THE INTERACTION OF SHIP RADIATED NOISE WITH THE SEA SURFACE

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The noise level at a point in the ocean is the sum of the signal received from many different noise sources. The signal from each of these sources is usually computed from its known or estimated level and the propagation loss over the great circle route between the source and receiver.

The factors identified as determining the accuracy of the computations are the characteristics of the source and the form of the propagation loss which is employed.

To treat the problem rigorously it is necessary to know the free field three dimensional amplitude and phase characteristics of the acoustic source. This information is not readily available and because the surface ship lies both in and beneath the sea surface, it is not at all clear how it should be represented. For noise modeling purposes it is frequently approximated by a point source at some depth (d), as shown in Figure 1. The problem with which we are concerned is the manner in which signal propagating over paths of type A should be combined with signal propagating over paths of type B, i.e., the Lloyd's mirror problem.

To a first approximation Figure 1 can be reduced to Figure 2 in which the source is located in the surface itself. The level of this source, relative to the free field source level (N dB) of the source, is then determined by our assumption as to how signals propagating over paths A and B should be summed.

Consider the following possibilities:

1) Path B does not exist. (Perhaps bow aspect on screw generated noise.) The level of the equivalent surface source is N dB.

2) Path B exists and paths A and B should be summed incoherently. The level of the equivalent surface source is (N + 3) dB.

3) Path B exists and paths A and B should be summed coherently. The level of the equivalent surface source is given by the dipole of the source and its surface image, Lloyd's mirror:

$$N_{eq} = N + 3 + 10 \log\left[1 - \cos\left(\frac{4\pi d}{\lambda} \sin \theta\right)\right] \quad (1)$$

Suppose we now measure the signal (S) from a surface ship at range R, under isovelocity conditions, and assume that case 2 applies. The free field source level will be approximately given by:

$$N_{eq} = N = S = 20 \log R - 3 \quad (2)$$

If we now use an incoherent model to predict the noise contribution at long range, the results for each of these cases are:

1) <u>Path B does not exist</u>. The underestimate of the free field source level of 3 dB is compensated by the overestimate of the number of paths by a factor of 2, leading to a correct result.

2) <u>Paths A and B are summed incoherently</u>. This was assumed in making the source measurement, leading to a correct result.

3) <u>Paths A and B are summed coherently</u>. The error in the equivalent surface source level is given by:

$$N_{eq} = 10 \log\left[1 - \cos\left(\frac{4\pi d}{\lambda} \sin \theta_o\right)\right] \quad (3)$$

where: θ_o is determined by the measurement geometry.

For noise prediction, we assume a large separation between source and receiver in a basin. Signal will propagate over many paths with angles at the source ranging from 0 to θ_1. The average equivalent surface source level is obtained by integrating over the dipole pattern yielding for small values of θ:

$$\overline{N_{eq}} = N + 3 + 10 \log\left[1 - \frac{\lambda}{4\pi d\theta_1} \sin\left(\frac{4\pi d}{\lambda} \theta_1\right)\right] \quad (4)$$

Thus the error made in the measurement, and the error made in the noise prediction do not compensate. The last term of Equation 4 is shown in Figure 3 for d = 25 ft and $\theta_1 = 15^o$. The effect of this term increases with increasing frequency below 150 Hz; above 150 Hz it oscillates and asymptotically approaches zero. As a result the error below 150 Hz will include the error in Equations 3 and 4, while above 150 Hz it is only the error measurement, Equation 3, which affect the results.

There are several subtle variations of this problem. Assume a known distribution of ships in a basin at the time that a noise measurement is made. Using an incoherent propagation loss model we can compute the equivalent average free field noise level of the ships by matching the predicted and received noise level. The results will be correct to within a small fraction of a decibel for frequencies above 150 Hz; below 150 Hz the results will depend upon the correct physical representaiton and will be underestimated by the amount given by Equation 4, as illustrated by Figure 3, if a coherent representation should be used. Since the underestimate depends upon the angle θ_1, different equivalent source level values will be determined for the same set of ships in basins with different acoustic properties. This is shown in Figure 4 for d_o = 25 ft, a frequency of 75 Hz, and θ_1 ranging from 5^o to 25^o.

These results lead to the conclusion that accurate modeling of noise contributions from surface ships requires that we know how to physically describe the source-surface interaction, which must be matched with the appropriate form of the propagation loss curve, particularly at the lower frequencies.

