International Symposium on
HYDROACOUSTICS AND ULTRASONICS
EAA Symposium (formerly 13th FASE Symposium)
Gdańsk-Jurata, 12-16 May 1997

The surface film effect on underwater noise of rain

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ABSTRACT

The spectrum of rain noise shows a peak at 13.5 - 15 kHz, stronger winds smear the peak. The spectral level (SL) at 15 kHz shows a linear dependence on the log of the rain rate with wind speed as a parameter. The presence of a monomolecular film on the sea surface results in a pronounced reduction of SL beneath the film by 10 log K. The damping ratio K(= α_c / α_o, where α_c, α_o are water wave damping coefficiants for film - covered and clean surfaces) is related to the viscoelastic properties, surface activity, concentration and diffusional coefficient of the surface-active substances composing the film.

INTRODUCTION

Naturally generated ambient noise in the ocean is created by breaking wind waves, spray and precipitation and has particular spectral features (Fig. 1) [1].
Splashing water droplets as noise sources are treated as being uniformly distributed over the surface, are modeled as incoherently radiating dipoles [2].
Upon striking the sea surface the vertical kinetic energy of the drop is converted into compressional water surface disturbance [3].The intensity of such a acoustic pressure pulse is proportional to $(\text{amplitude})^2$ of the disturbance which decreases with time with $\alpha_o = 4\,\gamma\,k^2$, α - the viscous energy temporal damping coefficient (γ - kinematic water viscosity, k - water wavenumber). For film - covered surfaces $\alpha_c = K \cdot \alpha_o$, where K - damping ratio determines wave-damping ability of the film and is related to the viscoelasticity, concentration, surface activity,

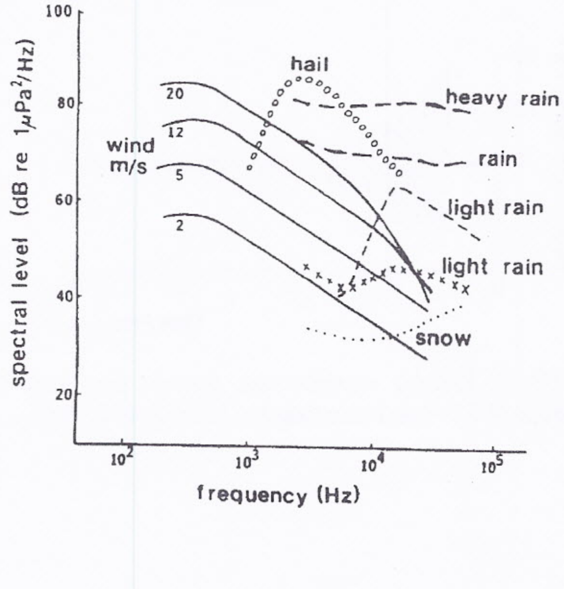

FIG. 1. Generalized oceanic ambient sound spectra

and diffussional coefficient of the substances composing the film [4] . The aim of the paper is to correlate the observed reduction
of SL beneath the film with the surface elastic parameters of the film.

SOUND LEVEL DEPENDENCE ON RAIN RATE

The shape of the impact sound pulse (Fig. 2 [5]) is explained as a weak water hammer. The vertical momentum flux carried by the rain M = ρ W R; W - is the fall velocity of rain drops just before the hitting the surface, R is the rain rate (mmh^{-1}), ρ - is the density of water in rain drops [6] .
Experimentally, the temporal decay constant α_o is determined by observing the time t_e required for the pressure amplitude to decrease to e^{-1} of its initial amplitude. For the impact in Fig. 2, t_e = 1,2 ms with the characteristic frequency f_e (=833,3 Hz) and $\alpha_o = 1/2\, t_e = 416,6\ s^{-1}$.
The mean intensity I_o of the noise sound averaged over the observation time t_a is proportional to :

$$\overline{I_o} = 1/t_a \int_o^{t_a} I\,(t = 0)e^{-\alpha_o t}\ dt \quad (1)$$

for a clean water surface, whereas for the film-coated one :

$$\overline{I_c} = 1/t_a \int_o^{t_a} I\,(t = 0)e^{-K\alpha_o t}\ dt \quad (2)$$

from (1) and (2) we have

$$\overline{I_c} = \overline{I_o} / K \quad (3)$$

and

$$10 \log \overline{I_c} = 10 \log \overline{I_o} - 10 \log K$$

$$(SL)_c = (SL)_o - 10 \log K \quad (4)$$

where $(SL)_c$ and $(SL)_o$ are sound levels due to rain (in dB) relative to 1 μ Pa^2/Hz
In constant wind conditions, SL appears to be proportional to rain fall rate [7] :

$$SL_o(dB) = A + B \log R \quad (5)$$

A, B are given in Tab. I of [7] .
At a constant R value, sound level SL_c, for film - covered surfaces exhibiting different K values as a function of rain rate is shown in Fig. 3, according to Egs. (4) and (5)

