Properties of the non-propulsive ship noise field as measured from a research vessel holding station in the Yellow Sea and relation to sea bed parameters

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I. INTRODUCTION

Ship noise measurements made as part of the 1996 Yellow Sea experiment undertaken by China and the U.S. at location 37° N, 124° E (depth 75 m) are analyzed. The measurements were made on a 16-channel vertical line array (VLA), with hydrophone separation 4 m, suspended from the Chinese research vessel *Shi Yan 3* (length 104 m) while it was holding station via anchor. The noise is thus non-propulsive, originating primarily from the vessel's ship service diesel generator (SSDG), and contains a series of harmonics, separated by 5 to 6 Hz that is characteristic of SSDG type noise [1]. In another work from this same experiment [2], signals from broad band sources in the form of interference head waves are analyzed, and a geoacoustic model for the seabed is inverted from these data. In this work, estimates of the vertical coherence of the SSDG noise are interpreted with the aid of this geoacoustic model. The noise data are from the evening of August 23, between 2200 and 2300 local time (UTC + 8 h).

II. PRESSURE SPECTRAL DENSITY OF THE NON-PROPULSIVE NOISE, AND DECAY OF INTENSITY WITH DEPTH

Figure 1 shows an estimate of the pressure spectral density as measured by hydrophones at depths 16 m and 64 m. Calibration uncertainties dominate the confidence intervals about the exact spectral levels, which we estimate to be +/- 3 dB. The spectral resolution is ~0.5 Hz, and the spectral levels of the harmonics readily exceed a background level of more broad-band character by 10-20 dB. Note that in the analysis below concerning vertical coherence, the same frequency resolution is used and estimates with frequencies corresponding only to these harmonics are interpreted as there is no question as to origin of the noise source.

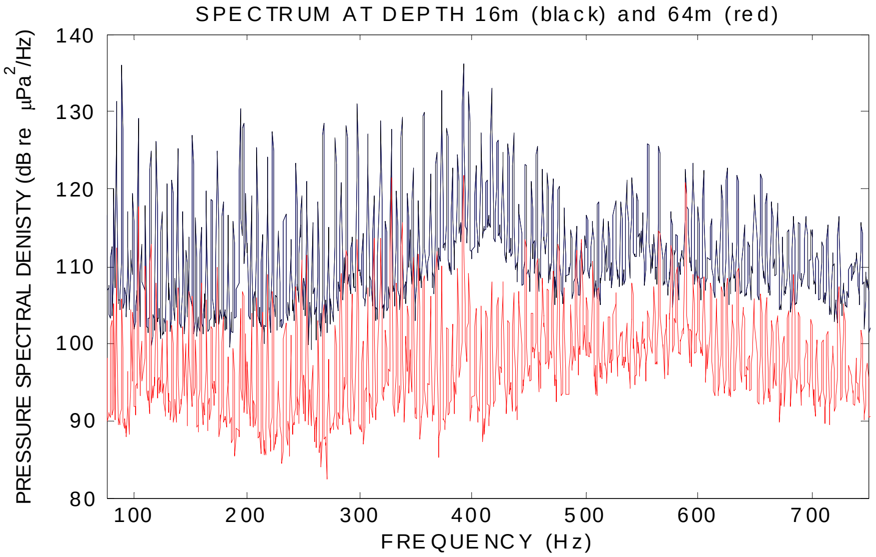

Fig. 1. Pressure spectral density of ship service diesel generator (SSDG) noise from the R/V *Shi Yan 3*.

