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Deriving mathematical manoeuvring models for bare hull ships using viscous-flow calculations

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CONTENTS

PLENARY LECTURES

INVITED SESSIONS

BUCKLING COLLAPSE ANALYSIS OF MARINE STRUCTURES
Organized by T. Yao and M. Fujikubo

MESHLESS METHODS IN MARINE ENGINEERING
Organized by A. Souto-Iglesias

METHODS FOR FLUID-STRUCTURE INTERACTIONS
Organized by T. Tezduyar

PREDICTION OF RESISTANCE COEFFICIENTS IN SHIP HYDRODYNAMICS
Organized by L. Eça and M. Visonneau

CONTRIBUTED SESSIONS

COMPUTATIONAL FLUID DYNAMICS

COMPUTATIONAL METHODS IN MARINE ENGINEERING

NUMERICAL-EXPERIMENTAL STUDIES

SHIP ANALYSIS

STRUCTURAL ANALYSIS

PLENARY LECTURES

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DERIVING MATHEMATICAL MANOEUVRING MODELS FOR BARE HULL SHIPS USING VISCOUS-FLOW CALCULATIONS

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1 INTRODUCTION

In the present paper, the work conducted by the author regarding efficient determination of hydrodynamic coefficients for manoeuvring ships within the manoeuvring work package of the EU project VIRTUE[1] is presented. Based on various viscous-flow calculations for steady drift motion, steady yaw motion and combined drift/yaw motion, a mathematical model for the bare hull forces and moments is derived. The results show that using accurate viscous-flow calculations, a considerable improvement in the prediction of the forces and moments on ships compared to conventional empiric methods published in open literature is obtained.

Two hull forms are considered in this study. The first ship is the Hamburg Test Case (HTC), a single-screw ship. The second ship is the MARIN LNG carrier with twin gondolas, see also Jurgens et al. [1].

2 CALCULATIONS

Series of calculations have been conducted in order to be able to derive the required hydrodynamic coefficients, see Table 1. More information regarding the solver used for the calculation, the method of solution, nomenclature and a sensitivity study conducted for the HTC can be found in Toxopeus [2]. The experimental values were obtained by HSVA within VIRTUE.

Table 1: Overview of calculations

Series	HTC	MARIN LNG
pure drift	$\beta = 0, 2.5, 5, 10, 15°$	$\beta = 0, 2.5, 5, 10, 20, 30°$
pure yaw	$\gamma = 0.1, 0.15, 0.2, 0.3, 0.4, 0.556$	-
combined motion	$(\beta,\gamma) = (5°,0.2), (10°,0.2), (6°,0.4), (10°,0.4), (15°,0.4)$	-

[1]Part of the work conducted for this paper has been funded by the Commission of the European Communities for the Integrated Project VIRTUE under grand 516201 in the 6^{th} Research and Technological Development Framework Programme (Surface Transport Call).

3 MATHEMATICAL MANOEUVRING MODEL

Mathematical manoeuvring models for the bare hull consist in general of two different components: (added) mass coefficients and damping coefficients. In earlier work (e.g. Vassalos et al. [3], Bulian et al. [4]), it was found that the sensitivity of the manoeuvrability to changes in the added mass coefficients is small. Therefore, no calculations are required to obtain the added mass coefficients and the added mass coefficients are approximated by using empiric formulae, see e.g. Clarke et al. [5].

The damping coefficients in the mathematical model are derived in several steps:

1. Linear coefficients for simple motions (slope of curves at $\beta = 0$ resp. $\gamma = 0$)
2. Non-linear coefficients for pure transverse motion and pure rotation using empirical relations (based e.g. on work of Hooft [6])
3. Other non-linear components for simple motions
4. Cross-terms, based on combined motions

This approach is chosen to enable accurate modelling of the linearised behaviour for coursekeeping (1.), realistic modelling of the low speed/harbour manoeuvring characteristics (2.) and accurate modelling of non-linear manoeuvres (3. and 4.). The following non-dimensionalised mathematical model for the transverse force Y and yawing moment N is obtained:

$$\begin{aligned} Y' &= Y'_\beta \cdot |\cos\beta| \cdot \sin\beta + Y'_\gamma \cdot \cos\beta \cdot \gamma + Y'_{\beta|\beta|} \cdot \sin\beta \cdot |\sin\beta| \\ &+ Y'_{\beta|\gamma|} \cdot \beta\,|\gamma| + Y'_{ab} \cdot \left|\cos^{a_y}\beta \cdot \sin^{b_y}\beta\right| \cdot \mathrm{sign}\sin\beta \end{aligned} \tag{1}$$

