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Multidisciplinary Design Optimization of a Heavier-Than-Water Underwater Vehicle Using a Semi-Empirical Model

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A heavier-than-water underwater vehicle (HUV) is unlike an unmanned underwater vehicle. The most notable characteristic is its ability to balance its weight with the hydrodynamic lift of water even though the weight is much greater than the buoyancy. Since the hydrostatic equilibrium is not based on the balance between the gravity and the buoyancy, the vehicle has a smaller volume, a larger payload, and better maneuverability. However, the design of the vehicle relies heavily on the abilities of naval architects. In order to ease the reliance on naval architects and to improve the prototype design, we propose a multidisciplinary system model using a semi-empirical model and three multidisciplinary design optimization methods. We applied all-in-one method, analytical target cascading method, and bi-level integrated system collaborative optimization method to the conceptual design of the vehicle in order to attain an optimal multidisciplinary design characterized by minimal total weight, long-range cruising capabilities, and high maneuverability. The results from the three different methods show that the general performance of optimized HUV was significantly better than the performances of prototype design, which suggests the feasibility and superiority of model and optimization methods.

INTRODUCTION

Unmanned underwater vehicles (UUVs) used for ocean exploration can be divided into two types: (1) Remotely Operated Vehicle (ROV) (Barry and Hashimoto, 2009), which is remotely operated via a tether or umbilical, and (2) Autonomous Underwater Vehicle (AUV) (Wynn et al., 2014), which is operated by implemented programming. Over the past decades, thousands of unmanned vehicles have been made for industrial and scientific purposes. In recent years, the demand for increased range, payload, and intelligent control have led to a new type of conceptual AUV. For instance, the Underwater Engineering Research Institute at Shanghai Jiao Tong University (Wu et al., 2010; Yan et al., 2012; Li et al., 2014) proposed a heavier-than-water underwater vehicle (HUV). The idea is based on the theory of aircraft, which is in turn based on the balance between gravity and lift. Commonly, AUV has a state of neutral buoyancy or they are lighter than water, as is true for the Autosub, Thesus, REMUS and Hugin AUV that are being developed in European and North American countries. Therefore, buoyant material or equipment is used and the vehicle becomes larger and heavier. However, the HUV works with negative buoyancy during underwater cruising, which is completely different from the way that an AUV works. Consequently, the hydrostatic equilibrium of the HUV is not based on a balance between gravity and buoyancy because the lift generated by the wings at a high speed is significantly greater than the gravity. Therefore, more payloads, such as batteries, can be carried by the HUV to ensure the long-range capabilities of the vehicles. Moreover, the dimensions of the HUV are smaller than those of a traditional AUV, which, combined with the addition of wings and fins, improves maneuverability.

In 2009, Shanghai Jiao Tong University (Wu et al., 2010) designed the first experimental HUV prototype, called the Flying Fish I. The results of the experiment (conducted in a circular tank) showed that the concept of the HUV was practical, as shown in Fig. 1. In 2012, Shanghai Jiao Tong University (Yan et al., 2012) designed the Flying Fish II, which was an engineering prototype, as shown in Fig. 2.

Korte et al. (1997) provided the definition of Multidisciplinary Design Optimization (MDO), which is a methodology for the

Fig. 1 Flying Fish I (Wu et al., 2010)

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