ANALYSIS OF MANOEUVRING HYDRODYNAMICS OF UNDERWATER VEHICLES

AMIT RAY

DEPARTMENT OF APPLIED MECHANICS

INDIAN INSTITUTE OF TECHNOLOGY DELHI

MAY 2010

ANALYSIS OF MANOEUVRING HYDRODYNAMICS OF UNDERWATER VEHICLES

by

AMIT RAY

Department of Applied Mechanics

Submitted
in fulfilment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

MAY 2010

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.

(Dr. S.N. Singh)
Professor
Department of Applied Mechanics
Indian Institute of Technology Delhi
New Delhi -110016, INDIA

(Dr. V. Seshadri)
Professor
Department of Applied Mechanics
Indian Institute of Technology Delhi
New Delhi -110016, INDIA

Date: May 2010

Place: New Delhi

Acknowledgements

With the blessings of Sri Gurudev, as this endeavour nears its destination, I have many people to thank for making it possible.

Professor V Seshadri and Professor SN Singh have guided this effort with their renowned expertise and attention to details. Their support, motivation and compassion have sustained me through many a difficult stretch. At every step, they were positive facilitators and enablers. This supportive ambience, coupled with their vast technical knowledge, has made this work possible. I am deeply thankful for their considerate guidance and cheerful encouragement at all times. I am also deeply grateful to Professor Debabrata Sen of IIT Kharagpur for his insightful guidance on the subject.

Valuable assistance in running many computational cases was provided by Mr. Ashok Benjamin and Mr. Desh Deepak. Their long hours of work produced numerous useful results, without which this work would have been greatly delayed, if not incomplete. Their efforts are gratefully acknowledged.

The work environment at the Naval Construction Wing, IIT Delhi, was the major enabling factor that allowed me to initiate this research in 2007. I am thankful to Captain VK Satyam for his encouragement during my tenure as adjunct faculty at IIT Delhi. I am deeply thankful to Commander R Vijayakumar for his encouragement and help in tackling pitfalls of CFD, as well as encouraging me to persevere with this effort. I am grateful to Commander PR Kulkarni for his guidance and inspiration. I am also thankful to the staff at NCW, especially Shri Dharam Singh, for their assistance.

Over the past (nearly) two years at IHQ / DNA, Commander Abhijit Majumdar was a pillar of support and I am thankful to him, as well as to Commander Bharat Tyagi, for their encouraging presence that made work so much more enjoyable. The work environment in the Directorate did not discourage this endeavour, and I am obliged to Commodore R Ghosh, Captain AK Dutta and Captain AS Mitra at DNA for their patronage.

I am thankful to Rear Admiral B Varadarajan for his guidance in giving initial direction to this research and to Commodore CS Rao for his interest and encouragement.

I am obliged to the Indian Navy for permitting me to undertake this doctoral research. I am grateful to Naval Research Board, DRDO, for sponsoring a research project that forms part of this study.

Finally, it was my wonderful family that made everything possible. My wife Sonali has been through many trying times when I have been distracted from family responsibilities by esoteric computations. For her extreme patience, tolerance and loving support, I am most grateful. These years of effort ate away into my time with her and our daughter Chetna: I can only thank them for cheerfully bearing with what has been my loss too. My parents have always been most supportive and encouraging. Words are inadequate to express my gratitude for everything they have provided me in life.

May 2010 (Amit Ray)

New Delhi Lt Commander

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.

Contents