Beyond Lloyd's mirror effects: accounting for diffuse scattering in the determination of source levels of ships

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SUMMARY

The effect of surface reflections, such as the Lloyd's mirror effects, is well known. Earlier International Standards for measurements of underwater radiated noise from marine platforms in deep water, such as NATO STANAG 1136:1995, ANSI/ASA S12.64-2009, and ISO 17208-1:2016, acknowledge the importance of surface reflections, but do not provide methods to account for their effects. The recent Standard ISO 17208-2 (2017) attempts to correct for the coherent Lloyd's mirror effects at low frequencies, but does not account for non-coherent energies diffusely scattered from rough surfaces. In this paper, we model the effect of reflections from both smooth and rough sea surfaces, taking into account both coherently reflected and incoherently scattered energies.

1 INTRODUCTION

Various plane wave-based coherent surface reflection coefficients and the Beckmann-Spizzichino reflection coefficient model have been used to study the effect of surface reflection on the determination of monopole source levels of ships from measurements at sea (Audoly and Meyer. 2017, ISO 17208-2, 2017). Such studies ignored the diffusely scattered acoustic energies.

For measurements using omni-directional hydrophones, which is the case in ANSI and ISO Standards, we believe that the diffusely scattered acoustic energies should be included. This is supported by theoretical considerations and experimental measurements (Boyd and Deavenport, 1973, Dahl, 2004). Further examples include measurements using explosive sources, which show that the surface reflection losses are essentially zero across frequencies from 0.4 to 6.4 kHz, wind speeds from 5 to 20 knots, and grazing angles from 10 to 55 degrees (Adlington,1963). More recent experiments show that when energy absorption from wind-generated bubbles are negligible, there is little energy reflection loss up to 20 kHz (Dahl et al., 2008).

2 RESULTS

Figure 1 shows an example of our results based on numerical modelling. The figure shows the correction needed for the determination of monopole source levels in addition to the spherical spreading considered in ANSI/ASA S12.64-2009 and ISO 17208-1:2016.

At low frequencies, the wavelengths are much greater than the depth of the source, which means that the reflected sound always destructively interferes with the incident sound due to the air being much lighter than water. This destructive interference leads to extra transmission loss than spherical spreading of the direct path alone. Therefore the extra loss, represented by positive corrections in Fig.1, must be added back to obtain the monopole source levels.

At the higher frequencies, the wavelengths are much shorter than the depth of the source and there are both destructive and constructive interferences between the direct and surface-reflected sounds as the frequencies vary within each 1/3rd octave bands. The collective averaging of the destructive and constructive interferences, leads to the same effect as intensity addition. Sound energy which would have radiated into an infinite space now radiates into a halfspace due to sea surface reflections. The high acoustic impedance contrast at the air-water interface means that there is an image source of equal strength radiating into the halfspace, doubling or a 3dB increase in received energy than spherical spreading of the direct path alone. This 3dB needs to be removed to obtain the monopole source levels. The extra 3dB correction applies for both flat and rough sea surfaces. The correction is essentially non-existent if one considers the surface-reflected coherent energy only because there is little coherently-reflected energy beyond 1 kHz.

Comparison of Fig.1 (a) & (b) shows that a rough sea of 15 knots wind does not affect the results at the lower frequencies, because the wavelengths are much greater than the roughness of the sea surface, and the sea surface reflects sound like a flat surface.

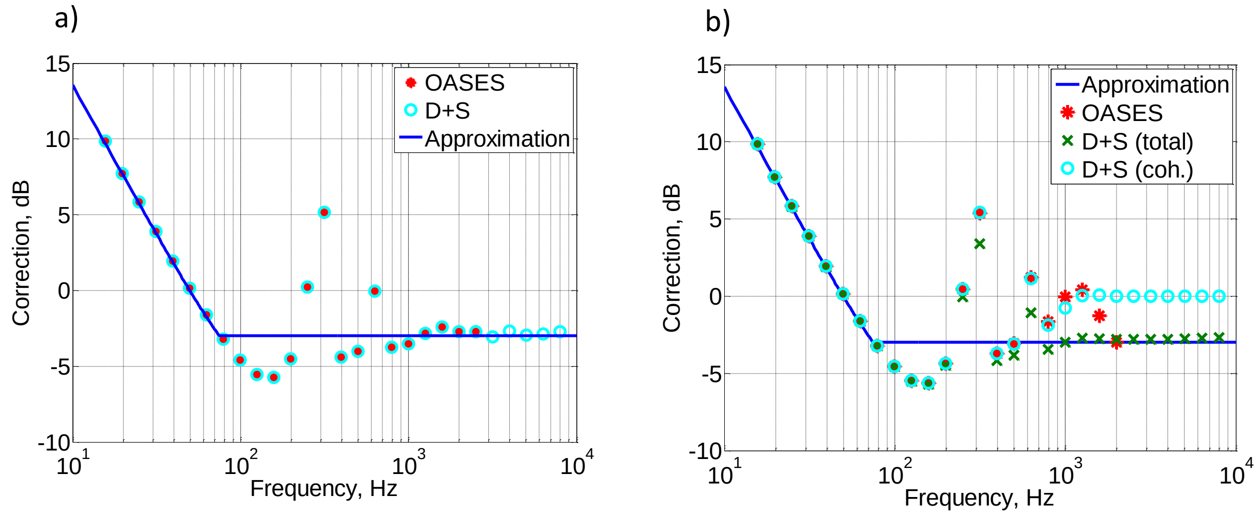

Figure 1: The correction, intensity-averaged in 1/3rd Octave bands, versus frequency for a monopole source at 5 m depth in deep water (where reflections from the sea floor are negligible). The hydrophone is at 50 m water depth and a horizontal range of 100 m. OASES is an acoustic model based on wavenumber integration. “D+S” is the summation of direct path and surface reflection. “D+S(coh)” includes surface-reflected coherent energy only and “D+S(total)” includes both coherent and diffuse-scattered energy. (a) flat surface (wind speed zero knots); (b) rough surface (wind speed 15 knots).

3 LIMITATIONS

Ships are extended noise sources which include multiple radiation mechanisms from the machinery, propeller, turbulent flow and wakes. Each noise generation mechanism also has its own spatial distribution and directivities. This paper has been limited to the consideration of an omni-directional point sources.

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