APPLICATIONS USING A SEAKEEPING SIMULATION CODE

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The computer code RATANA has been developed in order to simulate nonlinear and large–amplitude effects in ship motions. (See King, 1990). The present paper reports on progress in the continuing development of this package. The kernel of the code solves a coupled system of equations in body–fixed coordinates (Euler's equation). Various subroutines compute the forces required to solve the equations of motion. In principle, any type of force can be included, for example, Froude–Krylov and hydrostatics, linearised time–domain radiation and diffraction, nonlinear roll damping and active stabilisers. The use of a time–domain solver greatly eases the modeling of nonlinear external forces.

In the large–amplitude approach, adopted here, Froude-Krylov and hydrostatic forces are computed on the instantaneous hull position while the time–domain radiation and diffraction forces are computed using the linearised mean body position. The method is similar to that utilised by Adegeest, 1995 and appears to offer a good compromise between computational time and accuracy of the results produced. In order to use the instantaneous wetted surface in the calculations, the entire hull up to the highest waterline to be immersed must be paneled. The pressure due to the incident wave (Froude-Krylov pressure) is modified by so-called Wheeler stretching (Wheeler, 1970)

$$p_I(x,y,z,t) = \rho g \sum_n A_n e^{k_n(z-\eta_I)} e^{-ik_n(x\cos\beta_n + y\sin\beta_n)} e^{i\omega_n t} \qquad -\infty < z < \eta_I$$

where the incident wave elevation is taken as

$$\eta_I(x,y,t) = \sum_n A_n e^{-ik_n(x\cos\beta_n + y\sin\beta_n)} e^{i\omega_n t}$$

To calculate radiation forces, the impulse response functions can be entered directly if available, or can be obtained by Fourier transform of the added mass and damping coefficients obtained from a frequency–domain code such as DIODORE. A harmonic analysis is employed as a post–processor to decompose the temporal signals of motion, forces or other responses into mean values and harmonics of the fundamental frequency.

Using the mean body position for all the forces and linearising the equations of motion leads to a strictly linear time–domain simulation model. After transients have died out, the linear time–domain model yields purely sinusoidal responses, and the results should be identical to those obtained from frequency–domain calculations as well as to the fundamental component obtained from the large–amplitude model in the limit of vanishing wave amplitude.

Large–amplitude effects become important in roll motion in oblique seas. The effects of separation on active stabilisers with large incidence angles can be modeled. The large–amplitude formulation also appears to give good results for phenomena which are dominated by synchronous pitch motion in head seas. The calculation of drift forces (vertical for submarines, the hydrostatic term for added resistance of surface ships), has been treated with success. Treatment of the slamming problem, where relative motions and velocities in the bow region are important has recently been discussed, Fontaine, *et al.*, 1996.

As an example of calculations using the large–amplitude approach, a typical Naval vessel at 15 knots forward speed in head seas was chosen. A number of simulations in regular waves of varying frequency and amplitude were performed. Figures 1 and 2 show the heave and pitch transfer functions obtained from the harmonic analysis of the motion signals. The coefficients presented in the figures are the amplitudes of the various harmonic components of the signals normalised by the incident wave amplitude to the appropriate power. For example, for the heave transfer functions the mean, first, second, and third harmonics are denoted η_3^0/A^2, η_3^1/A, η_3^2/A^2, η_3^3/A^3, respectively. Thus normalised, the coefficients vary only slightly as functions of the wave-amplitude. For reasons of confidentiality, the values have been divided by a reference value, denoted $_{max}$, which is dimensionless constant.

