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Underwater Noise and Sound Produced By Aerial Sonic Boom

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INTRODUCTION

The sonic boom generated during aircraft supersonic cruise or rocket space launch has long been a concern for its impact on animals and their habitats. Penetration of sonic boom noise into the ocean raises the issue of underwater sound perception for the impact analysis that must be investigated based on an understanding of the physical characterization of the sound/noise in question and their effects on marine mammals' hearing and behavior response. This paper presents results of recent studies on the wavefield characterization of the underwater sonic-boom noise/sound, which, it is hoped, may provide a quantitative basis for investigating the audibility and behavior issues.

THEORY AND EXPERIMENT: SURFACE-WAVE INFLUENCE

The underwater wavefield in question can be predicted reasonably well by the theory of Sawyers (1) based on a model of flat ocean; the predicted features have been confirmed by laboratory and field measurements but for depths not far exceeding the sonic-boom signature length (2-4). Recent theoretical and experimental studies (5-7) show that secondary acoustic sources produced by the interaction of sonic boom with (ocean) surface waves generate downward propagating waves that can overwhelm the primary (flat-ocean) wavefield in the deeper part of the water, whereby the sonic-boom noise disperses itself into a packet of wavelets. The two examples serve to indicate the frequency range, the sound pressure level and (pulse) duration, and other waveform characteristics perceivable at various depth levels, which may be useful to audibility studies of deepwater infrasound.

INCIDENT N-WAVE: SUPERSONIC OVERFLIGHT

The plots in Figure 1 show an example of overpressure waveform (perceived in a rest frame) at 1,500 ft below sea level, which results from a standard N-shaped, sonic-boom wave of 300-ft signature length over water, produced by an aircraft at Mach 2.5 at an assumed cruising altitude (corresponding to $M_A = 2.38$ based on sea-level sound speed). The ocean surface is assumed to be wavy and is modeled by a surface-wave train with a 120-ft wavelength and 2.4-ft wave height. For the calculation, the peak overpressure at sea level is given 2 pounds per square foot (psf), and surface waves are assumed moving in a direction not far from the flight track (so that the sonic-boom wave hits the surface-wave train squarely). Although the result from the flat-ocean model (in dash-dot solid curve) gives a smoothly varying overpressure at levels well below 0.004 psf, the effect resulting from the interaction with surface waves (shown as finer curve with symbols) is seen to give far greater magnitude and distinctly different character. Under surface-wave influence, dominant sound signals occur in the 25-45 Hz frequency range, with a sound pressure in the 0.01-0.05 psf (114-128 dB re 1 μPa), high enough to be detectable over a duration longer than 3 s. The waveform featuring an envelope with four peaks and a frequency downshift from 45 to 25 Hz offers a distinguishable signature of this example.

FOCUSED BOOM FROM ROCKET SPACE LAUNCH

The plots in Figure 2 furnishes an example with a strongly focused sonic boom that occurred during the ascent of a rocket space launch (2, 3). It vastly differs from the standard aircraft sonic-boom model, owing largely to the long signature length, which is 1 km in this case, and a sharply peaked, (sea-level) waveform with a high peak overpressure of 8-9 psf. The surface Mach number is taken to be that of the horizontal wavefield movement, $M_A =$

1.08; the sea state is the same as in the preceding example (wave height 2.4 ft and surface-wave length 120 ft). The overpressure shown is that at 1 km below sea level where the flat-ocean model (in dash-dot curve) would predict a smoothly varying negative overpressure, an "underpressure" to be more precise; although its magnitude may not be considered small, it would not be detectable unless the sensor frequency could reach down to well below 0.1 Hz . On the other hand, with the help of surface waves, distinct signals with (wavelet/carrier) frequencies hundred times higher can be detected by monitors with sensitivity level of 0.01 psf (114 dB re 1μPa) in an 8-s duration. Here, the sound pressure represented by "p_2" (in light dots) is seen to reach its maximum peak slightly over 0.02 psf (120 dB re 1 μPa), while the wavelet frequencies are seen to downshifted from 5-6 to 3-4 Hz.

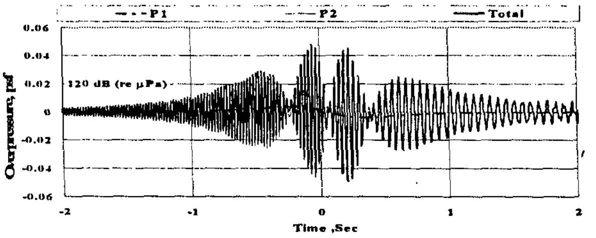

FIGURE 1. Overpressure waveform at 1,500 ft below sea level produced by N-shaped sonic boom with $M_A = 2.38$ (cf. text).

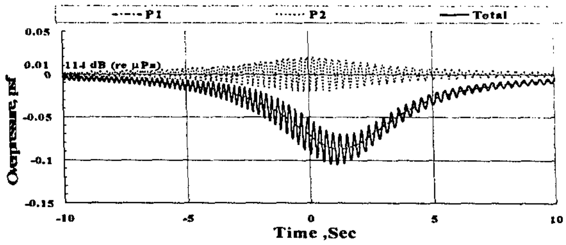

FIGURE 2. Overpressure waveform at 1 km below sea level produced by a space-launch focused boom (cf. text).

CONCLUDING REMARKS

Owing to its much lower attenuation rate, the time-dependent wavefield generated originally as a secondary effect by the interaction of sonic boom with surface waves is shown to dominate the deepwater wave field in each of the two preceding examples where the sonic-boom noise underwater is seen to take the signal form of a wave packet with slowly downshifting frequencies. From the view point of underwater sound perception and detection, the knowledge and understanding of the frequency range, sound pressure level, and the perceptible duration as well as other waveform characteristics are essential; the foregoing examinations and works in Refs.1-7 have suggested their relative importance to infrasound perception by marine mammals for the impact studies in question.

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