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INFRASOUND GENERATED BY LARGE SOURCES

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1. INTRODUCTION

Several experiments have been carried out recently to measure infrasonic propagation and intensity from :-

a) one of the largest Pipe Organs in the world - namely the Willis IV organ at Liverpool Anglican Cathedral.

b) Wind Farms in Wales.

2. TEST EQUIPMENT

Two different sets of test equipment have been used and compared :-

- **Vibration analysis** portable equipment 'VIBROSOUND'- developed by Nagus Electronics (primarily to measure local rock movements in coal mine seams and micro-seismic activity), which can be fitted with either a vertical seismometer or an accelerometer.
  This 24 bit instrument has a bandwidth up to 500 Hz and can store events up to 10 seconds in length on 20 Mb flash cards. These can be directly transferred into the PCMCIA port of an IBM computer for analysis using the MATLAB signal processing package.
  These results were measured and supplied by the Seismic Team of the University of Liverpool.

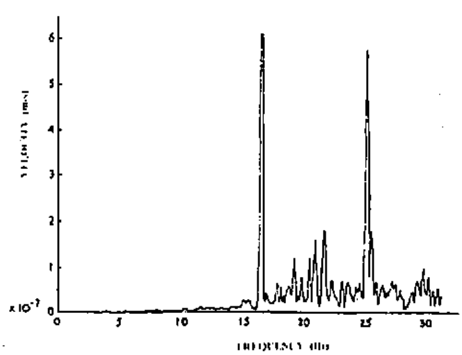
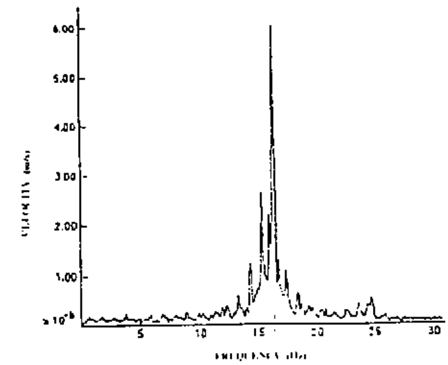


Fig. 1 - vibration analysis equipment showing typical frequency spectra. (bottom 'C' Liverpool Cathedral).

- **Portable** Seismometer unit developed from oil field exploration equipment in the U.S.A.. Events are stored digitally on an IBM laptop computer. The frequency range of this unit is 0.4 Hz to 30 Hz (with a marked fall off above 24 Hz). This instrument allows results of amplitude vs. time or amplitude vs. frequency to be displayed immediately after each recording.



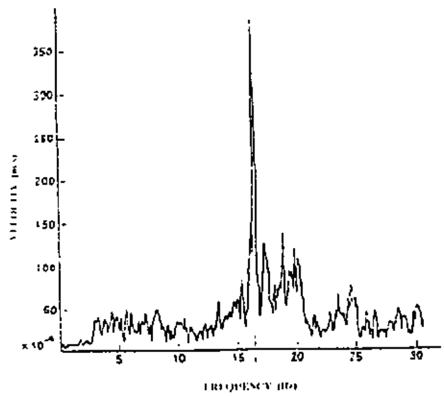


Fig. 2a - Airborne Fig. 2b - Structureborne

Portable seismometer showing typical frequency spectra.

Liverpool Cathedral (bottom 'C').

3. AIRBORNE AND STRUCTURE BORNE INFRASOUND

During the planning of the experiments a unique method was developed to separate these two components. It is obvious that like at audio frequencies, infrasonic radiation will travel by two means a) through the building - structure borne, and b) through the air - airborne.
Fig 3 shows the two methods of mounting the portable seismometer.

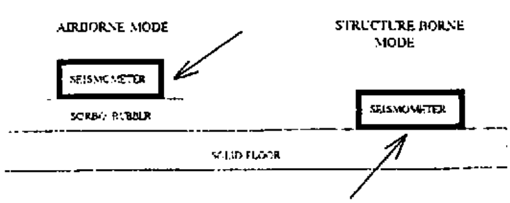


Fig. 3 - Methods of mounting portable seismometer.

Laboratory tests were carried out using a suspended loudspeaker driven from a pure tone oscillator generating frequencies from 10 Hz to 30 Hz.

The seismometer was suspended on a sorbo rubber pad and the airborne wave from the suspended speaker recorded. When this was repeated, with the seismometer mounted directly on the floor, the airborne wave was found to be greatly attenuated.
This therefore provided a method of separating the two signals :

Seismometer suspended gives *'Sa'* plus *'Sb'* (being the airborne and structure borne components).
Seismometer on floor will give *'Sb'* only.