The effects of large amplitude motion are strongest at frequencies near the peak of the pitch transfer function corresponding to a wavelength $\lambda = 130m$, or about 1.15 times the ship length, but the heave and pitch motions do not show very strong nonlinearities. For example, at this frequency there is a slight reduction (about 4%) of the peak of the fundamental pitch transfer function for the maximum value of the parameter $\lambda/A = 30$ shown in the figure, corresponding to a wave amplitude of $4.2m$. The mean heave displacement coefficient attains its maximum positive value of approximately 0.035 of the maximum where the coefficient of the fundamental is about 0.5 times the maximum. The mean heave displacement would thus reach less than 30% of the fundamental oscillatory component. The results obtained using the linearised version of the code (denoted 'LIN') are also shown for comparison along with the frequency–domain results. These latter two are in agreement to graphical accuracy.

Recent applications of the large–amplitude method include the calculation of shear forces and bending moments which show nonlinear effects even in moderate seas. Figure 3 shows the contribution of the Froude-Krylov and hydrostatic forces to the vertical shear force at various stations along the hull as functions of time. The frequency chosen corresponds to the maximum of the second harmonic shear force coefficient. The values of the shear forces in still water have been subtracted off, so only the contributions due to unsteady effects are presented. Only the last two periods of the simulation, those used in the harmonic analysis, are shown.

While the heave and pitch motions themselves are not found to be very nonlinear, the shear forces do contain strong mean, double-frequency and higher-order components at all the stations. These are clearly evident for the top figure ($\lambda/A = 30$), but much less so in the bottom figure where the signals appear much more sinusoidal, because of the small wave amplitude.

In figures 4 and 5 the results of the harmonic analysis of the signals at station 5 (solid line in figure 3) are shown. Note that the peak of the second harmonic response (shown in figure 5) is about 23% of the fundamental at the corresponding frequency. Thus, for the same $4.2m$ wave amplitude, the second harmonic component is approximately equal to the fundamental. Experiments are currently being performed on a segemented model of this ship. Comparisons with numerical results will allow assessment of the importance of nonlinenearities in structural loadings and the validition of the present model. If they can be made available, results will be presented at the workshop.

This work is the result of research supported partly by DGA/DRET, under contract number 95/2011 J. This support is gratefully acknowledged.

References

[1] Adegeest, L.J.M. 1995. Nonlinear hull girder loads in ships. Ph.D. Diss. Technical University of Delft.

[2] Fontaine E., L. Boudet, J.F. Leguen and A. Magee, 1996. Impact hydrodynamique d'un corps allongé et plat : Application au tossage. *Sixième Journées de l'Hydrodynamique*, Nantes.

[3] King, B.K. 1990 A Fast numerical solver for large–amplitude ship motions simulations, *The Fourth International Conference on Stability of Ships and Ocean Vehicules*, 299-306, Naples.

[4] Wheeler, J.D. 1970. Method for calculating forces produced by irregular waves, *Journal of Petroleum Technology*, 359-370.

