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Numerical analysis of stability and manoeuvrability of Autonomous Underwater Vehicles (AUV) with fishtail shape

G. da Silva Costa [a,b], A. Ruiz [b], M.A. Reis [b], A.T. da Cunha Lima [c,d], M.P. de Almeida [e,d], I.C. da Cunha Lima [b,d,f,*]

[a] Instituto Federal de Educação, Ciência e Tecnologia da Bahia, Camaçari, BA, Brazil
[b] SENAI-Cimatec, Salvador, BA, Brazil
[c] Instituto de Física, Universidade Federal da Bahia, Salvador, BA, Brazil
[d] Instituto Nacional de Ciência e Tecnologia, INCT-GP, Salvador, BA, Brazil
[e] Departamento de Física, Universidade Federal do Ceará, Fortaleza, CE, Brazil
[f] Pursuelife - Consultancy on Applied Science, Salvador, BA, Brazil

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ABSTRACT

This paper aims to understand the stability and the manoeuvrability of an Autonomous Underwater Vehicles (AUV) through the simulation of the drag, lift and torque acting on the hull by the passing seawater. These are important questions in deep water conditions where telecommand is impracticable. The present study is based on the behaviour of a stern shaped as a fishtail in three different ways, and considers several attack angles. The solutions of the Navier-Stokes equations are computed with the OpenFOAM library. An open source library based on the Finite Volume Method (FVM) using C++ language. An analysis of the effects of the fishtail shape on the resistance and stability is based on the calculation of the averages drag, lift and torque. A filtering on the Fourier transform of the torque is used to discuss the manoeuvrability in each case.

1. Introduction

Advances on high-performance computing brought the possibility of numerically solving differential equations with high degree of difficulty, and also extensive problems requiring high processing power in a relatively short time. This is the case of the dynamics of an autonomous underwater vehicle (AUV) under the action of forces and torques generated by a fluid flow in a turbulent regime governed by the Navier-Stokes equation (Schlichting and Gersten, 2003). The present work aims to understand how the shape of the vehicle stern influences its stability and manoeuvrability taking into account the interaction of the vortices injected by the stern into the turbulent wake with the AUV hull. The analysis is performed for different attack angles. We adopted a quasi-two-dimensional model for the vehicle, using a fishtail shape for its stern, as shown in Fig. 1 and described below. We explored the effects produced by progressive changes on the fishtail shape on the forces and torques applied by the fluid flow on the AUV body. The wet area is preserved in the calculation of the three shapes. The choice of a quasi-two-dimensional model provides a much simpler way to understand the effects of these forces and torques, at the time it makes the computation much faster and treatable.

Recent studies (Seo et al., 2008; Cao et al., 2014; Wu et al., 2014) explored the use of CFD (Computational Fluid Dynamics) tools to analyze hydrodynamical components in AUV and other submersed structures. In the present case we performed the CFD calculation on the OpenFOAM platform (OpenFOAM; Greenshields, 2015). The OpenFOAM platform has been widely used for evaluating the dynamics of underwater vehicles. The OpenFOAM is an open source set of solvers for differential equations using the Finite Volume Method (FVM) (Versteeg and Malalasekera, 2007; Fletcher, 2006) in C++ language. The choice for this tool box was made based on its ample possibility of interaction with several platforms in CFD, on its versatility for solvers customization and on the fact that it is open source and free. Other calculations have been performed for AUV models subject to ocean currents. Ref. Seo et al. (2008) focus on the pitch degree of motion, which is primordial for an underwater glider. In Ref. Mansoorzadeh and Javanmard (2014), besides experimental procedures, an evaluation of drag and lift coefficients vs. relative submergence depth was made. Combining experimental and analytical results Ref. Chakrabarti et al. (2014) highlights the importance of the penguin shape in drag decrement and the necessity of a modern

* Corresponding author. SENAI-Cimatec, Salvador, BA, Brazil.
E-mail address: ivandacunhalima@pq.cnpq.br (I.C. da Cunha Lima).

