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ON THE RADIATION OF SOUND FROM AN IMMERSSED CYLINDRICAL SHELL CLOSE TO THE SEA SURFACE

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ABSTRACT

Numerical methods for the prediction of underwater radiated noise from immersed structures play a key role in the naval and offshore industry to ensure high acoustic performance of systems or to preserve natural habitats. Most of the approaches so far assume that the surrounding fluid is homogeneous and unbounded. However, in many situations the structure can be close to interfaces, namely the sea surface and the sea bottom, such as navigation of underwater vehicles in shallow waters. The Lloyd's mirror effect describes the interference phenomena occurring when a sound source is close to the sea surface. This effect is easily accounted for with a source image approach, while the strong vibro-acoustic coupling between the structure and the interface is more complicated to deal with. In this context, an analytical method has recently been developed to predict the vibro-acoustic behaviour of an infinite length cylindrical shell close to the surface, based on the shell equations and Graf's addition theorem. In the present work, we compare this approach to a simplified one where the strong interactions between the surface and the structure are not considered. Results highlight these effects on a typical underwater structure

1 INTRODUCTION

Immersed cylindrical shells are often used to model the vibro-acoustic behavior of underwater structures [1]. Compared to a structure *in vacuo*, heavy fluid coupling has two main effects: added effective mass and increased effective damping through radiation [2]. This effect is well accounted for when the surrounding fluid domain is unbounded, and the problem has been largely addressed in literature. However, in some situations the structure can be close to the surface, potentially affecting its structural and acoustic responses. In this case we distinguish two phenomena. First, the so-called Lloyd's mirror effect occurs when a point source is close to the sea surface. It is characterized by interferences due to direct and reflected sound waves having close amplitudes but different phases [3],[4]. Second, the vibro-acoustic behaviour of

the elastic structure can be different in the presence of the interface. Previous work suggested that the vibrations of the cylindrical shell, and consequently the radiated pressure, can be impacted by the interface. These studies include analytical approaches to predict the structure-borne sound using the stationary phase theorem [5][6] or numerical approaches such as the boundary element method to determine the radiated far-field [7]. More recently, an analytical model has been developed to investigate the effect of the sea surface on an infinitely long cylindrical shell [8]. The present work aims at discussing some results in an industrial perspective and proposing further developments.

2 CHOSEN APPROACHES

Let us consider an infinitely long cylindrical shell of radius a , thickness h and excited by a line force, as shown in Figure 1(a). The structure is first immersed in an unbounded water domain. The quantity of interest in this work is the pressure radiated in the external fluid. The classical approach to this problem is to express the physical quantities as Fourier series over the circumferential coordinate θ , and to use a shell operator [9].

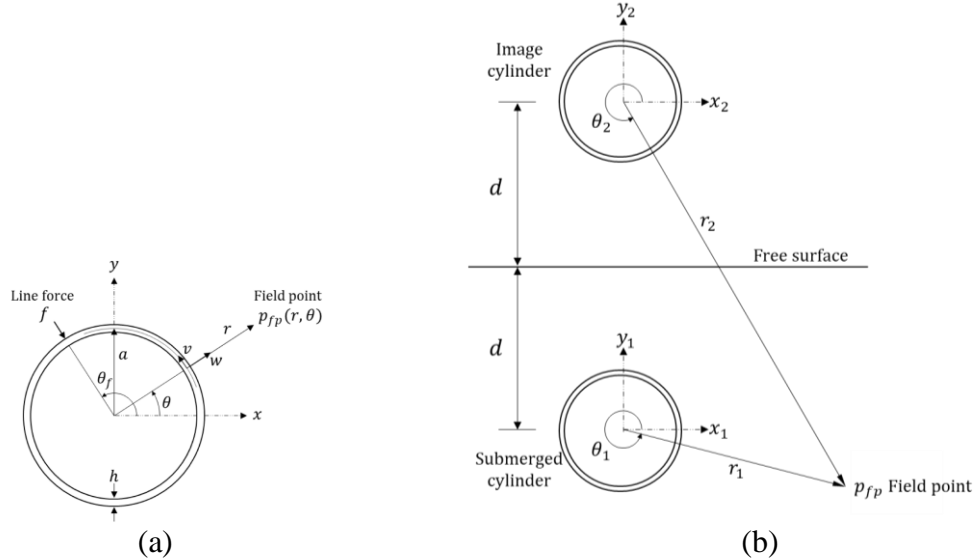


Figure 1: (a) Schematic diagram of the cylindrical shell in an unbounded water domain. (b) Schematic diagram of the cylindrical shell and its image due to the free surface [8].

In Figure 1(b), the influence of the free surface can be accounted for using two approaches:

- A simplified approach considering only weak coupling: this approach consists of summing the pressure radiated from the cylinder and the pressure radiated from its image source at a given observation point. The pressure radiated from the real and image cylinders are calculated separately using the model of a cylinder in an infinite unbounded fluid. A phase of π is added to the pressure radiated from the image cylinder to account for the pressure release condition at the interface [3] **Erreur ! Source du renvoi introuvable.**
- A fully coupled approach to account for the strong interactions between the cylindrical shell and the free surface. The impedance term based on Hankel functions of the unbounded problem is modified based on Graf's addition theorem and injected into the vibro-acoustic equations (see reference [8] for the detailed methodology).

3 RESULTS

The cylindrical shell is made of steel, has a radius of 4 m, a thickness of 40 mm and a line force is applied at -20° . The centre of the cylinder is at a depth of 18 m. The external fluid is water

and the internal fluid is air. The results are calculated and plotted on a circular domain of 100 m radius. The real part of the radiated pressure field for 3 cases corresponding to an unbounded fluid domain, weak coupling in the presence of a free surface and the fully coupled approach, is presented in Figure 2 at a frequency of 170 Hz (arbitrarily selected to illustrate the methods).

