

Wave Forces on A Surface-Piercing Sphere Undergoing Large-Amplitude Motions

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A three-dimensional time-domain approach developed earlier (Lin & Yue 1990) is here applied to study the wave forces acting on a surface-piercing sphere undergoing large-amplitude motions. In this so-called "body-exact" approach, the body boundary condition is satisfied exactly on the instantaneous underwater surface of the moving body while the free-surface boundary conditions are linearized. The problem is solved using a time-dependent free-surface Green function source distribution on the instantaneous submerged portion of the hull. The motions of the body are either specified or obtained by solving the equations of motion at each time step. With the exception of the free-surface linearization, there are in principle no practical limitations on the motions of the body.

The time-domain approach for ship related free-surface flow problems is not new. The solution for the transient Green function was given by Finkelstein (1957), and time-domain solutions were discussed by Stoker (1957) and Cummins (1962). For linear problems, the time- and frequency-domain solutions are related by Fourier transforms and no new information is obtained in principle in the time domain. For nonlinear problems such as a floating body performing arbitrary large-amplitude motions, a time-domain approach is more straightforward and in some sense essential.

While linear and even fully nonlinear time-domain results have been available for problems in two dimensions for some time, developments for the three-dimensional problem have been relatively recent. These include Korsmeyer (1988) for the linearized radiation problem without forward speed, and Liapis (1986), Beck & Liapis (1987), King (1987), and King et al. (1988) for the linearized problem with constant forward speed. For submerged bodies, results for linearized free surface but large body motions have been reported by Ferrant (1988), Beck & Magee (1990), and Magee (1991). Large-amplitude motion results for floating bodies have been obtained by Lin & Yue (1990).

A particularly interesting result in Lin & Yue (1990) is the hydrodynamic forces in phase and out of phase with the acceleration of a sphere undergoing large-amplitude heaving motions. These quantities can be considered the large-amplitude "added-mass" and "damping" coefficients respectively as they would be in the linearized limit. At the single nondimensional frequency $\omega=1.0$ they considered, the "added-mass" coefficient shows a clear decreasing trend with increasing heave amplitude, while the "damping" coefficient remains almost constant over the range of heaving amplitudes. Since it is known that the dependencies of the motion coefficients on amplitude can be sensitive to the forcing frequency at least for a submerged body (Ferrant 1988), the question arises as to whether the trends observed above is general for a surface-piercing sphere, and if not, what these frequency dependencies are. This is a

main focus of the present study. In addition, the extension to the case of a large-amplitude *surging* sphere is also considered. Of particular interests here is the behavior of the motion coefficients as a function of surging frequency and the amplitude Keulegan-Carpenter number.

An interesting numerical difficulty arises for very large amplitudes motions of the heaving sphere. Specifically, small intersection or "dead-rise" angles are encountered at the waterline at the top and bottom portions of the stroke. This leads to unsatisfactory accuracies and poor convergence with the number of panels on the sphere. The problem of small dead-rise body panels near the free surface is not uncommon in practical calculations involving non-wall-sided hulls, and a robust remedy here is critical to the continual success of these panel methods. In the context of the present time-domain approach using constant strength source panels, a near-waterline Galerkin scheme has been developed and implemented. Under this scheme, the normal velocity boundary condition on the near-surface panels are satisfied in an integrated sense. Through systematic tests, this new approach is shown to result in some improvement in the accuracy and convergence of the method. Indeed, the method has been found to be useful even for many wall-sided geometry cases.

Details of the Galerkin method, and numerical results and discussion for the large-amplitude heaving and swaying motions of a floating sphere as a function of frequency and Keulegan-Carpenter parameters will be presented at the Workshop.

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DISCUSSION

YEUNG: I wonder if the reduction of heave added mass as the motion amplitude increases comes mainly from the effects of the line integral. It would seem the "differential added mass" comes primarily from the bottom of the sphere and relatively little contribution comes from the "surface ring" at the waterline. If that is the case, it seems to suggest that the waterline integral affects the differential added mass for all vertical position on the sphere.

LIN & YUE: Our numerical results indicate that the waterline integral has relatively little contribution to the reduction of the added mass (typically 10% or less of the total reduction).