Catamaran Seakeeping Predictions

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1 Introduction

To solve the motions of a vessel sailing in waves the strip theory is a widely used method. The results are in most cases satisfactory. However, the method becomes less accurate if 3D effects become more important.

By research work done in the past [6] it became clear that for catamaran vessels at low and moderate forward speed the strip theory over predicts the heave and pitch motions if the interaction between the two hulls is included in the calculations. When a catamaran is sailing at high forward speed, the interaction between the two hulls will vanish since the waves generated by one hull can not reach the other hull of the catamaran. It was found that in that case the strip theory could predict the motions of the vessel with more satisfactory results.

Thus, to take interaction effects between the two hulls of a catamaran correctly into account a 3D method is needed.

2 The Boundary conditions

A Rankine panel method has been designed for monohull and catamaran vessels. In this method the hull surface and still water free surface are discretised using flat quadrilateral panels with a constant source strength singularity $(1/r)$ in the collocation point of the panel.

The total velocity potential is written as $\Psi(\vec{x},t) = \Phi(\vec{x})+\phi(\vec{x})+\varphi(\vec{x},t)$, where Φ is the double body potential, ϕ is the steady velocity potential and φ is the unsteady velocity potential. The assumption is made that the steady and unsteady potential are independent so that the steady and unsteady problem can be solved separately.

The exact free surface boundary condition on the unknown free surface is linearised to the still water free surface, assuming that the wave elevation from the double body potential allows such a linearisation. The free surface boundary condition for the steady and unsteady problem read, respectively:

$$g\frac{\partial\phi}{\partial z} + \frac{1}{2}\nabla\cdot\phi\nabla(\nabla\Phi\cdot\nabla\Phi) + \nabla\Phi\cdot\nabla(\nabla\Phi\cdot\nabla\phi) - \Phi_{zz}\nabla\Phi\cdot\nabla\phi + \frac{1}{2}\nabla\Phi\cdot\nabla(\nabla\Phi\cdot\nabla\Phi) - \frac{1}{2}(\nabla\Phi\cdot\nabla\Phi - U^2)(\Phi_{zz}+\phi_{zz}) = 0 \tag{1}$$

and,

$$g\frac{\partial\varphi_k}{\partial z} - \omega_e^2\varphi_k + 2i\omega_e\nabla\Phi\cdot\nabla\varphi_k + \nabla\Phi\cdot\nabla(\nabla\Phi\cdot\nabla\varphi_k) + \frac{1}{2}\nabla\varphi_k\cdot\nabla(\nabla\Phi\cdot\nabla\Phi) - \Phi_{zz}(i\omega_e\varphi_k + \nabla\Phi\cdot\nabla\varphi_k) - \frac{1}{2}(\nabla\Phi\nabla\Phi - U^2)(g\varphi_{kzz} + \varphi_{kztt}) = 0 \qquad k = 1,..,7 \tag{2}$$

where k is the mode of oscillation with $k = 7$ being the diffraction potential.

The hull boundary condition for each potential is that no water can penetrate the hull, thus:

$$\frac{\partial\Phi}{\partial n} = 0, \qquad \frac{\partial\phi}{\partial n} = 0, \qquad \frac{\partial\varphi_k}{\partial n} = i\omega_e n_k + m_k \quad k = 1,..,6, \qquad \frac{\partial\varphi_7}{\partial n} = -\frac{\partial\varphi_0}{\partial n} \tag{3}$$

where n is the normal vector pointing into the fluid domain. The incoming wave potential is given by φ_0. The m-terms in the unsteady hull boundary condition are calculated analytical, using Newman [3] and de Koning Gans [1]. The m-terms contain second order derivatives and especially the rotation terms are sensitive for errors in these derivatives due to the length factors with which they are multiplied. In equation (4) the m-terms are written out:

$$
\begin{aligned}
(m_1, m_2, m_3) &= -(\vec{n} \cdot \nabla)\nabla\Phi == -(n_1\Phi_{xx} + n_2\Phi_{xy} + n_3\Phi_{xz}, \\
&\qquad n_1\Phi_{yx} + n_2\Phi_{yy} + n_3\Phi_{yz}, n_1\Phi_{zx} + n_2\Phi_{zy} + n_3\Phi_{zz}) \\
(m_4, m_5, m_6) &= -(\vec{n} \cdot \nabla)(\vec{x} \times \nabla\Phi) = (ym_3 - zm_2 - n_2\Phi_z + n_3\Phi_y, \\
&\qquad zm_1 - xm_3 - n_3\Phi_x + n_1\Phi_z, xm_2 - ym_1 - n_1\Phi_y + n_2\Phi_x)
\end{aligned}
\tag{4}
$$

3 Solving the steady or unsteady potential

The Green's identity is used to solve the steady or unsteady potential. That is for the unsteady potential:

$$
2\pi\varphi_k(p) - \iint\limits_{FS,H} \varphi_k(q)\frac{\partial G(p,q)}{\partial n_q}dS + \iint\limits_{FS,H} \frac{\partial \varphi_k(q)}{\partial n_q}G(p,q)dS = 0 \tag{5}
$$

and a similar expression for the steady problem.

