VALIDATION GIVES NEW INSIGHTS INTO NONLINEAR INVISCID FLOW COMPUTATIONS

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We consider the stationary flow of an incompressible, irrotational fluid around a symmetric ship. Far upstream the fluid has the uniform velocity U opposite to the direction of the x-axis of our Cartesian xyz coordinate system with z pointing downward. The field differential equation is then Laplace's equation that holds everywhere in the fluid domain. Furthermore, for a unique solution of the potential and the a proiri unknown position of the free water surface, we state boundary conditions on all boundaries:

Neumann condition	Water does not penetrate the wetted hull surface
Kinematic condition	Water does not penetrate the water surface
Dynamic condition	At the free surface there is atmospheric pressure
Radiation condition	Waves appear only in a sector behind the ship
Decay condition	Far away from the ship there is uniform flow

As the problem will be solved using a Rankine panel methods, we can only model part of the free surface. Waves created by the ship must then pass through the artificial boundary without being reflected and disturbing the solution at the ship (Open-boundary condition).

There exist a number of Rankine panel methods to solve the problem stated so far by fulfilling iteratively the fully nonlinear free surface condition that is derived by combining the kinematic and dynamic boundary condition on the free surface. These fully nonlinear panel methods represent the state-of-the-art in computing the near-field potential flow around real ship hulls to support hydrodynamic hull design. Among those methods presented in past Workshops are *Jensen (1988)* and *Raven (1992)*. Other comparable methods have been developed in Sweden and the USA. The methods are all in essence very similar and differ mainly in numerical details, e.g. enforcement of radiation condition by various Finite-Difference operators or staggered grids, panel type employed, etc.

Papers and presentations on these panel methods usually give the impression that these methods are the 'final answer' and no further research is necessary on the wave resistance problem. This is not true! An extensive validation project compared not only integral values such as resistance, trim and sinkage, but also flow details such as wave cuts and local pressure distribution. Even if integral values are in excellent agreement flow details might differ in regions where potential flow assumptions should still hold. ("Nobody believes stern waves anyhow.") The main findings are

1. Grids on the ship hull should be a lot finer towards the bow to avoid discretization errors. Fig.1. demonstrates the influence of the hull grid on the quality of the results for a container ship. The first grid used 405 panel on the hull, the second grid 516 panel. The additional panel were mainly allocated at the first 20% of the ship's length. The second grid was also generated automatically from a CAD system resulting in a very even spacing of elements. Errors in computing the resistance were reduced from about 100% to the margin of experimental accuracy. The source strength distribution also implies a need for very fine discretization at the bow.
2. Longitudinal wave cuts are a more sensitive test criterium for accuracy of computations than integral values such as resistance, sinkage and trim. A comparison of

longitudinal cuts from experiments and computations shows generally good agreement for long waves, Fig.2, *Bertram et al (1992)*. However, short wave modulations are not captured by the panel method. The reason lies in a discretization that is too coarse. It remains to be investigated if a finer grid spacing in longitudinal direction will solve the problem. Wave modulations seen in experimental results seem to originate from the bow and propagate outwards. Possible techniques for local grid refinement in the bow region should be discussed.

3. All 'fully nonlinear' methods are limited to weakly nonlinear cases. No successful iteration for cases with strong nonlinear effects have been reported. Strong nonlinear effects are present for full hull forms at higher speeds and for ships with strong flare. All nonlinear panel methods known to us inherently assume that waves will not break. In this case the elevation of the water surface can be described as a function of the undisturbed water plane. However, at least at the bow region of real ships the water will always break. A practical method for modelling breaking waves is not known to us. We hope that a joint discussion will raise the awareness of this problem and give at least some ideas for future research to overcome this major block on the road to truely nonlinear methods.

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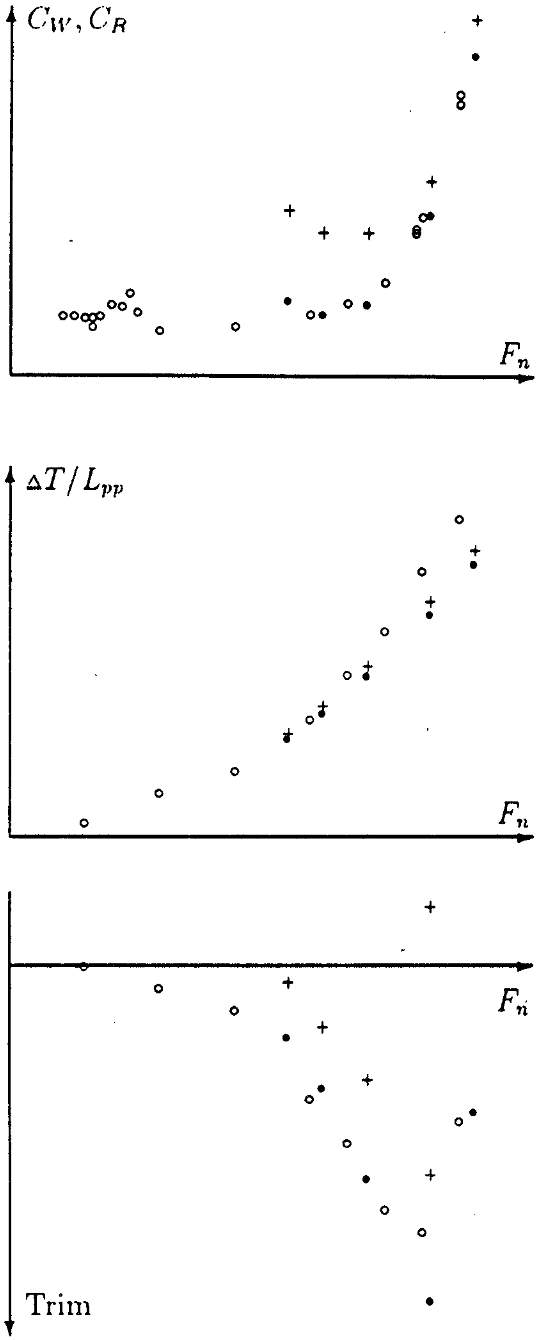