4. TESTS

Liverpool Cathedral - 20th Jan 1995.

Both sets of test equipment were used, with sensors in close proximity, to measure eleven different Organ notes (using the very large bass woods) from bottom 'C' (16.35 Hz) to 'A' sharp (29.14 Hz) for both sets of equipment. The vibration analysis equipment (because of its greater frequency range) also measured notes 'B' (30.87 Hz) to 'C' (65.4 Hz). Each note was continuously played, and recorded, over a 30 second period.

From the test results, the frequency of each Organ note was found to be very accurately displayed, with very little harmonic distortion - i.e. the notes were all very 'pure'.

This was repeated at six different locations (along the central axis of the Cathedral, Fig. 4), from the Organ area to the middle of the congregation seating. The results (fig 5) at 16.35 Hz (Lower C) show that the airborne component is between 3 and 7 times the structure borne, but it is found that the airborne component does not fall off so rapidly as the structure borne signal.

This is thought that the rooms and crypt below the floor of the Cathedral will attenuate the structure borne signal at a greater rate than the airborne reflected waves from the hard stone walls of the Cathedral.

It is also possible to 'feel' the low frequency bass woods of the Organ. One finds that these are hard to detect outside the choir area. It therefore seems that one cannot hear infrasonic radiation through the ear, but 'feels' the signals through the body, mainly via the spine. This is also confirmed by several Acousticians who have 'felt' effects in the lower spine from the Organ bass woods.

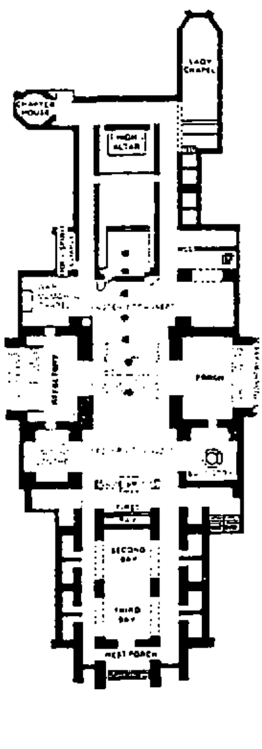


Fig. 4 - Showing plan view of the Cathedral

The Airborne signal in the Cathedral will be affected by Eigentones which are set up due to the walls, floor or roof, being a whole number of half wavelengths so setting up longitudinal standing waves. Parameters such as temperature and exact note frequency will change this effect and at the nodes one will not have an airborne component.

In the choir area, Eigentones are easily detected audibly .

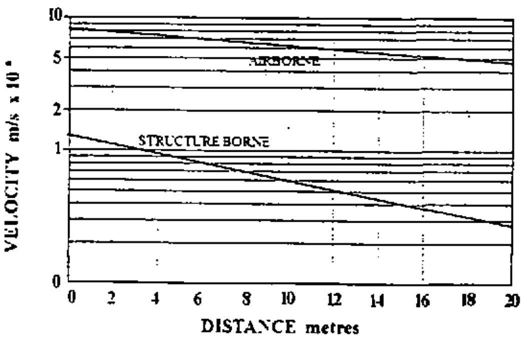


Fig. 5 - Showing difference between the airborne and structureborne components.

Tests near Windfarms - October 1994

The first tests (using only the vibration analysis equipment) were taken at different locations between 0.75 and 2 miles downwind of a windfarm, on the same elevation.

Figure 6a & 6b show results obtained from a vertical seismometer and accelerometer, both buried about a foot in the shallow earth, backing on to rock.

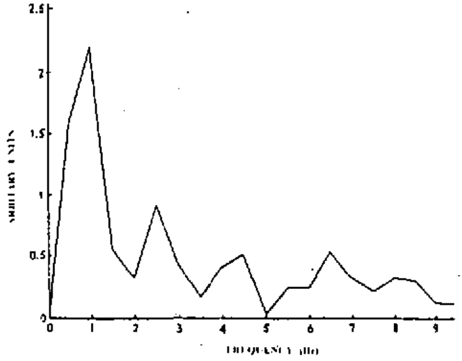


Fig. 6a - Vertical seismometer.

