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The Transmission of Triaxial Vibration to Pilots in the Scout AH MkI Helicopter

M.J. Griffin

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INSTITUTE OF SOUND AND VIBRATION RESEARCH

HUMAN FACTORS UNIT

THE TRANSMISSION OF TRIAXIAL VIBRATION TO PILOTS IN THE SCOUT AH MkI HELICOPTER.

M.J. Griffin

August 1972

ISVR Technical Report No. 58

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Joint Chairman, Operational
Acoustics & Audiology Group)

M.J. Griffin

ABSTRACT

This report describes three experiments designed to determine the triaxial vibration experienced by pilots in the Scout helicopter.

In the first experiment eight Scout helicopters were flown by the same pilot in seven different flight conditions. In each condition the mean and range of floor vibration were determined at frequencies of maximum vibration for each of three perpendicular axes. In the other two experiments eight pilots flew in a single Scout helicopter with known floor vibration characteristics. The spectra of triaxial head vibration during four flight conditions were determined from Trial Two. In Trial Three vertical vibration at the heads and at the interface between their bodies and the seat cushion were determined during the hover.

The vibration data obtained from the three experiments are presented together with detailed consideration of the differences in vibration level associated with the different flight conditions, vibration axes, helicopters and pilots. Subjective assessments of the vibration levels were made by pilots during the experiments and found to be inconsistent indicators of the measured vibration levels.

The confusion concerning the vibration experienced by helicopter pilots is discussed and recommendations for further research are presented.

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1. INTRODUCTION

1.1 Background

There has been speculation as to the possible effects of helicopter vibration on the performance, physiology and comfort of pilots, crews and passengers almost since the first helicopter flight. The currently increasing use of helicopters, the advent of long duration flights, and the demand that pilots perform complex tasks stimulates two pertinent questions. Why has consideration of the effects of the environment continued merely on a speculative basis, and what foundation, if any, underlies this speculation?

At best, research comment has been restricted to honest journalism. Hornick (1961), for example, states that :

> "After a person experiences a ride in a helicopter for the first time, his most dominant impression is likely to be one of the noise and vibration present during the flight."

In the more misleading literary offerings it is emphasised that, for example, certain vibration frequencies are present in helicopters and these same frequencies have been shown to result in visual acuity decrements in the laboratory. A cause and effect relationship is implied, but not proven. There is little attempted comparison of the relative amplitudes of vibration in the two cases! Unquestionably vibration can affect vision and pilots do have visual problems (e.g. O'Briant and Ohlbaum (1970), Griffin (1970)). What remains a matter of speculation is whether the unaided vision of pilots is significantly impaired and whether this impairment is associated with the vibration of the aircraft.

Vibration has been mentioned in a number of studies of crew performance in the helicopter environment. For example, O'Briant (1967) studied crew-members during an 18-hr helicopter flight and found no noticeable adverse effects or detectable physiological changes as a result of the flight. Similarly, in a laboratory study simulating the vertical component of recorded helicopter vibration, Dean et al (1964) found no evidence of performance or physiological degredation between seven forty-minute exposures in a six hour period. However, there is a suggestion of the subjects experiencing visual blurring, nose itch, face flutter and teeth chatter.

Seris and Auffret (1965) have attempted to measure the transmission of vibration to a pilot flying a helicopter and refer especially to the studies of helicopter pilot backache by Sliosberg (1962). It is implied that of the 128 pilots studied by Sliosberg, the 87.5% with back pains had acquired this condition as a consequence of the combination of low frequency aerodynamic vibrations and a poor seating posture.

A study of the effects of vibration on helicopter flight crews, by Ketchel et al (1969) states that the most important finding of the research was that :

> "An appallingly small smount of directly applicable experimental data exists on the vibration environment in operational helicopters".

They add that :

> "Almost no data have been collected under controlled conditions in an operational setting to determine the effects of this helicopter vibration régime on flight crew performance and physiology".

It becomes a reasonable assumption that the high degree of speculation on the subject is consequent upon the lack of experimental data. The deficiency is two-fold with both the vibration environment and the human response to this environment remaining largely unknown quantities.

No single study will patch the wide gap of knowledge and the experiments described here do not attempt to answer many of the questions that need to be asked. The research was primarily conducted to provide data for the interpretation of experiments which were evaluating the effects of vibration on visual acuity. However, in passing, it has been possible to collect data of little relevance to the primary aim but which, in view of our sadly lacking knowledge of the environment, may well be of interest to others concerned with the helicopter and human response to vibration.

1.2 The Present Experiments

This report is concerned with the measurement of vibration within a single helicopter type - the Scout AH Mk.I. (A description of this aircraft is to be found in Appendix 6). The primary interest is in the effect of the vibration environment on visual acuity and this is thought to be dependent on the characteristics of head vibration. The vibration may be expected to vary between and within populations of both aircraft and pilots. Three experiments were designed in an attempt to evaluate the mean values of the vibration and the variability due to different pilots and different aircraft of the same type.

In the first experiment eight Scout helicopters were flown by the same pilot in seven different flight conditions. In each condition the mean and range of floor vibration were determined over the spectrum for each of three perpendicular axes. In the other two experiments eight pilots flew in a single Scout helicopter with known floor vibration characteristics. The spectra of triaxial head vibration were determined from Trial Two during four flight conditions. From Trial Three vertical vibration at the heads of pilots and at the interface between their bodies and the seat cushion were determined during the hover.

An attempt has been made to correlate pilot assessment of the vibration with the levels of vibration found in Trials One and Two. Similarly, the levels of head and seat vibration determined in Trials Two and Three have been correlated with the physical characteristics of the pilots who yielded the data.

The information contained in this report reflects the vibration characteristics of both the helicopters and the pilots and each of these deserve more detailed consideration in their own right. It would certainly be of interest to find satisfactory explanations of the reported behaviour and, in particular, to predict the possible consequences of the vibration upon the safety, comfort and efficiency of the pilot. However, this is not the purpose of the present paper and speculative explanations will be avoided unless they are thought necessary to an understanding of the information being presented.

2. EQUIPMENT

2.1 Vibration Recording Apparatus

A portable vibration recording system was assembled by the author specifically for the measurement of vibration in environments such as the helicopter. The system has five units: (i) the vibration sensors (3 accelerometers), (ii) a 3-channel strain gauge amplifier, (iii) a 3-channel frequency multiplex encoding unit, (iv) a portable direct tape recorder, (v) a 3-channel frequency multiplex decoding unit. A schematic block diagram of the system is shown in Figure 2.1. The various calibrations of the system are listed in Appendix 1.

2.2 The Mounting of Accelerometers

The experiments described required the measurement of triaxial vibration at the floor and at the head. The accelerometers were mounted in mutually perpendicular directions on a U-shaped magnesium block 2.9cm by 2.2cm by 1.8cm and 23 grams in weight (see Sections 3.2.5 and 4.2.4). The measurement of vertical vibration at the pilot/seat interface was achieved by means of an accelerometer within a rectangular aluminium bar placed at this interface (see Section 5.2.3). The bar weighed 544 grams and was 35.5 cm long by 3.0cm wide and 2.0cm high with the underside of the ends cut away to fit neatly onto the cushion. The plate

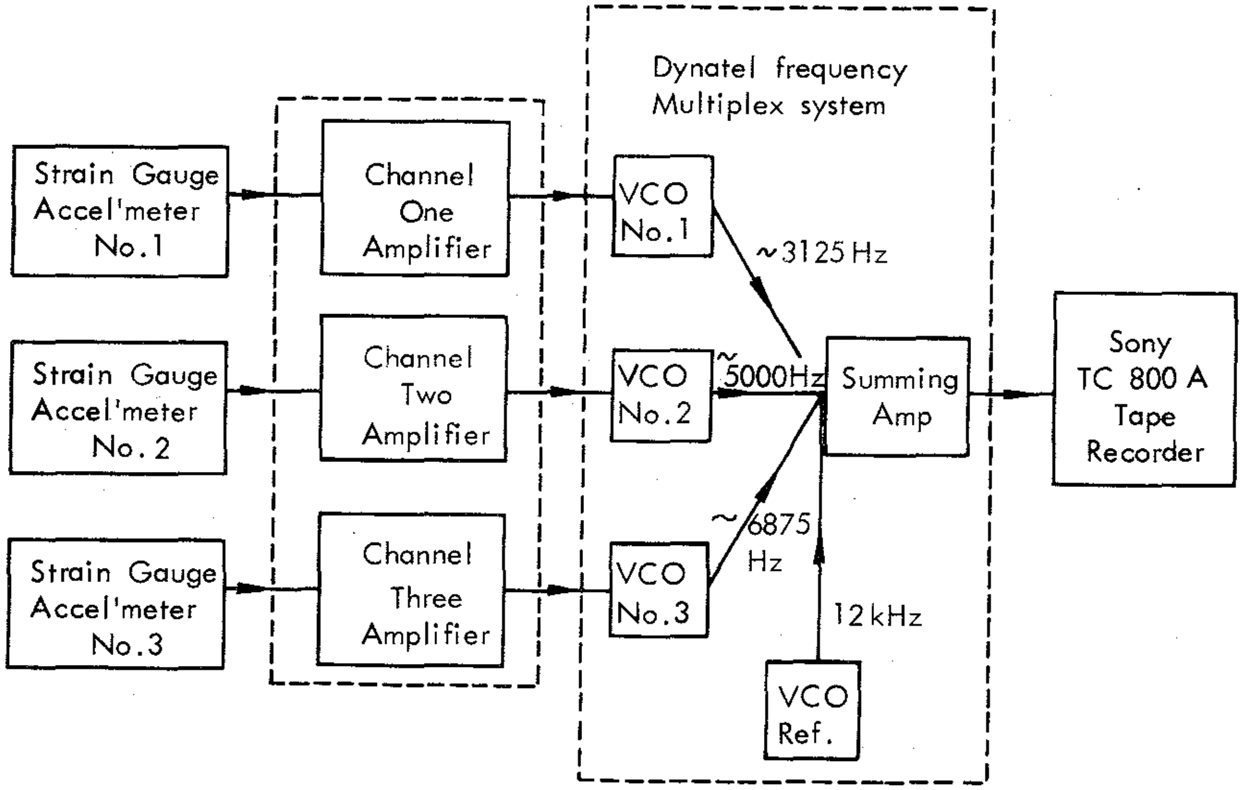


FIG 2.1 SCHEMATIC BLOCK DIAGRAM OF VIBRATION RECORDING SYSTEM (VCO = FREQUENCY MOD. VOLTAGE CONTROLLED OSCILLATOR)

shows the triaxial mount being used to measure head vibration and also the seat bar in position on a cushion from the Scout helicopter.

3. THE MEASUREMENT OF TRIAXIAL VIBRATION AT THE FLOOR OF EIGHT SCOUT HELICOPTERS (TRIAL ONE)

3.1 Aims

To determine the physical characteristics of translational vibration in the Scout helicopter and investigate how this varies between aircraft and in different flight conditions.

