



Application of potential flow methods to fast displacement ships at transcritical speeds in shallow water

Cam Algie^{a,*}, Tim Gourlay^b, Leo Lazauskas^{a,b,c}, Hoyte Raven^c

^a Bombora Wave Power, 9 De Laeter Way, Bentley, WA 6151, Australia

^b Perth Hydro Pty Ltd, Level 29, 221 St Georges Terrace, Perth, WA 6000, Australia, Australia

^c Maritime Research Institute Netherlands, P.O. Box 28, 6700 AA Wageningen, The Netherlands

ARTICLE INFO

Article history:

Received 16 May 2017

Received in revised form

10 November 2017

Accepted 19 November 2017

Keywords:

Ship squat

Resistance

Transcritical speed

Linear potential flow

ABSTRACT

Computer codes implementing three different numerical methods for the prediction of ship squat at transcritical speeds in shallow open-water are tested. SlenderFlow is a potential flow code specifically for ships in very shallow water, based on partially dispersive slender body theory. Flotilla is a potential flow code based on fully dispersive thin-ship theory. Rapid is a general nonlinear free-surface panel code. Code predictions of transcritical sinkage, trim and resistance in laterally unrestricted water were compared to the experimental results of Graff (1964) for two Taylor series hulls in a finite-width towing tank. Once tank width effects were accounted for, each of the three codes was found to give good predictions within the valid range of the underlying theory. A simple method for estimating transcritical wave resistance from trim is presented.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

Water depth has important effects on the flow of water around displacement vessels. Shallow water accelerates the water flow past the ship as compared to the deep water condition, causing an increased “squat”, or downward sinkage and change in trim. The wave pattern produced by the ship is changed in shallow water, causing different wave resistance characteristics to deep water. We shall be studying the above two effects in this article. Other important effects of shallow water include the effect of changing flow speeds on viscous resistance, as well as changed flow over the propeller and rudder [17].

For cargo ships travelling at moderate speeds, sinkage is typically in the order of 0.3–2.0 m, which may cause the ship to run aground if not properly accounted for. A large amount of research has been done on predicting sinkage and trim of cargo ships, which is summarized in PINAC [24]. Several of the formulae are based on Tuck's (1966) slender-body shallow-water theory, which predicts infinite sinkage as the Froude depth number $F_h = U/\sqrt{gh}$ approaches the “critical” value of 1. Bulk carriers, tankers, LNG

carriers and container ships, for which the methods are typically used, always travel at $F_h < 0.7$, so this singularity is not an issue in practice.

There are some displacement ships that can travel at “transcritical” Froude depth numbers $0.7 < F_h < 1.3$. These ships include: monohull warships such as frigates, destroyers and aircraft carriers; cruise ships; superyachts; catamaran ferries and warships; and trimaran ferries and warships. At transcritical speeds, the sinkage and trim formulae described in [24] cannot be used. Therefore, it is important that alternative methods for predicting maximum squat in this transcritical regime are established, and this is the main subject of the present paper.

Experience tells that viscosity has a negligible effect on sinkage and, mostly, also trim. Consequently, potential-flow methods of prediction can be expected to be largely adequate. Methods typically used for modeling transcritical flow in open water include dispersive slender-body theory [12], finite-depth thin-ship theory [29] or Rankine-source panel methods [25,28]. Raven, [28] notes the need for validation of free surface potential flow methods within the transcritical range. For finite-width canals, unsteady nonlinear potential-flow methods have been used [6,2]. Unsteady RANS-based CFD has been used for transcritical speeds in finite depths [1] but not finite widths to our knowledge.

* Corresponding Author.

E-mail addresses: camalgie1@gmail.com (C. Algie), tim@perthhydro.com (T. Gourlay), lazauskas@gmail.com (L. Lazauskas), H.C.Raven@marin.nl (H. Raven).

Nomenclature

Symbol Description Units

B	Hull beam m
C_p	Prismatic coefficient = $\nabla / (LS_{\max})$
C_v	Volumetric coefficient = ∇ / L^3
∇	Hull displaced volume m^3
εR	Specific residual resistance = $R_R / (\nabla \rho g)$
εW	Specific wave resistance = $R_W / (\nabla \rho g)$
ε_W^*	Estimated specific wave resistance = $R_W^* / (\nabla \rho g)$
F_h	Depth based froude number
F_L	Length based froude number
g	Acceleration due to gravity m/s^2
h	Water depth m
H	Hull depth m
L	Hull length (perpendicular to perpendicular) m
LCF	Longitudinal center of flotation
λ	Wavelength m
ρ	Density kg/m^3
R	Residual resistance force N
R_W	Wave resistance force N
R_W^*	Estimated wave resistance force N
S	Hull section area (orthogonal to x axis) m^2
s	Midship sinkage, positive downwards m
s_{bow}	Bow sinkage, positive downwards m
s_{stern}	Stern sinkage, positive downwards m
T	Hull draft m
θ	Trim angle, positive stern-down radians
x	Space coordinate (centred at waterline, midship, positive forward) m
w	Channel width m

Table 1

Station locations numbered from the stern.

