NONLINEAR STEADY SHIP WAVE PROBLEM FOR A SWATH SHIP

Volker Bertram
Institut für Schiffbau der Universität Hamburg

Jensen /1/ presented on the last workshop in Woodshole a method for solving the steady ship wave problem meeting the non-linear boundary condition at the free surface. For a Wigley hull and a Series-60 hull very good agreement with experimental data was shown and no convergence problems reported. A detailed description of the theory can be found in Jensen's dissertation /2/ and will therefore be omitted in this abstract.

For SWATH ships (SWATH = Small Waterplane Area Twin Hull) a number of methods have been developed for resistance prediction. They were all based on thin ship theory or slender body theory or a combination of both. According to Robert MacGregor of Glasgow University (personal communication) all existing programs were limited to SWATH ships with circular or ellipsoid cross-section of the buoyancy hull. When a SWATH ship of considerably different shape (Fig. 1) was designed, Jensen's program was modified and used for predicting the wave resistance. Frictional and viscous pressure resistance were predicted by approximate formulas as by other authors.

The hydrodynamics of a SWATH ship are in many regards more complicated then in regular rather slender mono-hulls as a Series-60. One problem is the rather ununsual shape of the cross section which can cause some difficulties in the non-linear computation. In Jensen's method the height of the free surface at the collocation points is changed in the course of the iteration. Close to the water-line collation points might thus be shifted inside the singularity distribution on the hull surface causing fatal errors. So the method was slightly modified. Each step the points are not only shifted in height but also in horizontal direction according to the current waterline. For a demihull this modification ensured rapid convergence (the error in the free surface was reduced by a factor of 10 in each convergence step) and proved to be necessary as even at moderate speeds the first step of iteration (Kelvin condition) predicted a partial surfacing of the round buoyancy hull.

Another problem in a SWATH ship is the presence of two interacting hulls. Each hull induces a slightly oblique flow at the other hull. If you want to take this effect into consideration, you have to apply similar techniques as they are used in aerospace for wings which encounter a flow at a slight angle. Then you use distributions of vortices or dipoles on top of your source distribution and fulfill some sort of Kutta condition on the trailing end of the wing. Like almost any other author at the time who tried SWATH ship resistance prediction, we shied away from the difficulties and time involved. We felt justified in this decision after looking at the velocities induced by just one demihull at the location of the other. For a double body model the velocities were virtually that of a uniform flow. For another SWATH ship Bai, Kim and Kim /3/ applied a thin ship/slender body method including a dipole distribution to meet a Kutta condition at the trailing end of each strut. This method is limited to linear solutions fulfilling only the Kelvin condition at the free surface. For this case they found that for the wave resistance no significant difference was observed but reported some differences in the local velocity field near the trailing edges of the struts.

For our SWATH ship with Jensen's modified method only in a few cases non-linear solution succeeded (Fig. 2). Computational results for total resistance are compared with experimental results of the HSVA. The qualitative agreement is acceptable giving local optima at the correct places. However, the absolute agreement of the results is rather disappointing if compared to Jensen's excellent results for mono-hulls. A similar observation was made in predicting sinkage of the SWATH ship (Fig. 3). The order of magnitude was right but humps in the experimental curve could not reproduced in computations. Trim was set to zero both in experiments and calculation. It was argued that a captain would correct trim by rearranging ballast in the SWATH ship.

Naturally, the question arises - and should be discussed: Why are there still notable differences between computation and experiments and how could the model be still improved? For the medium Froude-Number range there is a considerable phase shift between the waves on the inside and the outside of each hull before the computation breaks down. The point with the highest error in the free-surface condition and also the highest vertical accelaration was at the end of the strut. This seems to indicate that cross-flow effects might afterall be important for non-linear solutions despite Bai's et al. findings for linear solutions. By using dipole distributions in principle this difficulty should be removable.

More serious are the problems at high Froude numbers. Here the hot spot is behind the SWATH ship at the plane of symmetry. Two wave crests starting from the trailing edges of the struts superimpose resulting in a splash. One of the fundamental assumptions of Jensen's method - and any other panel method for potential flow prediction known to me - is the exclusion of breaking waves so that the free surface can be described as a function over an cartesian coordinate system. I do not see any remedy at hand for this case. Time-domain solutions for such complicated three-dimensional problems seem at present to be out of bounds - at least for naval architects.

While by no means totally convincing in its results, at least the presented method seems to be a step in the right direction for predicting flows around SWATH ships of arbitrary shape and catamarans.

