Influence of the Kutta condition on 3-d Ship Seakeeping Computations

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We present an indirect 3-d Rankine singularity method (RSM) in the frequency domain which captures all forward-speed effects. As both steady and unsteady flow contributions are captured three-dimensionally, the method is called 'fully 3-d'. The method is described in detail in Bertram (1998).

We consider a ship moving with mean speed U in a harmonic wave of small amplitude h. We assume an ideal fluid, using a perturbation formulation for the potential:

$$\phi^t = \phi^{(0)} + \phi^{(1)} + h.o.t. \tag{1}$$

$\phi^{(0)}$ is the part of the potential which is independent of the wave amplitude h. It is the solution of the steady wave-resistance problem. $\phi^{(1)} = Re(\hat{\phi}^{(1)} e^{i\omega_e t}$ is proportional to h. ω_e is the encounter frequency. Quantities with a hat denote a complex amplitude.

All motions u_i ($i = 1...6$) are assumed to be small of order $O(h)$ where h is the wave amplitude.

The harmonic potential $\phi^{(1)}$ is divided into the potential of the incident wave ϕ^w, the diffraction potential ϕ^d, and 6 radiation potentials, where ϕ^w and ϕ^d are divided into symmetric and antisymmetric contributions:

$$\phi^{(1)} = \phi^{d,s} + \phi^{d,a} + \phi^{w,s} + \phi^{w,a} + \sum_{i=1}^{6} \phi^i u_i \tag{2}$$

The steady flow contributions are determined in a 'fully nonlinear' wave-resistance code employing higher-order panels. This yields the steady dynamic trim and sinkage, the steady wave elevation and the first and second derivatives of $\phi^{(0)}$. The seakeeping (time-harmonic) problem to determine the $\phi^{(1)}$ is linearized around the steady solution, including fulfilling the boundary conditions on the steady (wavy) surface, using the actually wetted surface of the ship with trim and the steady wave profile.

The Kutta condition requires that at the trailing edge the pressures are equal on both sides. The Kutta condition is usually omitted in 3-d methods. It is unclear if this is due to some physical insight about the negligible effects or oversight. Our formulation for the Kutta condition requires zero complex amplitudes for the antisymmetric pressure:

$$-\rho(i\omega_e \hat{\phi}^{i,a} + \nabla\phi^{(0)} \nabla\hat{\phi}^{i,a}) = 0 \tag{3}$$

$i = 2, 4, 6$ for the antisymmetric radiation modes and $i = d$ for the antisymmetric diffraction part.

The unknown diffraction and unit motion radiation potentials can be determined independently. Rankine elements are located on the hull and above the free surface (desingularized). Collocation points are located only on starboard. Mirror images of all Rankine elements account for the port side.

For the diffraction problem, all motions u_i are set to zero. For a radiation problem, the relevant motion amplitude is set to 1 and all other motion amplitudes, the diffraction and incident wave potentials to zero. Then the free-surface condition and the hull condition are fulfilled in a collocation scheme. For the antisymmetric problems, also the Kutta condition is fulfilled at

the last column of collocation points at the ship stern. A corresponding number of Thiart elements (semi-infinite dipole strips on the plane $y = 0$), Bertram and Thiart (1998), are used. The dipole strips start amidships and have the same height as the corresponding last panel on the stern. Radiation and open-boundary condition (waves propagate only downstream and are not reflected at the outer boundary of the computational domain) are enforced by 'staggering' the Rankine sources for the free surface relative to the collocation points by one typical grid spacing downstream. The collocation scheme forms eight systems of linear equations in the unknown element strengths. The four symmetrical (likewise the four antisymmetrical) systems of equations share the same coefficient matrix with only the r.h.s. being different. All four cases are solved simultaneously using Gauss elimination. After solving the systems of equations, only the motions u_i remain to be determined.

The expressions to determine the motions are derived in principle from 'force = mass · acceleration'. This yields a system of linear equations for u_i ($i = 1, ..., 6$) which is quickly solved by Gauss elimination.

The S-175 containership was computed for the design condition with $F_n = 0.275$. The hull was discretized by 631 elements. Grids on the free surface had then in each case about 1300 elements.

