RADIATION BY A SUBMERGED CYLINDRICAL SHELL IN RESPONSE TO AN EXTERNAL NON-STATIONARY ACOUSTIC PULSE

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1. INTRODUCTION

Submerged circular cylindrical shells are very common in ocean engineering, and their analysis under various loading conditions has received a considerable attention over the past few decades. The present work concerns with the analysis of the acoustic field induced around such a shell when it is subjected to an external non-stationary acoustical pulse, or a very weak shock wave, and when no internal fluid is present. A detailed review of the relevant literature can be found in [1]. The problem is not new, and some of its aspects have been addressed as early as the 1950-1960s [2], with a number of studies concerned with more subtle fluid-structure interaction effects appearing in the last decade, e.g. [3]. It appears, however, that the fully evolved radiated field induced during the interaction has not been considered in enough detailed as of yet, which is the main goal of this presentation.

2. MATHEMATICAL APPROACH

The fluid is assumed to be irrotational, inviscid, and linearly compressible, and is therefore governed by the wave equation. The shell is assumed to be thin enough so that the linear theory of shells can be used, and, additionally, Love-Kirchhoff hypothesis is assumed to hold true as well; the respective shell equations can be found in [4]. The motion of the fluid is coupled to that of the shell through the dynamic boundary condition on the interface, and, additionally, we assume the zero conditions at the infinity, periodicity conditions with respect to the angular coordinate, and the zero initial conditions.

A mixed analytical-numerical solution has been developed, where the separation of variables was used in combination with the Laplace transform technique to obtain the diffraction and radiation pressure in modal form, and the finite differences were employed to obtain the harmonics of the shell surface displacements, with subsequent coupling of the two parts. The details can be found in [5]. The simulated images based on the solution developed were compared to the available experimental ones [3], and an excellent agreement was observed.

3. RESULTS AND CONCLUSIONS

A steel shell submerged into water was considered, and its thickness and radius were assumed to be 0.005 m and 0.5 m, respectively. The interaction with a cylindrical incident wave [5] with the rate of exponential decay of 0.0001314 s, and the pressure in the front of 10 kPa, was analyzed. For the system's parameters considered, it takes about 0.714 ms for the incident wave to move over the shell.

The interaction has been simulated, and the images of the dynamic pressure pattern in the fluid have been generated. Figures 1 and 2 show the acoustic field during the early interaction, t=0.286 ms. Two images depicting different pressure ranges are shown – figure 1 captures the entire range of the pressure observed, while figure 2 shows a low-magnitude close-up to ensure that all pressure components are visible equally well.

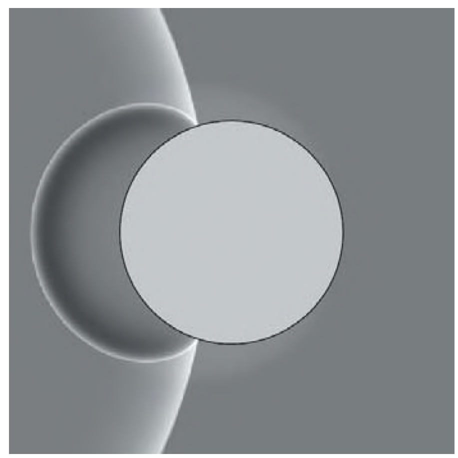

Figure 1. The acoustic field during the early interaction. The pressure of 10 kPa corresponds to the white halftone, and -7.5 kPa to the black one.

One can see that two different components of the acoustic field can be clearly identified: the high-magnitude component corresponding to the incident and diffracted waves (we refer to it as the "scattered field"), and the low-magnitude component corresponding to the radiation of the elastic waves propagating in the shell into the fluid (we refer to it as the "shell-induced field"). We particularly emphasize that the former waves propagate with the velocity equal to the acoustic speed in the fluid, whereas the latter is a "head wave" which, due to the fact that the acoustic speed in the shell is much higher than that in the fluid, propagates far ahead of the incident front.

