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Low Frequency Threshold Effects.

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Introduction

When the jet engine was introduced as a means of propelling comercial aircraft whole communities were exposed to a new and troublesome noise source. No realistic methods of estimating community response to this noise type existed, however public pressure was sufficient to demand the development of noise rating schemes such as Perceived Noise Level and its various derivatives (1). The Perceived Noisiness procedure was concerned with noise spectra above 50 Hz since little contribution to the overall sensation was expected from the lower frequencies.

Improved instrumentation and observation of low propagation losses for low frequency noise have resulted in an awareness of that low and infra-sonic frequency ranges could be important in community noise responses. Unfortunately we are now at the point where any descrepancy between recognised criteria and associated human reaction are too readily attributed to infra-sonic stimulation. It appears that some definitive work in the infra-sonic region would help this situation. Adequate definition of auditory effects of low and infra-sonic frequencies would be valuable.

Auditory effects naturally begin when a noise environment exceeds the level at which auditory detection occurs, that is, the threshold of hearing at a particular frequency. Sounds below this particular level can in no way be important in auditory perception. This paper deals with recent work on the threshold of hearing at low frequencies and will hopefully be the baseline for extension into higher level phenomena.

Apparatus

In this Department we have developed two distinct methods of presenting low frequency stimulation to the ear. These are: headphones and chamber presentation.

(1) Headphones

The headphones were developed from, loud speaker units of 0.3 m diameter which were directly coupled into noise excluding earcups. When the observers ear closed off the exit of the earcup the frontface of the loudspeaker worked into a total enclosed volume of about one litre.

Maximum sound pressure levels of 150 dB at 1Hz could be generated sufficiently free from noise and harmonic distortion for threshold investigation.

The frequency response of the system was flat to about 200 Hz so band limited noise as well as pure tones could be used for the stimulers.

2. Pressure Chamber

Six 0.46 m diameter loudspeakers were mounted on the sides of a 1200 litre cabinet. The chamber would accommodate a seated listener with an adequate margin of comfort. In this case the entire subject was immersed in the sound field in what perhaps could be regarded as a more natural situation than the headphones. Maximum levels available in this chamber are roughly 140 dB.

Monaural Thresholds

Initial threshold work used the headphones. Thresholds of hearing down to 1.5 Hz were obtained and were reported in reference (2). The most striking property of the data was the apparent change in slope of the threshold of hearing with frequency. This occurred at about 18 Hz where at the same frequency the tonality and 'smoothness' of the auditory sensation were lost.

At that time the slope change which was quite abrupt caused some concern to the author. However, after carefully checking the harmonic distortion of the system and repeating the threshold determinations the only possible conclusion was that the effect was real and it was somehow caused by a change in the aural detection process.

Binaural Earphone Thresholds and the Binaural Advantage

A dual channel headphone system was used to examine the binaural threshold of hearing. When these data were compared with the monaural thresholds it was apparent that the binaural case produced the more sensitive thresholds. To fully investigate the problem binaural and monaural thresholds were observed in the same sitting for a group of subjects.

When equal sensation levels were presented to each ear the advantage of binaural over monaural listening did not differ from the accepted value of 3dB as can be seen in Table 1.

TABLE 1

Frequency Hz	100	50	25	20	18	15	10	8	6	5
Equalised Binaural Advantage dB	3.06	2.13	3.26	1.95	3.41	2.94	2.91	3.16	2.62	2.58
Standard Error of Mean	0.13	0.33	1.47	1.22	0.36	0.11	0.04	0.36	0.27	0.04

TABLE 1 (continued)

Frequency Hz	4	3	
Equalised Binaural Advantage dB	2.69	2.76	
Standard Error of Mean	0.08	0.14	

OVERALL MEAN 3.1 ± 0.19 dB

There was no significant variation with frequency so one can conclude that the binaural threshold of hearing had the same shape, as but was 3 dB more sensitive than the monaural threshold.