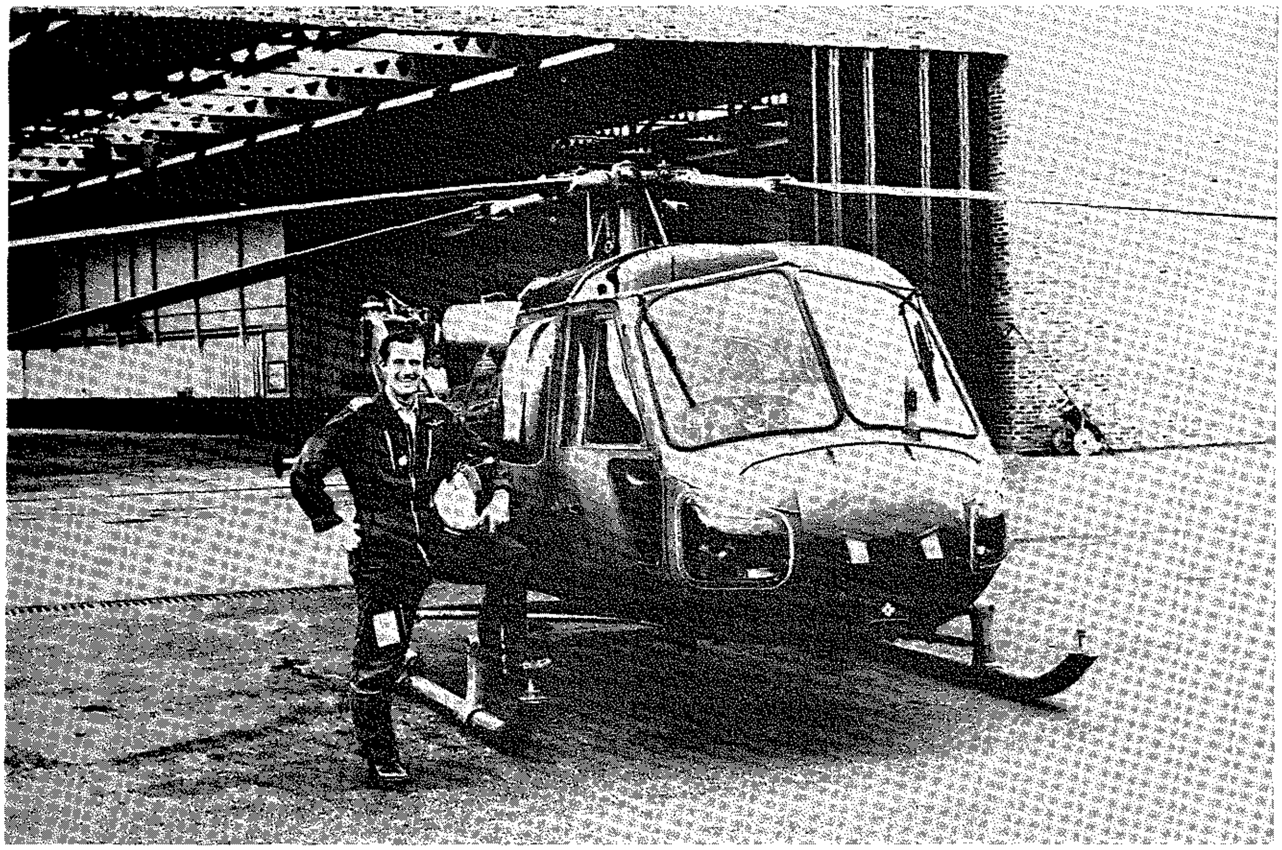
3.2 Experimental Method

3.2.1 Aircraft

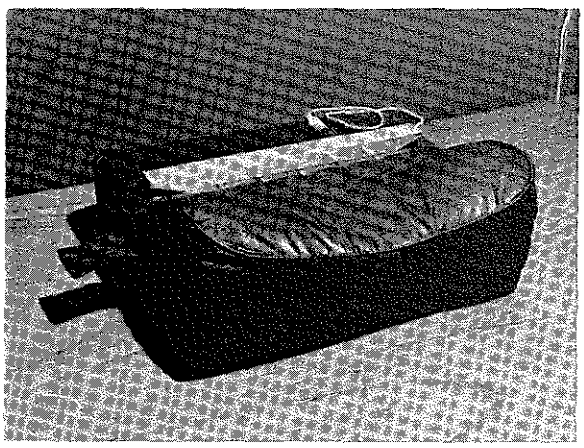
Eight similar Scout aircraft from the Army Aviation Centre, Middle Wallop, were used in this experiment. All aircraft had wooden tail rotors and were flown with two persons on board (the pilot and the experimenter). The "all-up" weight of the aircraft at take-off varied between 4800 lb and 5000 lb.

3.2.2 Pilot

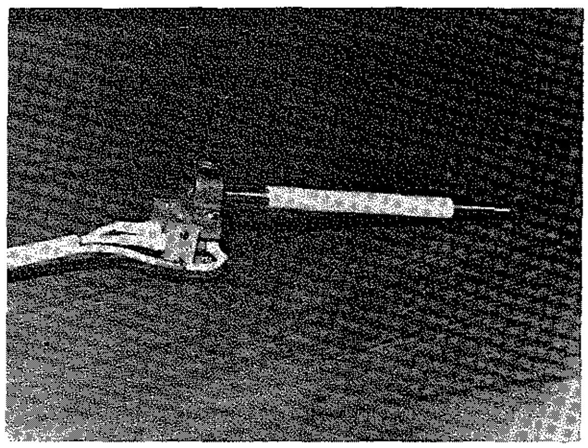
All eight aircraft were flown by the same pilot who was familiar with the Scout helicopter and had considerable experience of its normal and abnormal



A SCOUT AH Mk1 HELICOPTER AND PILOT



THE ALUMINIUM BAR USED TO MEASURE VERTICAL VIBRATION AT THE PILOT/SEAT INTERFACE.



THE MAGNESIUM MOUNT (and bite bar) USED TO MEASURE TRIAXIAL VIBRATION.

characteristics. The pilot wore an inertia harness and a mark 3B flying helmet throughout all flights.

3.2.3 Flight Conditions

The vibration of all eight aircraft was recorded for 60 seconds in each of seven flight conditions :

1. in the hover at 10ft above ground level
2. in 100kts forward flight at 1000ft above ground level
3. in 60kts forward flight at 1000ft above ground level
4. in 115kts forward flight at 1000ft above ground level
5. in 30° starboard turn at 1000ft above ground level
6. in autorotation from 5000ft above ground level
7. on the ground (aircraft on flat tarmac with the rotors turning)

Air temperature at ground level during the experiment was in the range 6°C to 12°C, atmospheric pressure 992mb to 1017mb and wind speed less than 20kts.

3.2.4 Subjective Assessment of Vibration

The pilot was asked to assign a number to "the amount of judder" in the first flight condition (hover) for each aircraft. For the following six flight conditions he estimated the magnitude of the judder in relation to that during the hover.

After the completion of the recording of vibration in each aircraft the pilot placed marks on two ten centimetre lines to denote his judgement of the overall judder and overall acceptability of the vibration of the aircraft.

0 ________________________________ 10

Amount of judder

____

Acceptable Unacceptable

3.2.5 Location of Accelerometers

The three accelerometers were mounted triaxially in the magnesium block. This block was then fastened to the floor on the starboard side of the aircraft immediately in front of the centre of the base of the pilot's seat. Adhesion was achieved with double sided adhesive tape (considered satisfactory for vibration below 100Hz). The horizontal axes of the accelerometers were such that they were parallel to the fore and aft and lateral axes of the aircraft. The vertical axis of the accelerometers was perpendicular to the floor of the aircraft.

The vibration recording apparatus and the experimenter were in the rear of the aircraft on the port side.

3.2.6 Calibration of Accelerometers

Before and after all flights the d.c. sensitivities of the system were recorded by turning each accelerometer through 180 degrees such that the gravitational force changed from a positive maximum to a negative minimum. It was later determined from the calibration signal that the sensitivity of the system had not deviated from its nominal value by an amount greater than anticipated from the information in Appendix 1.

3.3 Analysis Method

3.3.1 Spectrum Analysis

From preliminary inspection and analysis of the data it was determined that the spectra of vibration within the helicopter consisted largely of a number of discrete components which varied slightly in frequency. The number of components (more than six) made it impractical to determine the acceleration level of each component by visual inspection of the recorded waveform. The minor fluctuations in the frequency content of the data prevented useful Fourier analysis. Power spectral density (psd) analysis was tried and found to conform with theory.

Computer analysis for trial one was thus performed on the Myriad computer of the Data Analysis Centre of the Institute of Sound and Vibration Research, using a power spectral density program (p8). Analysis was performed on 20 seconds lengths of data over the frequency range 0 to 100Hz at a resolution (B_e) of 1Hz with an analogue to digital sampling rate (S_R) of 250 per second. The input data was filtered with a low pass analogue filter with a cut off rate of 48dB per octave set 3dB down at 125Hz (i.e. $\frac{S_R}{2}$).

Thus, highest frequency rate of interest = f max = 100Hz

sampling rate = S_R = 250 (>2 x f max)

sample length = T = 20 secs

number of samples = $S_R \times T = 250 \times 20 = 5000$

number of correlation lags $= \frac{S_R}{B_e} = \frac{250}{1} = 250$

degrees of freedom $= k = \frac{2N}{m} = \frac{2 \times 5000}{250} = 40$

A value of k = 40 is considered sufficient for statistical accuracy.

The spectrum levels in each 1Hz band were out-put on paper tape and plotted graphically on a fixed scale as the log of the spectrum level versus frequency. This involved the production of a spectrum analysis for each of the 3 directions for each of the seven flight conditions for each of the eight aircraft - a total of 168 analyses.

Analysis of different 20 second periods of the 1 minute length of recorded data per flight condition revealed only very minor changes in the spectrum and helped indicate the reliability of the analysis method.

Typical vibration spectra obtained during the 100 knot forward flight condition are shown in Figure 3.1.

3.3.2 Interpretation of spectrum levels

The paper tape outputs of spectrum levels from the Myriad computer were printed for visual inspection. The large amount of data obtained indicated that the vibration of possible importance to human reaction was mainly composed of seven or eight frequencies and these frequencies could be associated with the revolution rates of various mechanical parts of the helicopter. The broadening of some spectrum components (due to the finite cut-off-rate of the filters and the variations in the frequency of revolution of some of the vibration sources) meant that the energies of the individual spectral components were not entirely contained within single 1Hz bands. Consequently the total power within peaks, rather than the actual peak level, was the indication of the vibration level attributed to a particular frequency.

A computer program was written to calculate the total power of each of these components. For each frequency component this program computes and prints: (1) the spectrum level due to the given component for each of the eight aircraft;

