The Development of a Time Domain Simulation Method for the Prediction of Scattering Forces and Large Ship Motions in Waves

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In [1] a novel, quasi-linear expression was presented for the evaluation of scattering forces induced on a ship's hull progressing in waves by the wave action and ship motions. In a simplified form the expression can be written as:

$$dF(t) = -\dot{\beta}(t)\, d\mu + \beta(t)\, U\, d\mu' + \int_{-\infty}^{t} d\tau\, [-\dot{\beta}(\tau)\, dK(t-\tau) + \beta(\tau) U dK'(t-\tau)] \qquad (1)$$

with dF(t) denoting an elementary generalized scattering (radiation and diffraction) force, dependent upon time t, and $d\mu$, $d\mu'$ and dK(t), dK'(t) signifying respectively appropriately defined frequency independent generalized added masses and force memory functions. $\beta(t)$ is a generalized amplitude of the scattering potential with U representing the mean forward speed and $\dot{\beta}(t)$ denoting the time derivative of $\beta(t)$.

The expression (1) is obtained on the basis of the weak scatterer hypothesis according to which the disturbance introduced by the presence of the ship in the oncoming wave flow is of a smaller order of magnitude than the flow induced by the oncoming wave itself and than that of the amplitudes of ship motion, [2], [1]. At the adopted level of non-linear approximation the application of the hypothesis can be reduced to quasi-linear formulae of the type (1). In those formulae $\beta(t)$ is a functional of the oncoming wave potential and a function of the instantaneous ship configuration and linear and angular velocities. The values of $\beta(t)$ are obtained from an algorithm which ensures a best approximation of the impermeability condition satisfied on the wetted hull surface. The efficiency of the above expression was exemplified in [1] by results of time domain simulations of diffraction forces on fixed hulls and of large ship motions in steep waves. In all those applications $\beta(t)$ was assumed to be nearly harmonic.

The full implementation of (1) requires the use of appropriate techniques to derive the frequency independent added masses and force memory functions. Fig. 1 shows a heave force memory function derived from the 3-D damping coefficients computed over a finite range of frequencies. The derivation was performed by means of a novel technique which uses a Fourier series representation of the memory function. In Fig. 2 the added mass coefficients rederived from the memory function are compared with the coefficients obtained from the 3-D frequency domain computation. The irregularity in the original added mass coefficients most probably results from the presence of an irregular frequency. The analogous irregularity in the damping coefficients was smoothed out prior to the derivation of the memory function.

Since ß(t) in (1) provides a best approximation to the impermeability condition for a representation of the scattering potential by means of an assumed finite series of modal potentials, the error corresponding to a given representation needs to be monitored and the series must be extended if necessary. In Fig. 3 the upper line shows the root mean square relative error of a cross-sectional approximation based on a series of four body radiation potentials used as modal potentials. The line composed of crosses shows the same error for a series representation which includes additional modal potentials. The lowest line depicts the variation in time of the approximated normal velocity distribution, [1]. The comparison shows the effectiveness of extending the series representation in order to improve the approximation of the impermeability condition.

Figs. 4 and 5 show comparisons of scattering forces obtained by means of time domain computations (using $d\mu$, $d\mu'$ and $dK(t)$, $dK'(t)$) with experimental data. The comparisons illustrate the influence of the accuracy of the modal representation of scattering forces. Representations of scattering potentials by 4 (which appears to be a minimum number required in practice) and 5 cross-sectional modal potentials are considered.

In Fig. 4 amplitudes of yaw moment induced on a fixed Series 60 hull by regular waves, as predicted by the time domain simulations are shown against experimental data presented in [4]. The comparison is made for wave heading 60 deg. at zero forward speed over a range of wave length/ship length ratios λ/L. Figs. 5a to 5d depict an analogous comparison for heave and sway forces and pitch and yaw moments, at the wave heading 120 deg. and Froude number 0.20. The results indicate that good approximations of scattering forces can be obtained using the 5 mode representation. They also suggest that the suitability of any particular representation depends upon the mode of scattering force to be determined, the forward speed of the ship and on the ship's heading.

