SEAKEEPING OF HIGH-SPEED VESSELS

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There are currently worldwide interest in developing high-speed vessels for transportation of passengers and goods in open ocean areas. Normal operating speeds will correspond to Froude numbers larger than 0.6. In this report a numerical method to evaluate motions of a high-speed non-planing vessel is described. We will concentrate on monohulls. However the method may be generalized to multihulls.

Linear theory

Consider a vessel at high forward speed in regular sinusoidal waves. The incident waves can have an arbitrary propagation direction relative to the vessel. The water depth is infinite and the free surface is infinite in all directions. The motions of the body and the fluid is assumed to be small so that we can linearize the body boundary conditions and the free surface condition. The problem is formulated in terms of potential flow theory. The total velocity potential ϕ will be written as

$$\phi = Ux + \phi_S(x,y,z) + \phi_1(x,y,z)\, e^{i\omega t} \tag{1}$$

where U is the forward speed of the vessel, $Ux + \phi_S$ is the steady potential, ω is the circular frequency of encounter, t is the time variable, i is the complex unit and $\phi_1 e^{i\omega t}$ is the unsteady potential which is linear with respect to the incident wave amplitudes. We will approximate the boundary value problems for ϕ_S and ϕ_1 in the same way as Faltinsen (1983) did for bow flow around a ship. The consequense of this is that the near-field solutions of ϕ_S and ϕ_1 satisfy a two-dimensional Laplace equation in a cross-sectional plane of the vessel. The linear body boundary conditions and free surface conditions are kept in their original form. This means the free surface conditions are the classical free surface conditions with forward speed. Only "divergent" wave system are accounted for. At the aft end of the ship generalized Kutta-conditions are set up both for ships with transom sterns and ships with a clearly defined trailing edge.

The steady and unsteady forces and moments on the vessel are obtained by properly integrating the pressure. The damping coefficients B_{jj} are checked by deriving a formula based on conservation of energy in the fluid. The formula uses similar approximations that are made in formulating the boundary value problem.

The velocity potential was found by the solution procedure used by Faltinsen (1983). For each cross-sectional plane along the hull Green's second identity was used to represent the velocity potentials in terms of a distribution of fundamental two-dimensional sources and dipoles over a closed surface containing the body surface, the free surface and a control surface far away. The free surface conditions were used to step the solution from the bow to the aft end of the vessel.

It has been demonstrated that the results converge by increasing number of elements on the body surface, free surface and number of strips. The numerical results have been compared with numerical and analytical results for linear transient motions of a circular cylinder, results given by Tuck (1988) for the wave resistance of a parabolic strut and results given by Chapman (1975) for the added mass and damping coefficients of a flat plate oscillating in sway. The damping coefficients were checked by energy relations. The steady wave elevation around a Wigley hull was compared with complete linear three-dimensional methods for Froude number > 0.4. The agreement for all tests are generally satisfactory. The results demonstrate that it is reasonable to neglect the effect of the transverse wave systems at large Froude number both for the steady and unsteady problem. Further it is shown that conventional strip theories for ship motions are inadequate for high Froude numbers.

It has been demonstrated that use of very small elements near the intersection of the body and the free surface may create numerical problems. One reason to this may be locally high oscillatory behaviour of the velocity potential. This can be demonstrated by analysing the free surface elevation in front of a plate that at time $t < 0$ has zero velocity and at time $t \geqslant 0$ has a constant transverse velocity $U = U_0$ (see Fig. 1). The analytical solution has been derived by Roberts (1987). The numerical results have been obtained by replacing $\partial/\partial t$ with $U\, \partial/\partial x$ in the steady free surface condition. We note that the analytical solution has a highly oscillatory behaviour in the vicinity of the plate. By keeping very small elements on the free surface we are able to capture some of the local behaviour. However, it will be impossible by assuming constant variation of the velocity potential and normal velocity over each element to simulate the highly oscillatory behaviour. This will require infinite number of elements. A different approach would be to use a local analytical solution form in the numerical code. However, it is difficult to know this analytical solution form in a general case. On the other hand our inability to simulate the local highly oscillatory behaviour very close to the plate does not significantly influence the quality of our numerical predictions at a small distance away from the flat plate.

Nonlinear theory

Keuning (1988) has measured distribution of hydrodynamic forces along a ship that is forced to oscillate in heave at high forward speed. The tested Froude numbers were 0.57 and 1.14. Their results show interesting features. One is the importance of dynamic restoring coefficients. To explain this effect theoretically it is necessary to include the interaction between the unsteady and steady velocity potential. This effect is neglected in the linear theory described previously. The results also indicate that it is wrong to linearize about the mean free surface and that it may be better to use the steady wave elevation as a reference level. The importance of trim and lift on the added mass and damping coefficients are also demonstrated. We have therefore started development of an alternative theory. We still assume that the velocity potential satisfy a two-dimensional Laplace equation in the near-field of the ship. We find that the steady velocity potential has to satisfy a nonlinear free surface condition. The free surface condition for the unsteady velocity potential is linearized around the steady wave elevation along the ship. In the body boundary condition for the unsteady potential the effect of the steady potential is accounted for in the socalled m_j-terms. Presently we have no numerical results available. The intention is to present comparisons with the experimental results by Keuning and to discuss the importance of the interaction between the steady wave potential and the unsteady wave potential. This has relevance because several research groups are presently involved in developing computer program for ship motions based on distributing three-dimensional sources and dipoles satisfying the classical free surface condition with forward speed. This free surface condition neglects the effect of the steady disturbance potential due to the hull.

