SHALLOW WATER EFFECTS FOR SWATH SHIPS

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SWATH (small waterplane area twin hull) ships are designed for good seakeeping even at high speeds. Shallow water effects can be important for SWATH ship operations if fast SWATH ships operate in coastal areas or rivers. Existing SWATH ships with a displacement of more than 100 tons can be classified into two groups: "slow" SWATH ships operating at Froude numbers $0.2 \leq F_n \leq 0.3$ and fast SWATH ships operating at Froude numbers $0.7 \leq F_n \leq 0.8$, Bertram (1993). Fast SWATH ships are usually relatively small (less than 400 tons) and used as passenger ferries. These fast ferries for short or medium distances operate in coastal areas where the depth limitation affects the hydrodynamics. Questions arising in this context are:

1. How does the resistance increase?
2. How does sinkage increase?
3. How does the trim moment change?

Traditional model experiments to answer these questions are time-consuming and costly. Could a computational method be a substitute of sufficient accuracy? Previous SWATH computations on deep water showed recent improvements in predicting capabilities even though fully nonlinear solutions were not possible due to breaking waves, Bertram (1989,1993). Computations for slow ships in shallow water even with side walls captured major effects well but our experience was limited to under-critical speeds (Froude number based on water depth smaller than 1), Bertram and Jensen (1992). Therefore, computations for a SWATH ship on shallow water were now compared to model experiments for a wide range of depth Froude numbers covering under- and over-critical speeds. Computations were performed before model tests.

The computational method considers the steady flow of an ideal fluid around a twin-hull ship. The field equation for this potential flow is Laplace's equation that holds everywhere in the fluid domain. A well-posed problem formulation requires additional boundary conditions:

1. Water does not penetrate the wetted hull surface (Neumann condition)
2. Water does not penetrate the bottom of the sea (Bottom condition)
3. Water does not penetrate the water surface (Kinematic condition)
4. There is atmospheric pressure at the water surface (Dynamic condition)
5. The ship is in equilibrium (Equilibrium condition)
6. At the end of the strut the flow separates (Kutta condition)
7. Waves appear only in a sector behind the ship (Radiation condition)
8. There is uniform flow far away from the ship (Decay conditon)

The computational model of a Rankine panel method accounts only for part of the free water surface. This introduces an artificial boundary. Waves created by the ship must pass through this boundary without reflection ("open boundary" condition).

The problem is complicated because Kutta condition (6) and dynamic condition (4) are nonlinear and the exact boundaries of ship hull and water surface are a priori not known. An exact solutions would require fully nonlinear methods which are not available if areas with breaking waves are large. This is always the case for fast SWATH ships.

Positive experience for deep water justifies a simplification:

1. The nonlinear Kutta condition is substituted by the linear Joukowski condition: The cross flow component in horizontal y-direction is zero at the end of the strut of each SWATH demihull.
2. Dynamic and kinematic condition are combined and linearized. The resulting simple Kelvin condition is enforced at the undisturbed water plane $z = 0$.
3. Trim is fixed for SWATH ships. This generally applied assumption for SWATH ships reflects assumed corrections by the crew to keep the ship on an even keel by ballasting or using control foils.

A Rankine panel method with additional horseshoe vortices solves the problem stated so far. The conditions are fulfilled:

1.	Neumann	collocation
2.	Bottom	mirror images of all elements with bottom as reflection plane
3.	Kelvin	collocation
4.	Equilibrium	not, sinkage is calculated once without repeating calculations. Trim is fixed
5.	Joukowski	collocation at 0.5 typical grid spacing behind strut
6.	Radiation	staggered grids
7.	Decay	automatically
8.	Open boundary	staggered grids

Bertram (1993) gives the mathematical model with all essential formulae.

A research program of the German ministry for Research and Technology (BMFT) investigates fast and unconventional ships. Part of the program is concerned with systematic model series for SWATH ships. The method was applied to a typical SWATH configuration from this program, Fig.1. A gap between strut and hull in the aftbody was closed in the panel model. The errors in the global solution due to the change of geometry will be small as this region is poorly approximated by potential flow anyhow.

The computed wave resistance was always smaller than the measured residual resistance, Fig.2. The difference become most pronounced for transcritical speeds where the maximum of the resistance coefficient appears. It is subject to discussion to what extent this discrepancy is due to physical (viscous) effects. However, our panel method predicts for real ship geometries resistance with insufficient accuracy. (The same is true for most other comparable codes such as RAPID, SWIFT, SWAN, etc.) Recent research of Söding (1993) indicates that a collocation method should enforce an average condition over a surface patch rather than a condition at one point to improve accuracy. Incorporation of this approach may improve agreement for resistance considerably. I have no explanation why the computational maximum is closer to the critical Froude number than the experimental maximum.

Sinkage was reproduced surprisingly well, Fig.3. There appears a narrow range of overcritical speeds with dynamic lift (negative sinkage). The computations reproduced this lift. Experimental data show extreme scatter in this region making a comparison of quantitative values difficult.

