Experimental validation of a Rankine Panel Method

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1 Introduction

Over the past four years, a Rankine panel method has been designed at Delft University. The resulting program SEASCAPE can be applied to catamaran vessels. Special flow conditions are implemented to model the smooth separation of a transom stern flow. To validate the numerical work, a series of experiments with a catamaran model has been carried out in the towing tanks of Delft University and MARIN. The test results presented in this abstract are heave and pitch measurements in oblique waves.

2 First-order Rankine panel method

A first-order Rankine panel method has been implemented using flat quadrilateral panels and a constant singularity distributions on each panel. The nonlinear free-surface and hull boundary conditions have been linearised to, respectively, the calm water surface $z = 0$ and the mean position of the vessel, by means of Taylor expansions. The resulting boundary conditions have been presented in e.g. Van 't Veer (1997), and are almost similar to the linearisations used by Nakos (1990). The overall velocity potential is represented by a summation of three different potentials, the double-body base-flow potential $\Phi(\vec{x})$ (solved using the Hess and Smith (1962) method), the steady wave resistance potential $\phi(\vec{x})$, and the unsteady ship motion potential $\varphi(\vec{x}, t)$. The latter two potentials are solved using the Green's identity form of the boundary value problem. The motion response functions of the (catamaran) are solved in the frequency domain. The quadratic spline technique presented by Sclavounos and Nakos (1988) is used to discretise the tangential derivatives of the hull and free-surface boundary condition.

To obtain the motion responses in oblique waves, the calculation procedure is slightly different than for head waves. Besides the effect on the wave encounter frequency, the hydrodynamic coefficients (radiation potentials) are not influenced by the wave angle. The diffraction force however, is influenced by the wave heading, due to the effect of the incident wave in the hull and free-surface boundary conditions. This will result in different wave loading on both hulls.

If the solution vector on the port hull (or port side of the vessel) is denoted as $\vec{x}_p$ and $\vec{x}_s$ represents the solution on the starboard hull, the following matrix equation can be written down to solve the unsteady potentials,

$$\begin{bmatrix} G_{pp} & G_{ps} \\ G_{sp} & G_{ss} \end{bmatrix} \begin{bmatrix} \vec{x}_p \\ \vec{x}_s \end{bmatrix} = \begin{bmatrix} \vec{b}_p \\ \vec{b}_s \end{bmatrix} \quad \text{symmetry} \Rightarrow \quad \begin{bmatrix} A & B \\ B & A \end{bmatrix} \begin{bmatrix} \vec{x}_p \\ \vec{x}_s \end{bmatrix} = \begin{bmatrix} \vec{b}_p \\ \vec{b}_s \end{bmatrix} \tag{1}$$

The matrix G_{pp} represents the influences of a singularity on the port hull in a collocation point on the port hull, while the matrix G_{ps} represents the cross-influences between the two hulls. The elements of the matrices are calculated using the Green's influence coefficients and the discretised boundary conditions. Due to the geometrical symmetry around the centreline of the vessel, the sub-matrices with influence coefficients have symmetric properties as well, resulting in the matrix equation with A and B.

From equation (1) the two matrix equations can be extracted from which the solution vector on both hulls can be obtained by summation and subtraction of the two solution vectors,

$$\begin{aligned} [A+B](\vec{x}_p + \vec{x}_s) &= (\vec{b}_p + \vec{b}_s) \\ [A-B](\vec{x}_p - \vec{x}_s) &= (\vec{b}_p - \vec{b}_s) \end{aligned} \quad \text{leading to} \Rightarrow \quad \begin{aligned} \vec{x}_p &= \tfrac{1}{2}(\vec{x}_p + \vec{x}_s) + \tfrac{1}{2}(\vec{x}_p - \vec{x}_s) \\ \vec{x}_s &= \tfrac{1}{2}(\vec{x}_p + \vec{x}_s) - \tfrac{1}{2}(\vec{x}_p - \vec{x}_s) \end{aligned}$$

Using this technique only two matrix equations have to be solved and the forcing on each hull can than be derived by simple mathematics.