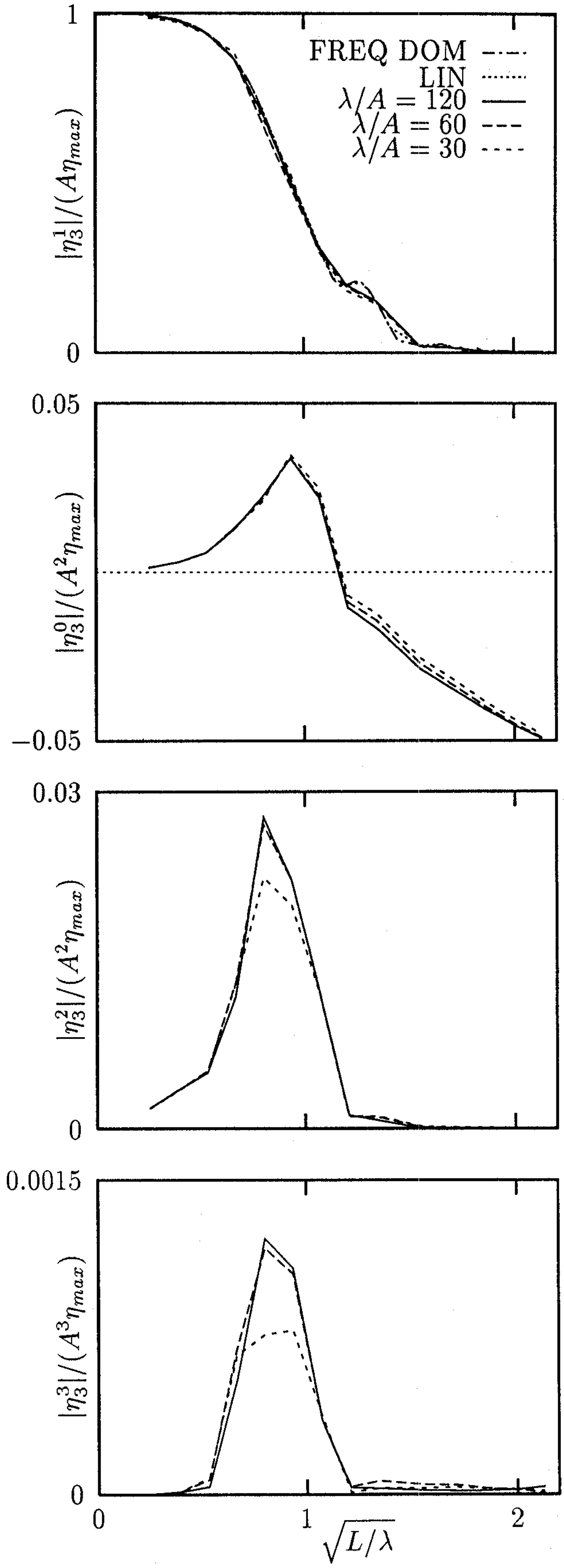

Figure 1: Heave motion transfer functions in head seas at 15 knots

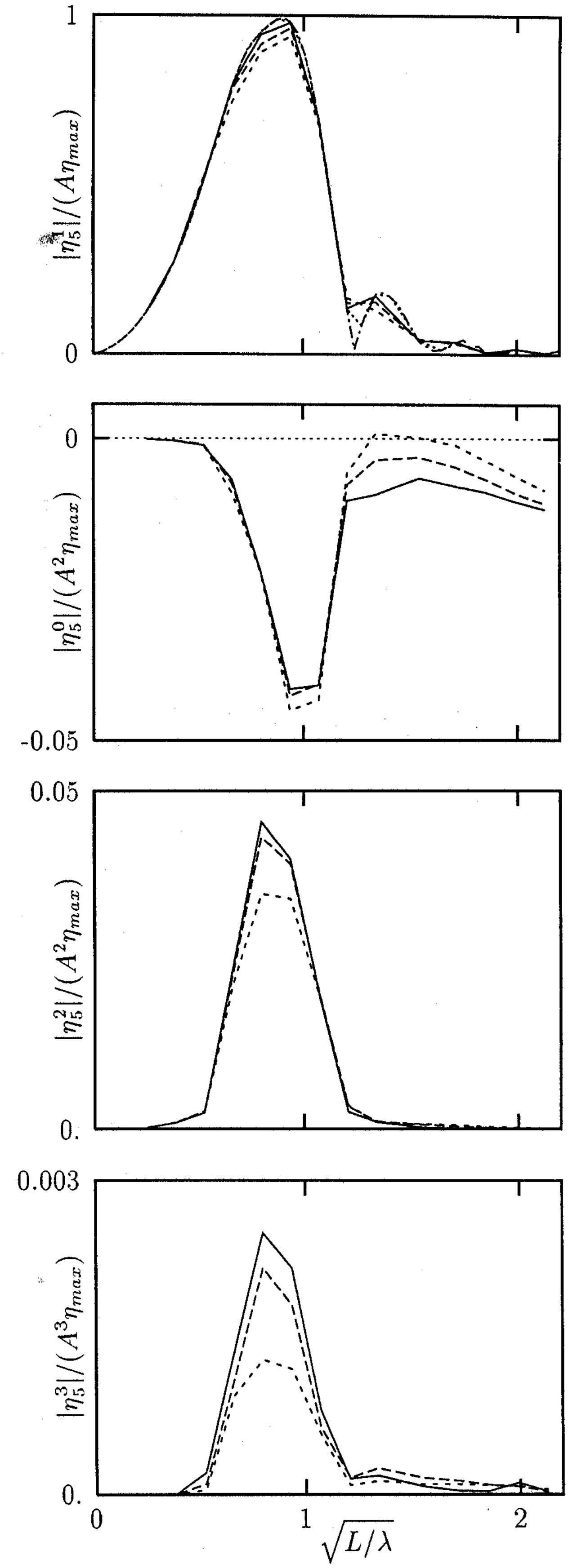

Figure 2: Pitch motion transfer