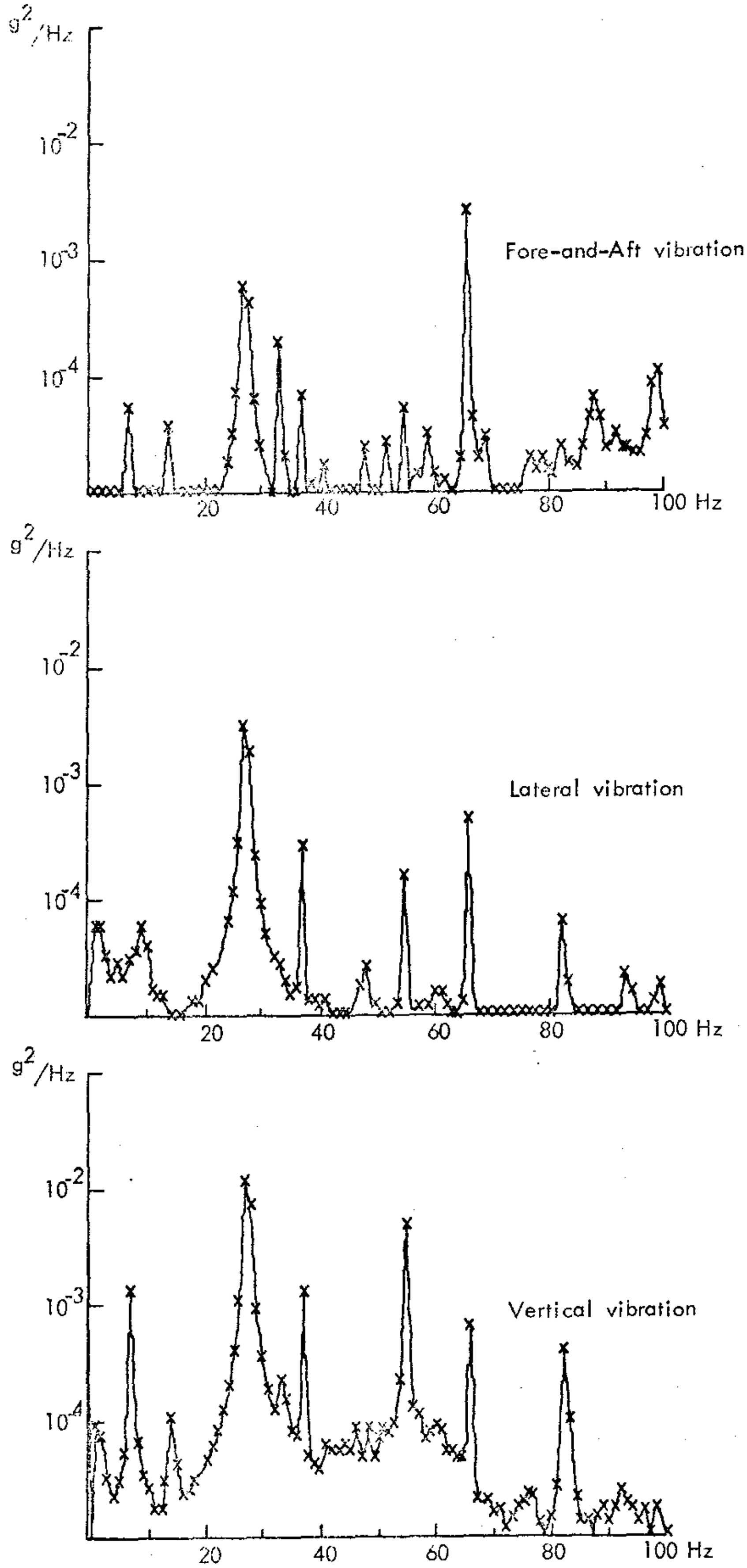


FIG 3.1 VIBRATION ACCELERATION SPECTRA AT THE FLOOR OF A SCOUT HELICOPTER DURING 100 kt FORWARD FLIGHT

(2) the average level of this component in the eight aircraft; (3) the standard deviation of the level of this component across the eight aircraft; (4) the r.m.s. acceleration level corresponding to the average power spectrum level; (5) the r.m.s. acceleration levels corresponding to the maximum and minimum spectrum levels contributed by the eight aircraft.

3.4 Results

3.4.1 The Vibration Spectrum

Nine peaks in the vibration spectra were clearly identified :

Approximate Centre Frequency		Probable Source
7 Hz	. . .	Main rotor frequency
14 Hz	. . .	2 x Main rotor frequency
28 Hz	. . .	4 x Main rotor frequency
32 Hz	. . .	Tail rotor frequency
37 Hz	. . .	Main tail rotor shaft <u>or</u> layshaft
56 Hz	. . .	8 x main rotor frequency
64 Hz	. . .	2 x tail rotor frequency
84 Hz	. . .	12 x main rotor frequency
95 Hz	. . .	Layshaft/primary gear intermediary.

In view of their relatively low levels the latter two frequencies (84 and 95 Hz) are not considered in the subsequent analysis. For the other seven frequencies the mean (Av.P) and standard deviation (S.D.P) of the power (g^2) in the eight aircraft is shown for each axis and the seven flight conditions in Appendix 2. Also shown are the corresponding mean and range of r.m.s. acceleration levels in these eight aircraft. The latter are plotted in Figures 1 and 2 of Appendix 2 for two of the seven flight conditions, (i.e. hover and 115 knots).

A four-factor (aircraft x vibration frequency x vibration axis x flight condition) analysis of variance has been performed on the individual spectrum level data. The analysis of variance table is shown below :

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares
A (frequency)	6	4744074228	790679038
B (flight condition)	6	886427624	147737937
C (axis)	2	632026834	316013417
D (aircraft)	7	60804478	8686354
AB	36	3131924266	86997896
AC	12	1742145556	145178796
AD	42	466224143	11100574
BC	12	245891169	20490930
BD	42	86766774	2065875
CD	14	156810922	11200780
ABC	72	862116005	11973833
ABD	252	462579965	1835634
ACD	84	1172075854	13953283
BCD	84	139709680	1663210
Residual	504	936581481	1858296
Total	1175	15726158986	

TABLE 3.0: Analysis of Variance Table for Triaxial Floor Vibration

By using the residual variance as an error term it will be found that there are two significant ($p < 0.001$) third order interactions in the above table. (These are the flight conditions x frequency x axis and frequency x axis x aircraft terms.) There are also significant main effects and second order interactions.

3.4.2 Effect of Flight Condition on Vibration Levels

The multifactor analysis of variance has shown that there are significant interactions between the various variables. A non-papametric determination of the changes due to the four variables has been employed which enables the ranking of the various levels within each of the four factors. It is, for example, of interest to know the flight conditions associated with the maximum and minimum levels of vibration at the various peak frequencies. This information was determined via the determination of the Kendall coefficient of concordance.

For each aircraft, axis and frequency combination, the measured vibration was ranked across the seven flight conditions from least vibration to most vibration. Twenty-one tables of ranks were thus constructed, each indicating the ranking of the seven flight conditions in all eight aircraft for a specified frequency and axis.

A typical table of ranks is shown for the lateral axis at 7 Hz :

	Aircraft								Sums of Rank Rj	Ranking of Rj
	AC1	AC2	AC3	AC4	AC5	AC6	AC7	AC8		
Hover	2	2	3	2	2	2	6	2	21	2
100 knots	6	6	2	4	3	7	4	5	37	5
60 knots	1	1	1	1	1	3	1	1	10	1
115 knots	5	7	5	5	4	6	3	6	41	6
30° turn	3	5	6	6	5	4	2	3	34	4
Autorotation	4	4	4	3	6	1	5	4	31	3
Ground	7	3	7	7	7	5	7	7	50	7

Kendall Coefficient of Concordance = W = 0.5804 (significant at $p<0.01$)

TABLE 3.1: Ranking of Measured 7 Hz Lateral Vibration in Different Flight Conditions

The Kendall coefficient of concordance was calculated for each such table of ranks. A high, or significant, value of the coefficient, W, implies the aircraft "agree" on the manner in which the particular vibration component varies with flight condition. The computation of this coefficient of concordance involves the summation of ranks to produce a single sum for each flight condition. If the seven values obtained are themselves ranked, then it is suggested, by Siegel (1956), that this pooled ordering is probably the best method of determining the order of the conditions in the absence of any other external criteria. The reliability of this ranking will tend to be greater the higher the value of the coefficient of concordance.

Tables 3.2a, b, c show the pooled ordering of the measured levels of vibration across the seven flight conditions at the chosen frequency peaks. Also shown are the coefficient of concordance and the levels of significance corresponding to this degree of concordance for each of the seven frequency peaks on each of the three vibration axes. The rankings entered in these tables are such that high values indicate the highest values of vibration.

3.4.2a Main Rotor Frequencies (7, 14, 28 and 56 Hz)

It is clear that the eight aircraft are in high agreement on the manner in which the amplitudes of the four frequencies associated with the motion of the main rotor blades vary with flight condition. The blade passage frequency (28 Hz) exhibits the most consistent changes and the rank orders are very similar in all three vibration axes. The magnitude of this vibration appears to be closely related to the aircraft speed such that it is least when the aircraft is stationary on the ground and a maximum when in forward flight at 115 knots.

	7 Hz	14 Hz	28 Hz	56 Hz	33 Hz	66 Hz	37 Hz
Hover	7	1.5	2	1	6	3	1
100 knots	3	5	5	2	5	6	7
60 knots	4	3	4	6	4	4	2
115 knots	6	7	7	5	7	7	5
30° turn	2	6	6	4	2	5	3
autorotation	1	4	3	7	3	2	6
ground	5	1.5	1	2	1	1	4
$W =$	0.4464	0.4202	0.7846	0.7321	0.2745	0.7679	0.2198
$p <$	0.01	0.01	0.001	0.001	0.05	0.001	0.20

TABLE 3.2a: Rankings of Sums of Ranks of Fore-and-Aft Vibration across Flight Conditions

	7 Hz	14 Hz	28 Hz	56 Hz	33 Hz	66 Hz	37 Hz
Hover	2	1	2	2	3	5	1
100 knots	5	6	5	4	6	6	4
60 knots	1	2	3	4	1	3	2
115 knots	6	7	7	7	7	7	6
30^{o} turn	4	5	6	6	5	4	4
autorotation	3	3	4	4	4	1	4
ground	7	4	1	1	2	2	7
W =	0.5804	0.5201	0.8996	0.7109	0.4442	0.7076	0.2221
p <	0.001	0.001	0.001	0.001	0.01	0.001	0.10

TABLE 3.2b: Ranking of Sums of Ranks of Lateral Vibration across Flight Conditions

	7 Hz	14 Hz	28 Hz	56 Hz	33 Hz	66 Hz	37 Hz
Hover	1	2	2	1	2	4	1
100 knots	5	6	5.5	5	6	6	4.5
60 knots	3	4	4	6	3	3	4.5
115 knots	7	7	7	4	7	7	6
30^{o} turn	6	5	5.5	7	4	5	3
autorotation	4	3	3	3	5	2	7
ground	2	1	1	2	1	1	2
W =	0.5603	0.5045	0.9565	0.5603	0.2919	0.7746	0.1975
p <	0.001	0.001	0.001	0.001	0.05	0.001	0.20

TABLE 3.2c: Ranking of Sums of Ranks of Vertical Vibration across Flight Conditions

The vibration at the main rotor frequency (7Hz) exhibits different changes with flight condition in each of the vibration axes. In the fore-and-aft axis vibration is greatest in the hover and least during autorotation, in the lateral direction it is greatest on the ground and least at 60 knots, and in the vertical direction it is greatest at 115 knots and least in the hover. The overall rank orders are significant at $p < 0.001$ in the lateral and vertical directions and $p < 0.01$ in the fore-and-aft direction.

The components at 14 Hz vary similarly in the three axes with least vibration on the ground or in the hover and most vibration at 115 knots. There would appear to be greater similarity between the rank orders at 14 Hz and 28 Hz than 14 Hz and 7 Hz.

The rank order of the 56 Hz component in the lateral direction is very similar to the rank orders of the 28 Hz components. However, in the vertical and fore-and-aft directions, there is a change such that the component is greater at 60 knots than at 100 knots and greater at 100 knots than at 115 knots. In the fore-and-aft direction there is also a further change in that the 56 Hz component is a maximum during autorotation. The rank orders were highly significant ($p < 0.001$) in all three axes at 56 Hz.

3.4.2b Tail Rotor Frequencies (33, 66 and 37 Hz)

The rank orders at the tail rotor frequency (33 Hz) represent concordance at generally lower levels of significance than those associated with the main rotor frequencies. The agreement between axes is limited to the tendency for least vibration when on the ground to most vibration at 115 knots.

There is greater concordance at the second harmonic of the tail rotor frequency (equal to the blade passage frequency of the tail rotor) with high levels of significance ($p < 0.001$) associated with the rank orders. There is also great similarity between the vibration axes with least vibration on the ground or during autorotation and most at 115 knots. There appears to be some overall similarity in the manner in which the ranking of the 33 Hz and 66 Hz components vary with flight condition. The rank orders of the vibration associated with the layshaft or main tail rotor shaft at about 37 Hz do not exhibit significant concordance over the seven flight conditions. The best agreement among the aircraft occurs in the lateral axis ($p < 0.1$).

3.4.3 Effect of Vibration Axis on Vibration Level

The mean vibration levels of the eight aircraft in each axis were ranked in every flight condition for each of the seven frequencies. A table of ranks was thus constructed for each frequency showing the ranking of the three axes in each of the flight conditions. An example is shown below for the 7 Hz component.

	Hover	100	60	115	30°t	Auto	Ground	Rj
F and A	2	1	2	2	1	2	3	13
Lat.	1	2	1	1	2	1	1	9
Vert.	3	3	3	3	3	3	2	20

$$s = (14 - 13)^2 + (14 - 9)^2 + (14 - 20)^2$$
$$s = 62$$

The corresponding coefficient of concordance = W = 0.632.

