

Trajectory Tracking of a Near-Surface Torpedo using Numerical Methods

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ABSTRACT: Prediction of ship's and underwater body's (submarines, torpedoes and missiles) trajectory is a very important job as far as defense and engineering are concerned. From the defense point of view, details of the trajectory would provide necessary information to the commander for the controllability of the vessel and the armaments it houses, in case of an emergency pertaining to the nation's safety. On the other hand for an engineer, the trajectory of the vessel and the armaments would provide a lot of information about aspects related to its controllability. This information can be very effective in the successful design, launch and navigation of the vessel and the armaments. Present work focuses on the trajectory prediction of a torpedo using numerical methods. A Japanese type 91 torpedo has been considered here. Computational Fluid Dynamics (CFD) simulations have been carried out in order to estimate the forces and moments acting on the torpedo by inducing harmonic motions. Two cases have been considered here viz. pure sway and pure yaw. The forces and moments have been subjected to harmonic analysis using Fourier series and the hydrodynamic derivatives have been calculated. The derivatives have been used in the Equations of motion and the trajectory of the torpedo at any instant of time has been calculated using an in-house developed MATLAB code.

KEYWORDS: CFD simulations, harmonic motions, pure sway, pure yaw, trajectory prediction detection

I. INTRODUCTION

Prediction of ships' and underwater body's trajectory is a very important job as far as defense and engineering are concerned, as its trajectory would provide a lot of information about aspects related to its controllability. The modern torpedo is an Autonomous Unmanned Underwater Vehicle (AUV) with an explosive warhead, launched above or below the water surface, propelled underwater towards the target and designed to detonate either on contact with its target or in proximity to it. The hydrodynamic performance of AUV is an area of interest having implication for control, launch, navigation, energy requirements and payload. Thus understanding the hydrodynamic performance of an AUV is essential to determine its capability to perform a successful mission. Present work focuses on the trajectory prediction of a torpedo using numerical methods.

Initial work on CFD simulations of ship-like bodies in maneuvering motion was carried out by [7]. More realistic quasi-steady state simulations were successfully accomplished in [3], [4], [6] and [11]. [10] carried out the CFD simulations on under water ellipsoids with prescribed sinusoidal motions. Same method with non-linear mathematical modeling has been adopted by [8] to a container ship. In [9] better meshing strategies for enhancing the results were presented. In the present work the afore developed methods and meshing techniques have been applied to a torpedo for the prediction of its trajectory.

II. HYDRODYNAMIC DESIGN AND ANALYSIS

For considering the motion of underwater bodies the hydrodynamic forces acting on all six degrees of freedom are important ([2], [5]). The six degrees of freedom are Surge (x), Sway (y), Heave (z), Roll (θ), Pitch (Φ), Yaw (Ψ) where the first three represent linear motions in x, y and z direction and the last three represent angular motions about x, y and z axes respectively. The equations of motion which have terms representing hydrodynamic forces and moments acting on the vehicle are often expanded about some convenient reference condition. This reference condition is usually taken to be the equilibrium condition of forward motion at a constant speed U. Also a rectangular Cartesian coordinate system is attached to the vehicle for this, where the centre of gravity of the vehicle is chosen as the origin. The path of the vehicle is then assumed to be intentionally altered slightly by deflection of various control

surfaces on the vehicle due to hydrodynamic effects. Thus the vehicle acquires components of translational velocity u , v and w in x , y and z axes respectively. Also it acquires angular velocities p , q and r about x , y and z axes respectively. The linear and angular velocities are obtained by differentiating the corresponding linear and angular displacements. Differentiating the corresponding linear and angular velocities we get the respective linear and angular accelerations. In the real scenario the hydrodynamic forces and moments acting on all six degrees of freedom are important, but here we are considering the surfacing motion of an underwater body which involves only horizontal forces and moments. All vertical forces and moments are balanced by buoyancy. Therefore only surge, sway and yaw motion need to be considered. The equations of motion are hence given by Eq. 1 through 3.