Station number	x (m)	
	A3	B5
1	−1.50	−1.50
2	−1.35	−1.36
3	−1.20	−1.23
4	−1.05	−0.95
5	−0.90	−0.68
6	−0.75	−0.41
7	−0.60	−0.14
8	−0.45	0.14
9	−0.30	0.41
10	−0.15	0.68
11	0.00	0.95
12	0.15	1.23
13	0.30	1.36
14	0.45	1.50
15	0.60	–
16	0.75	–
17	0.90	–
18	1.05	–
19	1.20	–
20	1.35	–
21	1.50	–

Table 2

Dimensions, ratios and coefficients of the A3 and B5 hulls at model scale.

L	H/T	B/T	L/B	L/T	C_p	C_v
3m	1.8	3	10.77	32.33	0.64	0.0017

2. Model test cases analysed

In this article, comparisons of the potential-flow methods are made with the model test results of [13] for Taylor Series A3 and B5 hulls. These we consider as the most representative of open water available, having been done in a tank width of 3.3 times the model length and 36 times the model beam. Other more recent model test programs [22,23] have been performed for displacement ships at transcritical speeds, but with more transverse restriction to the flow.

2.1. Hull models

To satisfy the different input requirements of the codes both the section area curve and offset data were required for each hull tested. For the A3 hull, these were determined from plots in [7]. Non-dimensional offsets were digitized at 21 evenly spaced stations on 12 evenly spaced waterlines (excluding the baseline). The lines plan for the B5 hull was obtained from [13]. The section area curve was calculated from this lines plan by numerical integration of vertical offsets from the waterline, for area, at each of 14 stations. Stations are evenly spaced, with the exception of an extra half-station at the bow and stern. The station locations for each hull are presented in Table 1.

The non-dimensional lines plan for each hull is presented in Fig. 1. The dimensions, ratios and coefficients that are the same for both of the two hulls are presented in Table 2. All code testing was conducted at the experimental model scale.

Two depth conditions ($h/L=0.125, 0.250$) were selected for comparison with code predictions. These depths were chosen to span the range typically experienced by vessel's operating at high speeds in shallow water. Real vessels frequently operate at $h/L=0.125$ ($h/T=4$) and in this depth are put at risk of grounding by large squat [12]. The deeper condition ($h/L=0.250, h/T=8$) does not pose a grounding risk, but was selected as an intermediate condition between shallow and deep water to investigate the

Real ships are unlikely to travel at transcritical speeds in laterally restricted water. In these circumstances, speed restrictions often exist and speed is reduced due to the potential for collision with other vessels or obstacles such as canal walls. Instead, transcritical squat is most likely to occur for vessels in laterally unrestricted water. Therefore, shallow open-water should be the benchmark case when assessing the practical value of theoretical methods of prediction.

In this article, we shall apply three completely different theoretical methods to the prediction of dynamic sinkage and trim for ships at transcritical speeds; and compare them mutually and with experimental data. One is a dedicated shallow water method (SlenderFlow) based on slender-body theory; one a free-surface potential flow code based on thin-ship theory (Flotilla); and one a general nonlinear free-surface panel code (Rapid).

Although we are interested in the performance of prediction methods in laterally unrestricted water, the towing tank test results available for comparison use finite-width tanks, for obvious practical reasons. Therefore, some analysis of finite-width effects must be made. To facilitate this, results obtained from additional Rapid modeling that included the tank walls and results obtained by [2] using a fourth code (ShallowTank) will also be presented. Shallow-Tank is specifically developed for unsteady flow around ships in channels and cannot be applied to laterally unrestricted water.

In the next section, we briefly review the experimental data and the test cases, and then describe the three different methods for laterally unrestricted water that were applied. Results obtained for sinkage, trim, squat and resistance are presented. In Section 5 a simple approximation for the wave resistance is derived, based on observations of the empirical results and complementing the computed SlenderFlow results. Conclusions are drawn in Section 6.

Download English Version:

<https://daneshyari.com/en/article/8059326>

Download Persian Version:

<https://daneshyari.com/article/8059326>

[Daneshyari.com](https://daneshyari.com)