Trim moment (Munk moment) was extremely well captured, Fig.4. I was surprised by the agreement because I considered trim to be numerically sensitive and influenced by viscous effects. The present analysis seems to contradict this; qualitative and quantitative agreement is sufficient for practical design purposes.

Acknowlegdement

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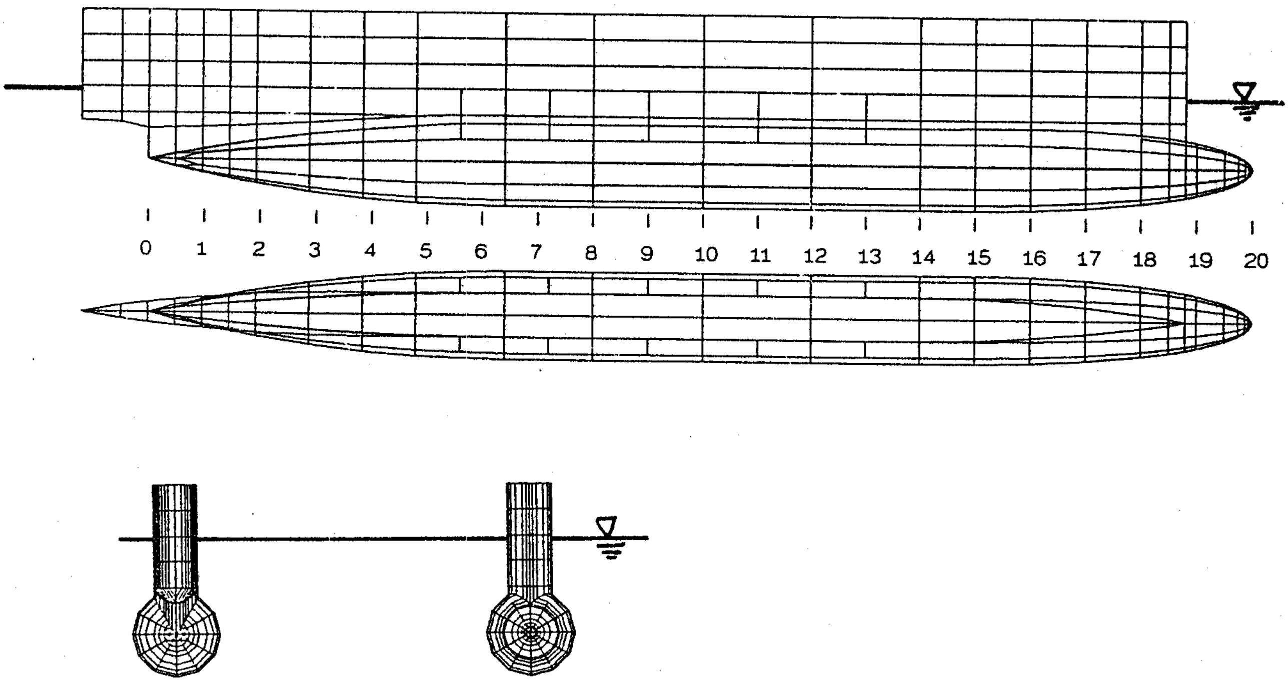