Fig.1: Wave resistance, dynamical sinkage and trim for container ship
○ experiment, +Grid 1, ● Grid 2

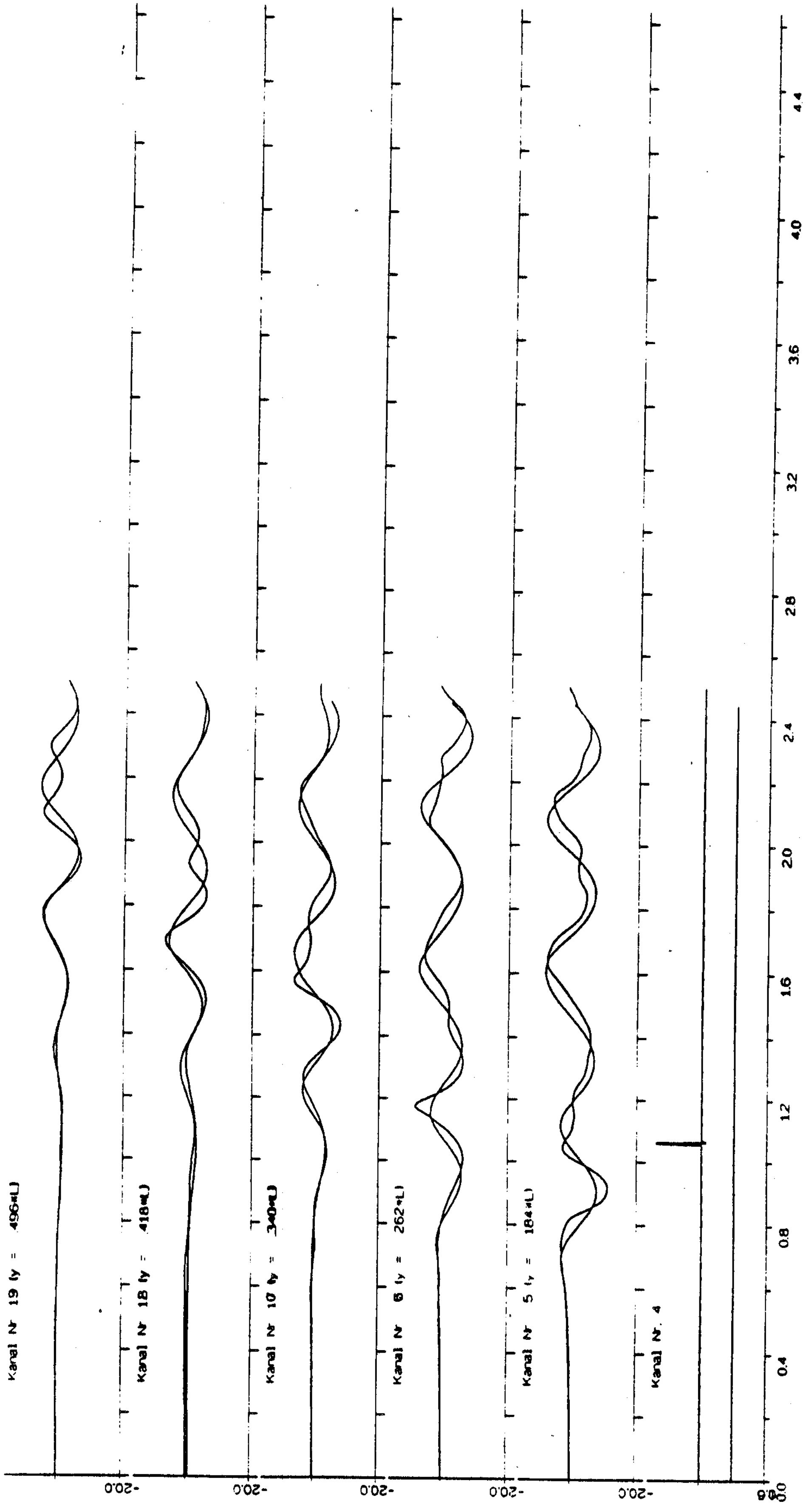

Fig.2: Modulations in experimental wave cuts are not captured by **computations with** nonlinear panel code