A THREE-DIMENSIONAL PANEL METHOD FOR CALCULATING WAVE-MAKING RESISTANCE

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A new approach is developed for calculating the wave-making resistance of vessels advancing on an otherwise calm water surface, [1]. The method is based on three-dimensional potential theory, and the flow is assumed to be steady. The fluid is divided into an inner and outer domain by two vertical control surfaces as shown in figure 1. These surfaces are parallel to the free stream, extending to infinity and one at each side of the body. The internal flow is matched to the external flow on the control surfaces in order to satisfy the radiation condition. The inner domain is bounded by the body surface, S_B, the free surface, S_F, the two vertical control surfaces, S_V, and a surface at infinity, S_∞. The outer domain consists of the rest of the fluid domain, which is two segments of a sphere, marked by the dotted lines in the figure.

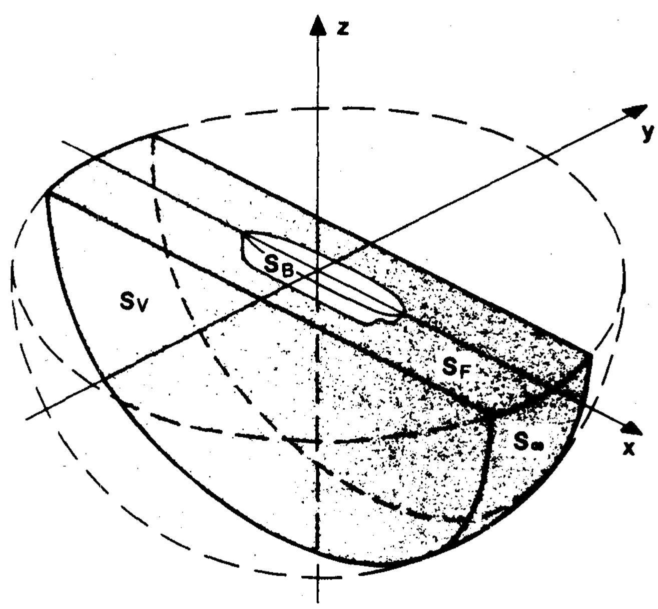

Figure 1: Inner and outer domains

The reason for introducing the vertical control surfaces is partly to restrict the computational domain and partly to obtain well defined radiation conditions. The numerical scheme shows that a disadvantage is that panels have to be distributed on a restricted part of the control surfaces in addition to the hull surface and the free surface. On the other hand many elements can be excluded from the free surface compared to other similiar methods. It is assumed that the wave effect will decrease rapidly with depth and a large part of the control surface can be truncated.

In addition to the two above-mentioned reasons for using two domains, the scheme also suggests using two different linearisations with respect to the free-surface condition. A low-speed linearisation is adopted in the inner domain and a free-stream linearisation in the outer domain (similiar to Kelvin's thin ship formulation). Assuming that the free stream linearisation is satisfactory in the outer domain, other linear or nonlinear boundary conditions on the free surface may be used.

Another possibility is to use a totally different numerical solution method in the inner domain. A finite difference scheme may be of interest when a local flow phenomenon is studied, and the fluid can be described by more complex equations.

The total potential is divided into three parts.

$$\begin{aligned} \Phi &= Ux + \phi \\ &= \phi_d + \phi_1 \\ &= Ux + \phi_0 + \phi_1 \end{aligned}$$

where

Ux = free-stream potential
ϕ_d = double-body potential
ϕ_0 = disturbance potential in double-body theory
ϕ_1 = disturbance potential in low-speed theory
ϕ = disturbance potential in thin-ship theory.

Note that when matching is performed on the vertical control surfaces, ϕ from the outer solution has to equal $\phi_0 + \phi_1$ from the inner solution.

A three-dimensional source-sink method is adopted in the numerical treatment of the problem, using a source function for an infinite fluid. A distribution of source density on the wetted part of the body, on a local part of the free surface and on the control surfaces has to satisfy the boundary conditions in the inner domain.

A numerical differential operator is used in order to satisfy the boundary condition on the free surface. A number of different operators have been tested and a four-point operator is selected in the final program.

The boundary condition on the control surfaces is obtained by using Green's second identity on the outer domain. The vertical control surfaces are assumed to be so far from the body that the waves will satisfy the linear free-surface condition. It is then appropriate to use the Kelvin source function, G_K, to describe the outer flow. It can be shown that the boundary condition on the vertical control surfaces is

$$\phi = \frac{1}{2\pi} \iint_{S_V} G_K \phi_n dS \qquad \text{on } y = \pm b \tag{.1}$$

The wave resistance can be calculated by two different methods. One is to calculate the pressure distribution on the wetted hull surface and to integrate for the force in longitudinal direction. The other is to use the inner solution combined with a control surface integration.

$$R_W = 2\rho \iint_{S_C} \phi_x \phi_n dS \tag{.2}$$

The concept of an inner and outer domain is especially attractive since it makes use of the matching surfaces as a part of the control surface, $S_C = S_V + S_\infty$. In the case where the vertical control surfaces are extended to infinity, only S_V will give a contribution to the integral.

The present method has proved to be successful in solving the linear wave-making problem. Results such as wave-making resistance, wave elevation, sinkage and trim are generally in good agreement with experimental data.

The test cases confirm the flexibility of the method with respect to body forms and Froude numbers. Some restrictions exists in the lower Froude number range caused by discretization problems of the free surface.

Only limited number of ship forms have been tested in the present work. Further development of the method should include a number of additional test cases. The high Froude number range ($F_n > 0.5$) is especially important. The knowledge thereby obtained, will be useful in refinements of the numerical method.

References

[1] AANESLAND, V. 1986. A Theoretical and Numerical Study of Ship Wave Resistance. *Dr. ing. thesis, Report UR-86-48. Norwegian University of Technology, Division of Marine Hydrodynamics.*

Newman: Have you observed any short waves at the waterline in your computational results, as the panel size is reduced?

Aanesland: When the control surfaces are as close as in the test case, with only two parallel rows of elements on the free surface, I observe a small oscillation on the downstream part of the bow wave. It might be due to instabilities, but when the control surfaces were moved away from the body they disappear.

Bertram:

1. Does your program account automatically for trim and sinkage or do you have to re-panel the hull after each run as Dawson did?

2. How many iterations do you use for your free model?

Aanesland:

1. I re-panel the hull, but it is done automatically by a pre/post-processor in order to save work.

2. In the presented results, I used 2 and 3 iterations depending on the Froude number.