3 Influence of the m-terms on hydrodynamic coefficients

The exact hull boundary condition for the radiation potentials are nonlinear since the instantaneous hull location and orientation are unknown a priori. Linearisation of the boundary condition (to the mean position S_0 of the vessel) has been carried out by Timman and Newman (1962), and can be written in an elegant way using the m-terms defined by Ogilvie and Tuck (1969),

$$\frac{\partial \varphi_k}{\partial n} = \frac{\partial \vec{a}_k}{\partial t} \cdot \vec{n} - ((\vec{a}_k \cdot \nabla)\nabla\Psi_0 - (\nabla\Psi_0 \cdot \nabla)\vec{a}_k) \cdot \vec{n} = n_k\dot{\eta}_k + m_k\eta_k \qquad k = 1, ..., 6 \tag{2}$$

where $\vec{a}_k$ is the oscillatory displacement vector of the hull, for the k^{th} mode, in respect to the mean position of the vessel: $\vec{a} = (\eta_1, \eta_2, \eta_3) + \vec{x} \times (\eta_4, \eta_5, \eta_6)$. The steady flow field is expressed by the potential Ψ_0. The last term in equation (2) is the correction term which accounts for the effect that the integration is carried out on S_0 and not on the instantaneous hull surface S.

The overall steady flow field can be written as: $\nabla\Psi_0 = \vec{U} + \nabla\Phi' + \nabla\phi$, where $\vec{U}$ is the ship's velocity. Using this decomposition, the exact m-terms consist of three different contributions. In view of general linearisations, the following m-terms are defined: 1) the Neumann-Kelvin m-terms, which include only the effect of $\vec{U}$, 2) the double-body m-terms, which include the effect of $\vec{U}$ and $\nabla\Phi'$, and finally 3) the complete m-terms, which include all three components.

Neumann-Kelvin m-terms: The Neumann-Kelvin m-terms are most commonly used in seakeeping theories. They are calculated using only the uniform stream velocity U and neglect thereby the correction term in the linearised hull boundary condition, which accounts for the effect of the oscillating body in the steady flow field. The resulting expression for the m-terms is:

$$\begin{aligned} (m_1, m_2, m_3) &= -(\vec{n} \cdot \nabla)(\vec{U}) = (0, 0, 0) \\ (m_4, m_5, m_6) &= \vec{x} \times (m_1, m_2, m_3) - \vec{n} \times \vec{U} = (0, -Un_3, Un_2) \end{aligned} \tag{3}$$

The Neumann-Kelvin m-terms are used in the strip-theory calculations and can be used in 3D Rankine panel methods as well, as approximation for the more complicated double-body m-terms.

The double-body m-terms: The double-body flow is a more realistic base-flow for describing the velocity perturbations around the (fully submerged) vessel than the uniform Neumann-Kelvin flow. The resulting m-terms are complicated due to the second derivatives of the base-flow potential,

$$\begin{aligned} (m_1, m_2, m_3) &= -(\vec{n} \cdot \nabla)(\nabla\Phi) \\ &= -(n_1\Phi_{xx} + n_2\Phi_{xy} + n_3\Phi_{xz}, n_1\Phi_{yx} + n_2\Phi_{yy} + n_3\Phi_{yz}, n_1\Phi_{zx} + n_2\Phi_{zy} + n_3\Phi_{zz}) \\ (m_4, m_5, m_6) &= \vec{x} \times (m_1, m_2, m_3) - \vec{n} \times \nabla\Phi \\ &= \vec{x} \times (m_1, m_2, m_3) + (n_3\Phi_y - n_2\Phi_z, n_1\Phi_z - n_3\Phi_x, n_2\Phi_x - n_1\Phi_y) \end{aligned} \tag{4}$$

Since the double-body velocities can be written as $\nabla\Phi = \vec{U} + \nabla\Phi'$, it is easily verified that the double-body m-terms include the Neumann-Kelvin m-terms. Since only the pitch and yaw Neumann-Kelvin terms are nonzero, the double-body contributions are of first-order for all other terms.

The spatial derivatives of the double-body velocities, are calculated on the hull surface using the spatial derivatives in the fluid domain. For each collocation point, three extra points are selected (in the direction of the panel normal vector) in which the second derivatives of the velocity potential are calculated. Using a quadratic spline, the derivatives on the hull surface are obtained.

The complete m-terms: The definition of the m-terms up till now only include contributions due to the velocity potential around a fully submerged body. The free-surface steady potential ϕ has not been incorporated in the hull boundary condition, while this free-surface velocity field is certainly present. However, based on order analysis, it can be verified that the contributions of $\nabla\phi$ are of secondary order compared to the $\nabla\Phi$ terms, and they are therefore not included in SEASCAPE.