$$\begin{aligned} N' &= N'_\beta \cdot \cos\beta \cdot \sin\beta + N'_\gamma \cdot |\cos\beta| \cdot \gamma + N'_{u\gamma c} \cdot |\cos\beta \cdot \gamma^{c_n}| \cdot \mathrm{sign}\gamma + N'_{\gamma|\gamma|} \cdot \gamma \cdot |\gamma| \\ &+ \left(N'_{\beta\beta\gamma} \cdot \beta + N'_{\beta\gamma\gamma} \cdot \gamma \cdot \mathrm{sign}\cos\beta\right) \cdot \beta\gamma \\ &+ N'_{ab} \cdot \left|\cos^{a_n}\beta \cdot \sin^{b_n}\beta\right| \cdot \mathrm{sign}\left(\cos\beta \cdot \sin\beta\right) \end{aligned} \tag{2}$$

With equations (1) and (2) as the mathematical formulation for the bare hull manoeuvring forces, the hydrodynamic derivatives are determined using the results of the available viscous-flow calculations presented in Table 1. Table 2 shows the obtained manoeuvring coefficients.

Table 2: Estimated bare hull manoeuvring coefficients

Step	Coefficient	HTC	MARIN LNG	Coefficient	HTC	MARIN LNG
1	Y'_β	0.1830	0.0416	N'_β	0.1403	0.0894
	Y'_γ	0.0250	-	N'_γ	-0.0270	-
2	$Y'_{\beta\|\beta\|}$	1.1100	0.9662	$N'_{\gamma\|\gamma\|}$	-0.0375	-0.1755
3	Y'_{ab}	-0.6552	-0.9802	N'_{ab}	0.1314	-0.0373
	a_y	3	2	a_n	1	3
	b_y	2	3	b_n	3	2
				$N'_{u\gamma c}$	-0.0073	-
				c_n	2	-
4	$Y'_{\beta\|\gamma\|}$	0.1635	-	$N'_{\beta\beta\gamma}$	-0.8682	-
				$N'_{\beta\gamma\gamma}$	0.2753	-

In Figure 1, good agreement with the experiments (designated exp) is seen for the results based on the viscous flow calculations (designated cfd) and based on the mathematical model (designated cfd-fit). Only the HTC results for the transverse force Y for pure yaw (γ) deviate from the measurements. The magnitude of the Y force during pure rotation is however very small and of less significance than the other force or moment components.