$$X = X_{\dot{u}}\dot{u} + X_{u^2}u^2 \tag{1}$$

$$Y = Y_{\dot{v}}\dot{v} + Y_v v + Y_{\dot{r}}\dot{r} + Y_r r \tag{2}$$

$$N = N_{\dot{v}}\dot{v} + N_v v + N_{\dot{r}}\dot{r} + N_r r \tag{3}$$

Where $X_{\dot{u}}$, X_{u^2} are the hydrodynamic coefficients or hydrodynamic derivatives for surge motion, $Y_{\dot{v}}$, Y_v , $Y_{\dot{r}}$, Y_r are the hydrodynamic coefficients for sway motion and $N_{\dot{v}}$, N_v , $N_{\dot{r}}$, N_r are the hydrodynamic coefficients for yaw motion. The equation for pure sway and yaw is comparable with Fourier series expansion up to 1st harmonic; and the Fourier constants are determined by numerically integrating the results of computer simulations. Forward velocity test is used to find damping coefficient X_{u^2} acting in x direction. The added mass coefficient $X_{\dot{u}}$ acting in x direction is obtained from some empirical relations. Thus we obtain all the hydrodynamic coefficients for surfacing motion of the given underwater vehicle.

III. DESCRIPTION OF MODEL AND SPECIFICATIONS

Here the Japanese type 91 torpedo is chosen for analysis with slight modification in the length and tail geometry to make it simplified with Length of model (L) = 5.094 m and mass of material (m) = 4428.97 kg

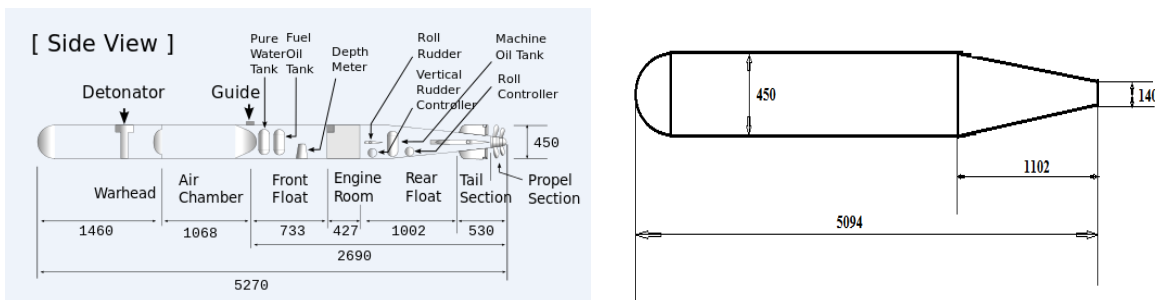


Fig. 1: Actual and Modified Dimensions (in mm)

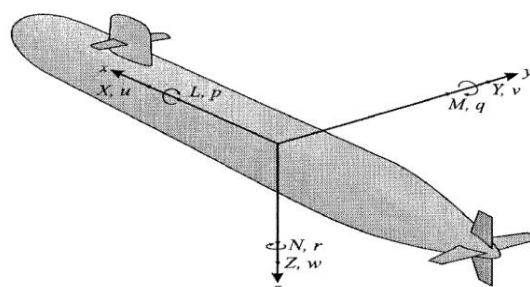


Fig. 2: Co-ordinate system for simulations [5]

IV. SIMULATIONS

RANSE based CFD simulations have been carried out in pure sway (translation about y -axis) and pure yaw (rotation about z -axis) by inducing rigid body motions on the torpedo in its sea environment. The meshing strategy adopted here is in accordance with [9]. The boundary conditions are as in [1]. Various motion parameters used to accomplish the simulations are given in Table 1.

Table 1 Motion Parameters

Motion Parameters	Values
Forward Velocity, U	2 m/s
Angular Velocity of Oscillation, ω	0.5 rad/s
Amplitude of Pure Sway Motion, y_0	0.3 m
Amplitude of Pure Yaw Motion, Ψ_0	0.0873 rad

Time histories of sway force and yaw moment in pure sway and yaw simulations have been shown in Fig. 3 and 4.

