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ScienceDirect
Journal of Hydrodynamics
2016,28(2):284-292
DOI: 10.1016/S1001-6058(16)60630-3

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science/journal/l0016058

Manoeuvring prediction based on CFD generated derivatives*

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(Received September 25, 2015, Revised November 11, 2015)

Abstract: This paper presents numerical predictions of ship manoeuvring motions with the help of computational fluid dynamics (CFD) techniques. A program applying the modular concept proposed by the Japanese ship manoeuvring mathematical modelling group (MMG) to simulate the standard manoeuvring motions of ships has been initially developed for 3 degrees of freedom manoeuvring motions in deep water with regression formulae to derive the hydrodynamic derivatives of the vessels. For higher accuracy, several CFD generated derivatives had been substituted to replace the empirical ones. This allows for the prediction of the maneuverability of a vessel in a variety of scenarios such as shallow water with expected good results in practice, which may be significantly more time-consuming if performed using a fully CFD approach. The MOERI KVLCC2 tanker vessel was selected as the sample ship for prediction. Model scale aligned and oblique resistance and Planar Motion Mechanism (PMM) simulations were carried out using the commercial CFD software StarCCM+. The PMM simulations included pure sway and pure yaw to obtain the linear manoeuvring derivatives required by the computational model of the program. Simulations of the standard free running manoeuvers were carried out on the vessel in deep water and compared with published results available for validation. Finally, simulations in shallow water were also presented based on the CFD results from existing publications and compared with model test results. The challenges of using a coupled CFD approach in this manner are outlined and discussed.

Key words: manoeuvring derivatives, shallow water, computational fluid dynamics (CFD), mathematical modelling group (MMG) model, KVLCC2

Introduction

Ship's maneuverability has drawn much attention nowadays, especially in shallow water which is of great importance for vessels navigating in port areas or channels. Generally speaking, it can be evaluated by free running model tests or numerical simulations using computers in the early design stage. From the point of lower costs and systematic study with minimum scale effects, the latter option has been the focus in recent decades[1]. With the progress of modern CFD techniques, simulation by a fully CFD approach is believed to give more accurate prediction. However, it is time-consuming and still not mature enough for practical applications. A more practical alternative is the method of computer simulation using the mathematical models which is known as the system based method. There are two distinct groups of mathematical models according to the manner in which to express the hydrodynamic forces and moments acting on the vessel. The group by decomposing the forces and moments into three separate parts on the bare hull, the propeller and the rudder respectively has been widely applied and was first proposed by the Manoeuvring Modeling Group at the Japanese Towing Tank Conference in the 1970's[2]. From then on, several different expressions of hull forces and moments have been established based on this modular concept for higher accuracy purpose. The expressions proposed by Kijima[3], adopted in the present original program as the regression formulae to estimate the hydrodynamic derivatives in the expression,are completed and suitable for modern ship forms. Validations were firstly carried out on the sample ship in deep water by using this original program to execute standard manoeuvers of a turning motion and a Zig-Zag motion with some of the hydrodynamic derivatives generated from CFD

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computations. Regarding the shallow water cases, the expression of the hull forces and moment is replaced by a 3rd order polynomial expression with derivatives obtained by model tests or CFD method from existing publications[4,5]. Typical phenomena due to the shallow water effects are illustrated by plotting the simulation results at different water depths together.

1. MOERI KVLCC2 general parameters

The MOERI KVLCC2 tanker hull and propeller is a benchmark test case for hydrodynamic applications. In the CFD work, simulations have been carried out with the vessel at 1:80 scale, while the MMG model simulation uses full scale. The Table 1 shows the general parameters for the vessel at full scale and 1:80 scale[6].

Table 1 KVLCC2 general parameters

Parameter	Full scale	1:80 scale
Length, L_{PP} /m	320	4
Waterline length, L_{WL} /m	325.5	-
Beam, B /M	58	0.73
Scantling draft, d /m	20.80	0.26
Displacement, Δ /t	320 438	0.61
Surface area w/o rudder, S /m^2	27 194	4.25
C_B	0.8098	0.8098
C_M	0.998	-
LCG from aft extent/m	171.10	2.14
VCG from keel, KG /m	18.60	0.23
K_{xx}/B	0.4	0.4
K_{yy}/L_{PP}	0.25	0.25
K_{zz}/L_{PP}	0.25	0.25
I_x	-	51.35
I_y	-	610.59
I_z	-	610.59
Propeller diameter, D_P /m	9.86	0.12
Propeller RPS, n		37.2
Propeller P/D_P at $0.7R$	0.721	-
Propeller, A_e/A_0	0.431	-
Lat. area of rudder, A_R /m^2	136.7	-
Height of rudder, H_R /m	15.8	-

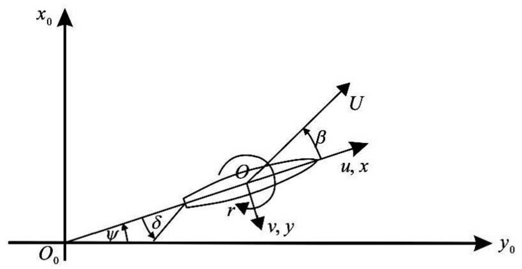

Fig.1 Coordinate system

2. Mathematical model

The vessel can be considered as a rigid body. Assuming that the hydrodynamic forces and moments acting on the vessel are quasi-steadily and the lateral velocities are small compared to the forward speed which is not fast enough to take the wave making effect into account and the metacentric height of the vessel is sufficiently large to neglect the roll effect on the manoeuvring motions, the 3 degrees of freedom motion equations are presented as follows with respect to the body fixed coordinates system fixed at mid-ship position as shown in Fig.1.

$$(m+m_x)\dot{u}-(m+m_y)vr-(mx_G-Y_{\dot{r}})r^2=X \tag{1a}$$

$$(m+m_y)\dot{v}+(m+m_x)ur+(mx_G-Y_{\dot{r}})\dot{r}=Y \tag{1b}$$

$$(I_{zz}+J_{zz})\dot{r}+(mx_G-N_{\dot{v}})(\dot{v}+ur)=N \tag{1c}$$

Here terms on the right hand side are the external force components and yaw moment. And they can be further divided into three parts based on the MMG modular concept with the subscripts H, P, R to represent the forces and moments acting on the hull, the propeller and the rudder respectively in Eq.(2).

$$X=X_H+X_P+X_R \tag{2a}$$

$$Y=Y_H+Y_P+Y_R \tag{2b}$$

$$N=N_H+N_P+N_R \tag{2c}$$

The definitions of other nomenclature and symbols in Eq.(1) can be referred to any literature describing a standard MMG modelling procedure. In order to give an accurate prediction of ship manoeuvring motions, the key steps are to evaluate the above stated forces and moments correctly by proper models.

2.1 *Hull forces and moments*

According to the polynomial expressions establi-

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