SOME IMPORTANT DISCREPANCIES BETWEEN SLENDER-BODY THEORY AND EXPERIMENTS IN THE DIFFRACTION PROBLEM

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In applying slender-body theory and the method of matched asymptotic expansions to the diffraction problem, the treatment of the flow fields along the entrance and the run of the hull has always been a problem. The limited available experimental data in the literature tend to be too ambiguous to help clear up the problem.

We present some data obtained from recent experiments that are remarkably at odds with slender-body theory and the method of matched asymptotic expansions. The data indicate some of the properties of the wave-induced pressure that must be appropriately accounted for in a wave diffraction theory if the solution is to be valid for all speeds.

In the experiments, we measured the amplitudes and phases of the periodic wave-induced pressures on the hull surface of a large 9-m model of a slender ship (a typical destroyer with a beam-to-length ratio of 1/8) in regular head waves at $F_n = 0$, 0.20, 0.29, 0.42, and 0.50. The model was rigidly connected to the towing carriage. Wavelength ranged from $\lambda/L = 0.1$ to 1.6, so that the frequency parameter $\tau = \omega_e U/g$, where ω_e is the frequency of encounter, U the forward speed, and g the gravitation accelaration, was greater than the critical value of 1/4 for $F_n > 0$. The standard waveheight-wavelength ratio (H/λ) of 1/50 was used throughout the tests, except that at $\lambda/L = 0.8$, linearity was confirmed by testing over a range $1/100 \leq H/\lambda \leq 1/25$ for $F_n = 0$, 0.29 and 0.42. The present model was made larger than those commonly used in towing-tank tests to improve the precision of the pressure measurement for $\lambda/L < 1$. A total of 14 pressure transducers including two at $0.2L$, and four each at $0.35L$, $0.5L$, and $0.65L$ (distances measured from the forward perpendicular) were installed. All the transducers were mounted on the model below 52 percent of the design draft, mainly to prevent them from emerging in the highest waves tested.

The variations of the measured pressure amplitudes with F_n were compared at two wavelengths, $\lambda/L =$ 0.5 and 1.0, for which runs were repeated at least five times at $F_n = 0$, 0.20, 0.29, and 0.42. Most transducers recorded $P_0 < P_{0.20} < P_{0.29} < P_{0.42}$, where P_x denotes the measured amplitude of wave-induced pressure at $F_n = x$ at a given transducer. However, some remarkable exceptions to this general pattern occurred when $F_n \geq 0.29$.

First, among the four transducers at $0.35L$, the highest above the baseline recorded $P_{0.29} < P_{0.42}$ for $\lambda/L = 0.5$, but the other three transducers exhibited the opposite trend. Secondly, both transducers placed at $0.2L$ recorded $P_{0.29} > P_{0.42}$ at $\lambda/L = 0.5$ and 1.0. These experimental results are inconsistent with slender-body theory and the method of matched asymptotic expansions, which predict increasing pressure with increasing F_n for a given wavelength (Faltinsen, PhD thesis, University of Michigan, 1971; and Sclavounos, PhD thesis, MIT, 1981), and which would not show opposite pressure trends such as $P_{0.29} < P_{0.42}$ and $P_{0.29} > P_{0.42}$ along a girth. This is because the strength of the two-dimensional near-field source distribution around the girth is unchanged with the speed U. The effect of U is introduced in the inner solution through matching with the outer solution, and the latter is assumed to depend only on the longitudinal coordinate.

These experimental facts prompt us to re-examine various basic assumptions of the theory and to scrutinize individual terms in the expansions. Although the standard assumption that the diffraction potential is slowly varying along the length of the hull appears valid qualitatively at moderate speeds, it may need to be modified at high speeds. For the present hull model, for example, the gradient of flow quantities in the longitudinal component may not be negligible in comparison with the transverse components along the entrance and run of the hull, and the diffracted waves and incident waves may be interfering significantly with each other. The interaction between the steady and unsteady disturbances may become significant at high speeds. The free-surface conditions are linearized under the assumptions that not only the amplitudes of the incident and diffracted waves, but also the disturbances associated with the steady forward motion of the hull are all small. The latter condition requires the hull form to be sufficiently slender and the forward speed to be moderate, or of order one in the asymptotic sense. However, as Newman and Tuck noted (Proc.

5th Symposium on Naval Hydrodynamics, 1964), there is probably no way other than by comparison with experiment to test whether or not the ship is sufficiently slender for all the neglected terms to be small.

We anticipate gaining further insight into the diffraction-pressure characteristics over the entrance and the run of the hull in the second part of our experiment scheduled for January 1988. A total of 20 pressure transducers will be placed on the same model at $0.1L$, $0.15L$, $0.2L$, $0.25L$, $0.75L$, $0.8L$, and $0.85L$. The outcome of this experiment and the progress in our theoretical investigation will be reported at the workshop.

Sclavounos: The discrepancies between the pressure trends predicted by slender body theory and those measured in your experiments appear to occur at high Froude numbers. Before resorting to a more accurate slender body theory, it would be appropriate to include in the pressure expression *all* terms linear in the diffraction velocity potential, including those coming from the quadratic term. They include products of gradients of the steady-state and the diffraction potentials and may be appreciable in the regime where the discrepancies are observed, both because the Froude number is large and because these measurements were carried out near the bow where the gradients of the steady-state flow are large.

Ando & Cumming: You are absolutely right. That is exactly what we are working on at this moment. We are as curious as you are to find out how slender body theory, in the present form, will fare *vis-a-vis* our experimental data. The terms you refer to, that is, those defined explicitly by the forward speed U are $O(\epsilon^{\frac{1}{2}})$ higher than the terms that depend on U only implicitly, according to the theory. So if the effect of the former overwhelms the effect of the latter, that would be an interesting phenomenon. One thing that we want to point out is that we could not detect the pressure response pattern in question near the stern where the flow may be strongly accelerated.

Faltinsen: I think the authors are presenting interesting experimental results. However I think they expect too much of the slender body theories that they compare to. The theories are not expected to apply for the higher Froude numbers.

Ando & Cumming: Maybe you are right. But then again, we do not know the magnitude of the ship speed when we say $U \leq 0(1)$. We can find out the limits of applicability of the theory only by comparison with experiment.

O'Dea:

1. Did you measure total wave exciting forces?

2. Your plot of harmonic analysis of a pressure signal shows absolutely no higher harmonic content. Did your measurement system have high enough frequency response to detect second harmonics, *etc*? [*i.e.* Transducer response, sampling rate and filtering.]

Ando & Cumming:

1. No, we did not. The model was rigidly fixed to the carriage. It would be interesting to check, although we would probably have to segment the hull into "strips" to get meaningful results.

2. Yes. By looking at the plots in the time domain, which showed waveforms that resembled sinusoidal form very closely, we can expect their energy spectra to be fairly narrow-banded, as we saw. If a signal contains any higher harmonics, the waveform in the time domain tends to appear corrupted.