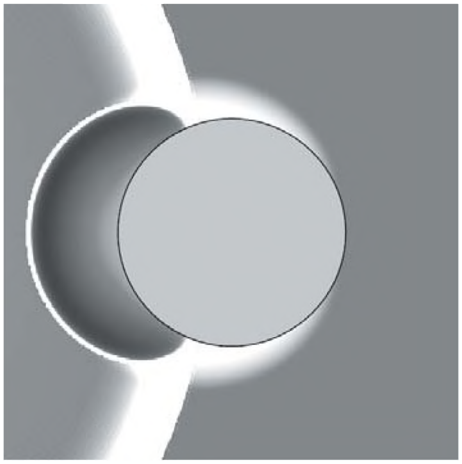

Figure 2. The low-magnitude close-up of the acoustic field during the early interaction. The pressure of 1 kPa and above corresponds to the white halftone, and -7.5 kPa to the black one.

The results observed are not new, and have been reported before, both experimentally and numerically, e.g. [3]. However, it appears that only the early interaction has been investigated in the work published (i.e., at the instants when the incident front has not yet moved into the shadow zone, and when the elastic waves have not completed their first full circumferential passage around the shell). Our objective is to look at the acoustic field during the late interaction, and to focus on the shell-induced field that results from the multiple passages of the elastic waves around the shell. We also note that in the experiments [3, figure 6], two different shell-induced waves were observed, S_o and A_o (symmetric and antisymmetric Lamb waves, respectively), whereas here we only observed one of them, S_o. This is due to the limitations of the shell model employed, but it does not appear to be a detrimental drawback of the study since the most rapidly propagating (and, therefore, most practically interesting) component, S_o, is captured really well.

Figure 3 shows the fully evolved shell-induced wave system during the late interaction, t=1.61 ms; the incident wave is not shown, only the location of its front. By the instant depicted, the incident wave moved over, and more than the diameter away from, the shell. There are five wavefronts propagating upstream and downstream visible in the snapshot, F1-F5. Each of these wavefronts corresponds to an individual passage of the elastic waves around the shell, and the highest pressure in the fronts corresponds to the superpositions of the elastic waves at the head ($\theta=0$) and tail ($\theta=\pi$) points of the shell. Thus, the images of the radiated field taken during the late interaction allow one to see the entire evolution of the dynamics of the process (as far as the radiation by the shell is concerned) in a single shot, which makes them a very useful analysis tool. We also note that due to the mentioned difference in the acoustic speeds, the first radiated front propagates considerably ahead of the scattered one (in the present case, the time difference is about 0.39 ms). This feature becomes particularly important when the response time is critical – when there are other structures located upstream of the primary shock-responding one, detecting the shell-induced field prior to the arrival of the incident wave itself allows for some extra time to take the measures necessary.

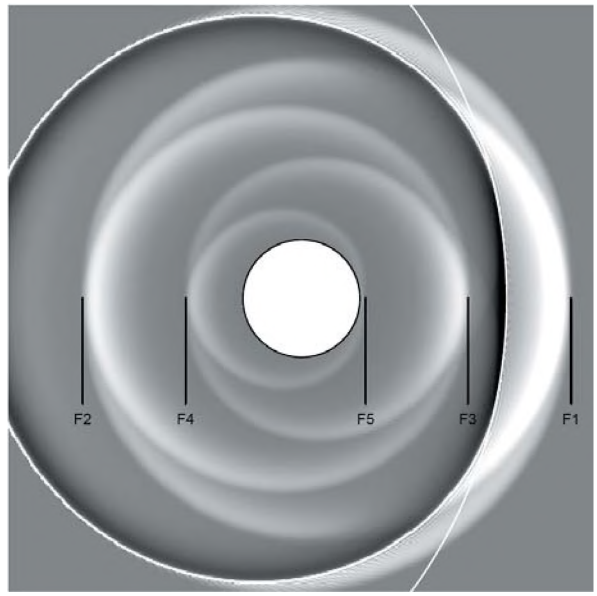

Figure 3. The fully-evolved radiated wave system, late interaction.

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