	7Hz	14Hz	28Hz	56Hz	33Hz	66Hz	37Hz
Fore and aft	2	2	1	2	3	1	2
Lateral	1	1	2	1	1	2	1
Vertical	3	3	3	3	2	3	3
p <	0.002	0.01	0.001	0.01	0.001	0.1	0.01
W =	0.632	0.755	1.000	0.877	1.000	0.387	0.796

TABLE 3.3: Ranking of Sums of Ranks of Mean Floor Vibration across Axes

The sums of ranks (R_j) were then ranked for each frequency component and are shown in Table 3.3. Also shown is the coefficient of concordance (which may be interpreted as indicating the degree of 'agreement' within the seven flight conditions as to the ranking of the axes) and the significance levels associated with this coefficient.

The main rotor frequencies (7, 14, 28 and 56 Hz) all result in greatest vibration in the vertical axis with lateral vibration being least, except at

28 Hz. All the rankings at main rotor frequencies represent significant concordance.

The tail rotor frequency (33Hz) is the only frequency which is not of greatest magnitude in the vertical direction. Vibration at 33 Hz is most in the fore-and-aft axis and least in the lateral axis and has a concordance value of unity. The second harmonic of the tail rotor frequency (66 Hz) is least fore-and-aft and most vertically but the concordance value is low and not significant ($p < 0.1$).

3.4.4 Effect of Aircraft on Vibration Level

The eight aircraft were ranked from one to eight according to the vibration level for each frequency-axis-flight condition combination. The tables of ranks so constructed were summed across flight conditions. Concordance values (indicating the extent to which rankings of each aircraft were the same in all flight conditions) were calculated and the sums of ranks were again ranked. Tables 3.4a, b and c show the overall aircraft rankings for each frequency in the fore-and-aft, lateral and vertical axis respectively. It is therefore possible to determine the extent to which an aircraft with excessive vibration in one frequency-axis combination has excessive vibration in other axes, and at different frequencies. However, the following discussion should be interpreted with care since the components vary similarly either because they have a common mechanical source or because the aircraft is generally less well maintained. Thus, while it is unlikely that the magnitude of tail rotor frequencies will be highly related to the magnitude of main rotor frequencies, it is apparent that aircraft eight has a low vibration in almost all frequency-axis combinations while aircraft four has generally higher than average vibration. The ranked values shown in Tables 3.4a, b and c have not, therefore, been compared statistically across frequency and axis.

Main Rotor Frequencies

The rankings at 7 Hz are all significant (i.e. the relative vibration levels in the eight aircraft are similar in the different flight conditions). Rankings in the fore-and-aft axis are similar to those in the lateral axis and indicate that an aircraft with little fore-and-aft vibration will have little lateral 7 Hz vibration and vice versa. The vertical rankings, however, are not similar to those in the horizontal axes.

	7Hz	14Hz	28Hz	56Hz		33Hz	66Hz		37Hz
AC 1	3	7	2	8		2	5.5		1
AC 2	1	3	6.5	7		5	8		3.5
AC 3	6	8	8	6		3.5	4		2
AC 4	8	4	6.5	3.5		6	1		8
AC 5	7	1	3	5		3.5	3		7
AC 6	4	5.5	4	2		7	2		6
AC 7	5	5.5	4	2		7	2		6
AC 8	2	2	1	1		1	7		3.5
p	< 0.001	0.001	0.02	0.1		0.001	0.05		0.001
W	= 0.5128	0.6309	0.3882	0.2767		0.8256	0.3674		0.7272

TABLE 3.4a: Ranking of Sums of Ranks of Fore-and-Aft Vibration across Aircraft

	7Hz	14Hz	28Hz	56Hz		33Hz	66Hz		37Hz
AC 1	3	4	5	7.5		4	3.5		6
AC 2	1.5	6	8	4.5		6	6		5
AC 3	5	7	5	4.5		2	2		4
AC 4	6	8	1	6		5	8		8
AC 5	8	3	7	2		3	5		7
AC 6	4	5	5	7.5		8	1		3
AC 7	7	2	2	3		7	7		1
AC 8	1.5	1	3	1		1	3.5		2
p	< 0.01	0.01	0.1	-		0.001	0.01		0.001
W	= 0.5577	0.5019	0.2843	0.1498		0.8890	0.4612		0.9142

TABLE 3.4b: Ranking of Sums of Ranks of Lateral Vibration across Aircraft

	7Hz	14Hz	28Hz	56Hz		33Hz	66Hz		37Hz
AC 1	7	6	7	8		3.5	4		8
AC 2	4	2	1	5		6	8		4
AC 3	8	8	4.5	6		5	6		3
AC 4	5.5	4	2	7		7	7		5
AC 5	5.5	3	8	3.5		3.5	1		6
AC 6	1	7	6	2		2	2		2
AC 7	2	5	3	3.5		8	5		7
AC 8	3	1	4.5	1		1	3		1
W	= 0.6299	0.7195	0.8639	0.2537		0.7031	0.5107		0.8234
p	< 0.001	0.001	0.001	0.2		0.001	0.01		0.001

TABLE 3.4c: Ranking of Sums of Ranks of Vertical Vibration across Aircraft

At 14 Hz the rankings are significant but there is little agreement in the fore-and-aft and lateral axis. There is some similarity between the rankings in the fore-and-aft and vertical axes.

The rankings of the 28 Hz component in the lateral axis are not significant ($p < 0.1$). This suggests that the magnitude of 28 Hz lateral vibration varies to a different extent with changes in flight condition in the different aircraft. In both the fore-and-aft and vertical axes there is significant concordance but no evidence that an aircraft with appreciable vibration in one of these axes will also have considerable vibration in the other.

Concordance coefficients at 56 Hz are low and not significant.

In no axis is there any striking agreement between the rankings at 7 Hz and 14 Hz, 7 Hz and 28 Hz, or 14 Hz and 28 Hz. This tends to suggest that these harmonic frequencies are, as one might expect, due in part to four separate sources of excitation.

Tail Rotor Frequencies (33, 66 and 37 Hz)

The tail rotor frequency (33 Hz) results in similar rankings across the eight aircraft in the fore-and-aft and lateral axes. However, the blade passage frequency of the tail rotor (66 Hz) has quite different rankings in the three axes. The 33 Hz and 66 Hz components have similar rankings in the vertical direction.

The rankings of the 37 Hz components in the three axes are all highly significant although there is little agreement between the three axes.

3.4.5 Subjective Assessment of the Vibration

The pilot's estimates of the magnitude of the judder in each aircraft have been ranked within the seven flight conditions as follows ;

	P.1	P.2	P.3	P.4	P.5	P.6	P.7	P.8
Hover	6	4	5.5	2	1	1.5	1.5	1.5
100 kts	2	4	5.5	5	4	4	6	4
60 kts	3	4	2.5	1	4	6	1.5	1.5
115 kts	7	7	7	7	6.5	7	7	6.5
30° str	5	4	2.5	5	4	4	4	6.5
auto	4	4	2.5	5	6.5	1.5	4	4
ground	1	1	2.5	2	2	4	4	4

TABLE 3.5: Rankings of Subjective Ratings of Amount of Judder in Different Flight Conditions (low ranks indicate less judder)

Low ranks indicate less sensation of judder than high ranks. When tied values occur the entries are assigned the average of the ranks they would have been assigned had no ties occurred.

As mentioned in Section 3.4.2, a similar ranking technique was applied to the vibration levels over the eight aircraft at each of the seven major frequencies and each of the three axes. A composite table of ranks was then compiled for selected frequency-axis combinations such that for each aircraft the pilot's rankings of the flight conditions are entered against the appropriate flight conditions which are tabulated in order from least to most vibration. The upper portions of these tables of ranks thus refer to flight conditions (unspecified) of least vibration while the lower portions refer to those with most vibration. If subjective rankings are similar to these objective rankings the entries (and sums of ranks) will be low in the upper portions and high in the lower portions of the tables.

Table 3.6 shows the rankings of the sums of ranks for the three vibration axes at 7 Hz and 28 Hz. At 7 Hz the concordance coefficients are low and imply that the subjective assessments are not directly related to the magnitudes of the 7 Hz components. It can also be seen that sums of ranks of subjective judgements do not increase convincingly with increasing amounts of measured vibration.

At 28 Hz there is high concordance (significant at $p < 0.01$) in all three axes and subjective rankings increase as vibration level increases. This suggests that the subjective assessments were based on the magnitude of the 28 Hz components or some factor that varies in sympathy with this component. In section 3.4.2a, it was stated that the magnitude of the 28 Hz component in all three axes appears to be related to the speed of the aircraft. It is not, therefore, surprising to find that the subjective assessments ranked against flight condition as in table 3.5 also exhibit significant concordance between the eight aircraft. The concordance coefficient is in fact slightly higher than that for any of the three axes at 28 Hz. It is thus possible that the pilot was basing his rating on some preconceived notion of the flight condition rather than the perceived level of vibration.

The 28 Hz vibration in the 115 knots flight condition is distinctly greater than in any other flight condition and the pilot has produced predictably high ratings. If the tables of ranks are constructed omitting this condition they will indicate the extent to which the pilot was able to distinguish vibration levels among the remaining flight conditions. The approximate coefficients of concordance have been calculated and are not significant ($p < 0.3$) for either the subjective ranking of flight condition or the subjective ranking of any of the three 28 Hz components.

		7 Hz			28 Hz		
		f & a	lat	vert	f & a	lat	vert
least measured vibration	1	1	1	2.5	1	1	1
	2	5	2	2.5	2.5	2.5	3
	3	3	6	1	2.5	4	2
	4	6	5	4	5	2.5	4
	5	4	7	6	4	6	6
	6	2	4	5	6	5	5
most measured vibration	7	7	3	7	7	7	7
W =		0.1244	0.2232	0.2472	0.3927	0.4199	0.4495
p <		n.s	0.1	0.1	0.01	0.01	0.01

TABLE 3.6: Rankings of Sums of Ranks of Subjective Assessments of Amount of Judder across Flight Condition

Inspection of the raw subjective and objective ranking data reveals no direct correlation between them for 14 Hz, 56 Hz, 33 Hz, 66 Hz, and 37 Hz components in any axis. It would appear that there exists no simple physical basis for the subjective ratings of the pilot other than in the most severe vibration condition at 115 knots. It may be that the pilot is basing his judgements on some integrated intensity sensation with unknown frequency and axis weightings. Alternatively, the combination of the pilot and the rating scale may be insufficiently sensitive to detect the changes in vibration that occur in the different flight conditions.

The subjective method that has been employed would appear to be inadequate to detect the vibration acceleration changes of the order of 4-to-1 that occur during normal flight in good conditioned aircraft. The ability of a pilot to detect a vibration indicative of an aircraft malfunction is a somewhat different situation. However, the data presented suggest that this pilot will not in general detect the fault until the vibration reaches a level easily detectable by suitable instrumentation. The pilot employed in this study may not be representative of other pilots, but it should be remembered that he is considered to have considerable experience at recognising such faults.

3.4.6 Overall Subjective Assessment of the Aircraft

After the flight in each aircraft the pilot gave ratings of the "amount of judder" and "overall acceptability" of the aircraft. Before leaving the aircraft he placed marks on 100 mm lines to indicate his judgement as described in Section 3.2.4.

All ratings on the scale were such that they suggested low levels of judder and high acceptability (i.e. the pilot was "leaving room" to make very much worse ratings). The scores (in mm) are shown in the following table :

Aircraft	AC1	AC2	AC3	AC4	AC5	AC6	AC7	AC8
Overall Un-acceptability	12	6	5	7	20	5	4	3
Amount of judder	13	18	13	17	20	5	7	3

TABLE 3.7: Overall Pilot Assessment of the Aircraft

It will be noticed that for all aircraft the judder rating is greater than, or equal to, the acceptability rating. The Kendall Rank Correlation Coefficient indicates that there is a significant ($p < 0.02$) correlation between the rating of the aircraft on the two different scales.

