Mechanisms of Wind Induced Low Frequency Ambient Sea Noise in the Deep Ocean

N. Yen and A. J. Perrone

Naval Underwater Systems Center
New London Laboratory
New London, Connecticut 06320 USA

Theories of wave interaction and turbulence has been extended to the study of noise generating mechanisms in the frequency range of 1 to 10 Hz. The ambient sea noise caused by a disturbed ocean is assumed as the result of the interaction of the surface wave, wind turbulence and wave turbulence actions which also satisfy the radiation condition. The noise spectrum level at the deep depth predicted from these noise generating mechanisms appears to agree in order of magnitude with the reported experimental data. Further discussion is directed to the effect of distance storms on the local noise level.

Several theories (references 1, 2 and 3) which address noise generating mechanisms have been extended in this study to explain the cause of ambient noise due to the surface wind condition and to compare the experimental data with the theoretical prediction in the frequency range from 1 to 10 Hz. Some of the detailed derivations of this work, together with 45 related references, are already documented in a NUSC technical report (reference 4).

The mathematical model of the ocean used in the analysis of wind induced noise is illustrated in figure 1. The ocean environment is divided into three regions in order to simplify the theoretical derivation of wind induced noise and still retain an understanding of the basic physics of the phenomenon observed in ambient sea noise measurements. In region I, where it blows far above the sea surface, wind can be considered as a laminar air flow. Region II is the air-water interface where it is believed some of the wind energy is being converted into acoustic energy. There are wind induced waves on the sea surface and wind turbulence just above it; below the ocean surface, there is turbulent flow caused by the waves breaking. All these distrubances around the air-water interface are sources of noise generation. Region III is the warer column and provides the medium for the propagation of acoustic energy.

The physical quantities, particle velocity, density, and pressure, which describe the disturbance around the air-water interface in region II can be considered to consist of the flow mode (varied slowly with respect to time and space) and the acoustic mode (the fluctuation part of fluid disturbance). Based on the physics of fluid mechanics with the assumption that the flow mode is irrotational and incompressible, the velocity potential can be described by the Laplace equation and related to pressure and density through Bernoulli's equation. For the frequency range of 1 to 10 Hz, surface tension is not important in forming the ocean surface wave, the dispersive relation of the gravity wave caused by disturbance at the air-water interface can be derived as:

$$g\, k_3 - \omega^2 = 0, \tag{1}$$

where g is the gravity, k_3 is the wave number in X_3 direction and ω is the radian frequency. The fluctuation part of the pressure change, p, the second order effect due to the disturbance in region II, can be approximated by:

$$\frac{\partial^2 p}{\partial x_i^2} \cong - \rho_0 \frac{\partial^2}{\partial x_i \partial x_j} \left[U_i U_j + U_i u_j + u_i u_j \right] \tag{2}$$

where ρ_0 is the density of the fluid (air or water), U's and u's are designated for the particle velocity components of the flow and acoustic mode respectively, (the repeated index in equation (2) denotes summation). The three right hand side terms in equation (2) indicate respectively, the pressure contributions due to wave-wave interaction, wave-turbulence interaction, and the Reynold stress of the turbulence. The pressure spectrum of p contributed from first two causes can be derived by using Fourier-Stieltjes integral representation of p, U's, and u's. Based on the reported oceanographic data of surface waves and wave turbulence, the pressure power spectrum due to surface wave interaction is:

$$P_{pp}(\omega,\bar{k}) \cong 10^6 \left(\frac{|k_3|}{|k|}\right)^4 \omega^{-6}\, e^{-1.44(g/\omega U)^4} \tag{3}$$

and due to wave-turbulence interaction is:

$$P_{pp}(\omega,\bar{k}) \cong 10^{-2} \left(\frac{|k_3|}{|K|}\right)^4 \omega^{-2}\, U \tag{4}$$

where U is wind velocity (in knots) far above the surface and k is the acoustic wave number. In deriving equations (3) and (4), only those components whose wave numbers satisfy the radiation condition (k_3 is real) are considered.

For the Reynold stress above the sea surface due to wind turbulence, the corresponding pressure power spectrum has the approximate form as:

$$P_{pp}(\omega,\bar{k}) \cong \frac{10^{-12}\, U^3 \delta \left(\frac{0.12\omega}{U_c}\right)\left(\frac{0.55\omega}{U}\right)}{\left[1 + 10^{-2}\left(\frac{\omega\delta}{U}\right)^3\right]\left[\left(\frac{0.12\omega}{U_c}\right)^2+\left(k_1+\frac{\omega}{U_c}\right)^2\right]\left[\left(\frac{0.55\omega}{U}\right)^2+k_2^2\right]} \quad (5)$$

according to wind tunnel experiment reported in the literature. The notation δ in equation (5) is the thickness of the turbulence layer and U_c is the final convection wind speed with respect to the moving surface wave.

The power spectra of such pressure fluctuations due to mechanisms expressed in equations (3), (4) and (5) can serve as the boundary condition for computing the noise field in region III. At deep depths in the water column, the acoustic wave equation can be used to describe the propagation of the pressure wave. The total pressure level detected by a sensor at certain locations between the disturbed surface and ocean bottom is the summation of all dominant propagation modes. Figure 2 shows the comparison of the prediction values from three noise generating mechanisms with the measured ambient noise data from the Bermuda area for Wind speeds from 20 to 40 knots. In general, all three noise generating mechanisms have the same order of magnitude as that of the measured data. However, judging from the shape of each individual curve with respect to frequency, it appears that the wind turbulence and the surface wave are dominant causes at the low end while the wave turbulence becomes the important noise generating mechanism for higher frequency components.

