Assessment of various turbulent models for drag prediction of DARPA Suboff model

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1. INTRODUCTION & OBJECTIVE

The importance of drag reduction in submarines lies in its ability to significantly enhance operational effectiveness and versatility. By reducing the drag, submarines could achieve higher speeds, improved maneuverability, and increased stealth, allowing them to respond swiftly to tactical situations, evade detection, and perform covert operations effectively. The DARPA Suboff submarine model was similar to Nancy et. al. [1] and the estimated resistance force acting on the surface of the submarine is validated with experimental work of Liu and Hung [2].

The objective of the present study is to analyze the fluid flow pattern over the surface of a submarine in a water body for optimizing its hydrodynamic performance. In this study, the drag analyses of an axi-symmetrical body with and without appendages DARPA Suboff has been done. The analyses have been carried out by assuming three-dimensional, turbulent, and incompressible thus the governing equations (RANS Equations) have been discretized with finite volume method (FVM). The study investigates the flow behavior of a submarine at varying speeds under two distinct cases: one near the water surface at 1.1 times the maximum diameter of the submarine and the other in a submerged state.

2. RESULTS & HIGHLIGHTS OF IMPOINTANT POINTS

In the first case, where the fully appended submarine operates close to the water surface, various turbulence models viz. LSST k-ω, QSST k-ω, LRST, QRST, ERST were assessed, assuming fluid to be steady and single-phase. For the purpose, numerical simulations were performed at different velocities ranging from 3.05 m/s - 9.15 m/s. Along with the resistance force offered by the fluid, the coefficient of drag is also found on the surface of the entire body. The resistance forces obtained are within the range when validated with the experimental data. In the second case, the submarine without appendages is submerged under water, where the flow is implicit unsteady and multi-phase. It was observed that, these advanced turbulence models are specifically tailored to capture complex turbulence phenomena in submerged bodies, enabling a detailed analysis of the flow characteristics and boundary layer behavior in this scenario.

The flow characteristics are obtained using scalar scene in STAR CCM+, a commercial CFD algorithm. Figure 1 illustrates the resistance force acting predicted through LSST turbulence model on the surface of the submarine and compares the experimental and computational results of the resistance force acting on the submarine body operating close to the water surface. From Figure 2 coefficient of drag plot, we can predict that as the velocity of the submarine increases the coefficient of drag decreases. Figure 3 illustrates the Volume of Fluid (VOF) contours of the submarine without appendages close to the surface with a speed of 3.02m/s at different orientation. Figures 3(i) and 3(ii) illustrate the VOF contours when observed perpendicular and parallel to the water surface respectively. High Resolution Interface Capturing (HRIC) scheme is used to show kelvin time wave pattern of the free surface.

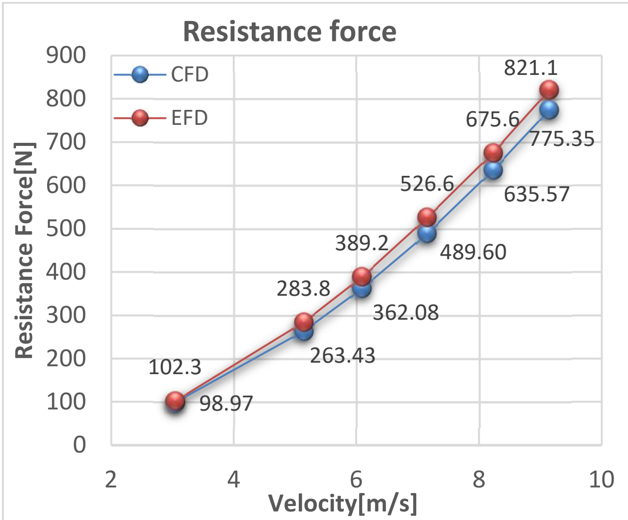

Figure 1: Resistance force on submarine surface [2]

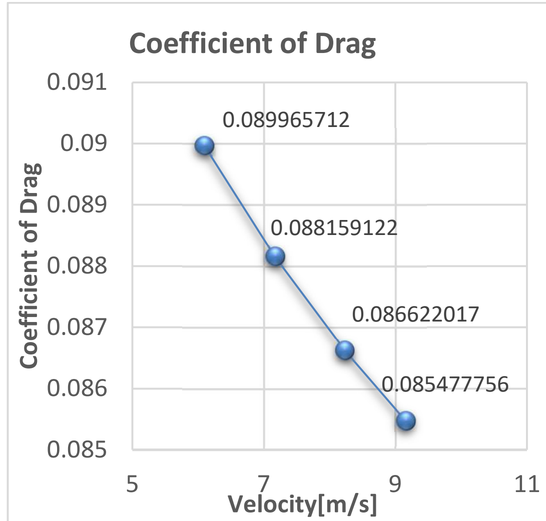

Figure 2: Coefficient of Drag [2]

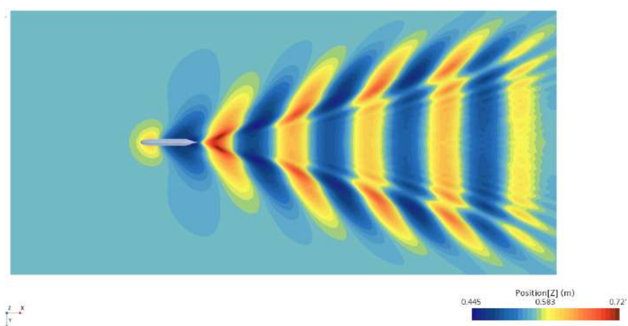

Figure 3(i): Scalar Scene of Volume of Fluid

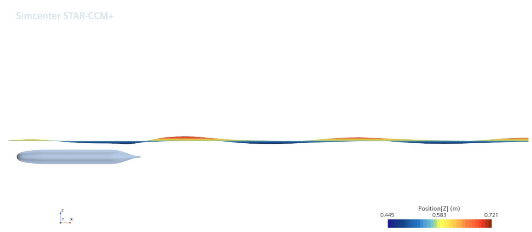

Figure 3(ii): Scalar Scene of Volume of Fluid

Throughout the study, various speeds of the submarine are considered to investigate the flow performance under different operational conditions. The coefficient of drag and the resistance offered by the fluid with different turbulence models have been estimated and compared with the experimental data. The results obtained from this study provide valuable insights into the hydrodynamic behavior of submarines.

Key words: DARPA submarine, STAR CCM+, Finite Volume Method (FVM), Resistance force, Coefficient of drag, Fluid structure interface.

REFERENCES

1. Nancy C. Groves, Thomas T. Huang and Ming S. Chang, "Geometric Characteristics of DARPA Suboff Models (DTRC MODEL NOS. 5470 and 5471)," 1989.
2. Han-Lieh Liu and Thomas T. Huang, "Summary of DARPA Suboff Experimental Program Data," S1974-030, 1998.