The Kendall Rank Correlation Coefficient was also calculated in an attempt to correlate the ratings of the amount of judder with the measured amounts of vibration as indicated by the rankings of the aircraft in Tables 3.4a, b and c.

There is one significant correlation (between judder rating and measured levels of 37 Hz lateral vibration: $p < 0.05$) although the 7 Hz levels in all three axes indicate the correct "trend" with $p < 0.2$.

The correlation with the 37 Hz lateral component appears surprising when considering its level in relation to the levels of 28, 33 and 56 Hz lateral components during powered flight. However, it may be significant that during the two flight conditions prior to making the rating (autorotation and on the ground) the mean 37 Hz lateral component is slightly greater than the mean r.m.s. acceleration levels of either of the adjacent peak frequencies.

3.4.7 Further Description of Vibration

The analysis of the vibration waveforms described in the preceding sections does not yield an unambiguous description of the floor vibration. Appendix 3 of this report details some attempts to define the nature of the vibration more precisely, although in the present context little emphasis is phaced on the need for such precision. (It has, however, been suggested (Grant 1961) that the sensation of helicopter vibration is highly dependent on a more detailed knowledge of the multi-axis nature of the vibration).

4. THE MEASUREMENT OF TRIAXIAL VIBRATION AT THE HEADS OF PILOTS IN THE SCOUT HELICOPTER (TRIAL TWO)

4.1 Aims

To determine the physical characteristics of translational vibration at the heads of pilots in the Scout helicopter during typical flight conditions.

4.2 Experimental Method

4.2.1 Aircraft

A single Scout helicopter was used for this experiment. The "all-up" weight of the aircraft varied between 4800 lb and 5000 lb at take-off.

4.2.2 Pilots

The aircraft was flown by eight different pilots on a single day's experimentation. All pilots wore the inertia harness in the Scout aircraft and a Mark 3B flying helmet.

4.2.3 Flight Conditions

The vibration was recorded for 60 seconds in each of four flight conditions :

(1) on the ground (with rotors turning);

(2) in the hover 10 ft above ground level;

(3) in 100 knots forward flight at 1000 ft above ground level;

(4) in 115 knots forward flight at 1000 ft above ground level.

The floor vibration of the aircraft was recorded in these flight conditions prior to the experiment and again in the hover only after the experiment.

4.2.4 Mounting of Accelerometers

The magnesium block described in Section 2.1 was attached to one end of a thin steel tube 15 cm in length. Nylon tubular sleeving was fitted tightly over the steel tube and a 14 cm rod attached to the end opposite the accelerometers. This rod was adjusted to be parallel to the axis of the fore and aft accelerometer. The complete assembly was then placed in the mouth of the pilot who was asked to bite firmly on the nylon tube and ensure that the bar, pointing forward, remained approximately horizontal. (This method of attaching the accelerometers to the head had been tested in the laboratory and found to be reliable and not excessively uncomfortable). The pilot was able to remove the "bite-bar" quickly in the event of an emergency and was only asked to keep it in place during recording sessions. The steel tube and nylon sleeve were changed for each pilot.

4.2.5 Subjective Assessment of Vibration

The instructions presented to the pilots before the experiment (see Appendix 4) informed them that they would be asked to : "number the four flight conditions in order of the amount of vibration in each, numbering the least as '1' and the most as '4'."

4.3 Analysis Method

The computer analysis described in Section 3.3.1 was modified such that the power spectral density information was stored after computation on a disc storage system which is part of the computer facility. This enabled the calculation of means and standard deviations across pilots without additional data handling. The parameters inserted in the power spectral density program were modified to suit independent revisions to the programme which also changed the resolution from 1 Hz to 0.976 Hz and increased the degrees of freedom to 78. The analogue data was passed through a band pass filter (1 Hz to 125 Hz) as described in Section 3.3.1.

The vibration data for each combination of the 8 pilots, 4 flight conditions, and 3 axes were plotted graphically on a fixed logarithmic scale as the power spectral density versus frequency. The data were also stored in digital form until all 96 computations had been completed. The blocks consisting of eight data files, each referring to one of the eight pilots in one of the four flight conditions and one of the three vibration axes, were recalled in turn. For each block the mean and standard deviation of the power spectral density levels were calculated at each frequency from 0 to 100 Hz. These mean p.s.d. levels were then converted to mean r.m.s. levels (by computing the square root of each mean power spectrum level) and output on paper tape. The mean power spectrum density and the mean r.m.s. levels were plotted graphically on a fixed scale as log of the power spectrum level versus frequency. The standard deviation (incorporating the Bessel correction) were calculated in a similar manner and graphs plotted of mean power spectrum density plus and minus the standard deviation. The mean r.m.s. levels so calculated are the roots of the mean square values and not means of the root mean squares.

4.4 Results

4.4.1 Floor vibration

The aircraft was flown in the four flight conditions prior to the trial and again in the hover only after the trial. There were small differences in the before and after spectra but their magnitudes were slight compared with the variance exhibited by the eight aircraft in the first trial. Thus, only the levels in the four flight conditions prior to the second trial were compared with the results from the first trial.

The spectrum levels in all four flight conditions were not found to fall within one standard deviation of the corresponding mean spectrum levels determined in Trial One for all situations. Table 4.1 shows the spectrum values corresponding to the acceleration at the peak frequencies and may be compared with the data in Appendix 2 obtained for Trial One.

It should be recognised that the measurements detailed in the next two Sections are only directly applicable to the single aircraft that was used. A weighting may be applied to the values to provide an estimate of the levels that would have been measured on, say, the 'average' aircraft from Trial One. However, such a weighting will require the adoption of a number of unproven assumptions. It is not clear for example, whether the pilot and seat are a linear system and it is not known to what extent the axes of the system behave independently.

4.4.2 Vibration Spectrum

Typical vibration spectra obtained during 100 knots forward flight are shown in Figure 4.1. Most of the nine peaks listed in Section 3.4.1 can be detected in these spectra although the spectrum levels are extremely low (less than 0.003g r.m.s.) at the higher frequencies. In addition to these peaks there is appreciable energy at frequencies below the main rotor blade passage frequency of 7 Hz. The spectrum cannot therefore be usefully be defined in terms of vibration level at peak frequencies alone. It is also of interest to observe the presence of a peak at 21 Hz (especially apparent during the ground run) which was not observed at the floor of aircraft in the previous trial or on the floor of this aircraft.

4.4.3 Effect of Flight Condition on Vibration Level

At 7 Hz the ranking of measured floor vibrations across flight condition are similar to those in Trial One (Tables 3.2a, b and c) with the exception of the low level of fore and aft vibration during the hover. (This aircraft was, unfortunately, exceptional in its low level of 7 Hz vibration in all axes during the hover but the ranking is only changed in the fore and aft direction).

		ground $g^2 x10^{-6}$	Hover $g^2 x10^{-6}$	100kts $g^2 x10^{-6}$	115kts $g^2 x10^{-6}$
	F & A	350	20	50	100
7Hz	Lat.	700	15	70	100
	Vert.	550	45	900	700
	F & A	25	7	20	30
14Hz	Lat.	55	6	30	30
	Vert.	30	65	60	40
	F & A	25	200	7000	18000
28Hz	Lat.	20	100	3000	10000
	Vert.	200	2000	9000	20000
	F & A	3000	300	1000	300
33Hz	Lat.	300	450	20	60
	Vert.	800	350	700	200
	F & A	500	700	700	300
37Hz	Lat.	1000	20	500	300
	Vert.	1050	350	2000	2000
	F & A	100	280	250	150
56Hz	Lat.	20	310	500	400
	Vert.	800	500	7000	10000
	F & A	250	550	750	2000
66Hz	Lat.	15	400	300	2000
	Vert.	100	600	700	2500

TABLE 4.1: Peak Spectrum Levels on the Floor of the Scout Helicopter Employed in Trials Two and Three.

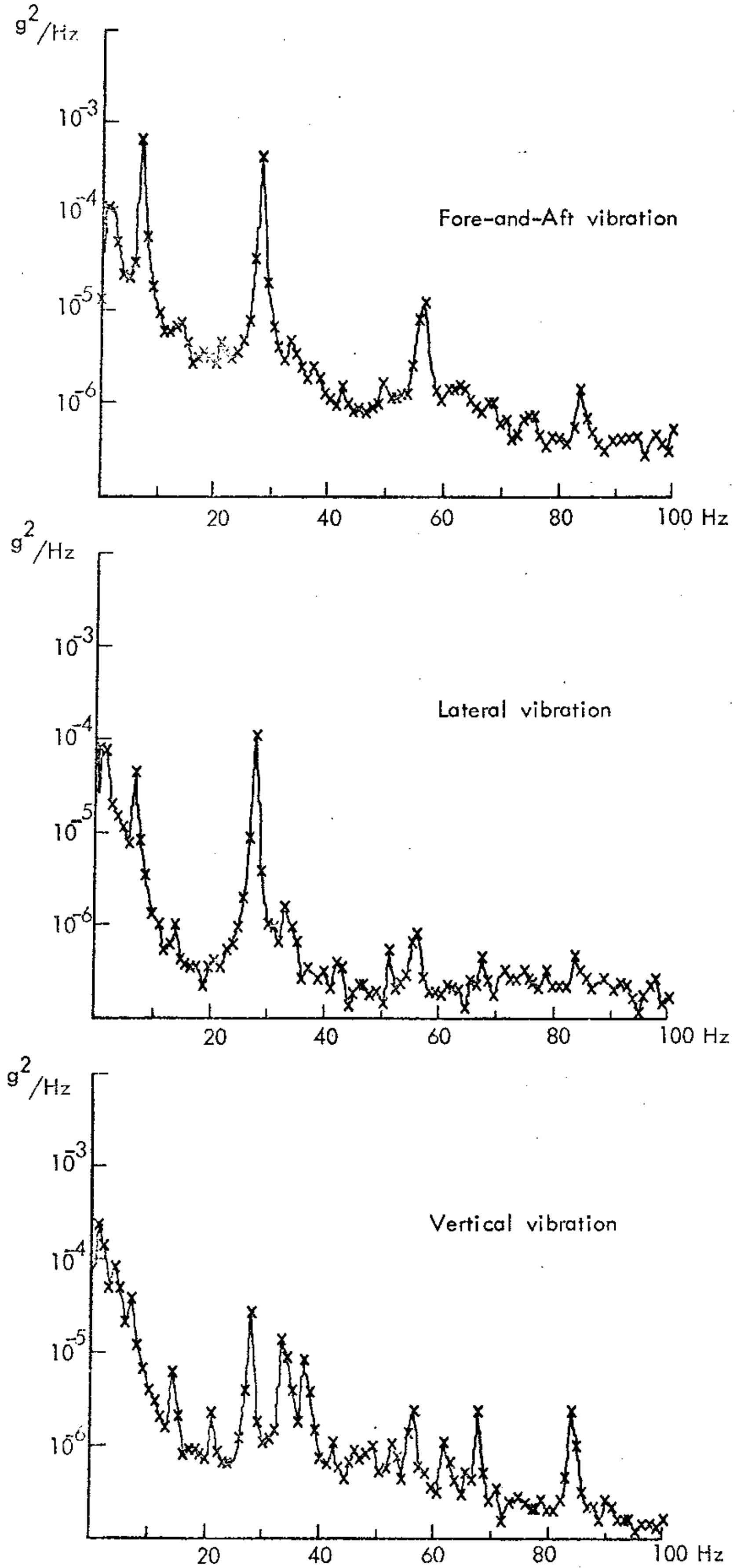


FIG 4 1 VIBRATION ACCELERATION SPECTRA AT THE HEAD OF A PILOT IN A SCOUT HELICOPTER DURING 100 kt FORWARD FLIGHT

For each pilot the 7 Hz vibration at the head has been ranked across the four flight conditions for each axis. The sums of ranks across pilots has been further calculated to determine the Kendall Coefficient of Concordance. There is significant concordance ($p < 0.01$) in all three axes (see Table 4.2) indicating a similar response across flight conditions by the eight pilots. In the fore-and-aft and lateral directions the overall rankings at the head (described by the Kendall Coefficient of Concordance) and at the floor are identical. In the vertical direction there is a change of order across the flight conditions in levels at the floor with the forward flight conditions now having greater levels than the hover or ground condition. This appears to be reflected in the order of the vertical levels at the head. There is thus limited evidence to suggest that, at this frequency, the horizontal translational movements of the head are to some extent consequent upon similar movements by the airframe. At 28 Hz the flight conditions are ranked the same in all three axes both at the floor and at the head. The rankings at the head are, again, significantly concordant ($p < 0.01$) among the eight pilots (see Table 4.2).

