A Study on the Design Optimization of an AUV by Using Computational Fluid Dynamic Analysis

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ABSTRACT

Autonomous Underwater Vehicles (AUV’s) provide an important means for collecting detailed scientific information from the ocean depths. The hull resistance of an AUV is an important factor in determining the power requirements and range of the vehicle. This paper describes a design method using Computational Fluid Dynamics (CFD) for determining the hull resistance of an AUV under development. The CFD results reveal the distribution of hydrodynamic values (velocity, pressure, etc.) of the AUV with a ducted propeller. The optimization of the AUV hull profile for reducing the total resistance is also discussed in this paper. This paper demonstrates that shape optimization in conceptual design is possible by using a commercial CFD package. The optimum designs to minimize the drag force of the AUV were carried out, for a given object function and constraints.

KEY WORDS: AUV; CFD (Computational Fluid Dynamics); Optimum design; Drag force; Drag Coefficient (CD)

INTRODUCTION

An unmanned AUV (Autonomous Underwater Vehicle) is a versatile research tool for maritime archaeology, oceanographic and marine biology studies, defense applications, and oil and mineral exploration and exploitation programs. Rapid progress in AUV development is steadily increasing the reliability and endurance of such vehicles to operate in the harsh marine environment. Much work, however, still needs to be done in terms of optimizing the hull design to minimize drag and increase propulsion efficiency.

In previous studies, designers have employed empirical formulas or used experimental derived data to estimate drag force of ships or submerged bodies such as AUVs. However, the conventional empirical formula is not able to accurately compute the drag of complex hull forms with appendages protruding from the hull. Although experimental testing using a tow tank or cavitation tank can produce very accurate predictions of drag, such testing requires considerable time and effort, and expensive test facilities to obtain the vehicle’s hydrodynamic characteristics. Consequently, a new drag estimation method is needed for development of a specific AUV, which can be applied to a conceptual design. The new method should be efficient, reliable, and also convenient for users.

In this paper, Computational Fluid Dynamics (CFD) tools are evaluated with the purpose of obtaining the hydrodynamic parameter (velocity, pressure, etc.) estimates of an AUV with a ducted propeller. The design of an AUV is optimized using CFD analysis to minimize drag force.

The methods reported in this paper for optimisation by CFD code are as follows: (1) CFD results analysis and comparison with theoretical or empirical equation for validation of reliability, (2) evaluation of an automatic element meshing method that generates a boundary layer which allows for appendages such as fins and ducts, and produces a stable and robust analysis, and (3) searching and identifying optimum design variables to produce minimum resistance.

INITIAL HULL DESIGN AND DRAG ESTIMATION OF THE AUV

Hull Design

At a conceptual design stage, the hull of an AUV can be divided into distinct sections, namely the nose, middle section, tail, and propeller duct. The AUV hull has been designed based on the Myring hull profile equations (Prestero, 2001) which is known to produce minimum drag force for a given fineness ratio, that is, ratio of its length to its maximum diameter \( l/d \). The curve shapes of the nose and tail sections are determined from equations (1) and (2), respectively.

\[
r(x) = \frac{1}{2} d \left[ 1 - \left( \frac{x-a}{a} \right)^{2} \right]^{1/8} \tag{1}
\]

\[
r(x) = \frac{1}{2} d \left[ \frac{3}{2c} \tan(\theta) \left( x - (a + b) \right)^{2} + \frac{d}{c} \left( x - (a + b) \right)^{3} \right] \tag{2}
\]

The designed shape of the AUV hull based on “Myring equation” and “NACA profile (NACA 6721)” is shown in Fig. 1. As the propeller blades rotate through the water, they generate high-pressure areas