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NATURAL SOURCES OF LOW FREQUENCY SOUND

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Introduction

In order to avoid possible overlapping with other lectures this talk will be restricted mainly to natural sources of infrasound. It appears that even if our atmospheric environment is silent as regards audio sounds yet there exists always sounds of infrasonic frequencies. These may be quite feeble in intensity involving pressure fluctuations as low as 0.1.dyn cm^{-2} but could be as high as 50 dyn cm^{-2}. The smaller pressure amplitudes are often termed microbaroms and are of a much lower value than the random pressure fluctuations accompanying winds say of 20 mph which are of the order of 500 dyn cm^{-2}, but are distinguishable since the latter will lack correlation between observing points placed several kilometres apart. The absorption of infrasound in the atmosphere arising from viscous and thermal conduction losses is much less thanfor audible sound, and assuming the classical law of attenuation is applicable at these very low frequencies it would mean that a 0.1 Hz sound wave travelling once around the earth would only suffer an energy loss of about 5%. The losses arising from scattering by hills, buildings etc., will also be very small for frequencies less than 0.3 Hz, i.e., for wavelengths greater than one kilometre. The Krakatoa volcanic eruption in 1883 gave rise to infrasonic waves which travelled round the world several times and the sound pressures were sufficiently large to be read on barographs all over the world.

Sources of Very Low Frequency Sound

Thunder

Thunder is a very evident source of atmospheric noise resulting from an electrical discharge, the lightning. The nature of the of the sound radiation will vary in detail with the discharge of which there are three main types; flashes to ground, air discharges (which terminate in space charge regions in the atmosphere) and cloud flashes (so called sheet lightning). Radar has revealed that discharges inside long banks of clouds often extend for 30 or even 100 miles and that the discharge is continuous.

There has been a considerable disagreement regarding the actual spectral peak frequencies of thunder and it appears to be closely related to the recording apparatus used. Measurements made with crystal and hot-wire microphones, cubic-box resonators etc., have tended to give lower values around 0.5 to 2.0 Hz, while users of condenser and dynamic microphones have obtained frequencies of 100 to 300 Hz.

In calculating the magnitude of the pressure pulse from a lightning stroke earlier investigators have assumed the lightning channel to be an infinite straight channel, whereas in reality it is highly tortuous and photographs taken at ranges of several kilometres reveal channel tortuosity down to a scale of 5 to 10 metres or less. (Fig. 1).

Neither a spherical or a cylindrical source provides a complete model for the pressure wave, although each is significant in restricted regions. The initial expansion for a short line segment will follow the cylindrical source solution but when the pressure wave radius is approximately equal to the segment length, a transition to a sperical wave expansion will occur.

Assuming that the diameter of the channel is smaller than the major irregularities, Few and Dessler give the dominant acoustic frequency as $f_d = c/2.6R_{sc}$ where c is the speed of sound. In the cylindrical case this gives the value $f_c = \frac{c}{2.6} (\pi P_o / E_\ell)$,

where P_o is the constant ambient pressure and E_ℓ is the energy per unit length of the discharge. Making the further assumption that all the energy of the lightning flash is converted to acoustic energy, and taking the total energy to be 10^{10} joules and the height of the flash to be 6 km, then $E_\ell = 1.7 \times 10^6$ joule m^{-1}, giving a minimum value for $f_c = 57$Hz.

The acoustic field of a cylindrical model bears a close resemblance to the wave originating from a supersonic object, while on the other hand a tortuous source would give rise to an irregular acoustic signal i.e., containing the rumbles and claps of thunder. Few has pointed out that it was only the strong claps of thunder which were well correlated in his cross-correlation analysis. By contrast the low-level rumbling was not well correlated, which indicates that, partially at any rate, it could arise from reflections and refractions in the atmosphere.

The power spectrum is the measurable property of thunder that is least affected by channel irregularities and assuming the channel has a uniform energy distribution along its length and the channel is mesotortuous (i.e. the ratio of geometric length of a line element to the relaxation radius, $R_c = [E_\ell / \pi P_o]^{1/2}$, is of the order of unity), Few has calculated the power spectrum shown in Fig. 2. This curve is in good agreement with the form of that obtained for the measured acoustic power spectra of a single thunder event (Fig. 3).

In recent cloud-ground thunder recordings made in Nigeria, by N.O. Ajayi, there were sections exhibiting a number of spikes and he showed for the first time that there was a close correlation with the discrete lightning pulses in the optical recording.

Turbulence

Turbulence in the atmosphere might be expected to be a source of sound and its study could have two possible applications. Firstly the radiated sound could form a significant background for surface measurements of infrasound, and secondly clear air turbulence, important in aircraft operation, might be detected by its acoustic radiation. Experiments have been made by Meecham and Wescott using systems of balloons at heights of about 60,000 feet and it was found that the ambient sounds have pressures ranging from 0.03 to 1.0 dyn cm^{-2} at a frequency of around 1 Hz. There was a fall-off in the spectrum at a rate of 6 dB/octave at higher frequencies and the authors showed that the observations were consistent with the view that the recorded sound was generated by turbulence. The turbulent model was substantiated by correlation measurements taken from two balloon-supported sensors, by the amplitude probability distribution of the sound signal and by ground sound pressure level measurements.

