Investigation of the motion control performance and hydrodynamic of a multi-winged towed vehicle with intentional instability

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ABSTRACT
The authors propose a towed vehicle with intentional instability for use in seafloor exploration. This towed vehicle has one pair of canard wings in addition to conventional main and tail wings. The hydrodynamic characteristics and the motion control performance of the multi-winged towed vehicle with the three control surfaces are investigated. First, CFD and experiments were conducted to investigate the effects of interference between the wings. Then, equations of the motion for the multi-winged towed vehicle were formulated and the simulations of the motion control were conducted. The calculations were performed for the longitudinal motion of the vehicle. Since this system has three control inputs (three wing angles) for two control outputs (pitch and heave), the control input to reach the target is not uniquely determined. For this reason, the authors reduced the number of control inputs by linking the angles of the tail and the canard wings at a certain ratio. The motion control simulations confirmed that the pitch and heave can be controlled almost independently, demonstrating the superiority of the multi-winged towed vehicle over conventional ones.

KEY WORDS: Towed vehicle; seafloor exploration; canard; CCV; interference.

INTRODUCTION
Underwater towed vehicles have been used in ocean exploration because of their advantages such as the ability to explore a wide area quickly and to operate for a long time because they are powered by an external power supply. In recent years, towed vehicles have been considered for use in seafloor exploration, such as surveying undersea ruins or monitoring fishing grounds. (Kato, 1990) The vehicle used for such applications must have the ability to maintain a constant altitude from the seafloor. In the case of sonic exploration of the seafloor, it is desirable to keep the attitude of the vehicle parallel to the slope of the seafloor (Ohta, Yoshida, Ishibashi, Sugekawa, Fan, and Kiyotaka, 2016; Nakamura and Hyakudome, 2019). However, most conventional towed vehicles have positive stability in themselves, and such vehicles are not suitable for surveying under the seafloor. A highly stable body does not track to its target well, and it is difficult to maintain a certain distance from the seafloor topography. The authors propose a multi-winged towed vehicle with intentionally low stability to solve this problem. In the design of this vehicle the towing point is located close to the dynamic center of the body, and canard wings are attached in addition to the conventional main and tail wings. In this study, the motion control performance and hydrodynamic characteristics of the multi-winged towed vehicle with three maneuvering surfaces are investigated.

DESIGN OF THE MULTI-WINGED TOWED VEHICLE
Conventional towed vehicles are designed to be self-stabilizing, which is the normal configuration for fixed-wing vehicle with main and tail wings. It usually controls 3DoF rotational motion around the x, y, z axes with three control surfaces elevator, rudder, and aileron. And the vertical and lateral transitional motions are indirectly controlled by these rotations. For example, when the vehicle decreases its depth, the pitching angle is first increased, and the accompanying change in the angle of attack increases the lift force to achieve the motion. In this way, the control system of conventional vehicle assumes that each direction is coupled. The coupled motion of the towed vehicle hinders the maneuver tracking the seafloor terrain. To achieve a high degree of freedom in motion control by removing the coupling motion, it is better to add new canard wings or thrusters in addition to the conventional main and tail wings. Although the stability of the vehicle will be reduced, the advantages of improved maneuverability will outweigh the disadvantages if active control is assumed. This is based on the concept of CCV technology, which is used to make aircraft more maneuverable.