Equation (5) is discretised using N number of flat quadrilateral panels. The unknown variables are discretised using a spline representation, as was presented by Nakos [2]. The spline function is a C-2 function, thus upto the second derivative can be discretised.

4 Some details of the Rankine panel method

A typical free surface panel discretisation for a catamaran problem is presented in Figure (1). The free surface grid is divided into three different grid area's, called `FS1`, `FS2` and `TR`. The transom grid is only pressent if the hull has a transom stern.

Most catamaran vessels have a transom stern to install the waterjet units for propulsion. However, the flow around a transom is typical nonlinear if the transom ends below the still water free surface. Due to the linearisations carried out before, the depth of the transom below $z = 0$ must be limited.

In solving the problem the different grid area's must be connected with each other using physical values at the connection lines. The extra conditions are introduced by assuming an extra set of unknowns, virtually positioned near each border panel of a grid area.

The disturbance due to the vessel are assumed to vanish upstream of the vessel. Practily this means that in the unsteady problem the reduced frequency τ must be greater than 0.25. Thus for the steady and the unsteady problem the conditions $\zeta = 0$ and $\partial\zeta/\partial x = 0$ are discretised at the instream side of the grid.

At the outer-border of the grid the second derivative of the potential in y direction is set to vanish.

Since the problem is symmetric around the x-axis no flow is going through the xOz plane. This means that at $y = 0$ the velocity V_y must be zero.

The continuity of the flow must be satisfied going from one grid to the other grid. This is carried out by discretising the potential itself and the normal vector of the velocity in the y direction and using these two conditions at the intersection. The same conditions are applied between the hull surface and the free surface grid.

If a transom stern is present it is assumed that the flow is leaving the hull surface smoothly, thus the condition $\partial\zeta/\partial x = \alpha$ where α is the transom edge angle, is prescribed in the extra collocation point of the transom sheet. The wave elevation itself is also fixed by the transom edge depth. Using the transom edge angle the wave elevation in the first collocation point aft of the transom becomes $\zeta = \frac{1}{2}h_x \tan\alpha$ where h_x is the first transom sheet panel length in the x direction.

5 Results

In Figure (2) the steady seascape is given for a Wigley catamaran at Fn = 0.30. The stern and bow wave system are clearly spotted. Where the two bow waves meet each other a high peak in the wave system is found.

In Figure (3) the heave and pitch motions of a wigley catamaran vessel are compared with data from experiments [5]. The 3D calculations are refered to as SEASCAPE. The strip theory calculations are performed with the program ASAP, in which ASAP 0 indicates that the interaction between the two hulls is not included in the calculations and ASAP 2 indicates that the 2D interaction between the hulls is taken into account.

The added mass and fluid damping results are presented in Figure (3) as well. A reasonable comparison is found over almost the whole frequency range.

To obtain an indication for the transom stern wave profile calculations, a comparison is presented, Fig. (4), between a non-linear calculation by Raven [4] and the linear calculation from SEASCAPE.

References

[1] H. J. de Koning Gans. *Numerical Time Dependent Sheet Cavitation Simulations using a Higher Order Panel Method.* PhD thesis, Delft University of Technology, January 1994. Delft University Press.

[2] D. E. Nakos. *Ship Wave Patterns and Motions by a Three Dimensional Rankine Panel Methos.* PhD thesis, Massachusetts Institute of Technology, June 1990.

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[4] H. C. Raven. *A Solution Method for the Nonlinear Ship Wave Resistance Problem.* PhD thesis, Delft University of Technology, June 1996.

[5] F. R. T. Siregar. Experimental results of the wigley hull formm with advancing forward speed in head waves. Technical Report 1024, Delft University of Technology, Ships Hydrodynamics Laboratory, February 1995.

[6] A. P. Van 't Veer. Catamaran seakeeping prediction. Technical Report 980-S, Delft University of Technology, October 1993.