The preceding information suggests that there is a relation between head vibration and aircraft vibration and that this relation is similar for most, or all, of the eight pilots. It would therefore seem reasonable to assume that the condition for maximum and minimum head vibration will coincide with that for maximum and minimum aircraft vibration. For the majority of the peak frequencies the vibration is most during forward flight at 115 knots. The minimum vibration flight condition is less well defined but of the four conditions used in the present trial the hover results in lower vibration at most frequencies.

Table 4.3 shows the r.m.s. accelerations corresponding to the mean spectrum levels, averaged over the eight pilots, for the hover and 115 knots flight conditions. Figures 4.2a, b and c show the greatest and least levels of vibration experienced by any pilot during the 115 knot flight condition. The range of vibration acceleration levels (up to about 10-to-1) portrayed by these graphs reflects the magnitude of individual differences among the eight pilots. The vibration level does not exceed 0.03 g r.m.s. at any of the peak frequencies for any pilot during flight.

7 Hz	HEAD VIBRATION			FLOOR VIBRATION		
	F & A	Lat.	Vert.	F & A	Lat.	Vert.
Ground	4	4	2	4	4	2
Hover	1	1	1	1	1	1
100kts	2	2	3	2	2	4
115kts	3	3	4	3	3	3

TABLE 4.2a: Overall Rankings of 7 Hz Components described by the Kendall Coefficient of Concordance, (a) at the head and (b) at the floor, for Trial Two

28 Hz	HEAD VIBRATION			FLOOR VIBRATION		
	F & A	Lat.	Vert	F & A	Lat.	Vert.
Ground	1	1	1	1	1	1
Hover	2	2	2	2	2	2
100kts	3	3	3	3	3	3
115kts	4	4	4	4	4	4

TABLE 4.2b: Overall Rankings of 28 Hz Components described by the Kendall Coefficient of Concordance, (a) at the head and (b) at the floor, for Trial Two

Hz.	HOVER g x 10^{-3}			115 knots g x 10^{-3}		
	F & A	Lat.	Vert.	F & A	Lat.	Vert.
1	8.3	10.8	8.0	2.5	1.1	2.8
2	7.7	9.5	6.3	5.0	2.6	5.7
3	5.7	5.3	5.7	5.9	3.1	6.3
4	5.4	4.4	6.2	5.5	2.9	9.0
5	5.4	3.5	5.5	5.8	2.8	9.8
6	5.3	2.8	4.5	6.7	2.8	7.6
7	12.9	3.3	7.6	20.6	7.1	18.9
8	4.7	2.2	3.2	8.8	2.5	5.8
9	4.1	2.0	2.9	6.9	2.1	4.8
10	3.3	1.9	2.9	4.7	1.6	3.3
14	2.4	1.0	1.4	3.0	0.8	3.3
21	1.6	0.6	0.8	2.0	0.5	1.6
28	7.8	3.5	3.1	15.9	7.1	9.0
33	2.8	0.7	3.0	2.1	0.7	2.7
37	2.7	0.7	3.2	2.1	0.6	2.3
56	1.3	0.5	1.1	3.5	1.4	2.3

TABLE 4.3: Mean Levels of Pilot Head Vibration averaged over 8 Pilots

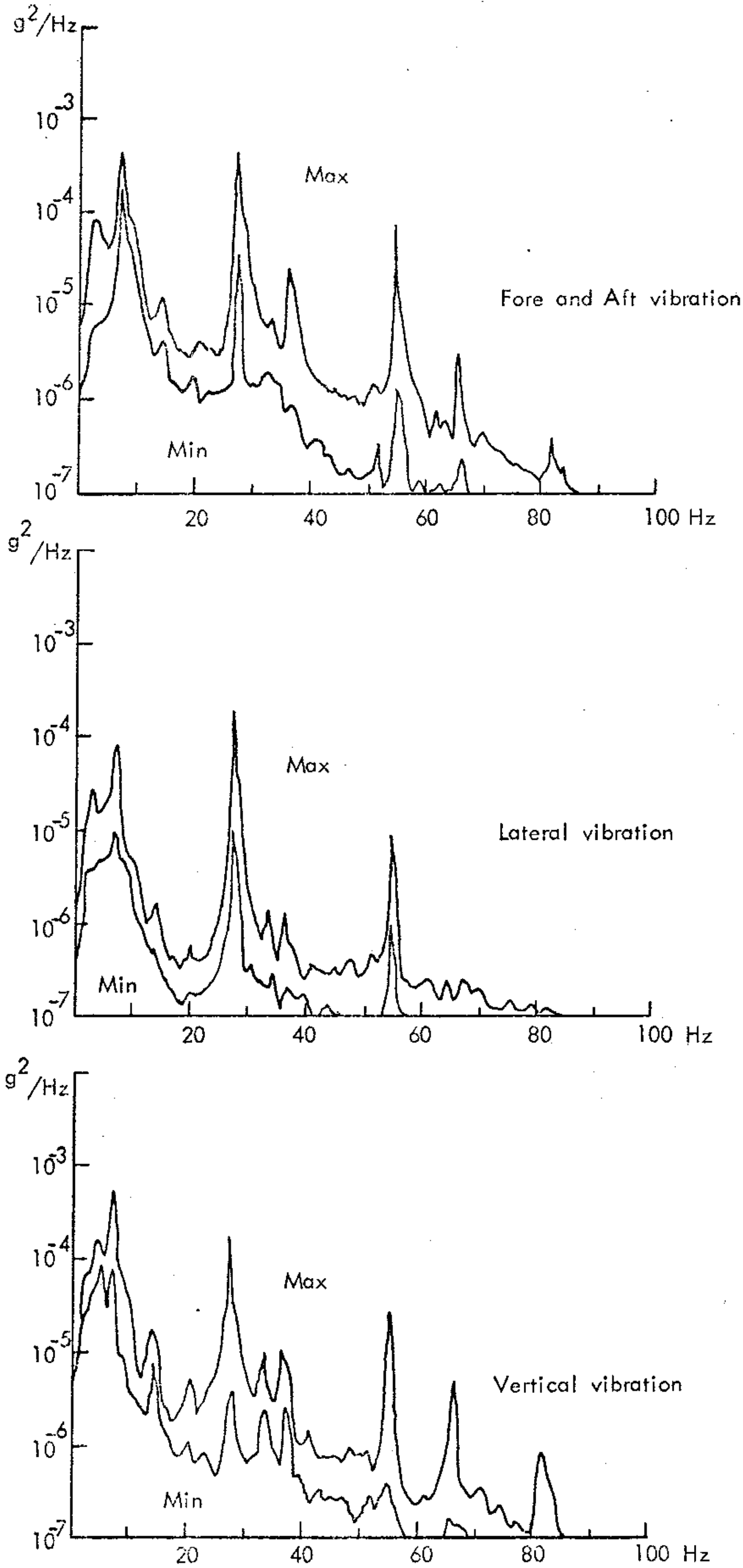


FIG 4 2 MAXIMUM AND MINIMUM VIBRATION ACCELERATION SPECTRA AT THE HEADS OF EIGHT PILOTS FLYING A SCOUT HELICOPTER AT 115 kts.

4.4.4 Effect of Vibration Axis on Vibration Level

The measured vibration levels at the seven peak frequencies at the head of each pilot have been ranked across axes during the 115 knots forward flight condition. The sums of ranks (over the eight pilots) and the Kendall Coefficient of Concordance have been determined. The ranking of the sums of ranks and the levels of significance of the ranking are shown in Table 4.4.

The high 28 Hz fore and aft vibration level at the floor of this aircraft (Table 4.1) during 115 knots forward flight results in a change from the overall rankings across axes found in Trial One (Table 3.3). At other frequencies the rankings at the floor are similar to those found earlier.

The overall rankings at the head show that lateral vibration is least at almost all of the frequencies. Indeed at 33, 37 and 66 Hz it is generally below 0.001 g r.m.s. The rankings of the fore-and-aft components are generally less than the vertical components. Thus, although fore-and-aft and lateral floor vibration are somewhat similar, the fore-and-aft head motion is greater than the lateral head motion. At 28 Hz there is a larger motion of the head in the fore-and-aft direction than vertically although the reverse occurred at the floor. It would appear that the fore-and-aft head motion is most often proportionately greater than would be expected from an inspection of the relative levels in each axis at the floor. This might well be attributed to two alternative factors. A nodding motion of the head could contribute to, but not be solely caused by, the measured fore-and-aft head motion. Alternatively, the impact of the seat back support could possibly be expected to be greatest in raising the levels of fore-and-aft head motion.

	7 Hz	14 Hz	28 Hz	56 Hz	33 Hz	66 Hz	37 Hz
F & A	2.5	2	3	3	3	3	3
Lat.	1	1	1.5	1	1	1	1
Vert.	2.5	3	1.5	3	3	3	3
W =	0.7656	1.0000	0.4219	0.4844	0.8125	0.8906	0.8906
p <	0.01	0.001	0.05	0.02	0.001	0.001	0.001

TABLE 4.4: Ranking of Sums of Ranks of Mean Head Vibration across Axes

4.4.5 Effect of Pilot on Vibration Level

An attempt has been made to rank the vibration level at each peak in the frequency spectrum across the eight pilots for each of the vibration axes in the 115 knot flight condition. The low levels of 33, 66 and 37 Hz vibration in the horizontal directions made this difficult and so ranks will only be presented for harmonics of the blade passage frequency (i.e. 7, 14, 28 and 56 Hz). (See Table 4.5a, b and c).

There are no significant correlations between the vibration rankings at any of the frequencies in one axis with the same frequency in another axis. (This is interesting and suggests that the triaxial vibration of the head is excited from three separate sources or via three separate transmission paths). Within both vertical and fore-and-aft axes there is a significant correlation ($p < 0.05$) between the rankings of the 7 Hz and 14 Hz components when tested by means of the Spearman Rank Correlation Coefficient. There are no other significant (i.e. $p < 0.05$) correlations within axes.

The questionnaires (see Appendix 4) completed by the pilots have yielded data on their physical characteristics. This data is also summarised in Appendix 4. Selected aspects of this data have been ranked across pilots and the Kendall Rank Correlation Coefficient determined to ascertain relationships between the chosen physical dimensions of the pilots (see Table 4.6). The highest correlation is between weight and hip circumference ($p < 0.005$) and there is also a significant correlation between the circumference around the forehead and the head circumference around chin and bregma ($p < 0.05$). There appears to be a non-significant correlation ($p < 0.1$) between height and weight, height and leg length and height and hip circumference.

An attempt has been made to determine any correlation between the selected physical characteristics of the pilots and the measured levels of vibration at their heads during 115 knot flight. Table 4.7 shows the relevant Kendall Correlation Coefficient for the harmonics of the main rotor frequency in each of the three vibration axes.

