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MEASUREMENT OF ACOUSTIC PROPAGATION THROUGH THE ATMOSPHERE

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ABSTRACT

There is great interest in measuring the attenuation of low frequency sound at ranges of several kilometres. Static experiments are difficult and laborious to carry out but the line spectra associated with helicopters moving at constant velocity and altitude can be used to give such information very rapidly.

Such experiments indicate the problems of reproducibility due to anomolous effects produced by the atmosphere, the topography and range.

The best indicator of range for particular meteorological and topographical conditions seems to be OASPL.

1 INTRODUCTION

There is great interest in measuring the variation in low frequency airborne sound attenuation with range and frequency for various meteorological and topographical conditions.

One method of gaining such information rapidly is by measuring the change in the intensity of the harmonic line spectra produced by the blade pass frequencies of rotary wing aircraft, particularly as the aircraft approach and depart on a direct heading at constant speed and altitude.

Static experiments are difficult and laborious to carry out. They require either that the source of sound and/or the microphones be moved spacially or that a large number of microphones be used. The time taken to move and set up the source again may vary from many minutes to hours so that the meteorological conditions may have changed significantly. If on the other hand the source of sound is stationary and a line of microphones at different ranges is employed the measurements can be made pseudo-simultaneously but under different topographical conditions. The experiment is in principle a different one to that of a moving source.

2 THE AIMS

The initial aim of the experiment was to measure the excess attenuation (above spherical spreading) of the acoustic energy at various harmonic line frequencies for a source of sound at a continuously changing range, in the hope that the range of the source could be deduced from the selective attenuation of the higher frequency components.

3 THE EQUIPMENT USED

A dual channel, AM, SONY TC153SD cassette tape recorder and two JVC MV543, 2KΩ microphones fitted with 6 cm diameter windshields were used to make the acoustic recordings. The system was calibrated using a BeK 1 kHz, 94 dB output piston phone. The recordings were later copied onto a Brüel and Kjaer, FM, four track tape recorder. An Irig B time code generator was used to put time code onto one of the unused tracks to aid analysis.

The wind speed and direction, temperature and relative humidity were monitored throughout the experiment. The ambient sound pressure level was monitored at regular intervals using a BeK sound level meter set on slow averaging and linear weighting.

The results were analysed using a BeK dual channel analyser.

4 THE METHOD OF MEASUREMENT

The absolute sound pressure levels of the harmonic spectral lines generated by the main and tail rotors of a helicopter travelling on a direct heading towards and passing over the recording site at constant velocity and altitude were measured and recorded. The true range of the moving helicopter from the recording site was deduced from an accurate measurement of the range at which the helicopter commenced its run, the time since the commencement of the run and the velocity of the helicopter. The time of commencement of the run, that is when the helicopter passed over the 5 Km mark was announced by the pilot using his radio transmitter and recorded on tape.

5 ANALYSIS

The tape recordings were analysed in a number of different ways. The overall sound pressure level (OAPSL) was plotted against time and hence range as the helicopter approached (fig 2). Frequency analysis was then carried out at various ranges showing how the spectrum shape changed with range.

The SPL's at various helicopter blade pass harmonics frequencies were plotted against range. The total transmission loss and absorption coefficient 'α' were calculated using the analysis detailed in Appendix I. The value 'α' includes effects due to atmospheric refraction and that due to ground reflections.

Appendix II indicates the frequencies effected by interference between the direct and reflected wave at 1 Km and 4 Km.

Results

Fig 1 shows the change in OASPL with range for a helicopter on a direct approach. There seems to be a good relationship between range and OASPL for a particular helicopter.

Fig 2 shows the change in the frequency spectral distribution with range from a rotary winged aircraft as it approaches the recording position from a range of 4 Km at constant velocity and altitude.

The harmonic spectral lines were tracked with time and a plot of absolute intensity versus range produced for each frequency. (fig 3) The small variations in frequency due to doppler shift at long range have been ignored. The absolute intensity change over a frequency range of a few Hertz is not significant.

