Maneuvering Prediction of the Tugboat Vessel Based on CFD Methods

Yangying He, Linying Chen*
School of Navigation, Wuhan University of Technology
Wuhan, Hubei, P.R. China

Qingsong Zeng
Green & Smart River-Sea-going Ship, Cruise, and Yacht Research Center, Wuhan University of Technology
Wuhan, Hubei, P.R. China

Song Zhang
School of Transportation and Logistics Engineering, Wuhan University of Technology
Wuhan, Hubei, P.R. China

ABSTRACT

An accurate maneuvering mathematical model is essential in ship motion prediction and autonomous navigation. This article analyzes the hydrodynamic characteristics and establishes a maneuvering mathematical model of an Azimuth-Stern-Drive ship. The virtual captive model tests are carried out with straight, oblique towing, and static turning conditions by CFD software Star CCM+. The hydrodynamic forces, moment, flow field tendency, and details are obtained. Meanwhile, 3-DOF MMG hydrodynamic derivatives are computed using the least square method. This work establishes an accurate maneuvering model of the bare hull and provides a better understanding of tugboat maneuverability.

KEYWORDS: CFD; MMG model; Virtual captive model tests

INTRODUCTION

Maneuvering mathematical model is the basis of ship trajectory prediction, motion control, and autonomous navigation. (Guo and Zou, 2017; He et al., 2022b). There are two kinds of manners for expression of the mathematical model, Abkowitz (Abkowitz, 1969) and MMG (Mathematical Modeling Group) (Ogawa et al., 1977). Due to the simple structural form and specific physical meaning of the hydrodynamic derivatives, the MMG model is widely used in ship engineering.

There are various methods for determining the hydrodynamic derivatives in the MMG framework, among which, the captive model test is the most reliable one. It concludes both static captive model test, such as the Oblique Towing Test (OTT) and Circular Motion Test (CMT) and dynamic captive model test, such as Planar Motion Mechanism (PMM) (Li et al., 2018) Compared to the static captive model test, the hydrodynamic derivatives obtained by the PMM test remarkably change due to the influence of motion frequency and the motion amplitude given in the test. It is challenging to select the proper values for the maneuvering simulations. To avoid uncertainty, the static captive model test is employed here instead of the PMM test (Yasukawa and Yoshimura, 2015). Compared with theoretical analysis and experimental tests, computational fluid dynamics method now could meet the accuracy requirements and save certain costs. Liu (Liu et al., 2019; Yao et al., 2021) predicted the sinkage and trim motion of KCS based on CFD method; Yao (Yao et al., 2021) studied the maneuverability of KVLCC2 with RANS resolution; and in the work of Piaggio (Piaggio et al., 2020, 2021), the hydrodynamic forces and moments of an escort tug at slow- and high-speed conditions are investigated via virtual static and dynamic constraint model tests. The conclusions indicate the capability of CFD method on ship hydrodynamic performance and maneuverability modeling. And in this work, CFD method is adopted to study the hydrodynamic forces and flow field characteristics of a modified tug ‘WillLead I’.

METHODOLOGY

Coordinate systems

Two right-handed Cartesian coordinate systems are adopted, i.e., the earth-fixed coordinate system $O_{e}-x_{e}y_{e}z_{e}$, and the body-fixed coordinate system $O-xyz$, see Fig.1. The origin of body-fixed coordinate system is located at the intersection of waterplane, the center plane and the mid-ship section. Its longitudinal axis $x$ is directed from aft to fore, the transversal axis $y$ is directed to starboard, and the normal axis $z$ is directed from top to bottom. Ship turning to the starboard side is defined as the positive rotating rate. $u,v,r$ are the surge velocity, sway velocity, and yaw rate; $\psi$ is the heading angle ($\psi = \varphi$); $\beta$ is drift angle defined by $\beta = \tan^{-1}(-v/u)$; $U$ is ship speed, defined as $U^2 = \sqrt{u^2 + v^2}$.