EFFECT OF STRUCTURAL ENHANCEMENT ON THE ACOUSTIC RESPONSE OF A SUBMERGED FLUID-FILLED CYLINDRICAL SHELL

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1. INTRODUCTION

Although shell-fluid(s) systems that are more complex than a single shell submerged into (and in some cases filled with) fluids have been studies in the context of the acoustic or shock loading for quite a while (e.g. [1]), it appears that most of the studies, both experimental and numerical, devoted to the visualization of the respective hydrodynamic fields appeared only during the last decade (e.g. [2,3]).

Despite the existence of the research effort mentioned, it appears that the studies where a thorough investigation of the evolution of the hydrodynamic patterns observed in a structurally enhanced system are very scarce, and for some systems simply do not seem to exist. This certainly appears to be the case for a circular cylindrical shell containing a rigid co-axial core, and we present some of our results for such a scenario.

2. MATHEMATICAL FORMULATION AND SOLUTION METHODOLOGY

We consider a thin circular cylindrical shell, assume that the deflections of the shell are small compared to its thickness, and assume that the Love-Kirchhoff hypothesis holds true, thus the respective linear shell theory can be used. We assume that the shell is filled with and submerged into identical fluids, and the fluids are assumed to be linearly compressible, inviscid, and irrotational, thus modeled by the wave equations. We furthermore assume that the shell contains a rigid co-axial cylindrical core.

The methodology we use has been developed in our earlier work [4,5] and it is based on combining the Laplace transform technique with respect to the time with the separation of variables with respect to the spatial coordinates. As a result, the solution is obtained in the form of Fourier series with time-dependent coefficients that are convolution integrals of the hydrodynamic pressure or the shell displacement and the so-called response functions, the latter representing the response of the fluids to the scattering by or radiation of the shell. The methodology has been extensively verified [4,5], and we feel that we can confidently use it for simulating more complex systems for which experimental data does not necessarily exist yet.

3. RESULTS AND CONCLUSIONS

A steel shell is considered with the thickness of 0.01 m and radius of 1 m (r_0), submerged into and filled with water. The interaction with a cylindrical incident wave [5] is analyzed, and the rate of the exponential decay of the wave is assumed to be 0.0001314 s while the initial pressure in the front is 250 kPa. A rigid co-axial core placed inside the shell is assumed to have different radii a, from a small one (a/r_0=0.10) to the one that dominates the internal volume (a/r_0=0.75).

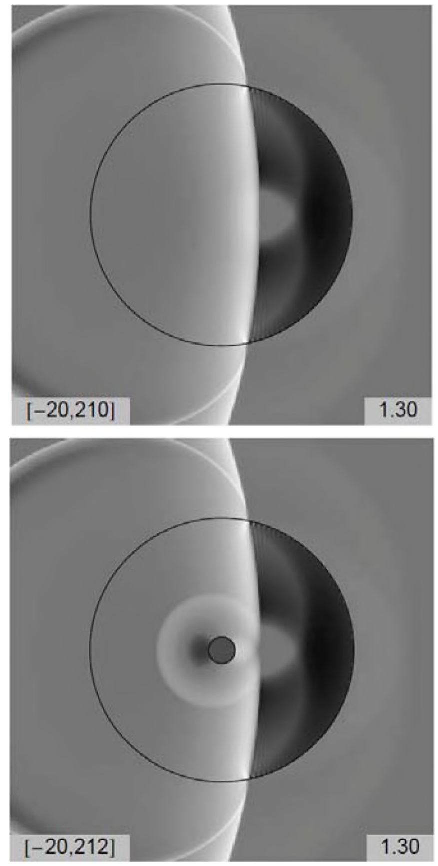

Figure 1. Comparison between the cases when no core is present (top) and when the core has a small radius (bottom).

Fig. 1 shows the comparison between the no-case scenario and the one where a small-radius core (a/r_0=0.10) is added to the system. The single numerical value on the right corresponds to the dimensionless time (with unity corresponding to the time it takes for the incident wave to travel the distance equivalent to one radius of the shell), and the two values on the left correspond to the pressure range shown, the lower value corresponding to the black halftone in the image and the higher value corresponding to the white one. It is apparent that the changes to the front of the internal pressure wave are rather insignificant, although the internal wave pattern is still quite different because of the core-reflected field present. All the main features, however, remain unchanged.