The draft of the *Shi Yan* 3 is 5 m, and the VLA was suspended directly from the gunwale (no outboard extent) at a position 36 m from the bow on the ship's starboard side. The shallowest hydrophone was at nominal depth 4 m, and thus slightly above, but offset, the ship's keel. It is of interest to examine the properties of the vertical component of acoustic intensity along this array. The approach taken is the FFT-based algorithm from Fahy [3] and estimates are made at 64.5 Hz and 103 Hz, corresponding to two of the aforementioned harmonics associated with SSDG noise. Although the lower frequency is slightly below the system's nominal high pass corner frequency (~75 Hz), the frequency nevertheless comes in strongly, and the wavelength, ~24 m, allows for a reliable finite difference approximation between hydrophones separated by 4 m to yield a quantity proportional to the vertical component of particle acceleration. Although for the higher frequency the criterion for this approximation is only marginally satisfied we nevertheless proceed, and the results (Fig. 2) for both frequencies are nominally consistent. The far field is identified when the reactive component falls off significantly compared with that of the active component, which occurs at **kz** ~ 7, where **k** is wave number and **z** is depth below the keel. From this value we infer an effective radiation length scale along the hull of ~36 m for radiation of airborne noise from the SSDG originating from inside the hull and transmitted underwater (a contribution to underwater sound from flexural waves propagating in the hull plating will exist only above the coincidence frequency, which is of order 10 kHz).

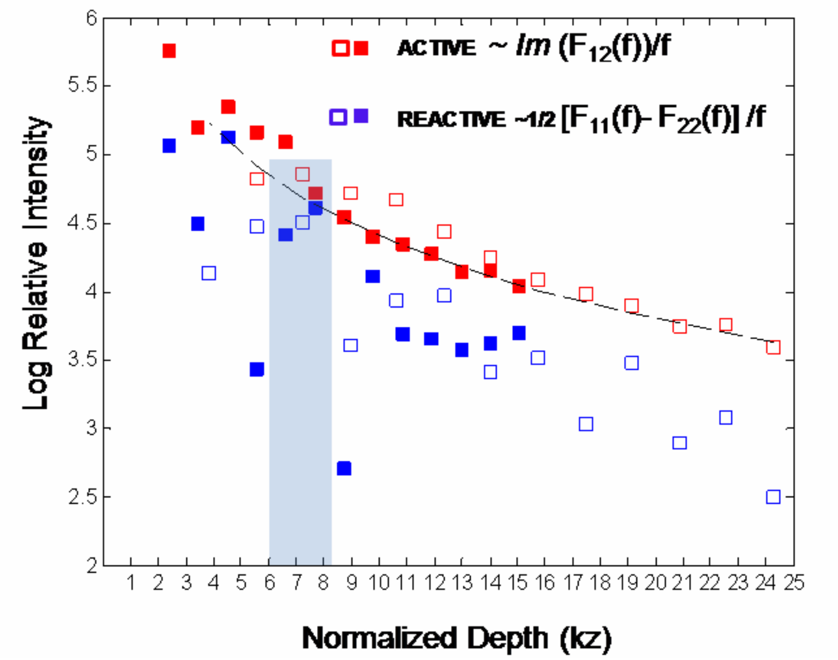

Fig. 2. Active and reactive vertical components of intensity plotted as function of measurement depth (**z**) referenced to the maximum draft of the vessel, times wavenumber **k** based on 64 Hz (solid markers) and 103 Hz (open markers). The far field transition is identified by the shading near **kz** ~7. The dashed line corresponds to a spherical spreading law. Subscripts 1 and 2 in the cross spectrum $\mathbf{F}_{12}$ represents a generic receiver pair separated by 4 m.

III. VERTICAL COHERENCE OF SSDG NOISE

Figure 3 shows estimates of vertical coherence of SSDG noise for 5 receiver depth pairs (the depth indicated on the right is the center of the two receivers), compared with a model. The coherence estimates represent the cross spectrum, e.g., $\mathbf{F}_{12}$(f), normalized by the square root of the product of the two pressure spectral densities $\mathbf{F}_{11}$(f) and $\mathbf{F}_{22}$(f), and the results are plotted as function of **k** times the 4-m separation **D**. As alluded to above, only a subset of frequencies, f_h, that are clearly identified with a harmonic component of the noise are considered in the estimates. The model utilizes ray theory owing to the high propagation angles involved. A set of eigenrays connecting a location on the hull with a receiver is found, in effect representing a direct path and one bottom bounce path, where the latter is reduced in amplitude according to the geoacoustic model in [2], and from which frequency-dependent phasing and spherical spreading loss is derived. The coherent sum of these ray-based components is considered a representation of the frequency-dependent Green's function between a source-location on the hull and a given receiver, say $\mathbf{g}_a$ for the receiver **a**. The $\mathbf{g}_a$ are coherently summed over an area consistent with aperture discussed above with the result being $\mathbf{G}_a$. A similar $\mathbf{G}_b$ is constructed for the second receiver and the model for coherence is $\mathbf{G}_a\mathbf{G}_b^*$ that is appropriately normalized.