The various sized-eddies will radiate sound at different frequencies which will be determined by the characteristic decay times of the eddies, while it is the eddy velocity amplitudes which will control the acoustic power radiated. The radiated intensity is proportional to the density and since this latter decreases exponentially with height it indicates most of the sound energy will originate below 60,000 ft.

Generation and Propagation of Shock Waves from Apollo Rockets at Orbital Altitude

The generation and propagation of shock waves from Apollo rockets at orbital altitudes, ie., around 188 km, have been investigated by Cotten, Donn and Oppenheim. They explain their generation as arising from the exhaust plume acting as a conical body of large cross-section moving at a supersonic speed with the rocket. The presence of the surface signal (1.3 Hz and higher) implies that the propagation in the upper atmosphere occurred as an N-wave shock cone but without the attenuation undergone by a saw-toothed wave of similar frequency. In the case of the rocket, energy is being continually supplied to the shock cone from the vehicle and its plume acting as a piston. It is not until the wave is below 40 km that the acoustic overpressures reduce to acoustic amplitudes and the acoustic attenuation then becomes quite negligible.

The authors applied steady state sonic boom theory to determine the relevant source parameters necessary for the signal to reach the earth's surface and then applied existing theories of attenuation, for both ordinary acoustic and of saw-toothed shocked acoustic waves, to show that any disturbance generated at the heights involved will be severely attenuated unless there is a considerable replenishment of energy from the source.

The period τ of the first N-wave in the signals received was 0.75 sec., so assuming the ground-level sound speed is 340 ms^{-1}, then $\lambda_{ground} = 0.75 \times 340 = 255m$.

Characteristics of Infrasonic Signals from Rockets

The amplitudes of these signals of $\sim$ 1000 km exhibit considerable seasonal variations; for rockets launched at Cape Kennedy detected in the N.E. coastal regions the signals are very weak during the summer but very strong in the winter months. This variation has been explained by Balachandran as due to the effect of stratospheric winds at around an altitude of around 50 km, which are westerly in winter and give rise to strong sound channels assisting acoustic signals.

Another interesting feature of the launch and re-entry groups of signals was their duration times of several minutes which will depend upon the angular width of the sound rays trapped in the sound channel, and the time taken by each ray to travel from the source, while the instant signal amplitude at a fixed point will be governed by the degree of interference.

Some other Sources

The passage of a jet stream, i.e. an air-strata $\sim$ 3 km thick moving with a speed of 30 to 80 ms^{-1}, through the atmosphere over the U.S.A. Atlantic coast, has given rise at times to large oscillations of barometric pressure at infrasonic frequencies. Also during great geomagnetic activity infrasonic waves of a few dyn cm^{-2} amplitude have been observed and associated with aurora activity. Microbaroms recorded in Switzerland have correlated with storms in the North Atlantic Ocean and with microseisms observed at Strasbourg. Similar results obtained in U.S.A. led Cook to suggest that the sound arises from the impact of the waves on the beaches.

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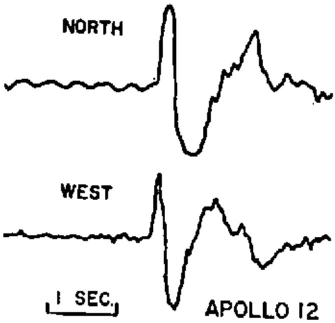
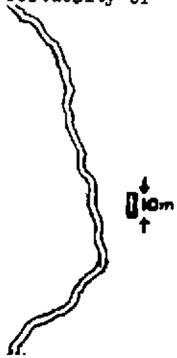
Fig. 4. Recorded Signals from



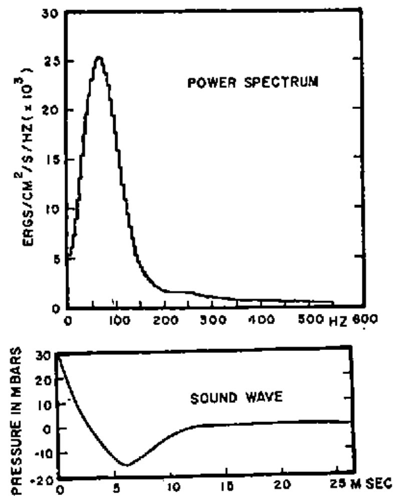
Apollo 12 Nov. 1969 (after Cotten and Donn)

Fig 1. Tortuosity of



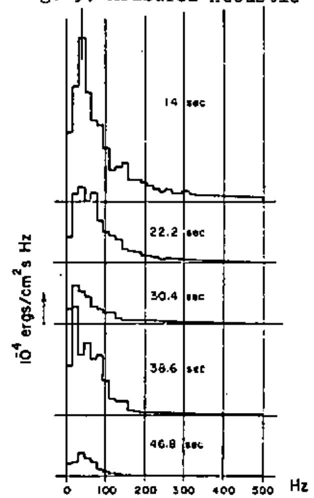
lightning channel(Few et al)

Fig. 2. Acoustic Power Spectrum



and Sound Wave for Short Line Source of Energy 10^6 Jm^{-1}

Fig. 3. Measured Acoustic



Power Spectra of a single thunder event. Sequential data windows used of 8.2 sec. duration. The times give lag between flash and beginning of data window (after Few)

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