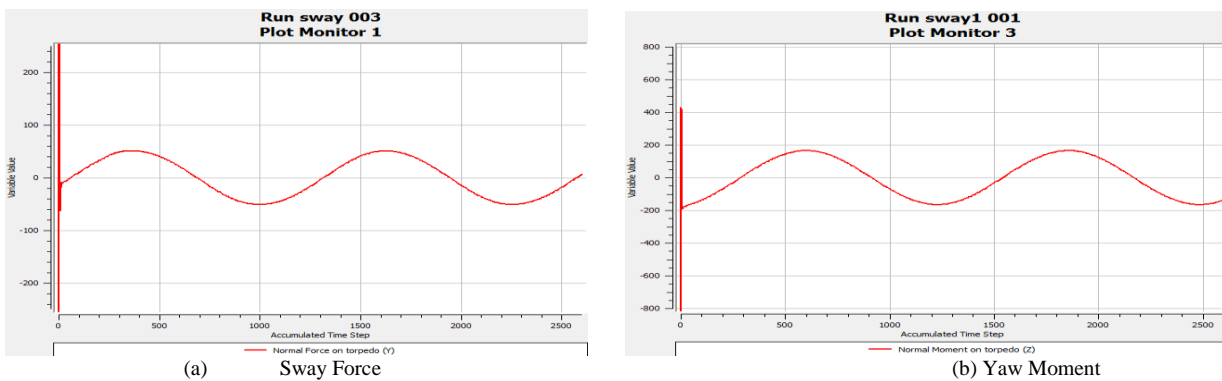


Fig. 3: Time histories of forces and moments in pure sway simulation

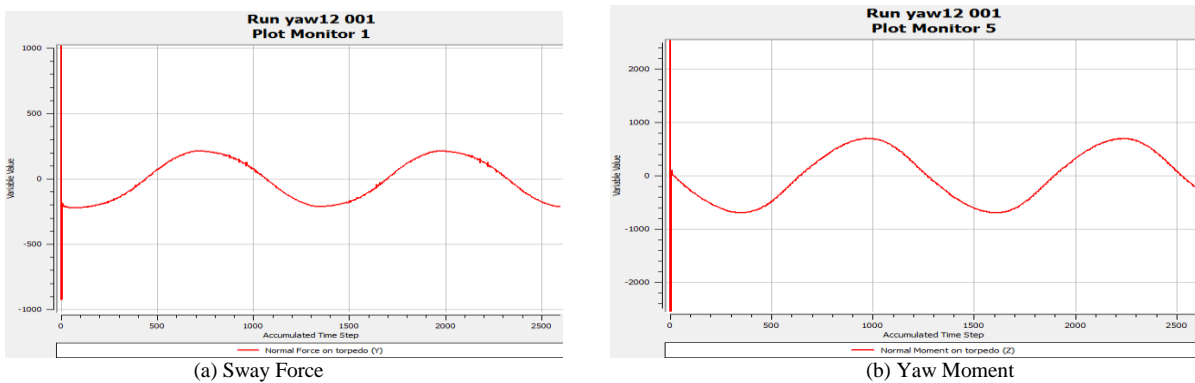


Fig. 4: Time histories of forces and moments in pure yaw simulation

Resistance versus forward velocity has also been plotted to get the derivatives dependent on forward velocity.

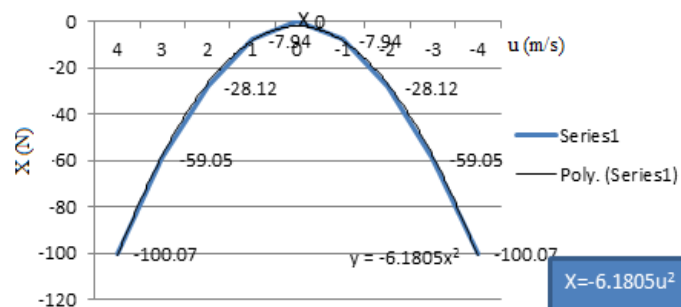


Fig. 5: Variation of resistance with forward velocity

V. RESULTS AND DISCUSSIONS

Results of CFD simulations have been subjected to harmonic analysis and hydrodynamic derivatives have been determined. A Program has been written in MATLAB to plot the trajectory of torpedo which takes the hydrodynamic derivatives as well as the specifications of torpedo as input. The forward velocity of torpedo is 12 m/s. Rudder angle is incremented uniformly from 0° to 5° through 10 seconds after which a constant rudder angle of 5° is maintained and obtained the turning circle manoeuvre plot of torpedo. Using the MATLAB results we study the behaviour of torpedo.