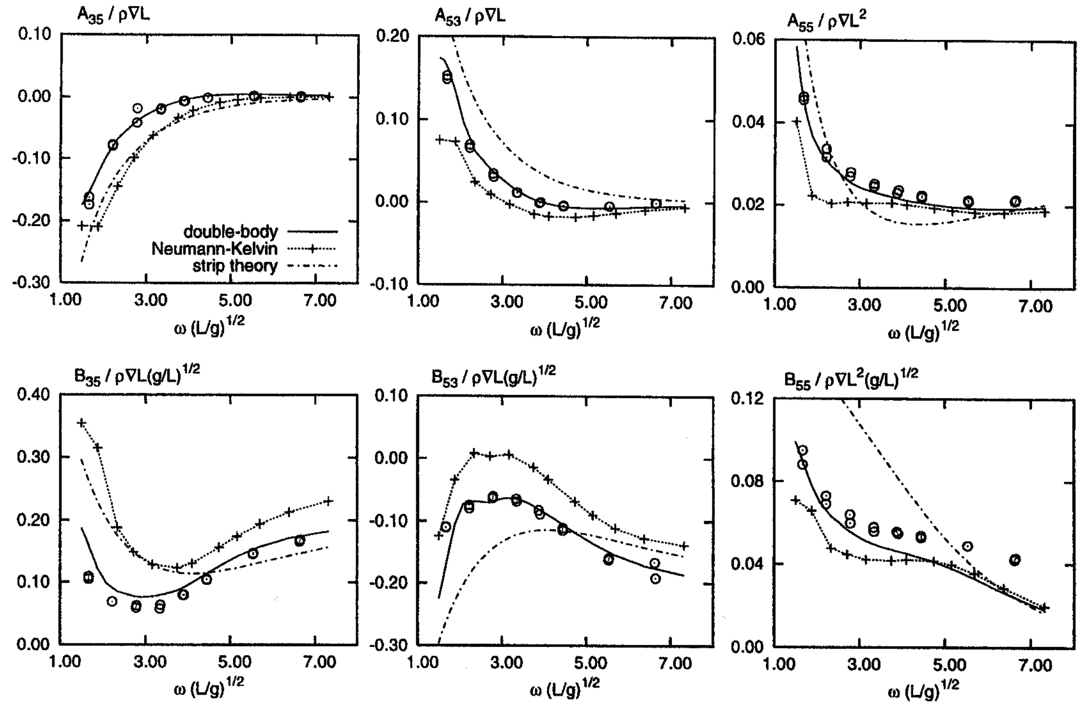

Figure 1: Comparison of added mass and fluid damping coefficients using different definitions for the m-terms. Wigley III, Fn = 0.30. Double-body and Neumann-Kelvin coefficients from SEASCAPE. Strip theory calculations from SEAWAY.

4 Test case: the Wigley III

The influence of the m-terms on the hydrodynamic coefficients for the Wigley III has been investigated. The Wigley hull form is often chosen for numerical validation since the hull surface can be easily discretised by any number of panels, and extensive experimental data exist, presented by Journée (1992). The calculations presented here, are all carried out using 30 panels lengthwise and 8 panels girthwise on the hull surface. The main parameters of the Wigley III model were $L = 3.0$ m, $L/B = 10$, and $B/T = 1.6$.

The hydrodynamic mass and damping coefficients, calculated using different m-term definitions, are presented in Figure 1. The experimental data obtained by Journée (1992), and the calculated coefficients using a strip-theory method (SEAWAY, developed at Delft University) are included as well.

Although the vessel is rather slender Figure 1 shows remarkable differences. In general, the 3D calculations using the double-body m-terms correlate excellent with the experimental data. All other predictions show a slightly worse correlation with the experiments, especially for the coupled fluid damping terms, B_{35} and B_{53}. It is interesting to notice that the strip-theory generally predicts more fluid damping in the coupling terms and pitch-to-pitch term B_{55}. While the trend in the fluid damping terms is much better predicted by the Neumann-Kelvin method, the error is opposite in the coupling terms; B_{35} is over-predicted and B_{53} is under-predicted. Similar conclusions follow from the comparison of the added mass values. Due to space limitations the results for A_{33} and B_{33} are not included, but the predictions for the heave-to-heave coefficients were all close to each other.