/1/ Jensen, G.
Numerical Solution of the Nonlinear Ship Wave Resistance Problem
3rd International Workshop on Water Waves and Floating Bodies, 1987

/2/ Jensen, G.
Berechnung der stationären Potentialströmung um ein Schiff unter Berücksichtigung der nichtlinearen Randbedingung an der Wasseroberfläche
IfS-Report Nr. 484, 1988

/3/ Bai K.J., S.E. Kim, J.W. Kim
The Cross Flow Effect on the Force and Moment acting on a SWATH Ship
17th Symposium on Naval Hydrodynamics, 1988

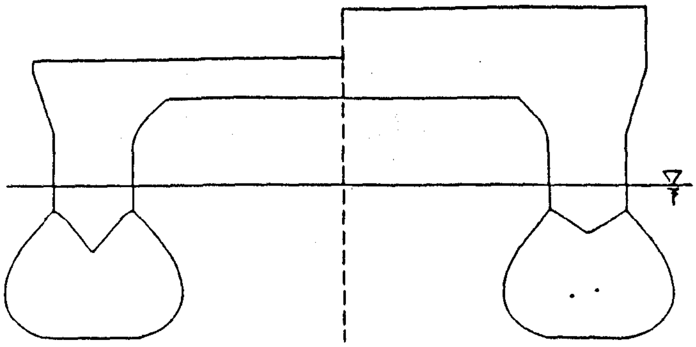

Fig. 1: sketch of typical cross section of investigated SWATH ship

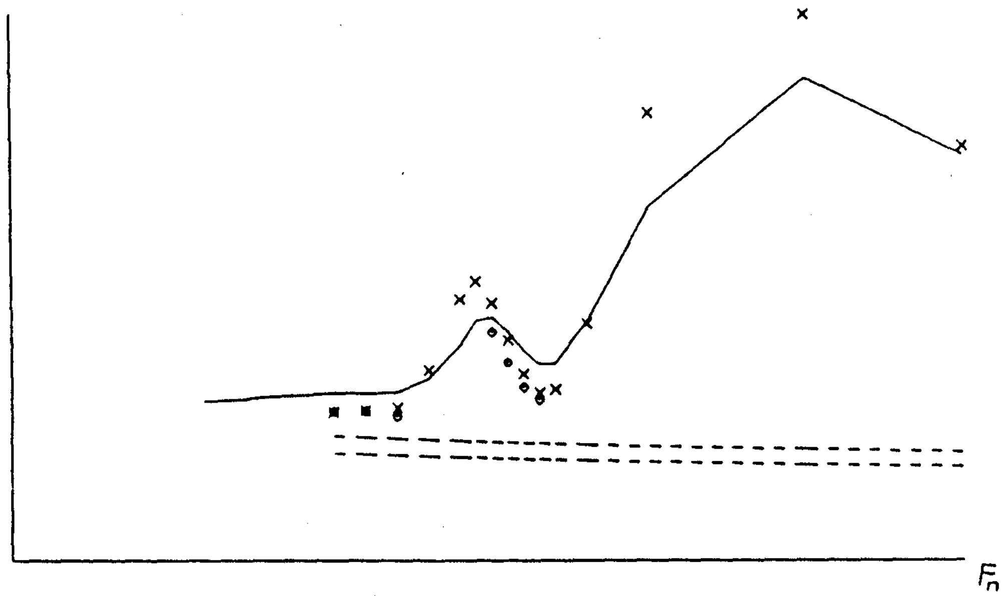

Fig. 2: resistance coefficients

C_F lower dotted line

C_V upper dotted line

C_T according to non-linear computation: ◊

C_T according to linear computation: ×

C_T according to HSVA experiments: solid line

DISCUSSION

Nakos: Would you comment on the conditions that should be met in order for the iterative scheme, for the non-linear problem, to converge.

Bertram: Collocation points should be placed on areas where waves are liable to break. The bow region is easily excluded. The point of breaking behind the ship introduces a certain arbitrariness or random aspect. With increasing F_n your "chances" of hitting a breaking wave region. In this regard the method has an upper limit of applicability.

Fein: The velocity mismatch at the trailing edge of a SWATH stut may be be reduced with a reduction of wave resistance by introducing asymmetry in the strut (hull at the water line). Also the first SWATH ship, the SSP KAIMALIND, had a similar wave resistance curve with a nonlinear first peak at Fr=0.3 the design point of your ships a higher design speed would be more favorable.

Bertram: I agree on both points. The proposed asymmetry, however, works only well for one Froude Number. I am not responsible for the design. Personally, I think the design is too small and slow to give you good clues about the possibilities of SWATH ships.

Cao: (1) Does it make signicant difference in the solution if you add two (or more) rows of collocation points upstream and two (or more) rows of source points down stream? I don't see the clear physical sense of the way of implementation of the radiation condition.
(2) Is the solution sensitive to the location of the source points above the free surface?

Bertram: (1) It does, but I do not recall quantitative results. Jensen tested this method extensively. He found that 1 row spaced a typical Δx gives the optimum. For cases where an analytical comparison is available, no other method (3-pt, 4-pt, spline-differencing schemes) works as good or better but all other methods need more CPU-time and make your code more complicated. Also this method does not introduce an artificial damping, which I have checked numerically in the 2-D case. Since the method is so simple, why don't you try it for yourself!
(2) No, I found similar results as you. If Δz is the vertical distance of source-layer and collocation-point-layer and Δx a typical spacing in x-direction we use $\Delta z/\Delta x=2$. But results for $\Delta z/\Delta x=1.5$ or $\Delta z/\Delta x=3$ the results should not change more than 1% in my estimation.