There are significant correlations between body size (height, $p < 0.05$; weight, $p < 0.02$; and hip circumference $p < 0.005$) and the magnitude of the 7 Hz vertical components at the heads of the eight pilots. There are, however, no correlations at 14 Hz or the other two frequencies in the vertical direction. There are no significant ($p < 0.05$) correlations at any frequency in the

	P1	P2	P3	P4	P5	P6	P7	P8
7 Hz	1	4	4	4	8	6	7	2
14 Hz	2	5	1	7	6	4	8	3
28 Hz	8	2	1	3	5	6	4	7
56 Hz	1	7	4	8	5	6	2	3

TABLE 4.5a: Ranking of Measured Levels of Fore-and-Aft Head Vibration Across Pilots at 115 knots.

	P1	P2	P3	P4	P5	P6	P7	P8
7 Hz	6	5	4	1	2	8	3	7
14 Hz	3	8	6	4	1	7	5	2
28 Hz	2	6	4	8	1	5	3	7
56 Hz	1	5	2	7	4	3	8	6

TABLE 4.5b: Ranking of Measured Levels of Lateral Vibration across Pilots at 115 knots.

	P1	P2	P3	P4	P5	P6	P7	P8
7 Hz	7	8	1	3	4	6	2	5
14 Hz	4	8	2	5	3	6	7	1
28 Hz	6	5	1	7	4	3	8	2
56 Hz	6	7	4	3	5	1	8	2

TABLE 4.5c: Ranking of Measured Levels of Vertical Vibration across Pilots at 115 knots.

Body Size	Height	Weight	Hip Circumference	Leg Length	Forehead
Height	-	-	-	-	-
Weight	+0.4642*	-	-	-	-
Forehead	+0.1428	+0.2500	-	-	-
Hip circumference	+0.5000*	+0.7857*****	-	+0.1428	+0.2142
Leg length	+0.5000*	+0.1785	-	-	-0.0714
Chin/ bregma	-	-	-	-	+0.5357**

* = $p < 0.1$; ** = $p < 0.05$; *** = $p < 0.02$; **** = $p < 0.01$;

***** = $p < 0.005$.

TABLE 4.6: Kendall Rank Correlation Coefficient (τ) indicating the correlation between the physical characteristics of the eight pilots in Trials Two and Three

Head Vibration	Frequency	Height	Weight	Hip Circumference	Leg Length	Chin/ bregma	Forehead
F & A	7 Hz	+0.2857	-0.0357	+0.2142	+0.2142	-0.1786	-0.3214
	14	+0.0714	+0.0357	+0.0714	+0.01785	+0.2500	-0.1071
	28	-0.1785	-0.2500	+0.1428	+0.1428	+0.2500	+0.0357
	56	-0.3214	-0.2500	-0.2857	-0.1428	-0.0714	-0.4642*
Lat.	7 Hz	-0.2142	-0.3928	-0.3571	-0.0714	+0.0714	+0.1785
	14	0.0000	+0.1071	-0.0714	+0.2142	-0.0714	+0.1428
	28	-0.2857	+0.0357	-0.0714	-0.2142	+0.4285*	+0.0357
	56	0.0000	+0.1785	+0.2142	-0.2142	+0.4642*	+0.1071
Vert.	7 Hz	-0.5714**	-0.6785***	-0.7857*****	-0.1785	-0.0714	-0.0357
	14	0.0000	-0.1071	-0.2142	+0.2857	+0.0714	+0.0357
	28	+0.1428	+0.2500	+0.1428	+0.2142	+0.4285*	+0.0357
	56	+0.1428	+0.2500	+0.1428	0.0000	0.0000	+0.2500

* = $p < 0.1$; ** = $p < 0.05$; *** = $p < 0.02$; **** = $p < 0.01$;

***** = $p < 0.005$.

TABLE 4.7: Kendall Rank Correlation Coefficient (τ) indicating the Correlation between the Measured Level of Head Vibration and Physical Characteristics of the Pilots. (Negative values imply decreasing vibration with increasing body size.)

lateral and fore-and-aft axes although there may be some association between the forehead measurement and the fore-and-aft 56 Hz component ($p < 0.10$). There would also appear to be evidence of those pilots with the larger chin/bregma measurements having greatest levels of vertical and lateral 28 Hz and lateral 56 Hz components.

Apart from those involving the chin/bregma the above correlations all imply that head vibration is less for the 'larger' pilots. However, there has been shown to be a tendency for the pilots of greater weight to have the greatest hip circumference, height, etc. It is therefore necessary to 'partial-out' the effect of hip circumference, for example, if we are to determine whether the correlation between the vibration level and weight is a true correlation or largely dependent on the correlation between hip circumference and weight. This has been achieved by means of the Kendall Partial Rank Correlation Coefficient. The values of the correlation coefficient (with and without 'partialling-out') between the 7 Hz vertical component and height, weight and hip circumference are shown in Table 4.8. It is not possible to associate levels of significance to values of the partial rank correlation coefficient, so the values with and without partialling out must be compared to deduce the relative dependence of the given correlation on the factor which is partialled out.

It appears that the above correlations between the vibration level and body weight, and vibration level and hip circumference are not very dependent on height. On the other hand, the correlation between vibration level and weight is very much dependent on hip circumference and the correlation between vibration level and height is dependent on both weight and hip circumference. The apparent conclusion is that 7 Hz vertical head vibration is primarily dependent on hip circumference and only incidentally correlated with body height and weight.

The correlations so far determined are for the 115 knot flight condition where most of the spectral components are greater than in the other flight conditions. Table 4.9 shows the values of the Kendall Correlation Coefficient for 7 Hz vertical head vibration in all four flight conditions. On the ground and during 100 knots forward flight the correlations with height, weight and hip circumference are in the same direction (i.e. negative) but at far lower levels of significance than in 115 knots flight. In the hover,

115 knots	Height		Weight		Hip Circumference	
	not part'd out	part'd out	not part'd out	part'd out	not part'd out	part'd out
7Hz vert v height	-	-	-0.5714	-0.3943	-0.5714	-0.3334
7Hz vert v weight	-0.6785	-0.5685	-	-	-0.6785	-0.1599
7Hz vert v hip c.	-0.7857	-0.7035	-0.7857	-0.5558	-	-

TABLE 4.8: Values of the Kendall Partial Rank Correlation Coefficient showing Correlations between body size and the level of 7 Hz vertical head vibration during 115 knot flight.

Flight Condition	Height	Weight	Hip Circumference	Leg Length	Chin/bregma	Forehead
115 kts	-0.5714**	-0.6785***	-0.7857*****	-0.1785	-0.0714	-0.0357
100 kts	-0.2857	-0.1786	-0.3215	0.0000	+0.2857	+0.4285*
Ground	-0.5000*	-0.3215	-0.3572	-0.2143	+0.3572	+0.3215
Hover	+0.4285*	+0.4642*	+0.6429***	-0.1072	+0.2857	+0.3214

* = $p < 0.1$; ** = $p < 0.05$; *** = $p < 0.02$; **** = $p < 0.01$;

***** = $p < 0.005$

TABLE 4.9: Values of the Kendall Rank Correlation Coefficient showing Correlation between body size and the level of 7 Hz vertical vibration during different flight conditions

however, there is a considerable difference with the correlation now being positive - that with the measure of hip circumference being significant at $p < 0.02$.

There would thus appear to be the surprising finding that at 115 knots 7 Hz vertical head vibration is most for the 'larger' pilots while during the hover the same vibration component is most for the 'smaller' pilot.

It is reasonable to assume that the above changes in the sign of the correlation coefficient reflect a change in the principal means whereby the head is caused to vibrate in the two conditions. There is no evidence of the pilots' adopting different postures in the two conditions, and the correlations in the on-the-ground condition suggest that changes in aircraft altitude are not the solution. The effect may therefore be due to changes in the physical characteristics of the vibration.

It is likely that the vibration of the head will arise from vibration transmitted to the body both via the bottom and back portions of the pilot's seat. The relative importance of the contributions from these two sources will, to some extent, depend on levels of vibration in the various axes. This possibility is used in Section 5.4.2 to develop a highly tentative model which might explain the observed differences between pilots in different flight conditions.

4.4.6 Subjective Assessment of the Vibration

The pilots ranked the four flight conditions according to their opinion of the amounts of vibration as mentioned in Section 4.2.5. Table 4.10 shows the rankings with low numbers indicating least vibration. Statistical tests were applied to the tables of ranks consequent upon the objective and subjective vibration data as described in Section 3.4.5. In this case the objective data are in the form of levels of head vibration.

There is significant concordance across pilots when the objective rankings of both 7 and 28 Hz vertical head vibration are tested for similarity to the subjective rankings of measured vibration level. However, although the pilots agree on the order they do not rank the condition correctly in terms of the actual levels of vibration at these frequencies. As before, it is not therefore surprising to find that the subjective assessments ranked against flight condition also exhibit significant concordance ($p < 0.01$) and that the coefficient of concordance is greater than when subjective ranks are ranked against measured vibration levels.

The absence of any simple physical basis for the subjective rankings of the pilot in the first trial is thus confirmed by the responses of the eight pilots in the present trial.

The eight pilots were also asked "How would you describe the vibration during this experiment?". Five of the pilots replied that it was normal for the Scout aircraft. Pilot P.1 said that it was average for the Scout - comfortable at 100 knots; Pilot P.5 commented that there was slightly more than normal 4R (28 Hz) and Pilot P.6 said that it was normal for the Scout except that it was unusual to find it vibrating so much on the ground.

	P1	P2	P3	P4	P5	P6	P7	P8
Ground	3	3	4	2	3	4	2	1
Hover	1	1	3	1	1	1	1	2
100 knots	2	2	1	3	2	2	3	3
115 knots	4	4	2	4	4	3	4	4

TABLE 4.10: Subjective Ranking of Amount of Vibration in Different Flight Conditions. (low rankings indicate less vibration)

These comments are not easily reconciled with the measured levels of vibration. The objective measurements indicate that the vibration of the aircraft differed in several respects from a normal Scout (see Section 4.4.1). The aircraft had less than normal 28 Hz vertical vibration during 100 knot flight and greater than normal fore and aft 28 Hz vibration. This could possibly reconcile the opinions of Pilots P.1 and P.5 but at the expense of completely undermining any absolute value of their comments.

5. THE MEASUREMENT OF THE TRANSMISSION OF VERTICAL HELICOPTER VIBRATION FROM SEAT TO HEAD

5.1 Aims

To determine the frequency dependence of the ratio of head to seat vibration in the Scout helicopter and relate this transmissibility to physical characteristics of the pilots. Also, to measure levels of vibration on the pilot's seat.

5.2 Experimental Method

5.2.1 Aircraft and Pilots

The same aircraft and pilots were used as in the previous trial (see sections 4.2.1 and 4.2.2).

5.2.2 Flight Condition

In view of the knowledge which has been gained as to the changes in the vibration spectra with flight condition it was thought to be possible to experiment in the hover only without being unable to evaluate the validity of extrapolating the results to other conditions. The repeated measurement of vertical head vibration for the eight pilots in the hover also enables a test of the repeatability of the head vibration measurement.

5.2.3 Mounting of Accelerometers

Two accelerometers were used in this trial. One was mounted in the tri-axial block on the end of the bite-bar so as to be sensitive to vertical vibration of this bar. The other was mounted within the rectangular aluminium bar (see Section 2.2) so as to respond to vertical movements of this bar when it is placed between the pilot and his seat. (A similar technique employing boxes has been successfully tested by Miwa & Yonekawa (1971) under laboratory conditions).

5.3 Analysis Method

The basic analysis of the vibration waveforms was identical to that described in Section 4.3. However, an attempt was also made to determine the ratio of vertical vibration at the head to vertical vibration at the seat. This was achieved by computation of the square roots of the power spectrum levels at head and seat for each pilot (to produce r.m.s 'g' spectra) and then dividing the r.m.s. acceleration at each frequency point in the head vibration spectrum by the corresponding acceleration at the seat. The function so obtained is defined as the pilot transmissibility function.

