

# Vibroacoustic response of a coated shell near a free sea surface

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**Abstract** - The vibroacoustic response of a coated cylindrical shell semi-immersed or fully submerged close to a free sea surface is studied. The coating comprises a soft material embedded with voids or hard inclusions. The analytical model accounts for local resonance of the inclusions, multiple scattering of waves between the inclusions, and strong fluid-structure interaction between the coated shell, the surrounding water, and the free sea surface. The influence of different coating designs and the free surface on the structural and acoustic responses of the semi- and fully immersed shells are presented. Results obtained analytically are compared with those obtained using the finite element method, showing excellent agreement.

## 1 MODELS

Fully coupled analytical models that account for the interaction of sound waves radiated by a coated shell partially or fully submerged in a heavy fluid and the free sea surface have been recently developed (Lin et al., 2024). Figure 1 schematically shows a coated cylindrical shell submerged near a free sea surface and its image (left) and the semi-immersed coated shell (right). The cylindrical shell is modelled using classical shell theory while the coating is a soft material and is approximated as an equivalent multilayered fluid using a homogenisation approach (Sharma et al., 2021). Inclusions embedded within the soft medium allow for a subwavelength acoustic coating design whose performance is strongly dependent on the resonance behaviour of the inclusions. Cavities in a soft medium primarily exhibit monopole resonance associated with pulsating motion, while hard inclusions exhibit dipole resonance arising from translational motion in the direction of sound propagation. The free sea surface is modelled as a pressure release boundary. For a fully immersed coated shell near a free surface, the image method is employed to capture the sound waves reflected by the free surface (Marsick et al., 2021). For a semi-immersed coated shell, heavy fluid loading is only considered on the wetted surface of the coating (Li et al., 2020). For validation of the analytical models, numerical models based on the finite element method (FEM) using COMSOL Multiphysics v6.1 were developed.

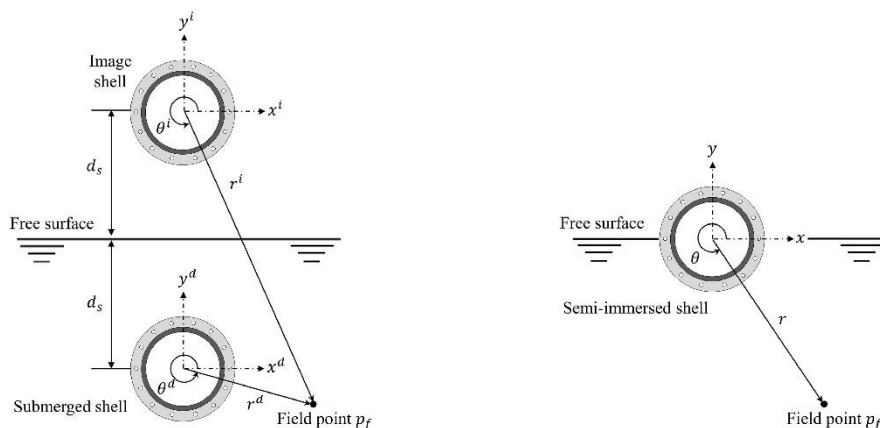


Figure 1 - Schematic diagram of a coated cylindrical shell submerged near a free sea surface and its image (left), and a semi-immersed coated shell (right).

## 2 RESULTS AND DISCUSSION

Figure 2 compares the radiated sound power obtained analytically and numerically for shells at a finite depth from the free surface (top row), and semi-immersed in water (bottom row), for an uncoated shell, a uniformly coated shell, a locally resonant coating with cavities (left column), and a coating with hard inclusions (right column). For the submerged shell at a finite depth (top row), the sound power radiated from an uncoated and a uniformly coated shell resembles that for an acoustic dipole. For a coated shell with cavities (Fig. 2, left), a large reduction in sound power occurs around the monopole resonance frequency of the cavities (~500 Hz). The low frequency peak around 75 Hz corresponds to a spring-mass resonance due to the presence of voids in the soft coating. For a fully submerged coated shell with hard inclusions (Fig. 1, top right), a localised reduction in sound power around the dipole resonance frequency of the hard inclusions of 450 Hz occurs. Ripples in the acoustic response are attributed to interference between the sound waves directly radiated from the shell and subsequently reflected by the free surface. For the semi-immersed coated shells, distinct peaks in the sound power at the structural resonances can be observed for a broad low frequency range. These peaks disappear with increasing frequency due to increased damping from the water.

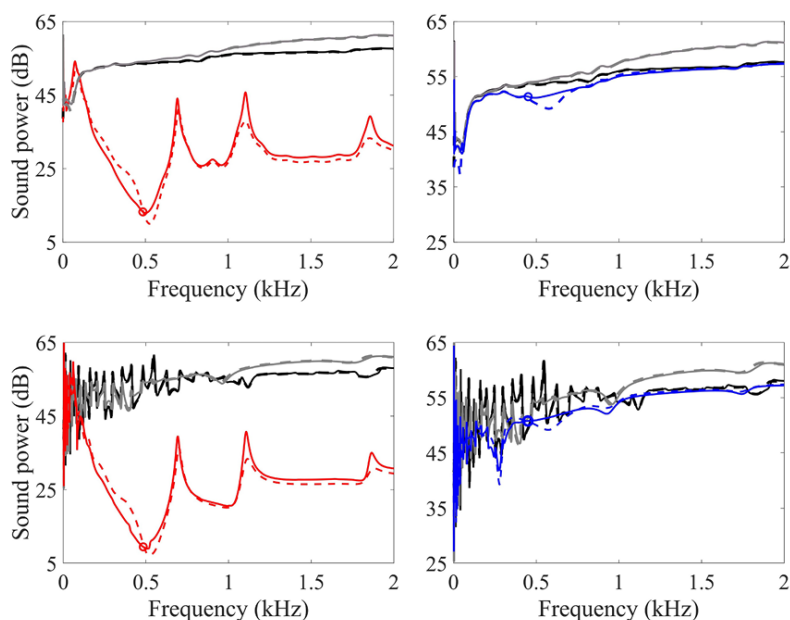


Figure 1 – Sound power (dB ref. 1 pW) from an uncoated shell (black lines), a uniformly coated shell (grey lines), a coated shell with 50 cavities (red lines, left column), and a coated shell with 106 hard inclusions (blue lines, right column), submerged in water at a distance six times the shell radius from a free surface (top row), and semi-immersed in water (bottom row). Results are obtained analytically (solid lines) and numerically (dashed lines). The monopole and dipole resonances are indicated by red and blue circles, respectively.

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