Table I lists the variation of sound pressure levels (SPL) with range. Fig (3) shows a plot of these values. It may be seen that the SPL's for all frequencies in the range 27–480 Hz change very slowly initially fall rapidly to beyond 3 Km and then rise dramatically between 4 Km and 5 Km. In general the absolute SPL's of the high frequencies are lower than the low frequencies. This may be attributable to ground effect and/or atmospheric ducting, but the effect is rather large. The first ground effect interference path difference minimum would be expected at about 18.5 KHz for a target range of 4 Km and 60 m altitude, while the first maximum would occur at abolut 37 KHz. These values have been calculated ignoring the contribution from the phase change on reflection. In any case the increase in intensity due to constructive interference could not exceed 3 dB.

Table II shows the total transmission loss between 1 Km and 4 Km. The total loss is assumed to be the sum of the spherical spreading and the atmospheric absorption loss. Ground effect loss has been ignored. The logarithmic absorption coefficient 'α' derived from these measurements is in the range from about 5 to 10 dB per Km. The total transmission loss is in the range 25 to 40 dB. The highest absorption coefficient 'α' occurs at about 135 Hz.

A typical helicopter frequency spectrum is shown by way of example (fig 4) at 1 Km frequencies up to 800 Hz. It may be seen that there is selective absorption even in the range 0 – 800 Hz. There is however an intrinsic decay in the harmonic line spectra for the BPF of both the main and tail rotors. This intrinsic decay is controlled by the shape of the time domain pulse. If this principle is to be used for ranging in general the intrinsic harmonic decay and absolute level at close range must be known. The spectrum close to the recording site changes rapidly due to a changing forward 'footprint' and rapid change in frequency due to doppler shift with range. This effect is more pronounced for low altitude helicopters.

<u>Summary</u>

To summarise:–

1) A rotary wing aircraft moving at constant velocity and height is a good source for acoustic atmospheric transmission measurements.

2) The change in OASPL, with range for a helicopter on a direct approach at constant velocity and altitude is a good indicator of range for a particular helicopter.

3) The change in the spectral distribution of the acoustic energy emitted by a rotary wing aircraft is a good way of measuring transmission loss and absorption coefficient.

4) There is an apparent large rise in the absolute OASPL at all frequencies up to 2 kHz for which there is no satisfactory explanation as yet. This applies to the measurements of the spectral changes for rotary wing aircraft between 15m and 60m referred to in this paper. Possible mechanisms are ground effect and refractive ducting.

5) It has been shown that there is significant selective frequency absorption even in the limited frequency range from 0 – 800 Hz.

6) There is an intrinsic decay in the harmonic line spectrum which depends upon the shape of time domain pulse.

Appendix I

Primary Transmission Losses

1) Spherical Spreading (inverse square law)

Power 'P' = intensity times area

$$\therefore \quad P = 4\pi r_1^2 I_1 = 4\pi r_2^2 I_2 \qquad (1)$$

If r_1 is taken to be 1 metre the transmission loss to r_2 is

$$10 \log \frac{I_1}{I_2} = 10 \log r_2^2 \qquad (2)$$

$$\text{Transmission loss} = 20 \log r_2 \qquad (3)$$

2) Absorption by the Air

If change in intensity I in travelling dr is dI then

$$\frac{dI}{I} = -n\,dr \qquad (4)$$

$$\therefore \int_{I_1}^{I_2} \frac{d_I}{I} = - \int_{r_1}^{r_2} n\,dr$$

$$I_2 = I_1 e^{-n(r_2 - r_1)} \qquad (5)$$

Put $\alpha = 10n \log_{10}$ (6)

Change in level between r_2 and r_1 becomes

$$10 \log I_2 - 10 \log_{10} I_1 = -\alpha(r_2 - r_1)$$

$$\text{or} \quad \alpha = \frac{10 \log I_1 - 10 \log I_2}{r_2 - r_1} \qquad (7)$$

The total transmission loss due to spherical spreading and absorption:-

$$T.L = 20 \log r + \alpha r \qquad (8)$$

if the reference distance is assumed to be unity e.g 1 metre and r is the transmission range.