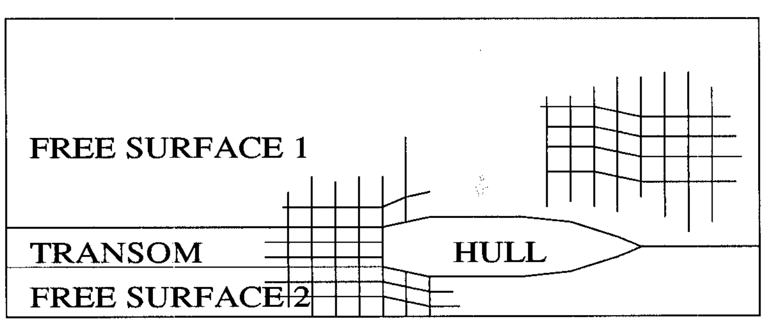

Figure 1: Calculation grid for a catamaran with transom

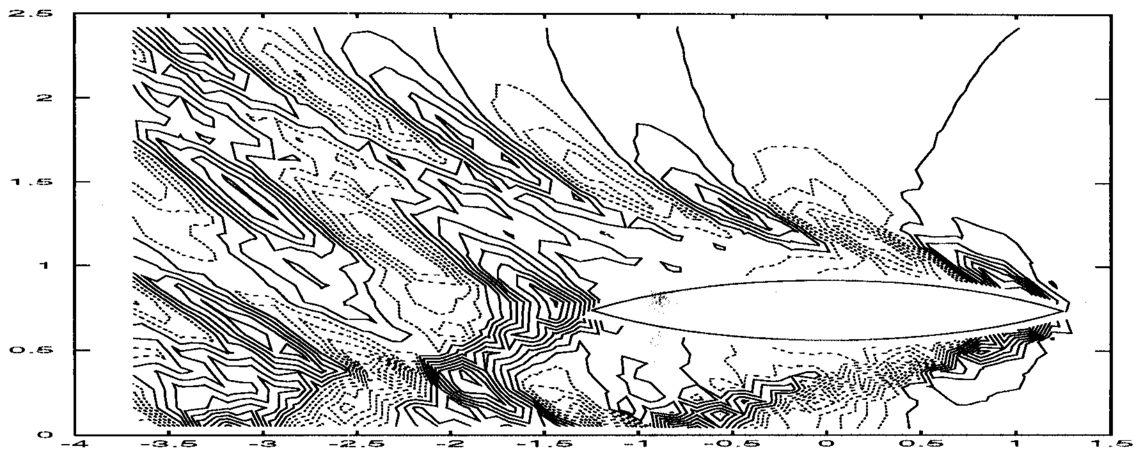

Figure 2: Steady Seascape, Wigley Cat L/B = 7, Fn = 0.30

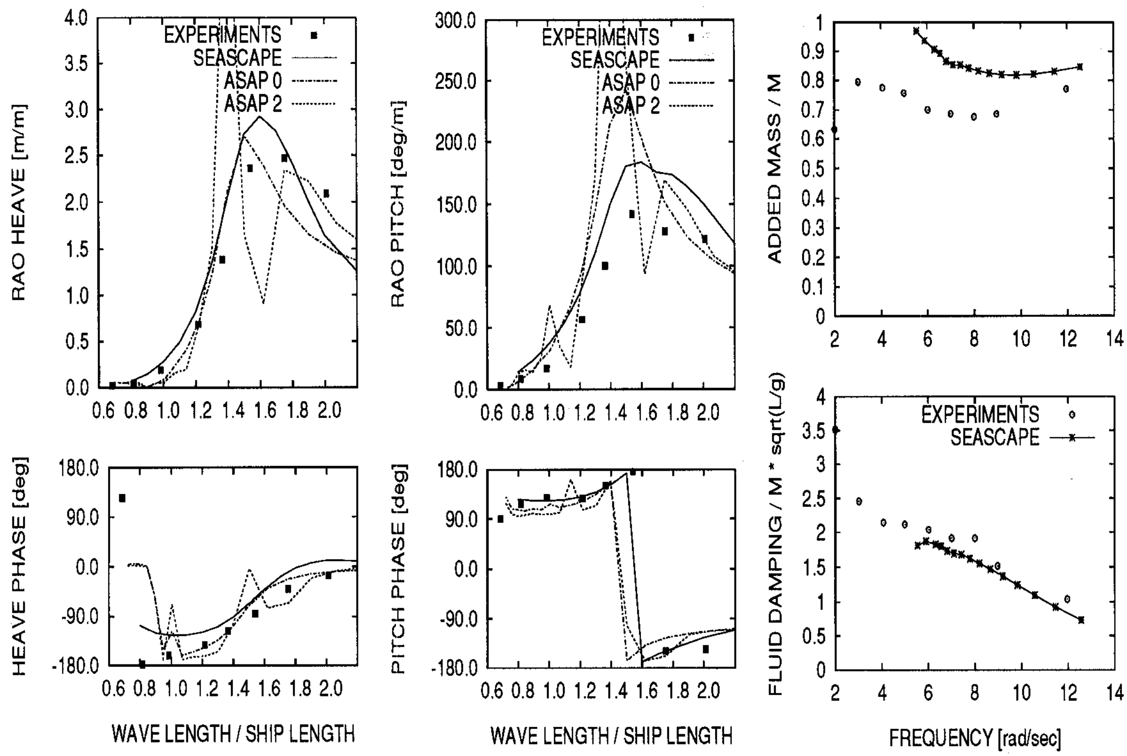

Figure 3: Heave, Pitch, and Added mass and fluid damping results
Wigley Catamaran, L/B = 7, Fn = 0.45