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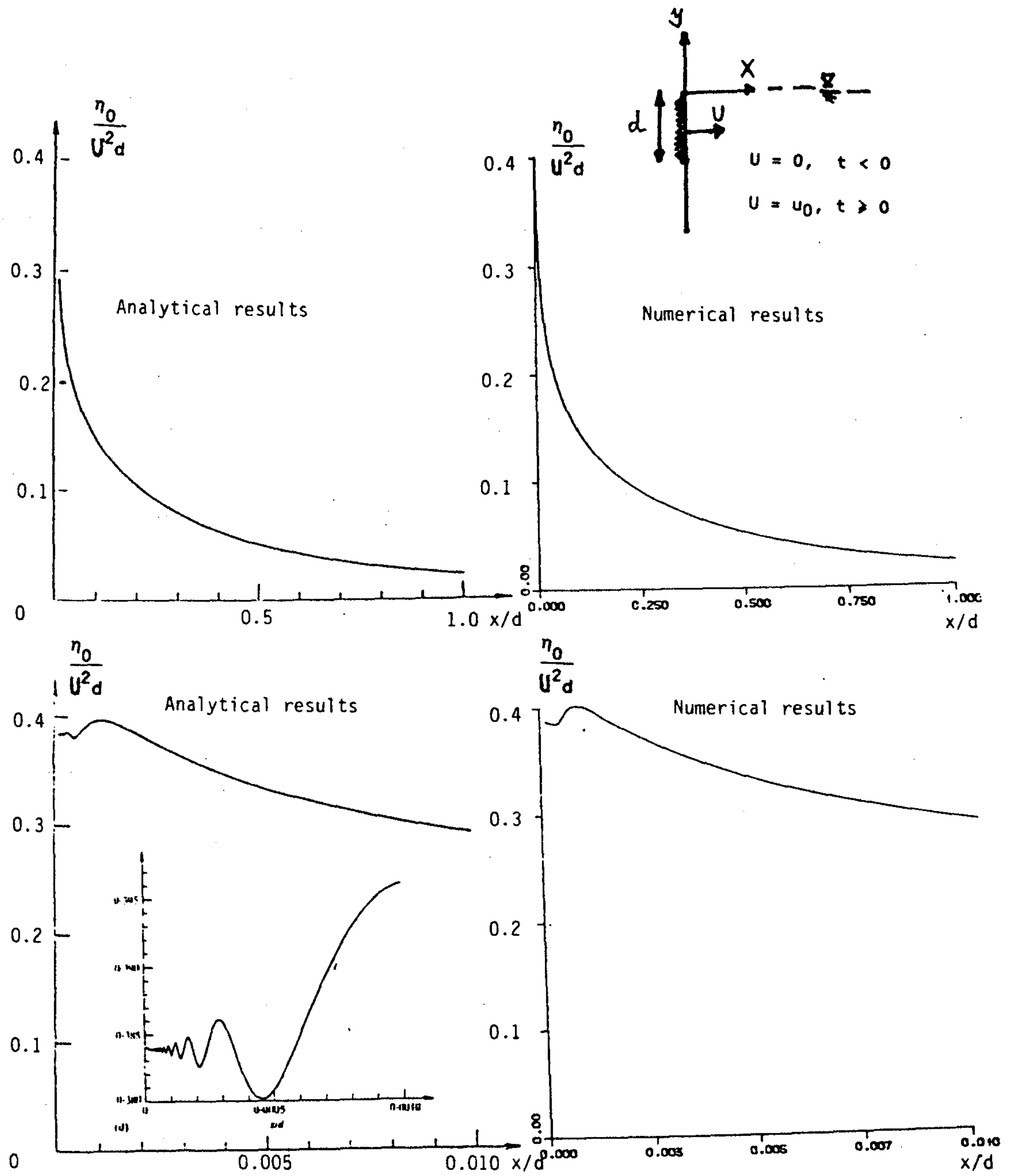

Fig. 1 The free-surface elevation in front of a plate at non-dimensional time $t(g/d)^{½} = 0.1$. The free surface is shown for three different length scales. Analytical results are from Roberts (1988). η_0 = free surface elevation.

DISCUSSION

Peregrine: Please indicate the solution method used in your nonlinear computations.

Zhao: We used the boundary element method.

Cao: How do you apply the radiation conditions in your computations, especially in the first and last strips, which are different from the other strips?

Zhao: For the first strip, we set $\phi = 0$ and $\frac{\partial \phi}{\partial x} = 0$ at $z = 0$. For the last strip, we assume that the flow leaves the last section tangentially in the downstream direction.