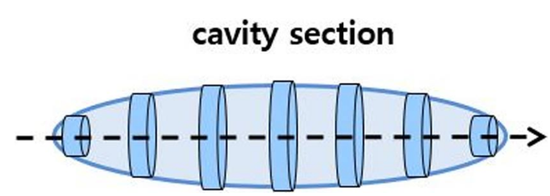

Fig. 1 Axisymmetric cavity and cavity sections