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Shape optimization of blended-wing-body underwater glider by using gliding range as the optimization target

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Abstract

Blended-wing-body underwater glider (BWBUG), which has excellent hydrodynamic performance, is a new kind of underwater glider in recent years. In the shape optimization of BWBUG, the lift to drag ratio is often used as the optimization target. However this results in lose of internal space. In this paper, the energy reserve is defined as the direct proportional function of the internal space of BWBUG. A motion model, which relates gliding range to steady gliding motion parameters as well as energy consumption, is established by analyzing the steady-state gliding motion. The maximum gliding range is used as the optimization target instead of the lift to drag ratio to optimizing the shape of BWBUG. The result of optimization shows that the maximum gliding range of initial design is increased by 32.1% though an efficient global optimization (EGO) process.

Keywords: Blended-wing-body underwater glider; Shape optimization; Gliding range; Energy consumption model; Lift to drag ratio

1. Introduction

Underwater glider as a type of autonomous underwater vehicles (AUVs), which glides through the ocean by controlling their buoyancy and converting the lift on wings into propulsive force to propel themselves forward (Bachmayer et al., 2004), has been widely used in oceanographic sensing and data collection.

Blended-Wing-Body Underwater Glider (BWBUG), such as Liberdade XRAY (ONR, 2006) and Liberdade ZRAY (Hussain et al., 2011), is a new kind of underwater glider in recent years. The disk body of the BWBUG is blended and smoothed into the wings, and it is also a wing and a pitch control surface. This configuration reduces interference drag and provides additional effective wing chord at the wing-body junction, so the BWBUG has excellent hydrodynamic performance.

In the shape design research of underwater gliders (Graver, 2005, Ma et al., 2006, Jenkins et al.), the lift to drag ratio is the most important index to determine the shape of underwater gliders. In the authors previous study (Sun et al., 2015), the lift to drag ratio, as the optimization target, was used to optimize the shape of BWBUG, and excellent hydrodynamic performance has been obtained, However, from the result, it can be seen that the design which has sharper nose and thinner airfoil of the centerline achieves higher hydrodynamic performance but loses large volume. Hence, the lift to drag ratio is not suitable as the optimization target of shape optimization, because the interior space is also a important index for BWBUG. In 2013, Jiancheng Yu et al. (Yu et al., 2013) have studied how to increase gliding range of underwater gliders by optimizing the gliding motion parameters. This paper's author got enlightenment from this research that the gliding range can be a suitable optimization target of BWBUG's shape optimization.

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In this paper, the research focuses on studying the feasibility and the effect of using gliding range as the optimization target to optimize the shape of BWBUG. The energy consumption model has been established by analyzing the steady-state gliding motion of the BWBUG. For a specific BWBUG, the hydrodynamic parameters were estimated by the commercial code Fluent, and the maximum gliding range was obtained by optimizing the motion parameters. The Efficient Global Optimization (EGO) (Jeong et al., 2005) method is applied to solving this expensive black-box function optimization.

2. Parametric geometric model

2.1. Shape parameters of BWBUG

Fig. 1 shows the definition of the BWBs planform. The oval body is blended and smoothed into the wing by two cubic Bezier curves (Farin, 2002). Each cubic Bezier curve is drawn by four control points, and (z_1,z_2,z_3) represents the spanwise coordinate of the control points.

Typical symmetrical airfoil NACA 0012 is used as a baseline airfoil. As shown in Fig. 2, any section of the airfoil is designed with changing thickness of NACA 0012 (=12.0%c, c is the chord length of local section). Thickness is defined at the centerline (t_1c), the merging point (t_2c), and the section between the center-line and the merging point ($t_{body}c$) as shown in Fig. 3. To maintain spanwise monotonic distribution of the relative thickness, t_{body} is decided by following equation.

$$t_{body} = \left(1-\frac{z}{z_3}\right)\cdot t_1 + \frac{z}{z_3}\cdot t_2 (0 \le z \le z_3) \tag{1}$$

In order to determine the BWBUGs shape, 10 non-dimensional parameters which include 4 wing parameters, 4 body parameters and 2 airfoil parameters were defined as shown in Table 1.

In the authors' previous study (Sun et al., 2015), the relative sensitivities of the design variables have been analyzed as shown in Fig. 3. According to the sensitivities, L/D is sensitive to the change of t_2,t_1,n_1,n_2 and *angle*, and is insensitive to the change of n_3,AR,TR,DR and CR. In this paper, these high sensitivity parameters are used as the variables of this shape optimization design, and the values of the low sensitivity parameters are defined as the optimal design.

2.2. Volume of BWBUG

According to these shape parameters, the volume of the BWBUG can be obtained by computing a definite integral of the area of the foil section as shown in Fig. 4. The volume of the BWBUG can be expressed as

$$V_{UG} = 2\int_0^{b_t} S(z)dz \tag{2}$$

where $s(z)$ is the area of the foil section at the z plane. Because every foil section of BWBUG is NACA00 series airfoil, the $s(z)$ can be computed as

$$S(z) = S_{NACA0010}\cdot[C(z)]^2\cdot t(z) \tag{3}$$

where, $S_{NACA0010}$ is the area of NACA0010 airfoil with unit length, $c(z)$ is the chord length of local section, and $t(z)$ is the relative thickness of local section. So the volume of the BWBUG can be computed as

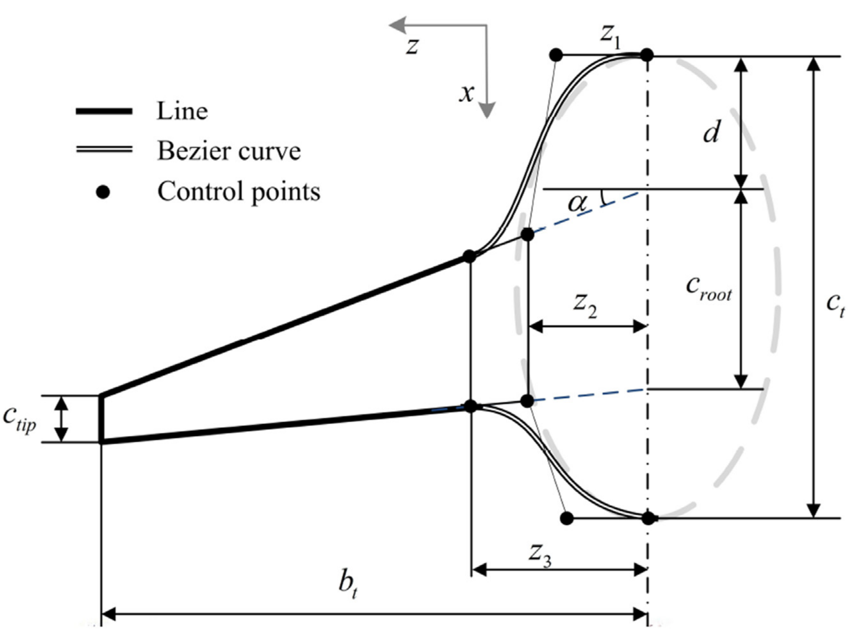

Fig. 1. Definition of planform.