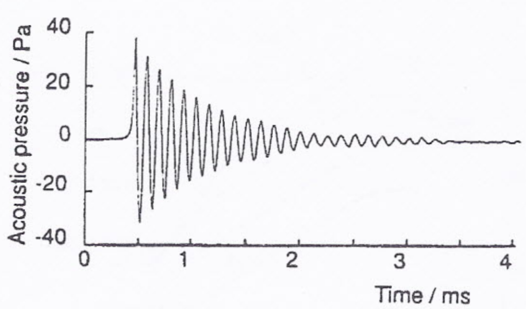

FIG. 2. Regular entraintment. Sounds produced by drops of 3.0 -mm impacting at a velocity of 2.0 m/s.

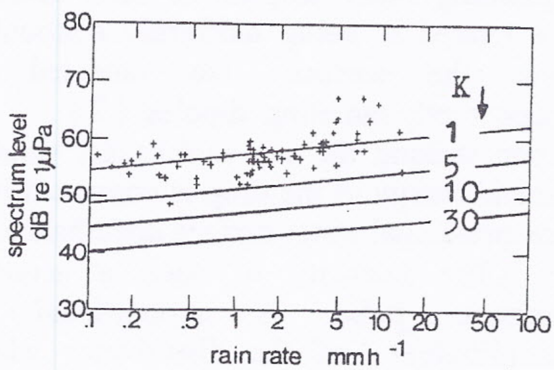

FIG. 3. Samples of noise spectrum level at 15 kHz plotted against rain rate.

DISCUSSION, DATA EVALUATION

The wave-damping ability of surface films expressed by K - damping ratio [8] depends on the dilational elasticity modulus E, which relates a drop of the surface tension ΔT following the relative area change of the film $\Delta A/A$:

$$\Delta T = |E| \, \Delta A/A \qquad (6)$$

but particular value of $|E|$ depends on the time scale of the deformation process (here t_e) referred to the relaxation time t_r of the diffusional exchange of molecules (film ↔ subsurface water) resulting from the film deformation as follows :

$$|E| = \frac{E_o}{\sqrt{1 + 2\tau + 2\tau^2}} \qquad (7)$$

$$E_o = -dT / d \ln A$$

$$\tau = \frac{(c/a + 1)^2 \, a}{\Gamma_\infty} \sqrt{\frac{D}{2\,\omega_e}} \qquad (8)$$

$(\omega_e = 2\pi / t_e)$

c - surfactat concentration
a - coefficient of surface activity
D - diffusion coefficient
Γ_∞ - saturation surface concentration

In the case of readily soluble substances ($a = 10^{-3} - 10^{-4}$ kmol/m^3), diffusion reduces the value of $|E|$ ($t_r = 10^{-4}$ s) and K is low (1,5 - 3). For insoluble films ($a = 10^{-6}$ kmol/m^3 and lower) $|E| \approx 20 - 40$ mN/m , (t_r -several minutes), and K = 15 - 40.

The author obtained for oil substance films spread onto the water surface
$|E| = 8 - 16.8$ mN/m
and K = 10,7 - 16,5 [9].
The sound level reduction Δ SL, reported by others [5] after adding surfactants to water were 10 dB (see Fig.14) and 18 dB (see Fig.15) which corresponds to K values according to Eg. (4) - K = 10 and K = 63. It demonstrates that we are concerned with strong compact surface films. It must be pointed out that the wind has a certain effect on the rain noise. The wind speed increase $\Delta V = 2$ m/s leads to Δ SL = 2,5 dB.
In addition, when rain drops with a certain diameter (of the order of 1 mm) hit a plane surface they entrain air bubbles that radiate noise in the course of volume oscillations like Helmholtz resonators [10], that was not accounted for in this study.

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