References:

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[2] J.S. Pawlowski, "Elements of a Non-linear Theory of Ship Motions in Waves," in preparation.

[3] E.V. Lewis and E. Numata, "Ship Motions in Oblique Seas", Transactions SNAME, 1960.

[4] P.A. Lalangas, "Lateral and Vertical Forces and Moments on a Restrained Series 60 Ship Model in Oblique Regular Waves "R-920, Oct. 1963, Davidson Laboratory.

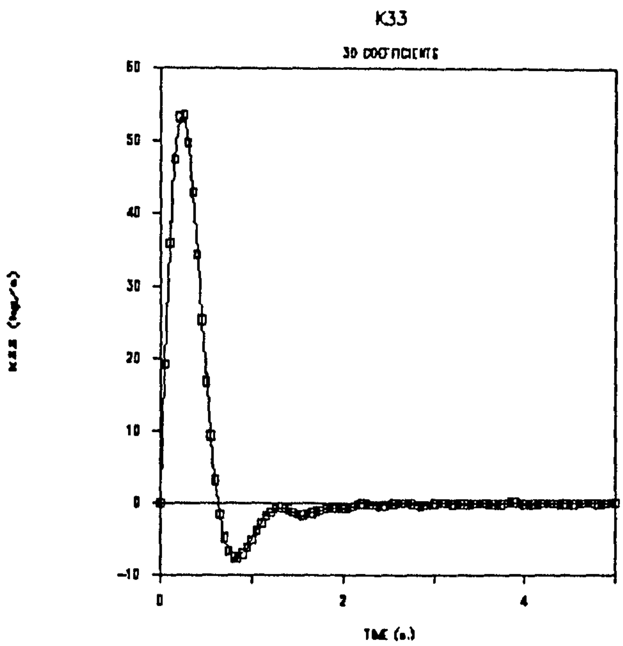

Fig. 1

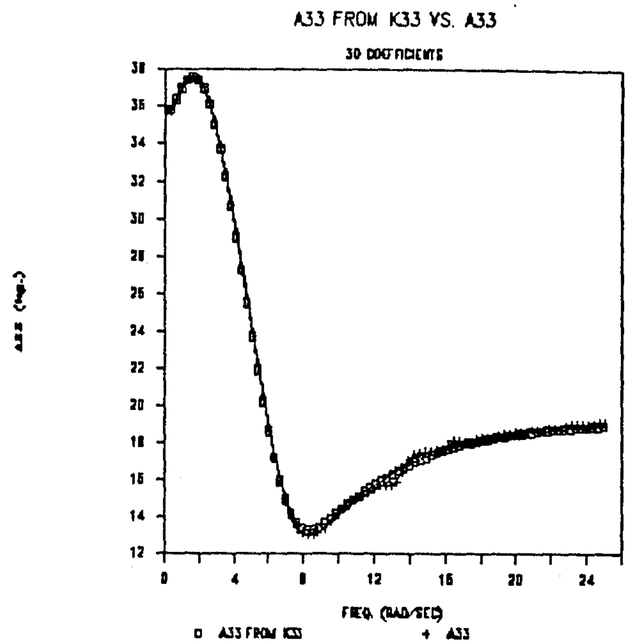

Fig. 2

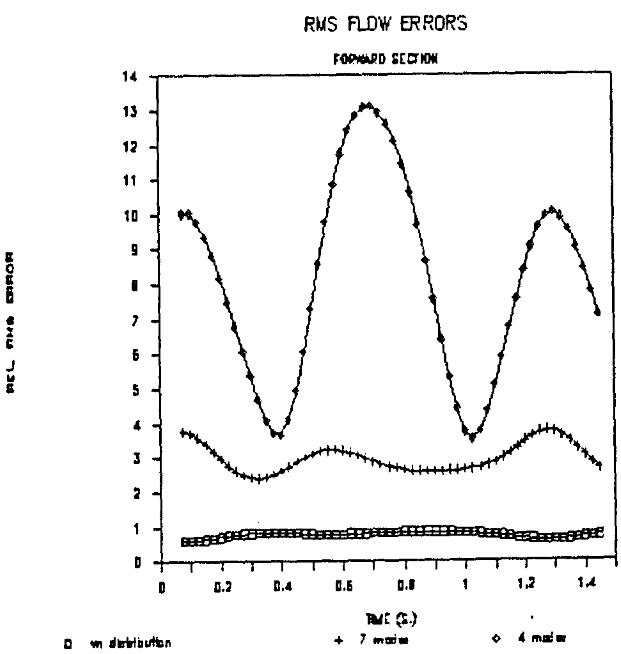