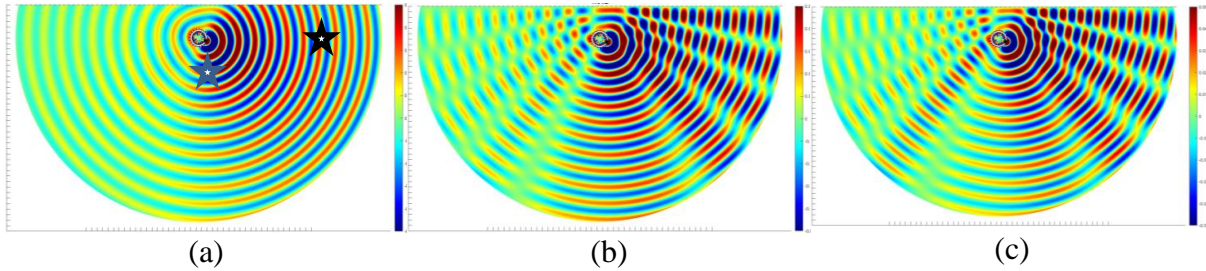


Figure 2 : Real part of the pressure at 170 Hz: (a) in an unbounded medium, (b) using the weakly coupled approach, (c) using the fully coupled approach.

In Figure 2(a), the free surface is drawn but not considered in the calculation. One can see that the radiated pressure is of higher amplitude on the right-hand side of the picture, in front of the mechanical line force. Figure 2(b) shows the sum of the pressure radiation from the cylinder and its image. The phase difference between the pressure radiated from the source and its image exhibits strong interference patterns. These patterns are well-known for a point source and characterize the Lloyd's mirror effect [3],[4]. Figure 2(c) shows the response of the coupled problem, as in [8]. The result is similar to the result in Figure 2(b), showing that for this configuration the influence of the surface is mainly due to the Lloyd's mirror effect. However, some differences can be observed locally. For example, in the region vertically under the cylindrical shell, the amplitude appears smaller than in Figure 2(b). This is due to the shadow zone created by the shell with regards to the waves radiating upwards and being reflected down. This phenomenon is not modelled by the weakly coupled approach.

The two stars in Figure 2(a) show the approximate position of two points of interest for which the frequency response between 100 Hz and 1500 Hz is plotted on Figure 3. The first point is located directly under the cylindrical shell, at a distance of 30 m from the centre of the shell. The second point is on the same horizontal axis as the centre of the cylinder, at a distance of 100 m. The amplitude of the pressure (in dB ref 1 μ Pa) is plotted for the three approaches described in section 2. The following observations are reported:

- For the point located under the shell (Figure 3(a)), the black curve (response in an unbounded medium) and the blue curve (fully coupled approach) are superimposed, showing that the surface has little influence on the radiated pressure at this location. However, the simplified approach (red dashed curve) introduces additional oscillations around the fully coupled solution, predicting a stronger Lloyd's mirror effect than it actually is.
- For the point located on the side (Figure 3(b)), the effect of the surface is important as the blue and red curve (simplified and fully coupled approaches) are very similar. The Lloyd's mirror effect at this location is dominating the strong coupling with the surface.

4 CONCLUDING REMARKS

The results shown in this paper confirm on a different test case the observations made in reference [8], namely that a strong interaction between the structure and the interface can occur in some situations. The main parameters in the problem are the observation point, the location of the line force and the distance between the cylindrical shell and the interface. The analysis shows the interest of having a fully coupled model to predict the radiated pressure from an immersed structure close to the surface. The model mentioned in this paper has only been

developed so far for the case of an infinitely long cylindrical shell excited by a line force. To cover a wider range of applications, next steps consist in characterizing the behaviour of a point-driven infinite cylindrical shell as well as including internal structures such as stiffeners.

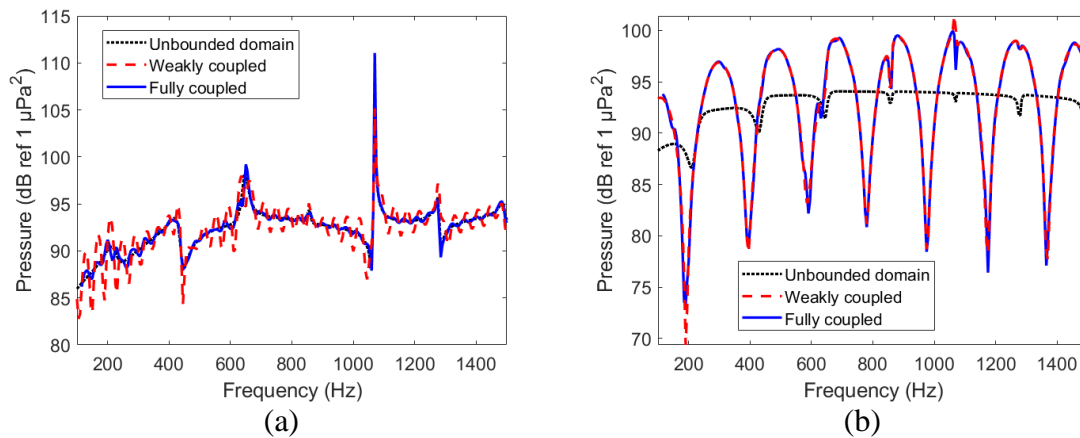


Figure 3: Radiated pressure as a function of the frequency (a) for the point located 30 m below the cylindrical shell and (b) for the point located 100 m on the side of the shell.

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