functions in head seas at 15 knots

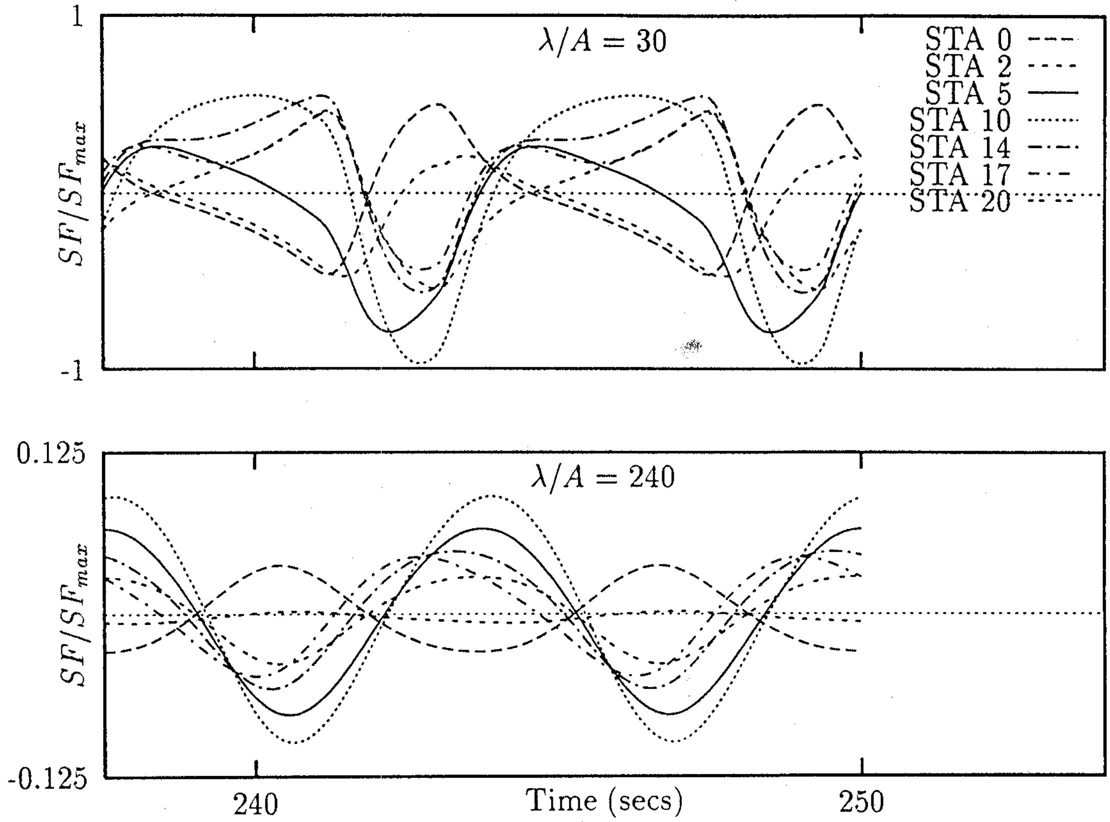

Figure 3: Shear forces versus time at various stations in head seas at 15 knots at two wave amplitudes