Figs.1 and 2 compare results for oblique waves to experiments for $\mu = 150°$ and $\mu = 120°$. Results for heave and pitch agree well with experiments. The Kutta condition has only significant effects for yaw and sway at low frequencies and for roll near resonance. Here the Kutta condition simulates to some extent the effect of viscous damping and reduces drastically (by factors between 2 and 4) the motions. However, additional viscous effects (those that would be apparent also at zero speed) reduce for roll in reality the motions even more. For yaw and sway, no experimental data are available, but we expect that autopilots in experiments will prevent the large predicted motion amplitudes of the computations.

For low angles of encounter, the Kutta condition failed to improve consistently results. Improvements here are subject to further research.

BERTRAM, V. (1998), *Numerical investigation of steady flow effects in 3-d seakeeping computations*, 22. Symp. Naval Hydrodynamics, Washington

BERTRAM, V.; THIART, G. (1998), *A Kutta condition fo ship seakeeping computations with a Rankine panel method*, Ship Techn. Res. 45, pp.54-63

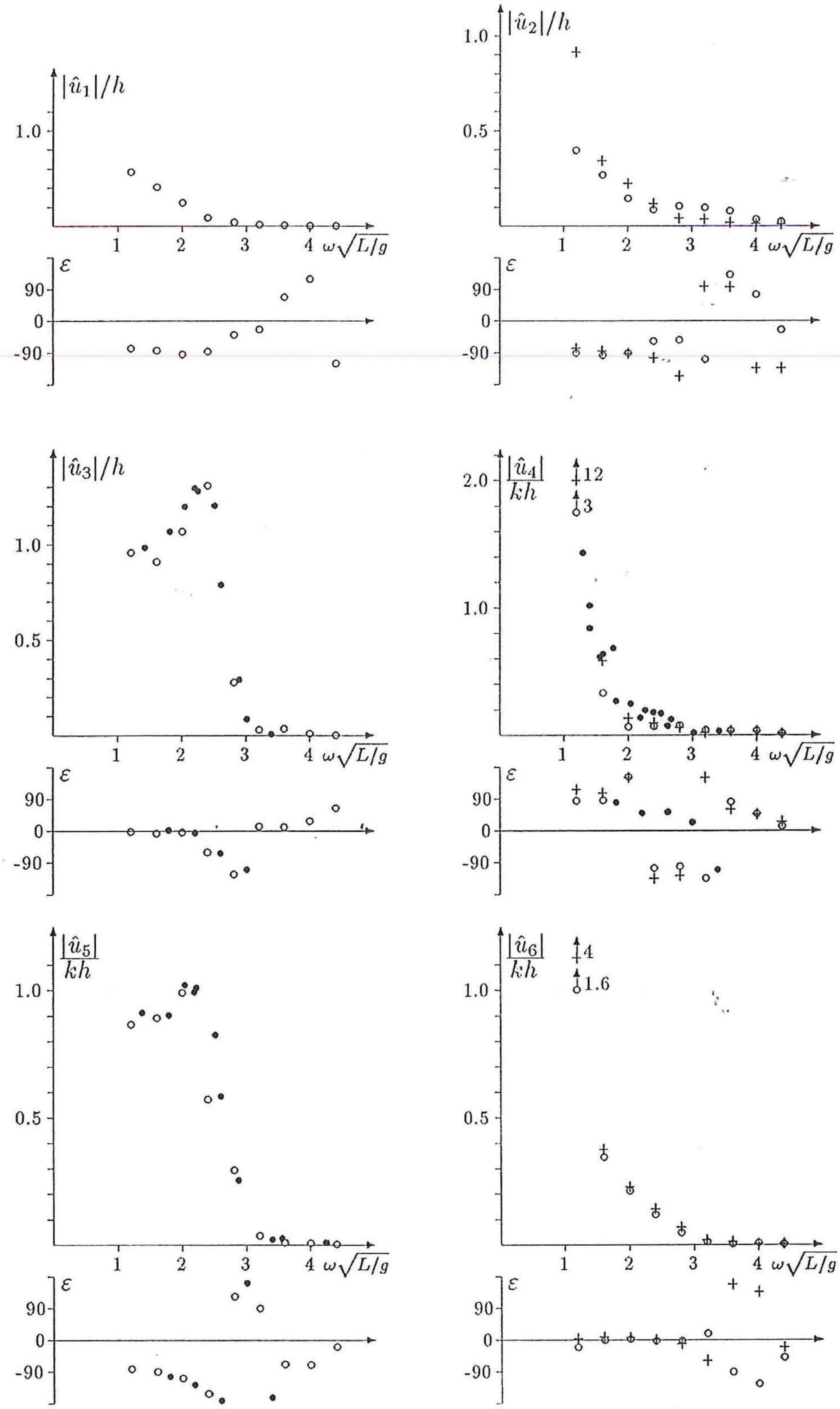

Fig.1: RAOs for S-175, $\mu = 150°$, $F_n = 0.275$; • experiment, + RPM without Kutta condition, ∘ RPM with Kutta condition

