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# Virtual simulation of maneuvering captive tests for a surface vessel

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**ABSTRACT:** *Hydrodynamic derivatives or coefficients are required to predict the maneuvering characteristics of a marine vehicle. These derivatives are obtained numerically for a DTMB 5512 model ship by virtual simulating of captive model tests in a CFD environment. The computed coefficients are applied to predict the turning circle and zig-zag maneuvers of the model ship. The comparison of the simulated results with the available experimental data shows a very good agreement among them. The simulations show that the CFD is precise and affordable tool at the preliminary design stage to obtain maneuverability performance of a marine vehicles.*

***KEY WORDS:*** Maneuvering; Computational fluid dynamics (CFD); Hydrodynamic derivatives; Oblique towing test (OTT); Planar motion mechanism (PMM).

## INTRODUCTION

Maneuverability is an important quality of marine vehicles. It should be controlled during various design stages and at the end of building the vessels. It has influences on efficiency and safety of marine transportation system. Maneuvering of a marine vehicle is judged based on its course keeping, course changing and speed changing abilities. International Maritime Organization (IMO) recommends criteria to investigate ship and other marine vehicles maneuvering quality (IMO, 2002a; 2002b).

Maneuverability of a ship or another marine vehicle may be predicted by model tests, or mathematical models or both. Mathematical models for prediction of marine vehicle's maneuverability may be divided into two main categories called as hydrodynamic models, and response models. The hydrodynamic models are of two types and recognized as the hydrodynamic coefficient models such as Abkowitz (Abkowitz, 1969) model and modular models such as MMG (Yoshimura, 2005) model. The Abkowitz model is based on the Taylor series expansion of hydrodynamic forces and moments about suitable initial conditions. The MMG model decomposes hydrodynamic forces and moments into three components namely: the bare hull; rudder; and propeller and also considers the interaction between them. The response model investigates the relationship for the motion responses of the vehicle to the rudder action and used to investigate the course control problems (Nomoto, 1960).

The hydrodynamic models, such as the Abkowitz formulation, contain several derivatives that are known as the hydrodynamic coefficients. These hydrodynamic coefficients should be determined in advance to proceed into the predicting the maneuvering characteristics of a marine vehicle. These hydrodynamic coefficients are named as added mass and damping

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coefficients. All of them are functions of the geometry of the vessel and the added mass coefficients depend on the acceleration of the vessel while the damping coefficients are velocity dependent. The added mass coefficients can be computed through the solution of the non-viscous fluid flow around the vessel. The damping coefficients are due to the wave formation in the free surface of the water and the effect of the viscosity. The total damping coefficients may be obtained through the solution of viscous fluid flow around the vessel.

There are several methods to obtain hydrodynamic coefficients such as analytical approach, semi empirical formulas, captive model tests, and Computational Fluid Dynamics (CFD). Analytical approach is based on potential flow theory and therefore the effect of viscosity is ignored. It can provide the added mass coefficients and the part of damping coefficients due to the wave formation on the free surface of water. Semi empirical formulas are obtained using linear regression analysis of captive model test data. They can provide the coefficients only for some specific geometrical shape and are inaccurate when the particulars of vessel are outside of the database. The captive model tests provide the hydrodynamic coefficients through the running the tests: Rotating Arm Test (RAT) or Circular Motion Test (CMT) and Planar Motion Mechanism (PMM) test. The PMM test is done in a towing tank and the RAT is run in a maneuvering basin.

The PMM tests may be done in a straight path when the model has a drift angle with the fluid flow. Such a test is called as Oblique Towing Test (OTT) and provides the damping coefficients depending on the translational velocities. The oblique towing test is a stationary test since the model is running with a constant velocity in a straight path and therefore, there is no acceleration involved. The PMM tests may also be done in a sinusoidal path with various orientation of the body. These types of tests are also called as dynamic tests since the body is acted by inertia forces. The dynamic tests can provide the acceleration and velocity dependent hydrodynamic coefficients. Two of the most important PMM tests are pure sway and pure yaw tests. These types of model tests need special equipment and are expensive, time consuming and their results include the scaling effects due to inconsistency of Reynolds number between the ship and the model.

CFD can also be used to obtain the maneuvering hydrodynamic coefficients of a marine vehicle such as a ship by virtual simulation of the captive model tests. CFD methods use the Navier-Stokes equations to model a given fluid flow. There are various approaches to solve the fluid flow equation for a viscous flow such as the flow around a maneuvering ship. These methods may be listed as Direct Numerical Simulation (DNS), large eddy simulation (LES) and Reynolds averaged Navier-Stokes (RANS) methods. DNS and LES need very high computational capacity. RANS models are time-averaged formulations of fluid flow motion equations and are based on statistical tool known as Reynolds decomposition.

Application of RANS to solve the maritime problems goes back to (Wilson et al., 1998) who have obtained unsatisfactory results. By the increasing growth of computing capacities and recent progress in RANS models, stunning advances in this field are achieved. Nowadays, CFD is crucial tool for various aspect of a marine vehicle hydrodynamics such as ship resistance and propeller performance not only for research but also as a design tool. One of the most recently and important application of CFD in marine industry is computation of hydrodynamic coefficients of marine vehicles by simulating the captive model tests. Sarkar et al. (1997) develop a new computationally efficient technique to simulate the 2-D flow over axisymmetric AUVs by using the CFD software PHOENICS. Nazir et al. (2010) and, Zhang et al. (2010) apply the commercial CFD software Fluent to obtain hydrodynamic coefficients of 3-D fins and an AUV, respectively. Tyagi and Sen (2006) compute transverse hydrodynamic coefficients of an AUV using a CFD commercial software. The hydrodynamic forces and moments on an AUV due to the deflection of control surfaces are investigated using ANSYS Fluent commercial CFD software by Dantas and de Barros (2013). Ray et al. (2009) apply CFD software Fluent to compute linear and nonlinear hydrodynamic coefficients of the DARPA Suboff submarine in an unrestricted fluid flow. The above presented studies use CFD methods to calculate the hydrodynamic coefficients of underwater marine vehicles. However, the CFD methods are also used to predict the hydrodynamic coefficients of ships. Stern et al. (2011) review the several works have been done in SIMMAN workshop to simulate captive maneuvering tests. Simonsen et al. (2012) simulate the fixed OTT for the KCS model by employing the commercial CFD software STAR-CCM+ to calculate the hydrodynamic coefficients. Hajivand and Mousavizadegan (2015) simulate OTT for the DTMB 5512 model by applying OpenFOAM software. They study the effect of dynamic trim and sinkage on hydrodynamic coefficients.

The Star-CCM+ software is applied to simulate the OTT and dynamic PMM tests for a DTMB 5512 ship which is a 1/46.6 scale geosym of DTMB model 5415 shown in Fig. 1. Particulars of the model are given in Table 1. The OTT simulations are done for wide range of the drift angles to obtain nonlinear damping coefficients. The dynamic PMM test simulations are done