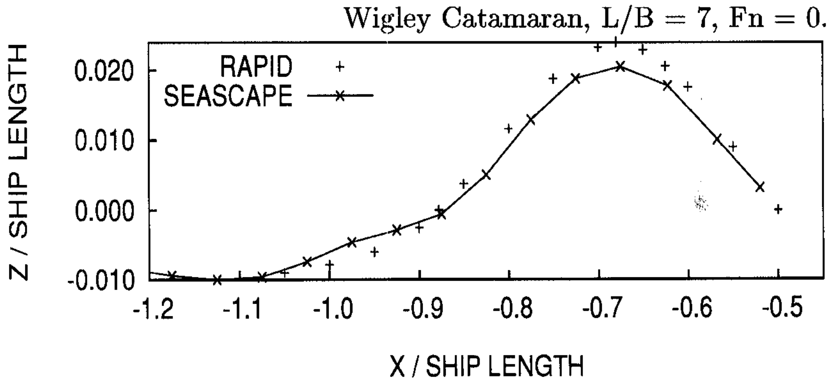

Figure 4: Transom stern wave, Fn = 0.40, RAPID results from Raven [4]

DISCUSSION

Newman J.N.: The highly-tuned heave resonance at $U = 0$ is not really due to wave interactions between the hulls, but to a Helmholtz "pumping" mode in 2D or a longitudinal standing wave in 3D. Do you have any ideas about how this resonant mode is affected by forward velocity?

Van't Veer R.: Thank you for your interesting question about interaction phenomena.
At zero forward speed the added mass and damping coefficients are measured for several heaving twin cylinder configurations by Lee et. al (1971). In most of the measurements the heave added mass drops to negative values where at the same time the fluid damping value goes to zero. This 2D resonance frequency is indeed related to the Helmholtz pumping mode, or can be seen as the behaviour of a moonpool. The resonance frequency can be approximated using the horizontal watercolumn between the two hulls extended with half a circular cylinder underneath. Which yields $\omega = \sqrt{\rho g h / \left(\rho h T + \pi h^2 / 8 \right)}$ where h is the distance between the two hulls and T is the draft of the hull.
With increasing forward speed the moonpool effect will decrease since the watercolumn is not bounded at the fore and aft side. In experiments lately carried out with a catamaran vessel, added mass values close to zero were measured at $Fn = 0.30$ at low frequencies. This indicates in my opinion that a weakened moonpool effect can exist in 3D, if forward speed is not to high. At higher Froude numbers the added mass values became more or less constant over the tested frequency range, indicating no profound interaction effects.
Lee, C.M., Jones, H. and Bedel, J.W.: 1971, Added mass and damping coefficients of heaving twin cylinders in a free surface, *Technical Report 3695*, Departement of the Navy Naval Ship Research and Development Center, Bethesda.

Rainey R.C.T.: Standing on the extreme aft deck of the high-speed catamaran *"Hoverspeed France"*, during her sea trials in Hobart (a harbour discovered by your countryman and my ancestor Abel Tasman, incidentally), I was much struck by the beautiful transom-shaped "groove" cut in the water behind the ship. Its effects appeared to dominate the wave pattern left behind. You mention this in connection with Figures 1 and 4. Can you tell me how the wave resistance of a catamaran compares with the simplest effects of this "groove", i.e. with the horizontal hydrostatic force that would be felt on the transom at zero speed in still water (and thus is felt, in the opposite sense, by the rest of the hull)? Catamaran designers always appear to minimise the draught of the transom, at the expense of its breadth, which is consistent with minimising this hydrostatic force (since it is proportional to breadth X $draught^2$).

Van't Veer R.: Thank you for your question in relation to the wave resistance.
The flow around a transom stern is an interesting topic and rather challenging since viscous effects can play an important role. This is especially the case at low Froude number where the transom flow does not leave the transom edge smoothly and a 'dead water' region behind the stern exists. Minimising the transom stern draught (or area) is expected to decrease the resistance since the flow separation will decrease and less energy is lost in the wake pattern.
At higher forward speed or when the transom stern draught is decreased the flow is likely to detach smoothly at the transom edge leaving a nicely shaped 'groove' cut in the water behind. Since the transom stern remains dry there is no horizontal hydrostatic pressure present at the transom. I expect that to obtain a smooth flow detachment it is not always necessary to minimize the transom edge draught, but that it is more important to obtain a smooth hull curvature with a small buttock curvature.