

ANALYSIS OF MANOEUVRING HYDRODYNAMICS OF UNDERWATER VEHICLES

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ANALYSIS OF MANOEUVRING HYDRODYNAMICS OF UNDERWATER VEHICLES

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CERTIFICATE

This is to certify that the thesis titled '**ANALYSIS OF MANOEUVRING HYDRODYNAMICS OF UNDERWATER VEHICLES**', being submitted by **AMIT RAY** is report of bonafide research work carried out by him under our supervision. This thesis has been prepared in conformity with the rules and regulations of Indian Institute of Technology Delhi, India. We further certify that the thesis has attained a standard required for a Ph.D. degree of the Institute. The research reported and results presented in the thesis have not been submitted in part or full to any other Institute or University for the award of any degree or diploma.

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Abstract

The study, prediction and optimization of manoeuvring characteristics of underwater vehicles are critical for their safe and efficient operation in unforgiving ocean depths.

Hydrodynamic Coefficients (HDCs) are commonly adopted to characterize the manoeuvring response of ships and submarines. HDC values are dependent on the geometry of underwater vehicles and these values are necessary in trajectory simulation programs for predicting the manoeuvring response of an underwater vehicle. HDCs for a particular geometry are typically evaluated by empirical methods (in early stages of design) or by model testing (after the geometrical configuration is finalized). In early stages of design of underwater vehicles, there is maximum scope for varying those geometrical characteristics of the vehicle that affect its manoeuvring qualities the most. However, in these stages, the empirical methods used for determination of HDCs are not very accurate. More accurate estimates using model testing (which is expensive and time-consuming) can be obtained only after the geometry of the vehicle design has been finalized, and merely serves to determine the manoeuvring performance of the vehicle, with little possibility of optimization.

The primary aim of this study has been to identify methodologies of applying general-purpose Computational Fluid Dynamics software (RANSE solver) to evaluate manoeuvring characteristics (HDCs) of underwater vehicles during preliminary stages of design. Such an approach attempts to overcome the drawbacks of lack of accuracy in empirical methods and the

expense and time requirements of scale-model-testing, while also avoiding the approach of developing customized, computationally expensive CFD software for the purpose.

The theoretical background of various aspects of the subject of manoeuvring studies of underwater vehicles has been described, including the Navier-Stokes equations, the definition of Hydrodynamic Coefficients and the mathematical approach for trajectory simulation using rigid body equations of motion.

An extensive review of the published literature on the techniques and approaches for prediction of manoeuvrability characteristics of submarines and AUVs has been presented. The techniques touched upon include empirical and semi-empirical methods, potential flow methods, bifurcation analysis, model testing, Recursive Neural Networks, system identification, CFD techniques and full-scale trials. The current state-of-art for the manoeuvrability prediction process has been described, as well as the strengths and weaknesses of the various approaches for manoeuvrability studies of underwater vehicles. The requirement for more accurate estimation of vehicle hydrodynamic coefficients (HDCs) at the early stages of design has thus been established.

General-purpose RANSE solver has been used with modest computational resources to determine quasi-steady 'hydrodynamic coefficients' (HDCs) of a generic underwater vehicle, for which experimental manoeuvring data are available. HDCs are a function of the body geometry and can be used to simulate the trajectory of the body (using Euler equations of motion) for various manoeuvres. By computing steady flow past the body at

various angles of attack, the oblique flow and rotating arm model tests have been numerically simulated. By plotting the forces and moments on the body for various angles of attack (and angular velocities), the respective HDCs were obtained from their very definition. These computations have been undertaken for un-appended (bare hull) as well as appended (submarine-like) configurations.

A semi-empirical (Slender Body) method has been used to determine those HDCs that could not be determined using CFD. In order to gain better insight into the entire process of manoeuvrability prediction, parametric studies have been performed for motion stability of underwater vehicles. The HDCs determined have been used for parametric studies to explore the effect of changes in geometric characteristics of the vehicle on its dynamic stability.

A flexible trajectory simulation program has been created, for which the HDCs determined have been used as inputs. The effects of variation in HDC values are examined using this trajectory simulation program. Sensitivity studies have been undertaken to identify the most significant HDCs. Realistic error bounds for the prediction process have been identified, and compared to the uncertainty expected in full-scale validation of trajectories for underwater manoeuvres. Other axisymmetric body geometries have also been considered.

It has been shown that the described approach of using general-purpose CFD software (RANSE solver, for steady flow in viscous fluid) for prediction of quasi-steady HDCs, requiring modest computational efforts, offers significant improvement in the accuracy of trajectory simulation, as compared to HDCs estimated by semi-empirical methods alone.

Thus, the approach of using CFD to determine critical viscosity-dependent vehicle HDCs, with remaining HDCs being estimated by empirical (slender body) methods, can be effectively used during early design stages of underwater vehicles to determine manoeuvring characteristics with greater accuracy and speed.

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