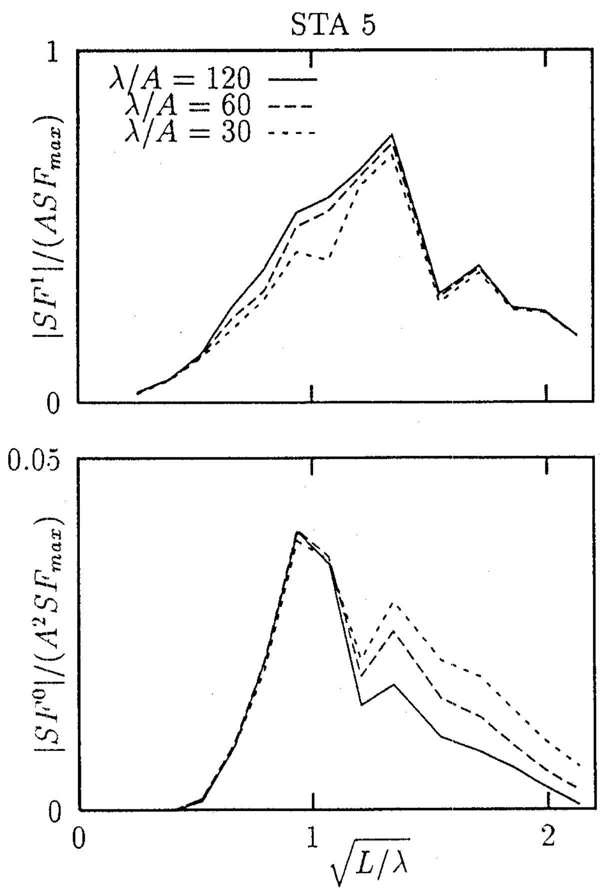

Figure 4: Amplitudes of the mean and first harmonics of the shear force at station 5

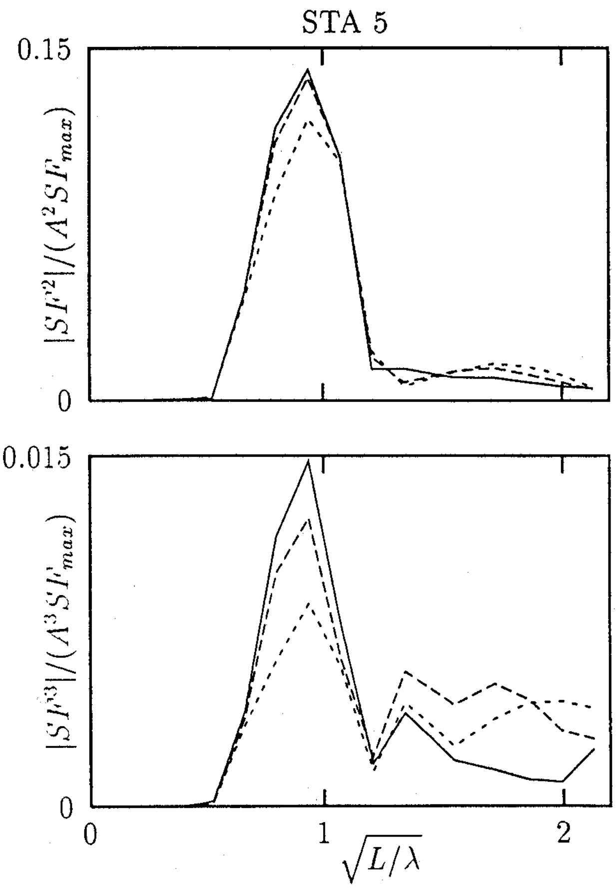

Figure 5: Amplitudes of the second and third harmonics of the shear force at station 5