Fig.1: Discretization of SWATH model

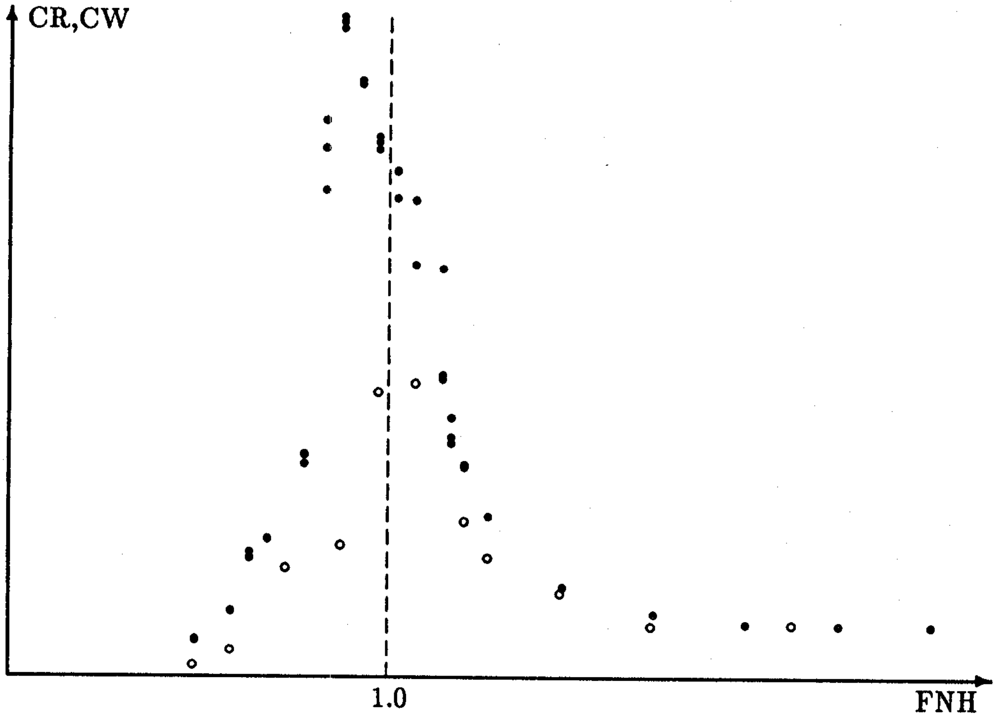

Fig.2: Wave/residual resistance for SWATH ship, • experiment, ○ computation

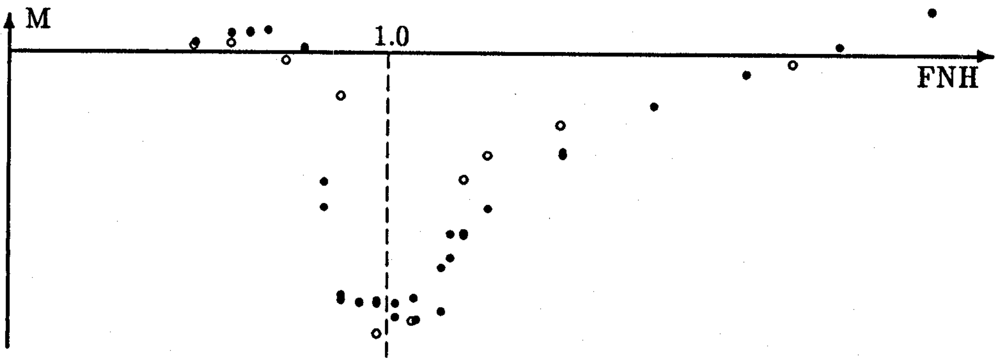

Fig.3: Trim moment for SWATH ship, • experiment, ○ computation

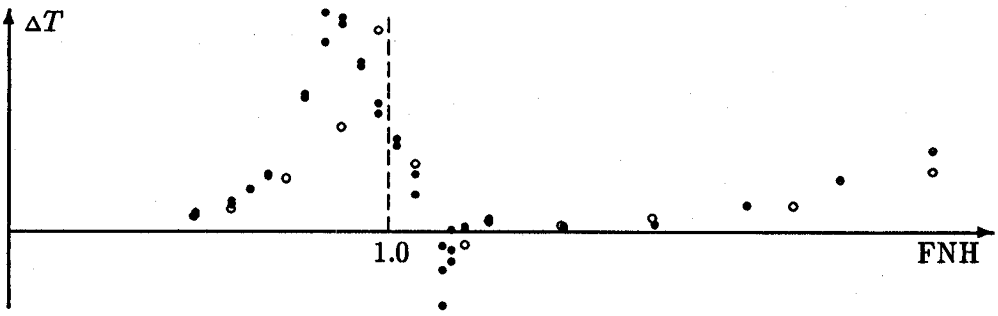

Fig.4: Sinkage for SWATH ship, • experiment, ○ computation

DISCUSSION

Wang B.: Fig.2 shows a large difference between experiment and computation near the $Fn = 1$. There must be solitary wave. So, the radiation condition (7) "Waves appear only behind the ship" seems not suitable. There are solitary waves in front of the ship when Fn near 1. How do you consider it?

Bertram V.: I do not consider the solitons. I suspect the most important factor contributing to the difference is the sinkage which is not considered in determining C_R. If solitons were the main factor, the measured results should show more scatter than seen in Fig.1.

Lu Y.: What is the open-boundary condition that used in your mathematical model?

Bertram V.: The open-boundary condition is not formulated mathematically. The numerical technique of shifting the panels downstream by one grid spacing is used to enforce the condition in the numerical model.

Grue J.: In a sea of shallow water of unbounded horizontal extension, solitary waves are generated ahead of the ship when the Froude number $Fn = U/\sqrt{gh}$ is larger than one. The energy is then transported first upstream (via the solitons) then out to the sides, leading to an increase in the wave resistance. (Reference: Fieir Pedersen, J. Fluid Mech. 1989.) Have you observed this in your experiments and your theory?

Bertram V.: Solitons were observed by my colleagues at Duisburg Towing Tank. Obviously a steady theory will not capture these. For supercritical speeds the solitons do not contribute substantially to the resistance in this case, Fig.2.

Yeung R.W.: The periodic generation of solutions at constant forward speed takes place only when the tank walls are sufficiently narrow. This should not be mixed up with the initial transients. If such upstream solitons should occur, a nonlinear theory is required and the normal collocation procedures used in such a code to control directionality of waves might not be appropriate, or have to be properly adjusted.

Bertram V.: I agree, although John Grue obviously does not. I am not yet convinced that a nonlinear theory/method is required for practical purposes. The transcritical speed region is of rather academic interest as real ship do not operate for an extended period at transcritical speeds.

Maruo H.: The wave resistance at the transcritical speed was extensively investigated by Prof. Inui in 1940s' and 1950s', both experimentally and theoretically. The generation of solitons was clearly observed. Please refer to the literatures on this investigation.

Bertram V.: Solitons were observed, but are not that important in this case, I think. They do not explain the large difference between C_R and C_W.