Fig. 3

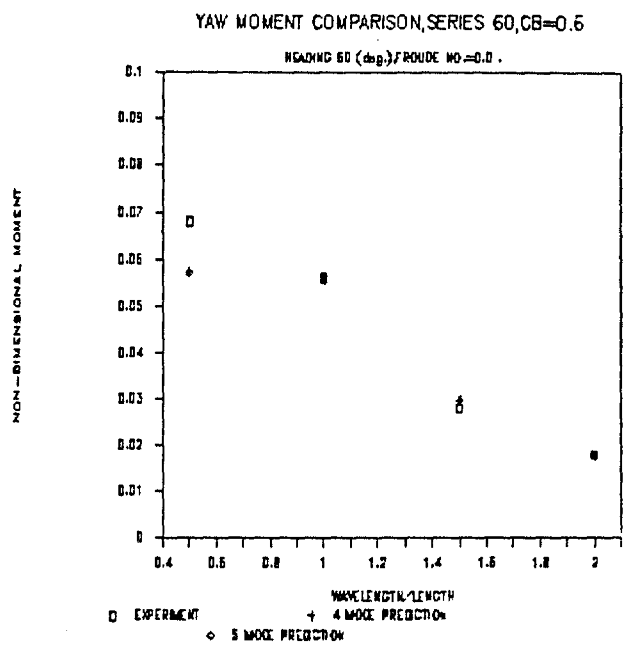

Fig. 4

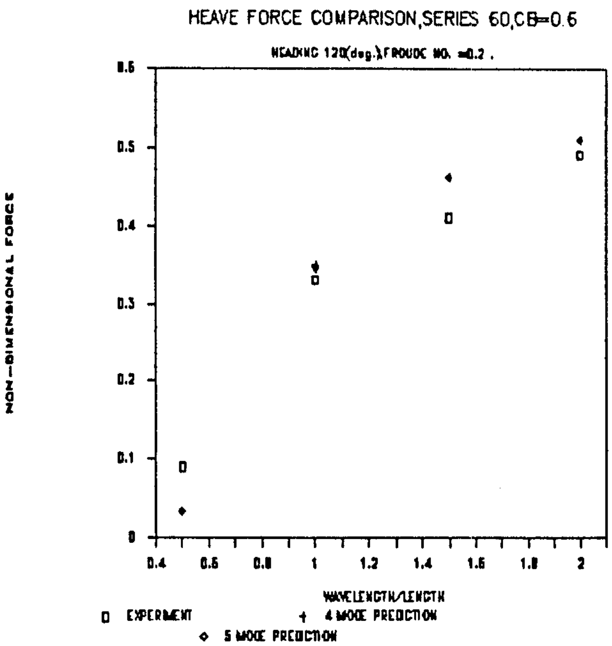

Fig. 5a

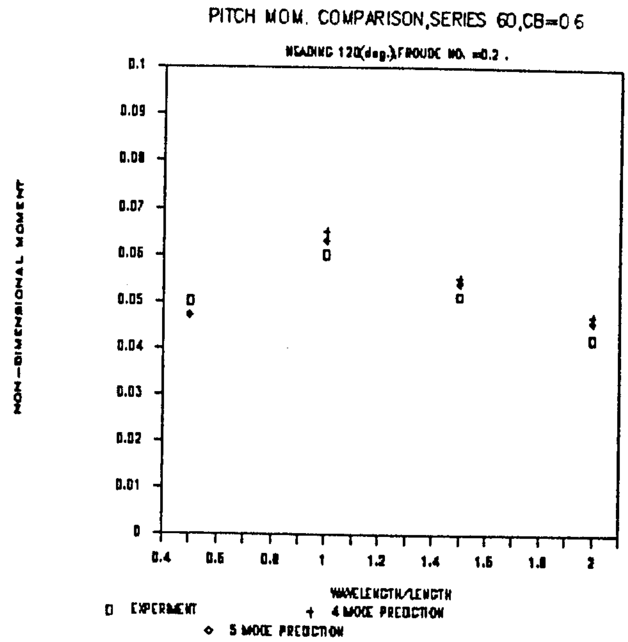

Fig. 5b

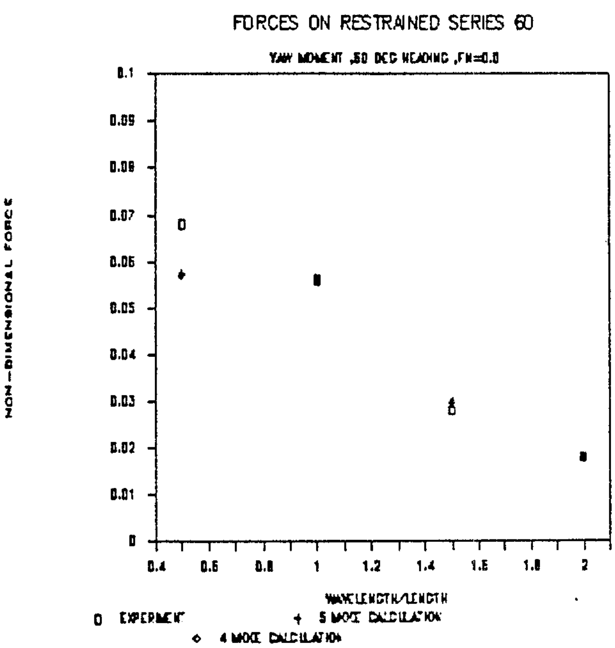

Fig. 5c

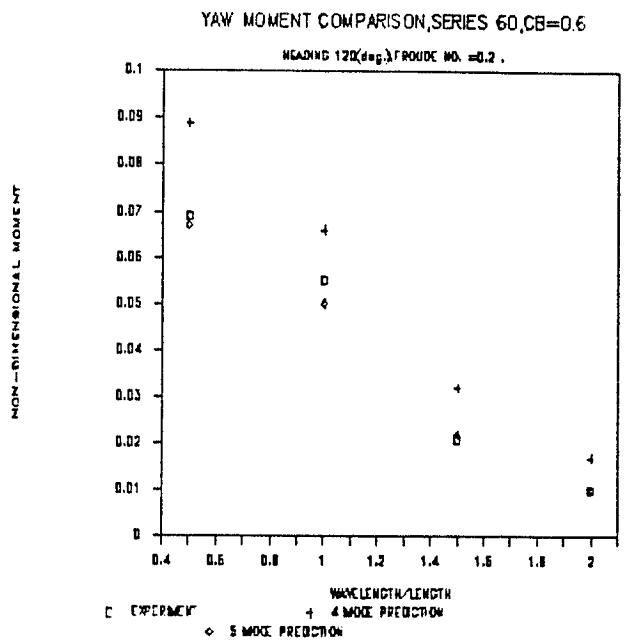

Fig. 5d