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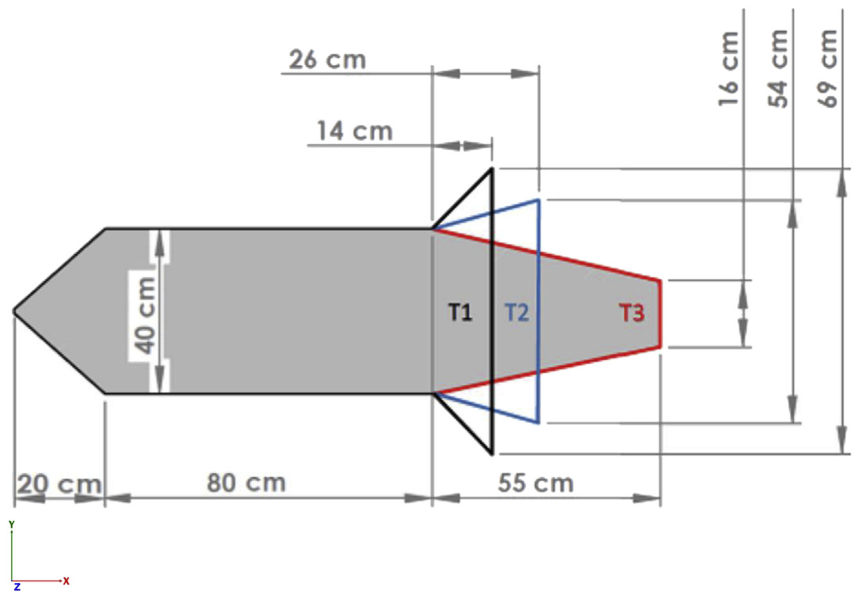

Fig. 1. 2-D AUV Models. Wet area is conserved in all three stern shapes.

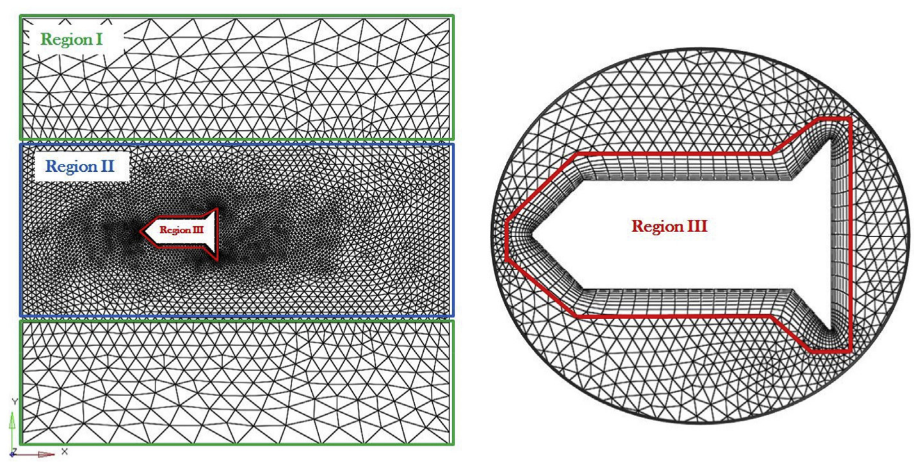

Fig. 2. The mesh of the domain is divided into three regions, taking T1 as an example. The figure shows region I limited by the green lines with a less refined mesh; region II, limited by the blue lines with an intermediate refinement; and region III, highly refined, enclosing the boundary layer. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

type of rudder for manoeuvrability control, since the penguin shape helps to lower the drag, but brings less stability. Numerical investigations with complex meshing developments performed on the Pirajuba AUV in Ref. Dantas and Dee Barros (2013) has shown satisfactory results using CFD tools when investigating manoeuvrability by analyzing the hydrodynamic efforts of the vehicle.

In this work we study the effects of the fishtail shape, as seen in Fig. 1, on the stability and manoeuvrability of AUV models when subjected to ocean currents. The forces and torques on the AUV body are calculated for different attack angles, in an attempt to identify parameters for optimizing the AUV shapes, in addition to establish a methodology for the analysis of manoeuvrability based on frequency filtering on the torque time series. At this point it is worthwhile to make explicit the meaning of quasi-two-dimensionality used in this work. First, we must say that the finite volume method used by OpenFOAM requires, necessarily, a three-dimensional domain (Greenshields, 2015). When building the mesh in this domain we can force a reduction on the dimensionality by defining a single cell in one of the directions. In the present case the reduced dimension is on the z-direction, where the single cell corresponds also to the thickness of the AUV. By doing this, no flow is allowed below or above the AUV. The fluid flows only on the xy-plane. In consequence, drag is the force acting on the AUV on the same direction of the general flow, considered as the x-direction, and lift is the force acting on the direction perpendicular to the flow, namely the y-direction. Both forces acting on the xy-plane, the torque consequently has component only on the z-direction, perpendicular to the plane where the AUV lies. This torque is responsible for the yaw motion, the rotation around the z-axis. Lift and drag forces act together and must be balanced by the forces provided by the thrusters. On the other hand, the control system has to respond also to the torque generated by all forces acting simultaneously. This torque acts on the AUV generating angular acceleration in the axis of yaw, the z-direction, the angular acceleration depending on the moment of inertia. The automated navigational system must respond immediately to angular acceleration, but it also must neglect high frequency components of this random motion. This is the reason, here, for performing the spectral analysis on the torque. The choice of the so called quasi-two-dimensional motion reduces enormously the computational difficulties on meshing and on the time processing. This choice also makes it much clear the physical properties behind the interaction of the turbulent flow and the shape of the AUV stern. It also contributes to