In general

$$10 \log \frac{I_1}{I_2} = 20 \log_{10} \frac{r_2}{r_1} \qquad (10)$$

for spherical spreading

$$10 \log \frac{I_2}{I_1} = -a(r_2 - r_1) \text{ dB/unit length} \qquad (11)$$

The transmission loss is

$$20 \log_{10} \frac{r_2}{r_1} \qquad (12)$$

α is the logarithmic absorption coefficient.

The absorption of sound also depends strongly upon frequency and relative humidity.

The excess attenuation above spherical spreading is given by the empirical formula

$$A = 7.4 \left[\frac{f^2 r}{\varphi}\right] 10^{-8} \text{ dB}$$

The total loss is

$$T.L = 20 \log_{10} \frac{r_2}{r_1} + 7.4 \left[\frac{f^2 r_2}{\varphi}\right] 10^{-8} \text{dB}$$

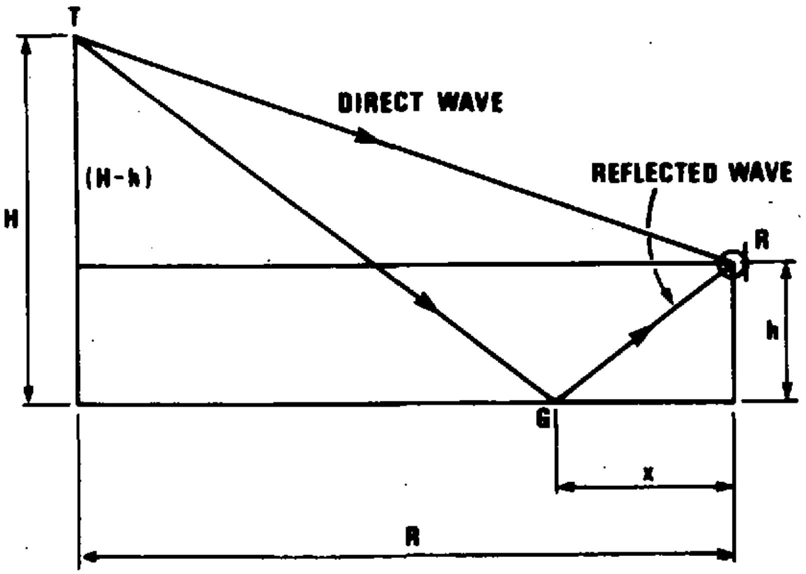
f is frequency in Hz

φ is % relative humidity

r_2 is distance from source to receiver

The agreement between the experimental results for attenuation and the prediction is poor at low frequencies.

Appendix II



The path difference between the direct and reflected wave is

$$TGR - TR \begin{cases} = (2n - 1)\lambda_2 \text{ for a minimum} & (1) \\ = (2n)\lambda_2 \text{ for a maximum} & (2) \end{cases}$$

$$\therefore \Delta\ell = TGR - TR = \left[H^2 + (R - x)^2 + h^2 + x^2 \right] - \left[H - h \right]^2 + R^2 \qquad (3)$$

By similar triangles

$$\frac{H}{(R-x)} = \left[\frac{h}{x}\right] \qquad \therefore\ x = \frac{hR}{(H+h)} \qquad (4)$$

Put $h = 0.3m$

$H = 60m$

$$\therefore\ x = \frac{0.3}{60.3} R = 4.9751 \times 10^{-3}.R \qquad (5)$$

$$\therefore\ \Delta\ell = 3600 + R^2(1 - 4.9751 \times 10^{-3})^2 +$$

$$0.09 + (4.9751 \times 10^{-3} \times R)^2 - 3.564109 + R^2 \qquad (6)$$

Put $R = 1000m$ $\therefore\ \Delta\ell =$ <u>0.0358m</u>

$\lambda = 0.0358M$ for Max $\rightarrow$ 9.4KH $\lambda = 0.0716m$ for Min $\rightarrow$ 4.7KHz