Extending this analysis to estimate the ambient sea noise level due to distant storms should also consider the propagation loss (mainly spreading and bottom losses) as well as the fetch size. The dominant modes will mainly be contributed from the refracted-surface-relected path and depend very much on the velocity profile.

REFERENCES

1. Isabovich, M. A. and Knryanov, B. F., "Theory of Low Frequency Noise in the Ocean," Soviet Physics-Acoustics, 16, pp. 49-58 (1970).

2. Marsh, H. W., "Orgin of the Knudsen Sprectra," J. Acoust. Soc. Am., 35, pp. 409-410 (1963).

3. Goncharov, V. V., "Sound Generation in the Ocean by the Interaction of Surface Waves and Turbulence," J. Atmospheric and Ocean Physics, 6, pp. 1189-1196 (1970).

4. Yen, N. and Perrone, A. J., "Wind Induced Low Frequency Ambient Sea Noise: Mechanisms and Modeling," NUSC Technical Report 5833, Naval Underwater Systems Center, New London, Connecticut 06320, USA.

(Work supported by ONR Code 480 and Code 600 LRAPP Program)

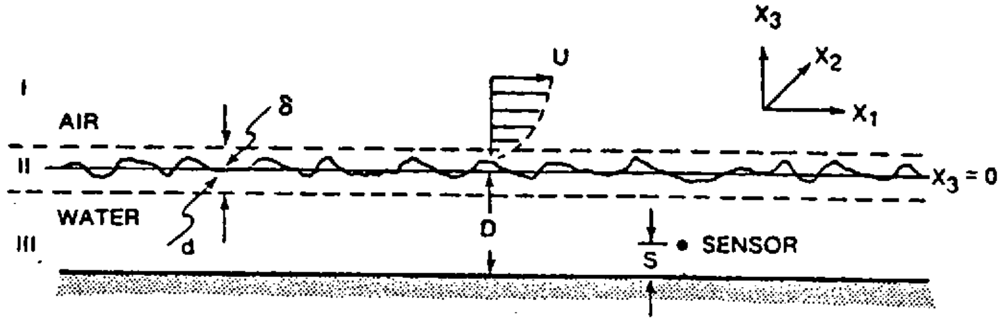

Figure 1. Mathematical Model of Ocean

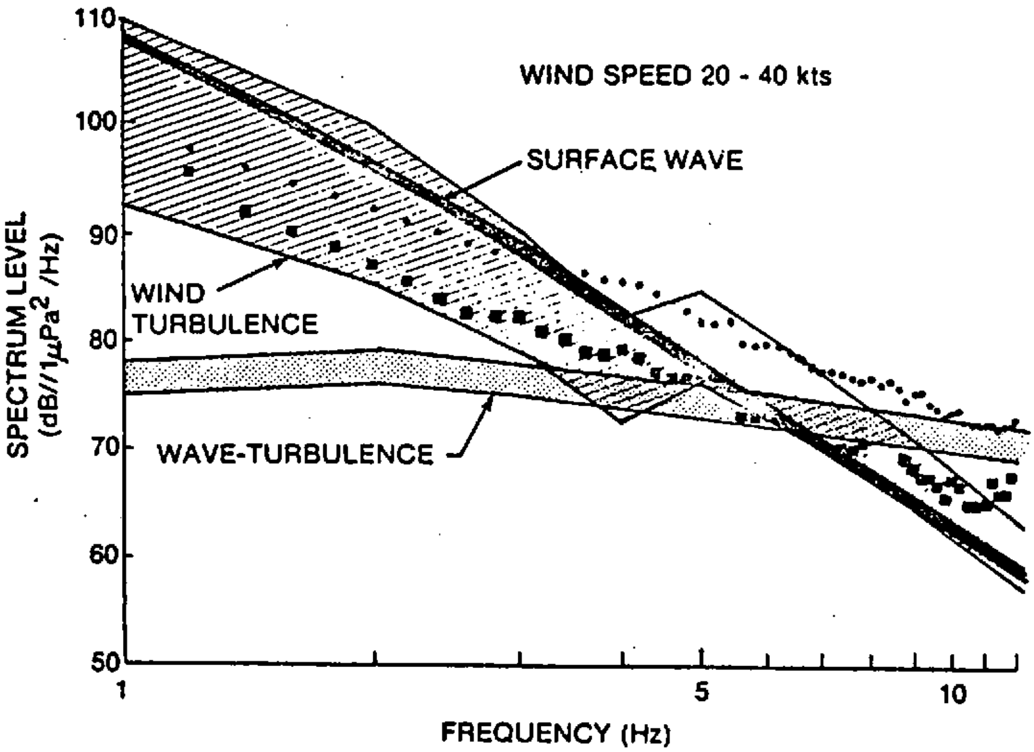

Figure 2. Meaurement and Theory - Bermuda, 1966
(Water Dept 900 M/2600 ft)