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Assessment of ship manoeuvrability by using a coupling between a nonlinear transient manoeuvring model and mathematical programming techniques*

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Abstract: In this paper, a numerical method based on a coupling between a mathematical model of nonlinear transient ship manoeuvring motion in the horizontal plane and Mathematical Programming (MP) techniques is proposed. The aim of the proposed procedure is an efficient estimation of optimal ship hydrodynamic parameters in a dynamic model at the early design stage. The proposed procedure has been validated through turning circle and zigzag manoeuvres based on experimental data of sea trials of the 190 000-dwt oil tanker. Comparisons between experimental and computed data show a good agreement of overall tendency in manoeuvring trajectories.

Key words: ship manoeuvrability, hydrodynamics coefficients, nonlinear transient dynamics, sensitivity analysis, mathematical programming

Introduction

Controlling ship manoeuvrability, especially when approaching ports in foggy weather or by night time, is a vital concern. Nowadays, it is still tedious to perform real ship manoeuvres in an open sea or to carry out fine simulations using complex 3-D CFD calculations. In spite of their fast calculations, system-based simulations need numerous tests to adjust the manoeuvring hydrodynamic coefficients (hull, rudder, propeller,...) in order to achieve quantitative agreement with the experimental measurements. In this context, manoeuvrability turns out to be an essential ability to perform a safe navigation of any ship against the danger of collisions and stranding.

Thus, enhancement of ship manoeuvrability in different approaches is introduced more and more in the early design stage of ships and vessels. It is important to understand the ship manoeuvrability in the early design stage. In order to force the vessel motion to follow a prescribed trajectory, accurate prediction of hydrodynamic forces acting on a ship hull and interaction among them, propeller and rudder is essential. A literature survey[1-3] showed that there exist three methods for ship manoeuvrability prediction: the experiment-based method, the system-based method and the CFD-based method. A general overview of methods for ship trajectory prediction is given in Fig.1.

Manoeuvring experiments can be accomplished in two different ways, depending on the testing purpose, facilities and equipment, as free sailing or captive model tests. Objectives of manoeuvrability test are: the verification of manoeuvrability to fulfill the

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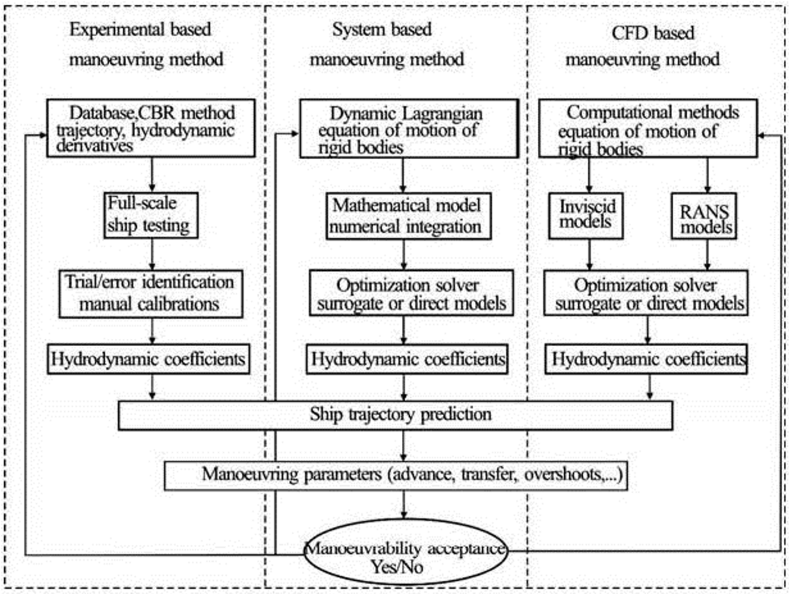

Fig.1 Overview of methods for ship trajectory prediction

International Maritime Organization (IMO) criteria, and the determination of hydrodynamic manoeuvring coefficients. Although this method is effective, unfortunately, experimental determination of the hydrodynamic coefficients might be tedious and expensive.

The CFD–based method allows determining not only the motion of the ships but also the flow field around ships by solving a set of Reynolds-Averaged Navier-Stokes (RANS) equations[3,4]. Lately, the CFD–based method has been extended for free-running simulations, including measurable data from experimental fluid dynamics for ship manoeuvres in calm sea and in the presence of waves. In their numerical investigations, Fonfach et al.[5] used CFD with both free surface model and rigid wall free surface assumption to study the interaction between a smaller tug and a larger tanker moving in parallel and close to each other at low speed in shallow water. For surge force, sway force and yaw moment in different water depths and Fr, they showed that CFD results give better agreement with experimental fluid dynamics than available Potential Flow (PF) results.

The system–based method is a major simulation task to predict ship manoeuvrability[2]. Computation time is much shorter than that of CFD–based method since such method needs only solve the equations of motion using a prescribed mathematical model and manoeuvring coefficients. System–based method requires approximately a few minutes of computation on a personal computer for one free-running trial while CFD method needs a few hours or even days depending on the turbulence and propulsion modeling and the mesh size.

System–based methods have been extensively investigated by researchers[6-8]. A simplified mathematical formulation can be obtained by using Taylor's series expansion method. The course keeping stability of the ship can be investigated on the basis of the stability of the solutions of the linear equations of motion, if only first-order terms of this expansion are considered. However, the manoeuvres at high rudder deflection angles require the consideration of nonlinear hydrodynamic and inertial components. This leads to the utilization of nonlinear hydrodynamic models, which include higher-order terms of Taylor's series expansion of the hydrodynamic external forces and moments[6].

Generally the manoeuvring coefficients are supposed to be constant. Nonetheless, recently Araki et al.[3] showed a great disparity of manoeuvring coefficients when including waves in which the encounter frequency is low. The complexity of the hydrodynamic processes caused by the wide variety of ship shapes, sizes and motions leads to a multitude of mathematical models. Thus, to obtain an optimized trajectory and also a better understanding of ship manoeuvring it is necessary to improve the understanding of the hydrodynamic forces acting on the hull, the rudder and the propeller. Several mathematical models of dynamic ship motion have been proposed in the literature to identify the hydrodynamic parameters[9,10]. Yoon and Rhee[11] investigated a mathematical model based on the Estimation-Before-Modeling (EBM) technique, which is an identification method that estimates parameters in a dynamic model. The algorithm was validated using real sea trial data of a 113 K tanker. Viviani et al.[12] carried out a numerical study based on optimization techniques that used a Multi-