Put $R = 4000m$ $\therefore\ \Delta\ell =$ <u>0.009M</u>

$\lambda \triangleq$ 37 KHz for maximum $\lambda \triangleq$ 18.5 KHz for minimum

<u>The sound pressure levels of low frequency helicopter BPF harmonics attenuated by the atmosphere. Helicopter travelling at 150 knots and at an altitude of 60M.</u>

SOUND PRESSURE LEVEL IN dB RELATIVE TO 20μN/M^2							
RANGE KM	BPF MAIN				BPF TAIL		
	(1) 26.9Hz	(2) 53.8Hz	(3) 107.6Hz	(4) 134.5Hz	(1) 160	(2) 320	(3) 480
0 (overhead)	85	92	90	84	87	74	67
1	80	92	90	87	81	76	67
2	67	80	71	70	67	58	55
3	54	60	55	55	54	50	45
4	53	57	56	47	47	45	42
5	73	75	70	61	72	47	46

TABLE 1

Total Transmission Loss and the Logarithmic Absorption Coefficient α due to Atmosphere

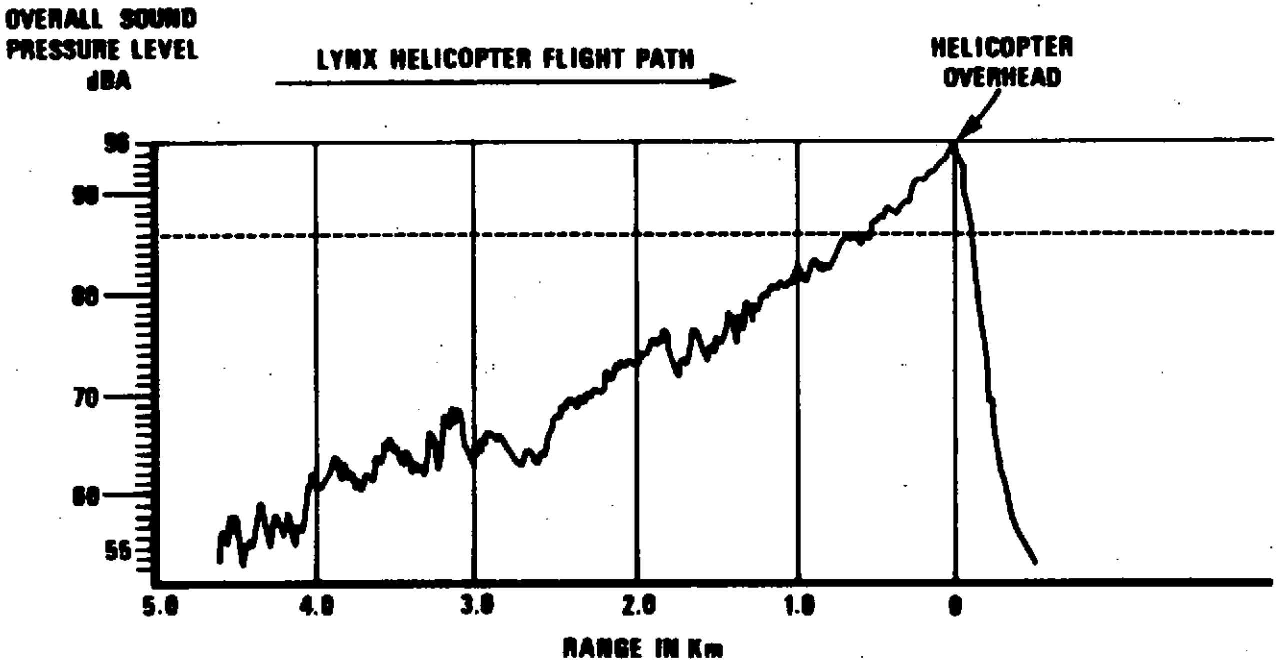
	Frequency	Total Transmission Loss (TL) between 1KM and 4 KM	TL - 9.54	$\alpha = \frac{TL - 9.54}{3}$
Main Fundamental-BPF (1st Harmonic)	26.9 Hz	26 dB	16.46 dB	5.48 dB/KM
" 2nd Harmonic	53.8 Hz	35 dB	25.46	8.49 "
" 3rd Harmonic	80.7 Hz	34 dB	24.46	8.15 "
" 4th Harmonic	107.6 Hz	33 dB	23.46	7.82 "
Tail Fundamental-BPF	134.5 Hz	40 dB	30.46	10.1 "
" 2nd Harmonic	160 Hz	34 dB	24.46	8.15 "
" 3rd Harmonic	320 Hz	31 dB	21.46	7.15 "
" 4th Harmonic	480 Hz	25 dB	15.46	5.15 "