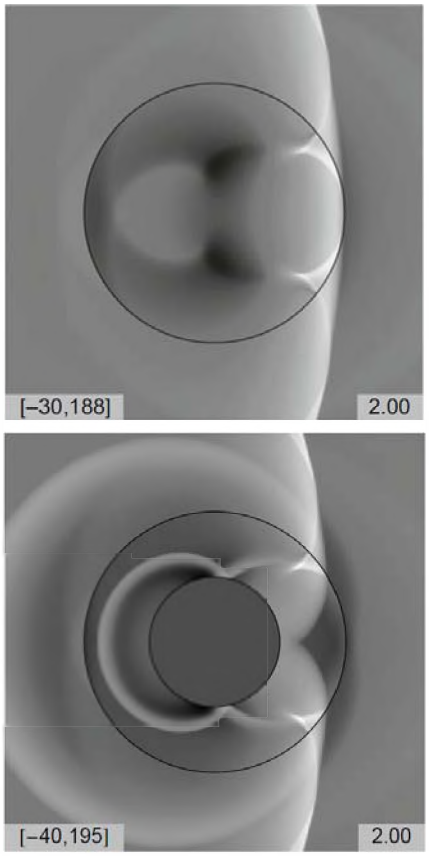

Figure 2. Comparison between the cases when no core is present (top) and when the core has a medium radius (bottom).

Fig. 2 shows a similar comparison for a medium-size core (a/r_0=0.50). In this case, the changes to the internal wavefront are very dramatic, and the influence of the presence of the core is clearly visible. Two core-reflected fronts are visible as well, one that is still inside the shell and one that has propagated into the external fluid.

Fig. 3 shows a snapshot for the case where the core dominates the internal volume (a/r_0=0.75; the respective no-core case is not shown since it is very similar to that seen in Fig. 2). In this case, the pattern is quite a bit more complex than even in the medium-size core case. In particular, three waves are seen in the external fluid in addition to the incident-scattered field, all of which are a result of the transmission of the core-reflected waves outside the shell. The multiple reflection pattern in the layer between the shell and the core is apparent, and it is interesting to point out that the layer seems to exhibit some properties of a waveguide.

The observations made are very interesting and reveal some fundamental facts about the interaction when the structural complexity of the original single-shell system is increased. Namely, it is now clear that the phenomenological nature of the internal field (e.g. the presence of the high-pressure focusing) can be controlled by means of incorporating additional structural elements into the system.

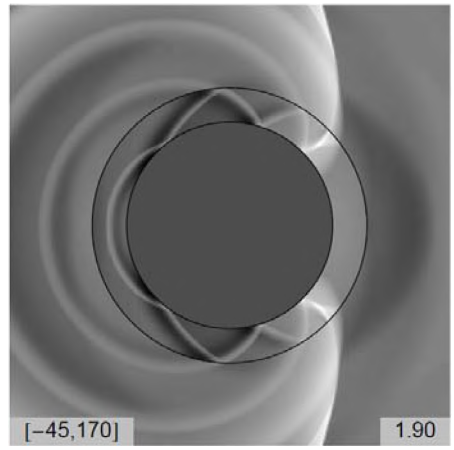

Figure 3. The reflection pattern for the case of a large core.

Furthermore, based on these preliminary observations, it appears that the case of two different fluids would exhibit a number of even more interesting features, especially when the sound speed in the internal fluid is lower than in the external one. Even more interestingly, our preliminary studies for a shell loaded by a shock wave with a double front also indicate that when the present system is subjected to such a loading, one should expect to see dramatically more complex reflection patterns, especially for large core sizes. We intend to investigate these aspects in the future.

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ACKNOWLEDGEMENTS

S.I. and K.W. acknowledge the financial support of the Natural Sciences and Engineering Research Council (NSERC) of Canada. S.I. also acknowledges the financial support of the Killam Trusts and the Faculty of Engineering, Dalhousie University.