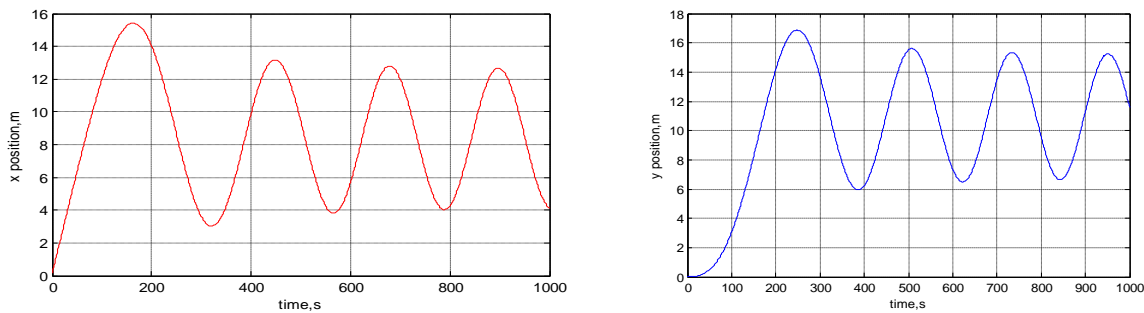


Fig. 6: Plots showing variations of x position (m) & y position (m) with time(s).

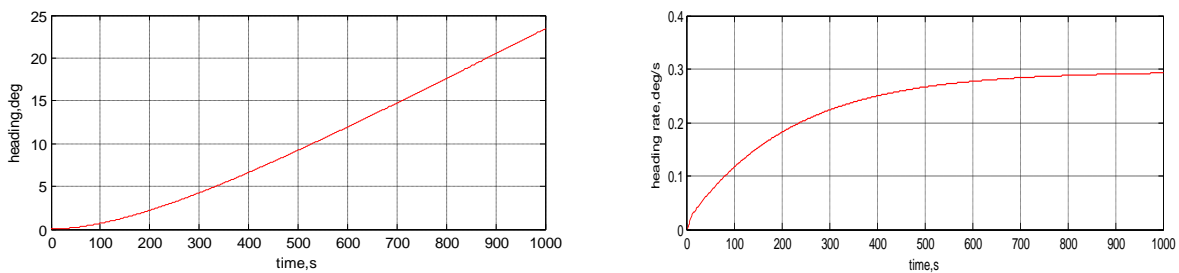


Fig. 7: Plots showing variations of Heading Angle (deg) & Heading Rate (deg/s) respectively with time(s)

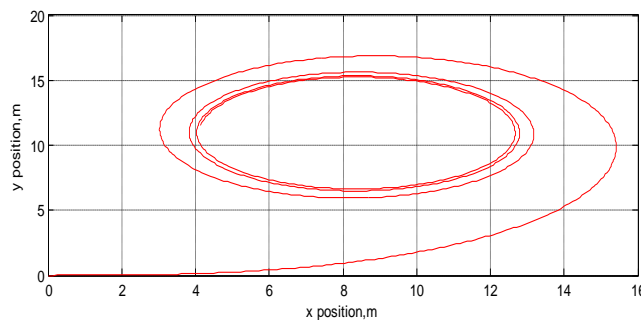


Fig. 8: Plot showing y position (m) v/s x position (m) (turning circle manoeuvre).

VI. CONCLUSION

The results obtained after simulations are found to be satisfactory and it gives the standard manoeuvre of a particular torpedo. Hence it is seen that using this numerical technique we can predict the path of torpedo in standard and desired manoeuvres. The method can be also be used to predict the trajectory of an enemy submarine if its dimensions are known. Now that we have assessed the maneuverability of the torpedo and also the done the prediction of its path, guidance of the torpedo to hit its target can be achieved through an autopilot.

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