$$TL = 20 \log_{10} \left[\frac{R_2}{R_1} \right] + \alpha(R_2 - R_1)$$

Spherical spreading Atmospheric absorption

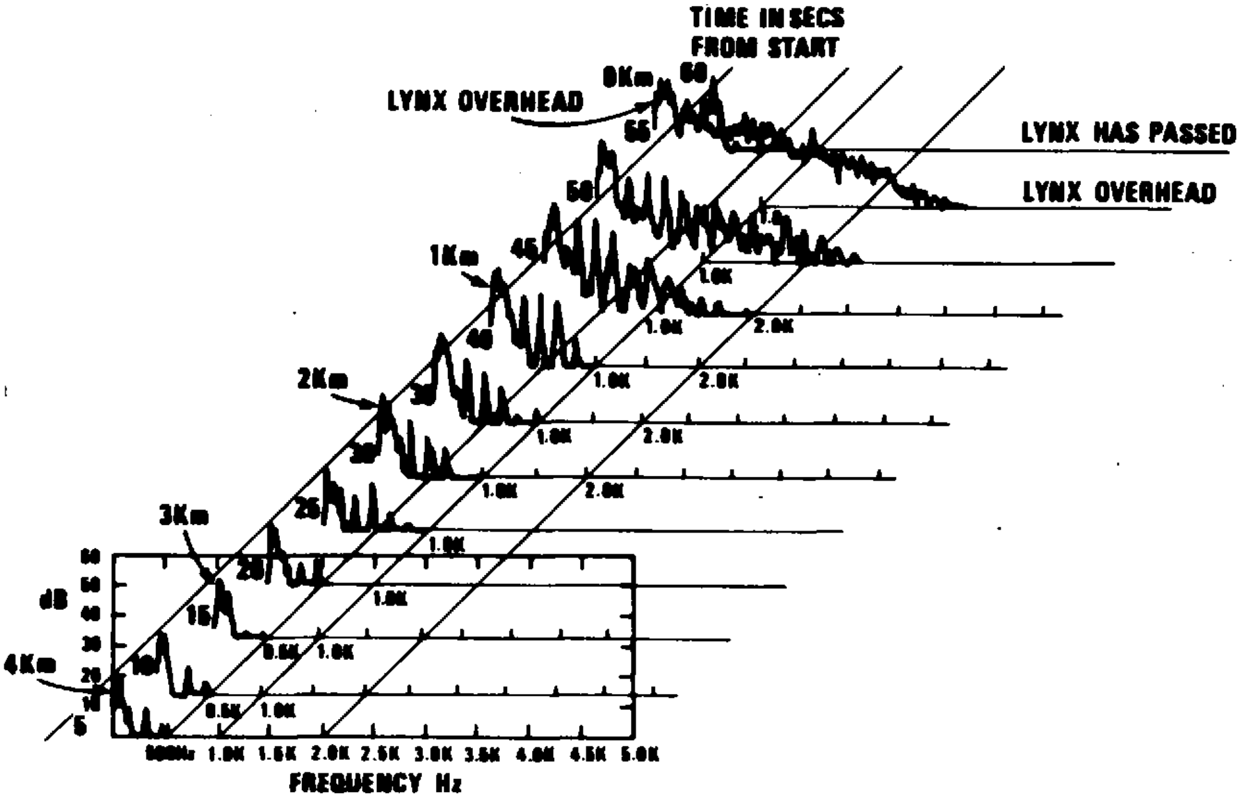
Ground effect due to phase change on reflection has been ignored but it is contained within the absorption term. Path difference interference maxima and minima do not occur at these ranges for this transmitter/receiver geometry.