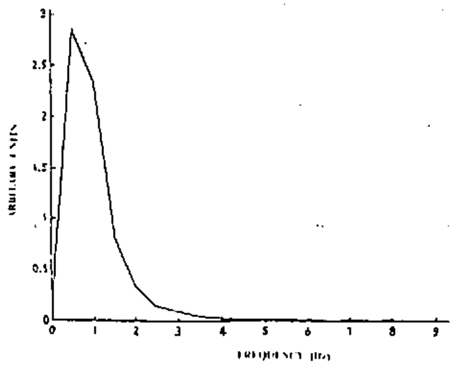


Fig. 6b - Accelerometer.

All three transducers show (from a typical frequency spectra) that there are odd numbered harmonics of the fundamental blade rotational frequency (0.8 Hz, 2.4 Hz and 4.0 Hz being examples).

The blade rotation was visually timed at 43 rpm and therefore the main seismic wave is related to the rotational period of the three bladed machines.
Because of many machines working out of phase, some of the results are different in that the maxima were not at the same frequency.

The wind speed was about 20 knots, and it was possible to hear the turbines with a characteristic 'beat' (at about 0.8 Hz), by using a landrover vehicle, with it's door open, acting like a large Helmholtz resonator.

Further experiments at Windfarms - March 1995

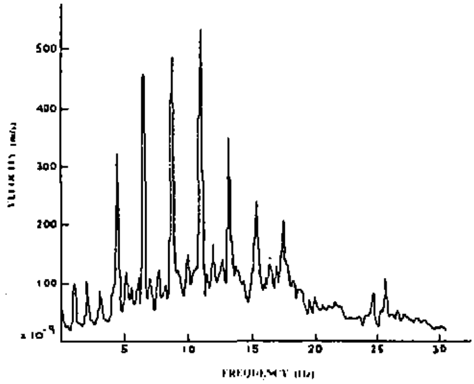


Fig. 7 - shows results which were repeated in eight places, in a location ¾ mile UP WIND of the windfarm, with a 20 knot westerly prevailing wind.

The speed of the turbines was measured visually at 43 rpm.

The results clearly show a second harmonic (and higher harmonics) spaced 2.15 Hz above for the nearer position. The fundamental harmonic, which appears not to be recorded, is due to destructive interferences. The seismometer was picking up the earth seismic wave. Tests on the sorbo rubber mat showed very little airborne component, which would be expected being upwind .

Calculations show that the 2.15 Hz spaced frequency peaks relate to each blade of the turbine (possibly when each blade passes the tower base). These blades may cause air pockets to push the tower 2.18 times a second causing the seismic wave as measured in Figure 7.

Figures 8 & 9 show the background signal of periodic frequency 1Hz plus harmonics.
This could be due to an electromagnetic signal, believed to be part of the speed control of the turbines (Ref. 5). Figures 8 & 9 were the result of tests 2 miles distance upwind from the windfarm, and shows no 2.15 Hz signals, but only the turbine speed control pulses.

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The geology of the test area is such that the seismic wave would pass through several geological layers. This would mean that the waves would not travel in straight lines.

Fig. 10 (which is the test result from the top of the Cathedral tower) shows the patterns for wind noise that contain many sharp peaks and are predominant in the region above 10 Hz. On the Liverpool University equipment a number of peaks predominantly in the 20 to 30 Hz region were displayed. Wind noise is generally heard in the human ear as a 'roar' without characteristic frequency. This was also picked up in recent wind farm tests and are quite identifiable.

An experiment was planned and carried out when strong winds were driving all the turbines and the weather was very unstable.

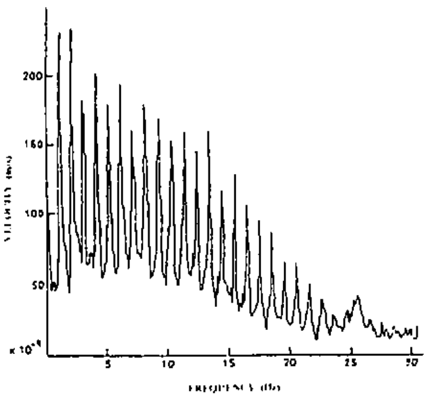

Fig. 8 - Windfarm background.