(Work supported by Long Range Acoustic Propagation Project, Naval Ocean Research and Development Activity, U. S. Department of the Navy.)

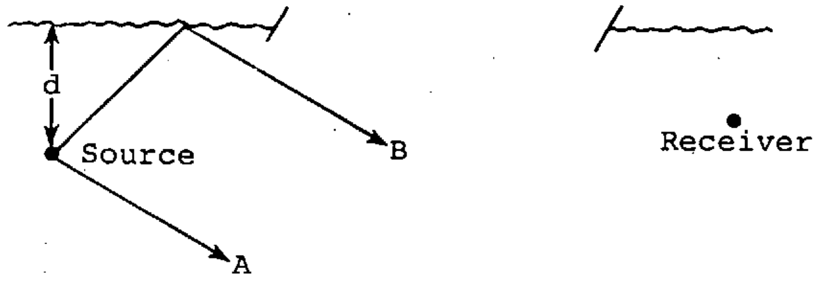

Figure 1
Representation of Ship as a Point Source

Figure 2
Equivalent Ship Source at the Surface

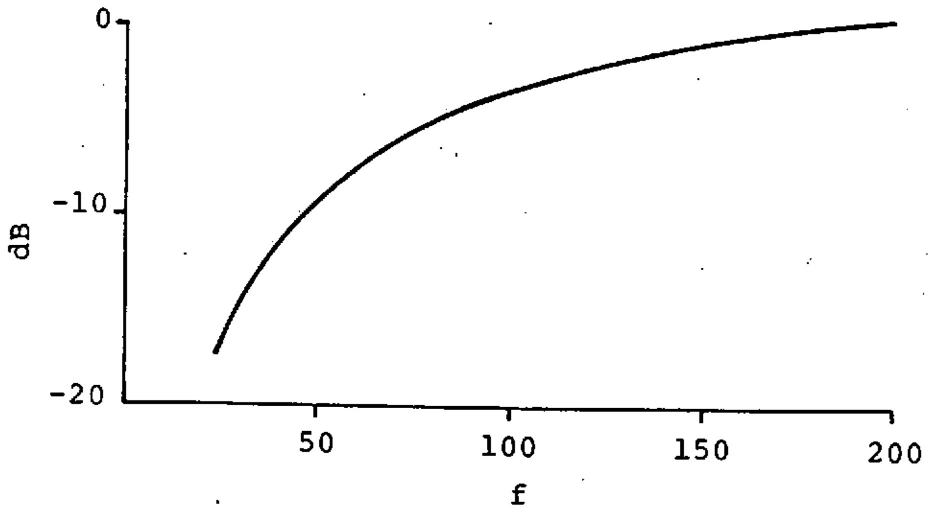

Figure 3
Numerical Values for the Term

$$10 \log\left[1 - \frac{\lambda}{4\pi\theta_1} \sin\left(\frac{4\pi d}{\lambda_1}\, \theta_1\right)\right]$$

$d = 25$ ft, $\theta_1 = 15^\circ$

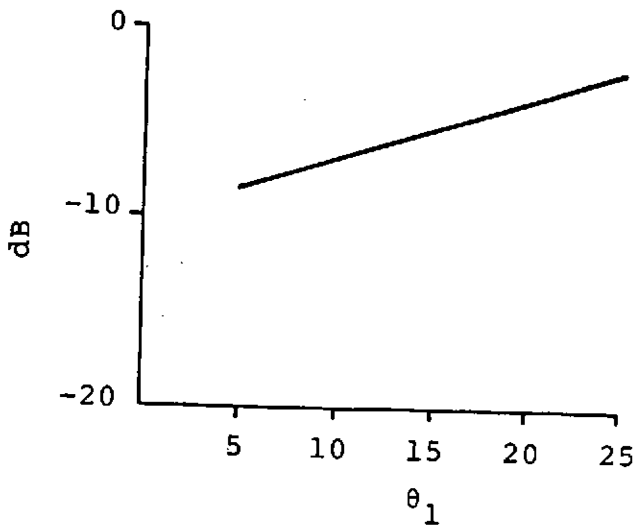

Figure 4
Numerical Values for the Term

$$10 \log\left[1 - \frac{\lambda}{4\pi\theta_1} \sin\left(\frac{4\pi d}{\lambda_1}\, \theta_1\right)\right]$$

$d = 25$ ft, $f = 75$ Hz