The influence of the bottom acoustic impedance can clearly be seen in both data and the model: oscillations in both tend to damp out for more shallow receiver pairs as here the weaker bottom bounce path undergoes greater spreading loss. For softer seabeds with reduced bottom impedances the oscillation would weaken, and the coherence would approach that of a free field; for a higher bottom impedance the oscillations would increase. (The presentation will demonstrate the influence of varying impedance.)

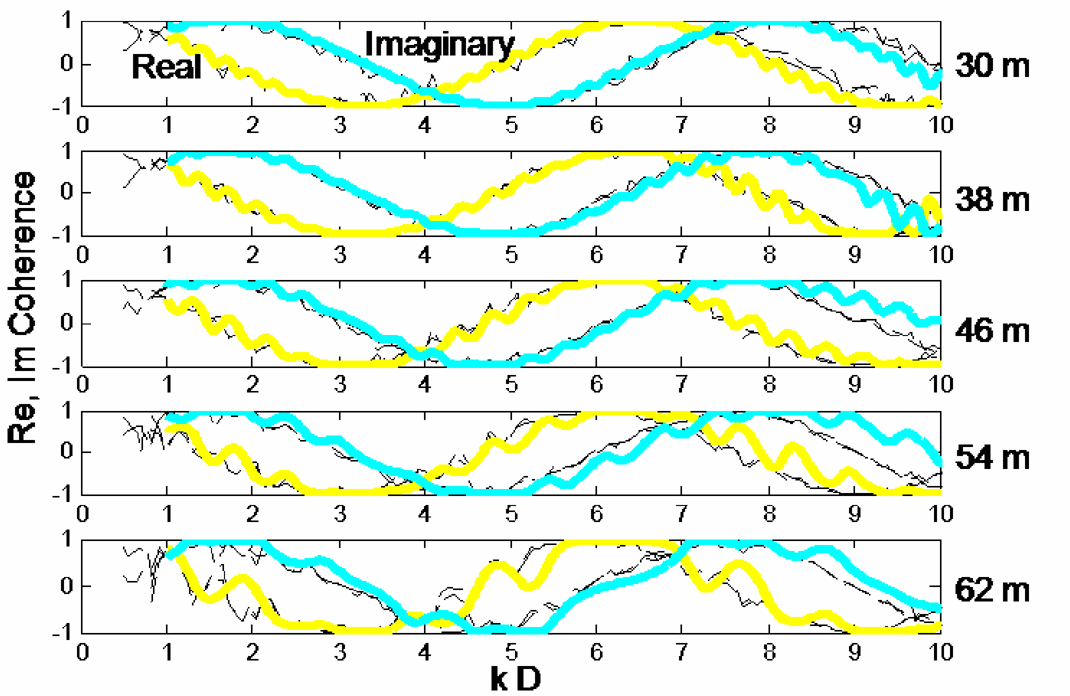

Fig. 3. The complex vertical coherence of SSDG noise between pairs of receivers separated by 4 m. Model derivations are shown of the real part (yellow line) and imaginary part (blue line) of coherence. Estimates of coherence real and imaginary parts (from two periods separated by about 30 min) are represented by the black lines. The receiver pair mid-point depth (m) is given on the right, and results are plotted as function of wave number **k** times separation **D** (4 m).

IV. CONCLUSION

Properties of noise radiation beneath a ship in shallow water are more complicated than those in deep water conditions. Complexities are introduced by the influence of the seabed, which is readily observed in estimates of vertical spatial coherence. Ray theory (or otherwise an approach that accommodates high propagation angles) is essential in modeling these effects. An effective radiation length scale linked to the far field transition was identified for this noise source, which was non-propulsive noise, originating primarily from the vessel's ship service diesel generator (SSDG), indicating the length scale of coherent radiation from the ship's hull of O(10) m. The scale is frequency dependent and it is essential to account for this scale in modeling the noise.

REFERENCES

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