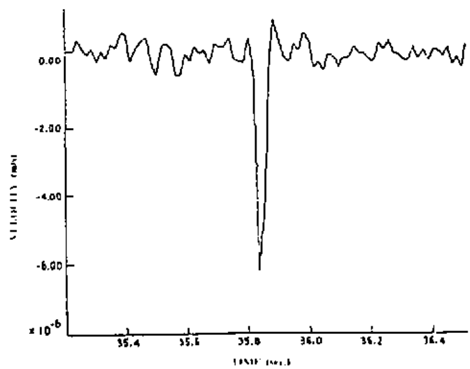

Fig. 9 - Expanded pulse.

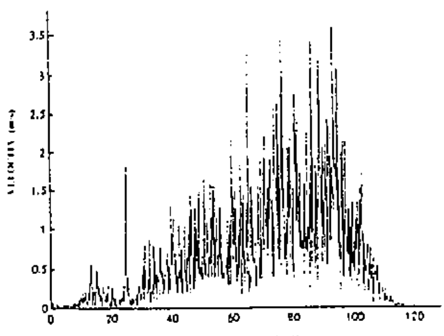

Fig. 10 - From the top of the Cathedral tower.

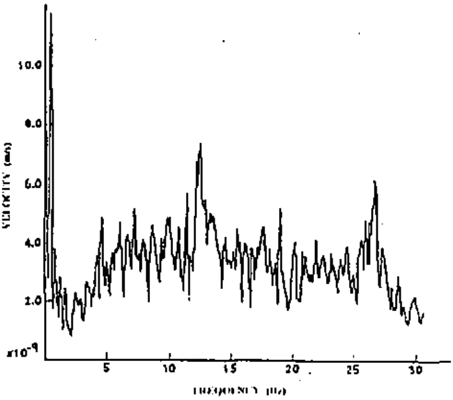

Fig. 11

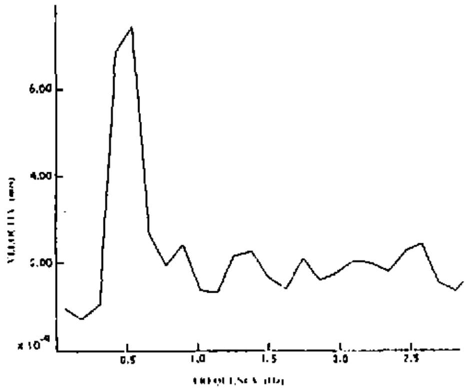

Fig. 12

At the Powys County Observatory twenty miles from two windfarms and thirty miles from two more, the experiments were repeated several times (fig. 11 & 12). A fundamental frequency in the order of 0.6 Hz is clearly seen.

At first this was thought to be an oscillating tree, but the seismic unit is buried two feet faced on to rock where the nearest tree now is several hundred yards away.
Use of the seismometer in woods in times of wind does not show any similar patterns.

We are sure that the peak shown in figures 11 & 12 is from a windfarm with generators rotating at 37 rpm.

5. MEDICAL EFFECTS

Work is currently in progress investigating illnesses of several people living within in a mile of a large windfarm (ref. 1). These people are suffering from stomach upsets and sleepless nights.

The infrasonic displacement in the body may only be of one micron, but the long term regular pattern often lasting for hours (and even days) may be a big factor.

It is planned to pass a radio pill into the bowels and measure the change of p.h. with a patient near the noise source and also far away from the source.

6. FUTURE WORK

It is now very necessary to look at other infrasonic sources such as roads. In many towns a number of people have sicknesses thought to be associated with houses that rattle due to traffic noise.
A psychological experiment is planned for Liverpool cathedral for the congregation to state whether they can hear the very large Organ bass woods in different positions in the Cathedral.

However there is an opinion expressed by musicians that the pedal notes do help to add quality to many other pipes in the normal acoustic spectrum. Therefore is the FM component of a 16 Hz pipe coupled to pipes perhaps 8 to 10 octaves higher ? Can the human ear detect this ?

7. CONCLUSION

Two good examples of infrasonic structure borne waves have been analysed namely windfarms involving up to 60 MW of power, and the Liverpool Cathedral Willis pipe organ driven from a 30 kW compressor.

It is believed that the structure borne component causes annoyance particularly after long continuous periods.

The airborne component mixed with high harmonic notes may cause a very satisfactory tone.

Work done in the U.S.A. and Japan as well as Germany (ref. 2,3 and 4) predicts that people within two miles of windfarms may get severe medical effects from windfarms.
We hope our work will clarify this.

ACKNOWLEDGMENTS

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Dr. Peter Styles and his team of the Earth Sciences Dept. at the University of Liverpool.

This work is part of a proposed thesis for a Masters Degree.

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