Binaural Chamber Thresholds

When whole body exposure to infrasound became available threshold data were collected. The subjects reported body vibration in this type of sound field, especially below 10 Hz. The binaural threshold data for the group (see Table 2) agreed with previously reported earphone data adjusted for binaural listening. The expected discrepancy between the two data sets, that is the difference between earphone and free field thresholds established for more common frequencies above 100 Hz was not present. The discrepancy is generally thought to be caused by physiological noise in the small enclosed volume around the ear when earphones are used. The large enclosed volume of the headset probably minimized this error.

TABLE 2

Frequency Hz	20	15	12	10	8	5
Threshold of hearing binaural, wholebody.	85.2	92.06	97.0	99.5	102.4	111.05
Standard Error of Mean	0.62	0.37	0.59	0.56	0.69	0.61

TABLE 2 (continued)

Frequency Hz	4	2	
Threshold of hearing binaural, wholebody	112.39	121.4	
Standard Error of Mean	0.79	0.48	

Whittle recently measured similar thresholds (3). His data again demonstrated the same frequency dependance as the investegations reported in this paper.

Existing Low Frequency Tone Threshold Data

When the existing data for binaural hearing thresholds from headphones (adjusted for two ears where required) and the various chamber experiments were compared they demonstrated good agreement on both overall sensitivity of the hearing mechanism and its frequency dependance. Visual inspection of the data suggested that two distinct data sets were present. Within each set the behaviour of the threshold of hearing could be described by a simple linear relationship between sound pressure level and log (frequency) however the slope in each set was different.

The best fit lines to the available data had slopes of:-

22.2	dB/Octave	for frequencies above 20 Hz
12.3	dB/Octave	for frequencies below 20 Hz

The cross-over point for the two regions appears to be 92dB at 15.5 Hz. A good approximation to the threshold of hearing below 100 Hz and above about 2 Hz may be obtained by constructing lines with the required slopes above and below this point.

Tone Versus Octave Band Noise Thresholds

The headphone mentioned previously had a flat frequency response up to about 200 Hz making the system very convenient for reproducing banded noise. When the noise threshold data were compared to the tone data there appeared to be a difference betweeen the two sets and this difference was frequency dependant. A more detailed investigation of this effect was performed. Noise and tone data were collected at the same sitting to allow more accurate comparison. This investigation determined that between 30 Hz to 100 Hz no significant difference existed between tone and noise threshold data, below 16 Hz however the noise thresholds were some 4 dB more sensitive, this difference was significant at the P = 0.001 level. A full account of this result can be found in reference 4.

Discussion

The threshold of hearing for pure tones has been determined by several investigators. These data show a pleasing agreement in the low frequency region. We are therefore in a position to determine whether or not a low frequency tone will be heard.

Whittle reference (3) has extended this area to higher levels and has evolved a preliminary set of equal loudness contours for tones. These contours still demonstrate the slope change even at supra-threshold levels.

The usefulness of equal loudness contours lies in the means they provide for calculating the overall loudness of a complex noise. Infrasonic energy from aeroplane engines has a broadband character since the thresholds of hearing for noise bands appear to be more sensitive than for pure tone, the possibility exists that the equal loudness contours will also differ. The calculated loudness of a prodominantly infrasonic noise would under these circumstances be underestimated if contours derived from pure tone work were used.

REFERENCES

1. Federal Aviation Administration, Dept. of Transportation, "Noise Standards: Aircraft Type Certification, Part 36" Docket No. 19337, Amdt 21-27, 34 F.R. 18355, November 18, 1969.

2. N S Yeowart, M E Bryan and W Tempest, "The Monaural M.A.P. threshold of hearing at frequencies from 1.5 to 100 c/s". J Sound Vib 6, 335, (1967).

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4. N S Yeowart, M E Bryan and W Tempest, "Low frequency noise thresholds", J Sound, Vibration, 9, 447, 1969.