5 Test case: the DUT catamaran in oblique waves

The aim of the research project was to develop a seakeeping prediction tool applicable to catamarans. Therefore, a series of experiments have been carried out with a catamaran model. A lines plan of the vessel is presented in Figure 2.

Model experiments in head waves have been carried out at Delft University and at MARIN the model has been tested in oblique waves, $\beta = 165$ and 135 degrees. In oblique waves, the experiments were carried out at three different Froude numbers, Fn 0.35, 0.60 and 0.75. In Figure 3 the heave and pitch results are presented

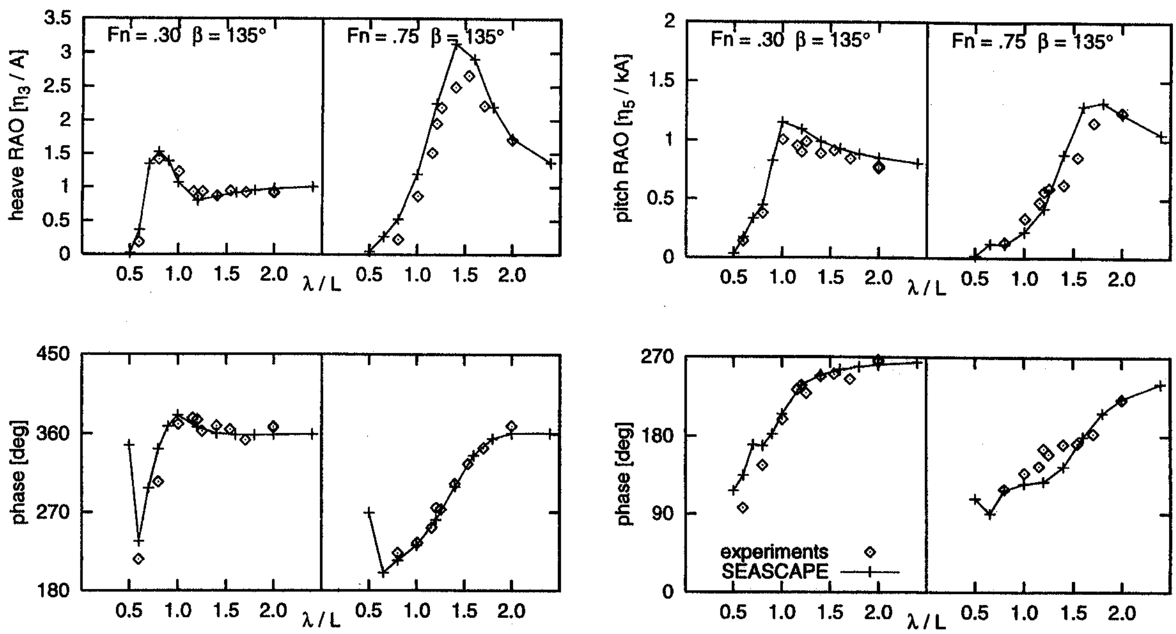

Figure 3: Heave and pitch motion response, DUT catamaran, oblique waves

for β = 135 degrees. The calculations are performed using the double-body m-terms. The hull surface grid consisted of 20 panels lengthwise and 10 panels girthwise along one demi-hull. The steady trim and sinkage (significant at Fn = 0.75) are taken into account in the calculations.

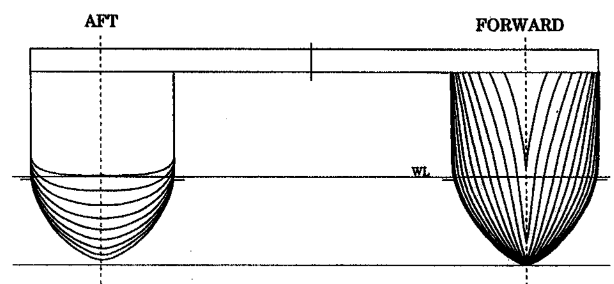

Figure 2: Lines plan DUT catamaran

6 Conclusions

It has been shown that the m-terms have a significant influence on the hydrodynamic coefficients. Using the double-body m-terms good correlations with experimental data were obtained.

Using the proposed calculation procedure for oblique waves, good correlations between experiments and calculations were obtained for the heave and pitch motions of a catamaran vessel.

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