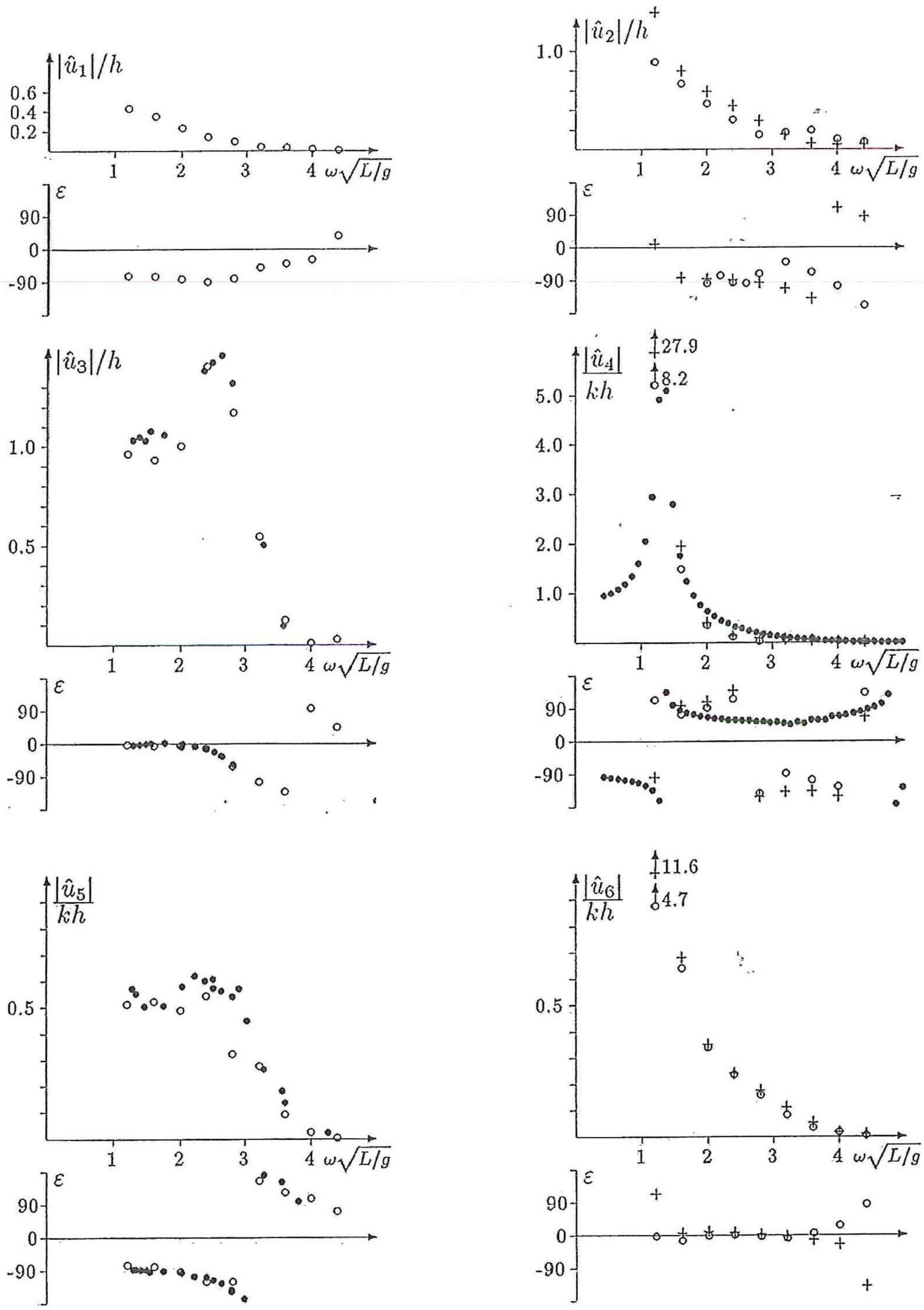

Fig.2: RAOs for S-175, $\mu = 120°$, $F_n = 0.275$; • experiment, + RSM w/o Kutta, ∘ RSM with Kutta