TABLE II



VARIATION IN OASPL OF LYNX HELICOPTER AS IT FLIES OVER RECORDING SITE FROM A RANGE IN EXCESS OF 5Km. VELOCITY WAS 150 KNOTS (80/SEC) & ALTITUDE WAS 15M

FIG 1 OASPL AGAINST RANGE



LYNX HELICOPTER OVERFLYING RECORDING POSITION FROM A RANGE IN EXCESS OF 5Km AT 150 KNOTS (80/SEC) AT 15M ALTITUDE

FIG 2 CHANGE IN SPECTRAL SHAPE WITH RANGE

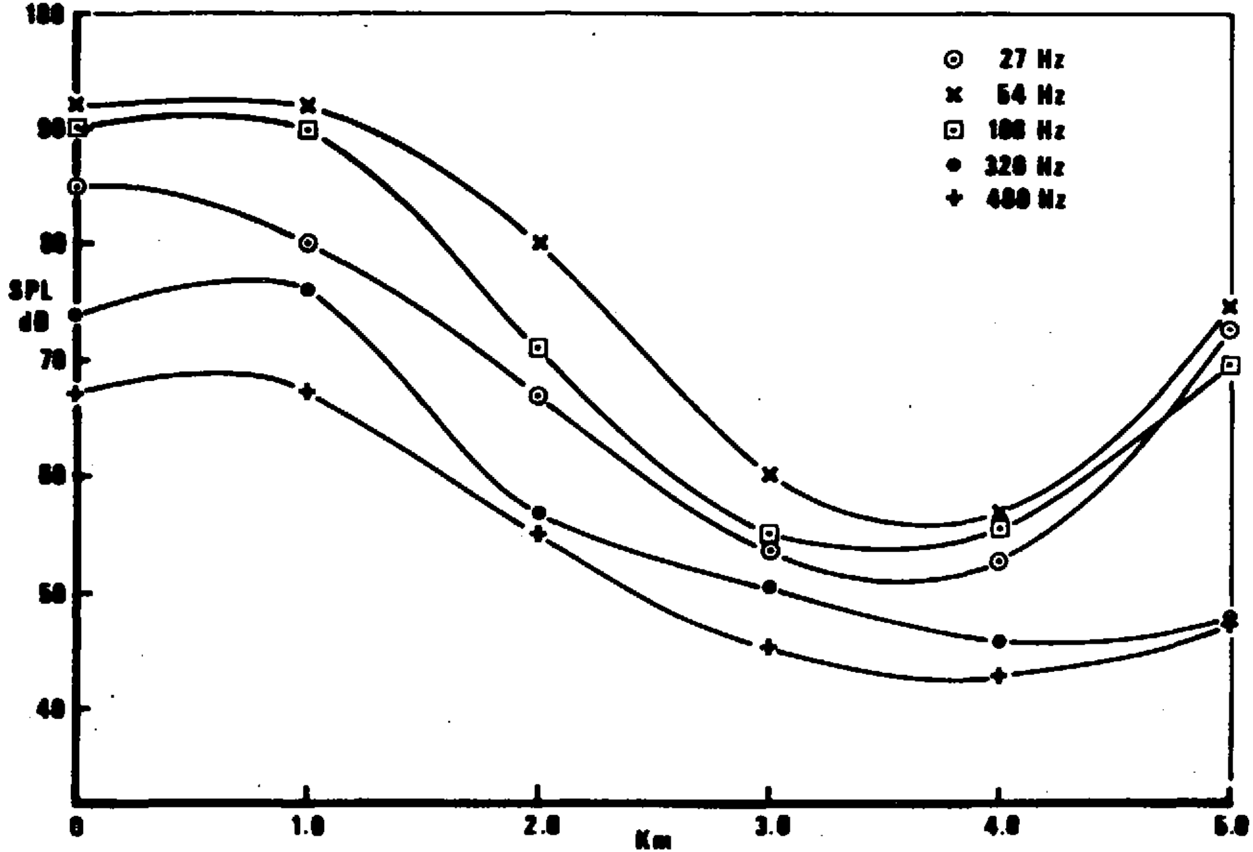


FIG 3 PLOT OF INTENSITY AGAINST RANGE FOR VARIOUS HARMONIC FREQUENCIES

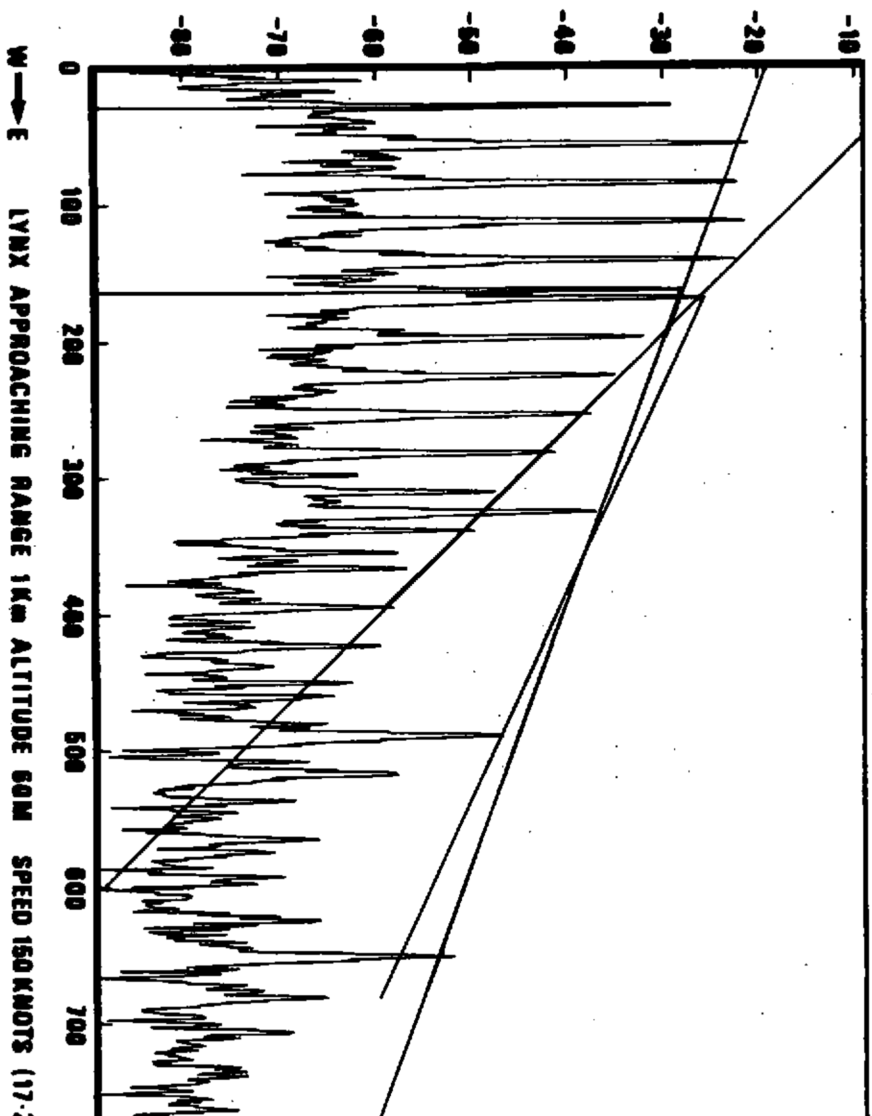


FIG 4 FREQUENCY SPECTRA