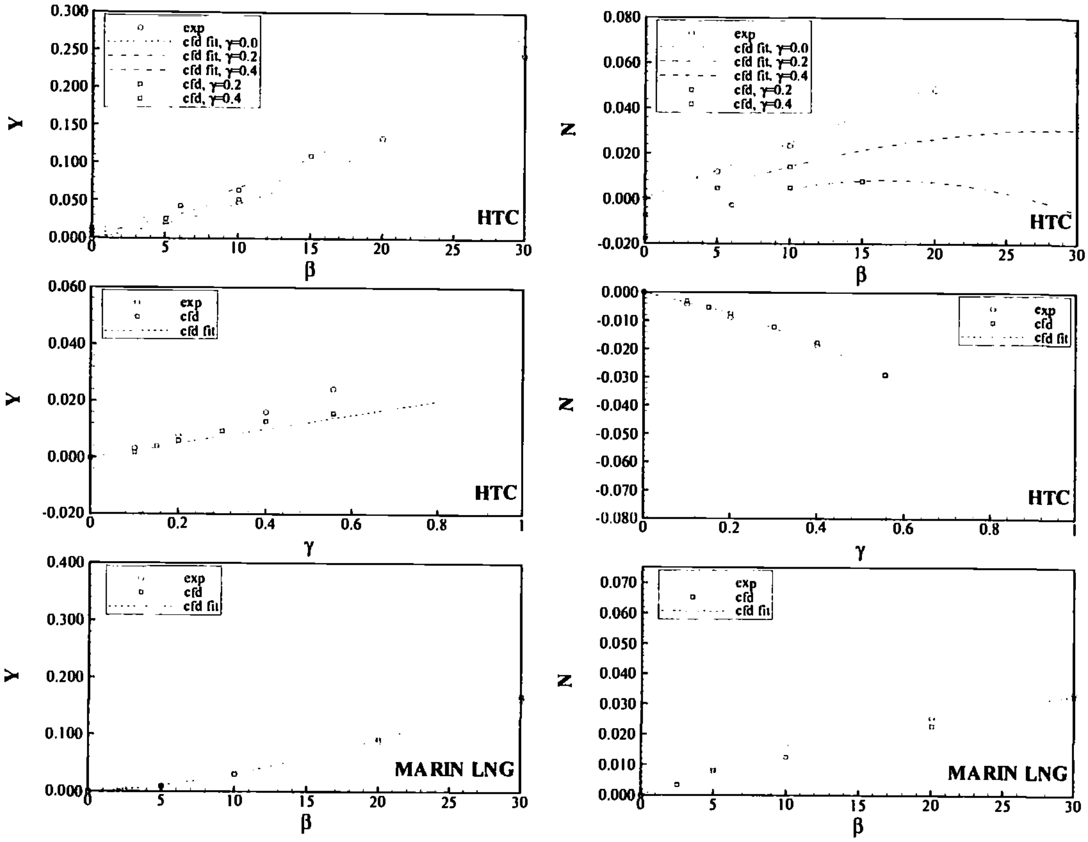

Figure 1: Comparison between experiments and predicted forces and moments

In Table 3, the linear derivatives for the HTC are given according to empirical formulae in open literature. Furthermore, the derivatives based on the measurements (exp), on the viscous-flow calculations (cfd) and on the slender-body theory (sb, see e.g. Toxopeus [7]) are presented. The errors in the predictions compared to the experimental values are shown in Figure 2. The error is defined as $error = (prediction/experiment - 1)$. It is seen that in general, both the viscous-flow calculations and the slender-body coefficients approximate the experimental values better than the other empiric formulae. Especially the de-stabilising (N'_β/Y'_β) and stabilising $N'_\gamma/(Y'_\gamma - m')$ arms are closer to the experimental ones.

4 CONCLUSIONS

The study presented in this paper demonstrates that the forces and moments acting on a ship hull in manoeuvring conditions can be accurately predicted using viscous-flow calculations. Comparisons with empiric formulae proposed in the past show that better linear hydrodynamic derivatives can be obtained when using CFD.

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Table 3: Comparison of linear coefficients, HTC

Method	Ref	Y'_β	N'_β	N'_β/Y'_β	Y'_γ	N'_γ	$N'_\gamma/(Y'_\gamma - m')$
Kijima	[8]	0.373	0.134	0.359	0.158	-0.054	0.730
Vassalos	[3]	0.373	0.110	0.294	0.067	-0.053	0.323
Clarke	[5]	0.357	0.139	0.390	0.067	-0.053	0.323
Norrbin	[5]	0.365	0.130	0.356	0.092	-0.078	0.553
exp		0.175	0.137	0.782	0.032	-0.039	0.192
cfd		0.183	0.140	0.767	0.025	-0.027	0.130
sb	[7]	0.253	0.151	0.598	0.058	-0.038	0.215

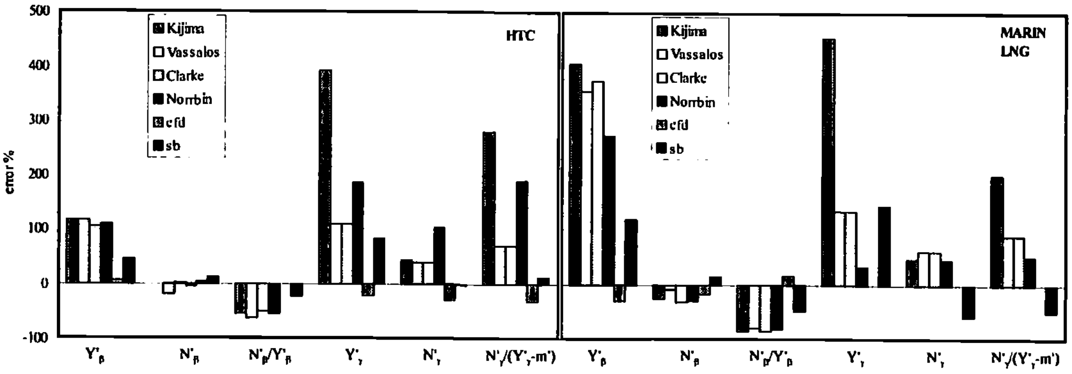

Figure 2: Comparison between errors in prediction of linear coefficients