Graphical outputs of the two power spectrum levels and the two acceleration spectrum levels were obtained together with plots of the transmissibility functions for each pilot. As before, mean power spectrum and acceleration spectrum levels were plotted. In addition linear plots of the mean power spectrum level and the standard deviation of this level over the eight pilots were obtained.

The digital printout consisted of the computed r.m.s. head and seat acceleration values over the frequency range together with the corresponding values of the transmissibility. The mean power spectrum levels of the eight pilots were also printed. Also a statistical description of the two vibration waveforms was obtained.

5.4 Results

The values of transmissibility that will be quoted in this Section should be recognised as being dependent on the definition of transmissibility. Apart from the variabilities that might be introduced by the use of computational procedures other than those described in Section 5.3, the shape of the transmissibility function may be expected to be particulary dependent on the positioning of the accelerometer on the head (this is to be expected particularly as a consequence of any angular head motions - e.g. nodding) and the unknown importance of the back-rest to the pilot's seat.

5.4.1 Mean Vibration Levels and Transmissibility

Figure 5.1 shows both the mean head and seat acceleration spectra plotted to a logarithmic scale. Figure 5.2 shows the same data on a linear scale adjacent to the plots of the standard deviation of the head and seat vibration on an identical scale. It is clear that the mean head r.m.s. acceleration is less than that of the seat at high frequencies (above about 15 Hz) but greater than the seat at low frequencies (below about 10 Hz). In consequence the greatest mean r.m.s. acceleration component at the seat is at 28 Hz but at the head it is at 7 Hz. The values of the standard deviation can be seen to be large, especially for the head vibration where they are of comparable size to the mean values. This represents a large intersubject variability.

The mean levels of vibration from 1 to 40 Hz are shown again in Table 5.1. For comparison purposes the mean vertical head levels obtained during the second trial are also shown, together with the mean levels of transmissibility. The latter are obtained by division of the mean head acceleration levels by the corresponding seat acceleration levels, and are shown again in Figure 5.3. It is to be observed that this transmissibility

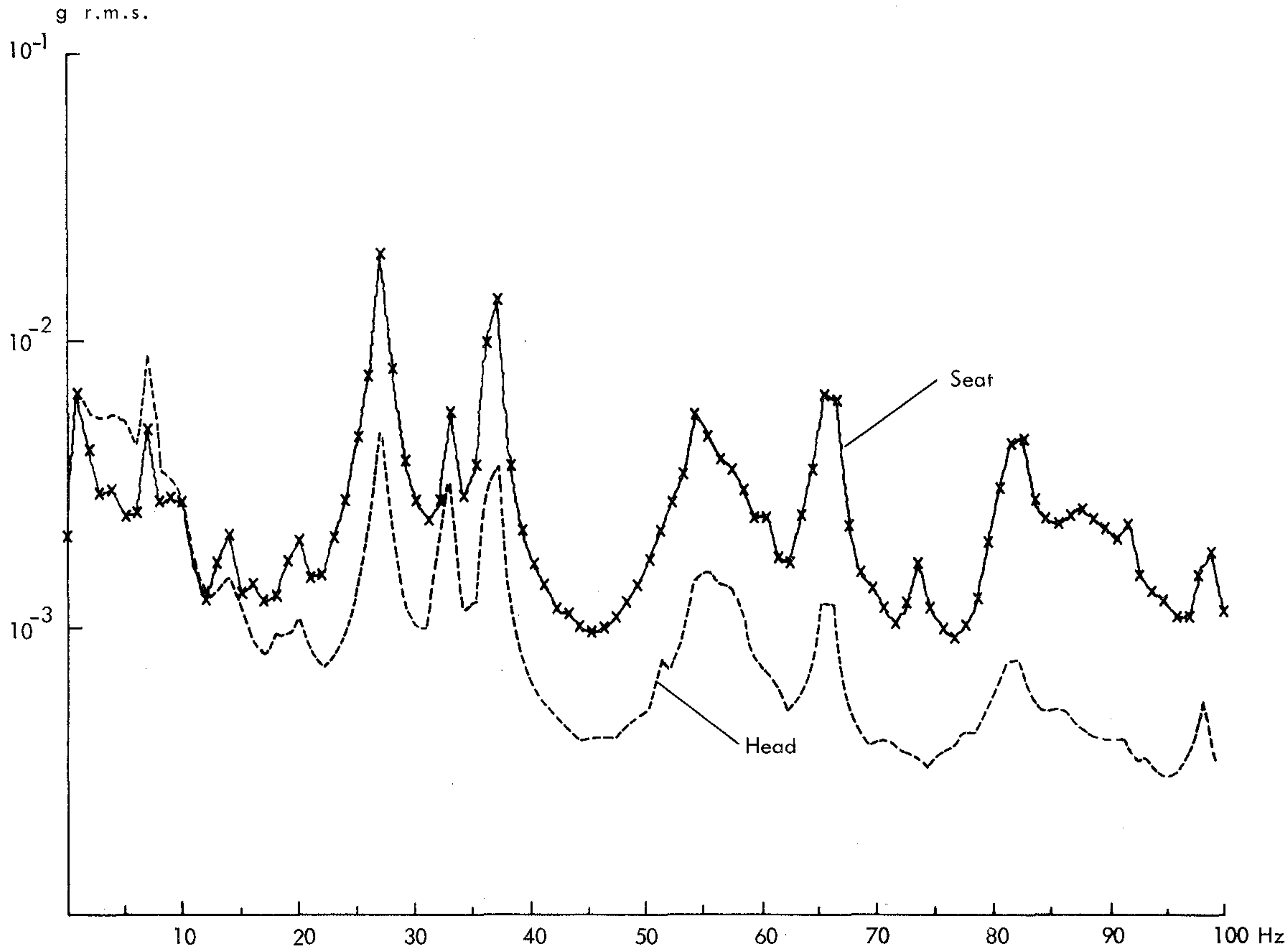


FIG 5.1 MEAN VERTICAL VIBRATION AT THE SEAT AND HEAD OF EIGHT PILOTS DURING THE HOVER

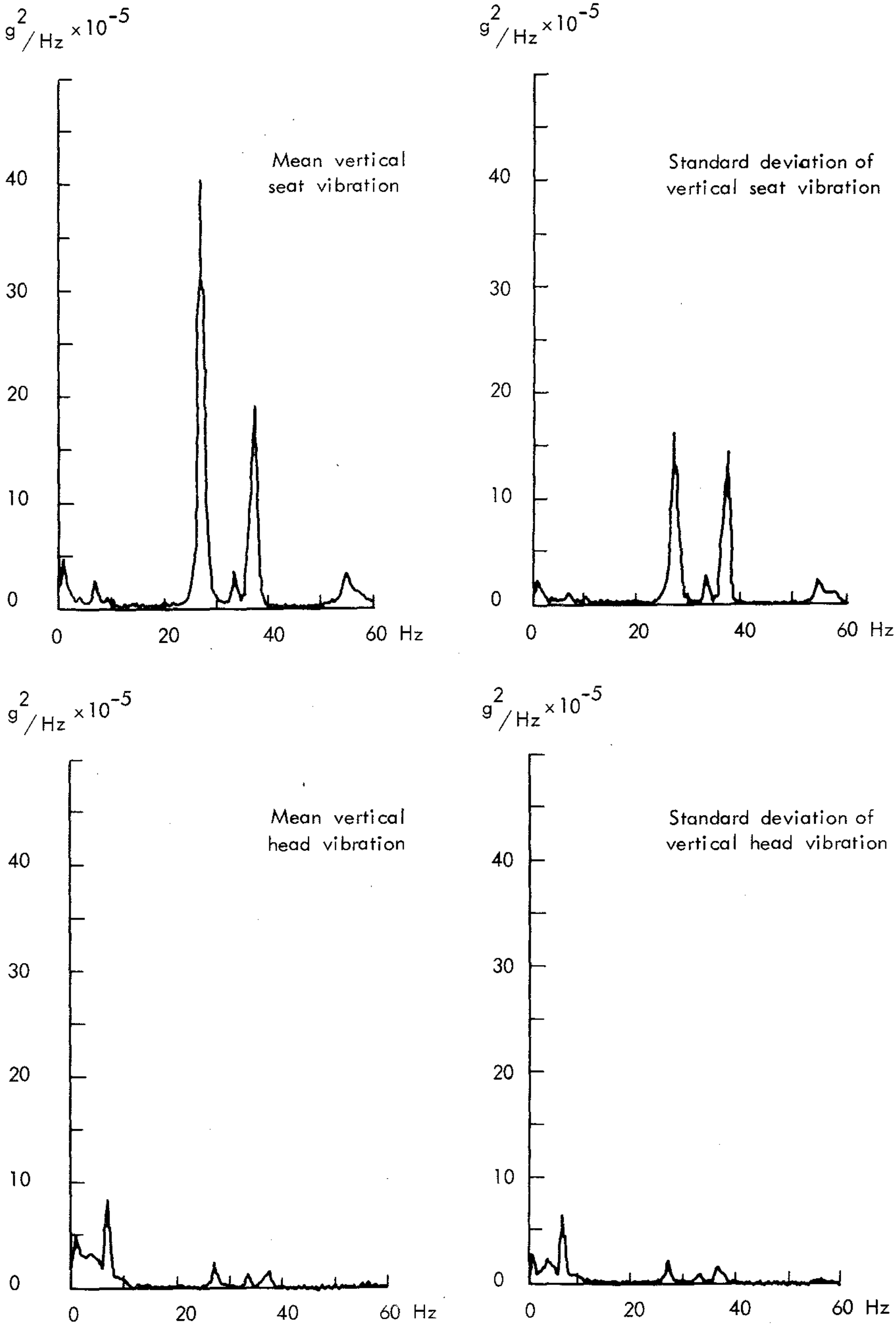


FIG. 5.2 MEAN AND STANDARD DEVIATION OF VERTICAL VIBRATION AT THE SEAT AND HEAD OF EIGHT PILOTS DURING THE HOVER.

function exhibits a distinct peak at around 5 Hz which represents greater levels of vertical vibration at the head than at the seat.

5.4.2 Effect of pilot on vibration levels and transmissibilities

Table 5.1 has indicated the mean and standard deviation of the vibration levels and transmissibilities. In general the differences between pilots at one frequency are of the order of two or three to one in terms of vibration acceleration level. An attempt has been made, therefore, to correlate the vibration data with the physical characteristics of the pilots. Table 5.2 shows values of the Kendall Rank Correlation Coefficient calculated for seat and head vibration levels and transmissibility at selected frequencies. At 7, 14, 28 and 33 Hz all values of the coefficient are entered. At other frequencies the values are only presented where they are of some particular interest. All correlations with significance levels of $p < 0.1$ are shown.

It is immediately obvious that there are again positive correlations between the level of 7 Hz vertical head vibration and height, weight and hip circumference. In addition there is now confirmation of a positive correlation ($p < 0.05$) between head size (around the chin to bregma) and the level of 28 Hz vertical head motion. There is also evidence of the level of 21 Hz head vibration being negatively correlated with body size although this is not significant ($p < 0.1$) and, in view of the low level of the 21 Hz component, unlikely to be of any practical importance.

We may now consider the effect of pilots with different physical characteristics on the measured level of vertical vibration at the horizontal pilot/seat interface. At 7 Hz there is a positive correlation with body size which is particularly evident between hip circumference ($p < 0.01$) and vibration level. At most other frequencies, the correlation coefficient takes a negative value although only at 21 Hz is it significantly negative. (This high negative correlation of seat vibration at 21 Hz with height, weight, and hip circumference, may well explain the negative correlation observed between these aspects and head vibration). There are a few high values of the correlation coefficient suggesting a possible relation between head size and seat vibration. However, these are not significant at $p < 0.05$ and their occurrence is likely to be entirely due to chance.

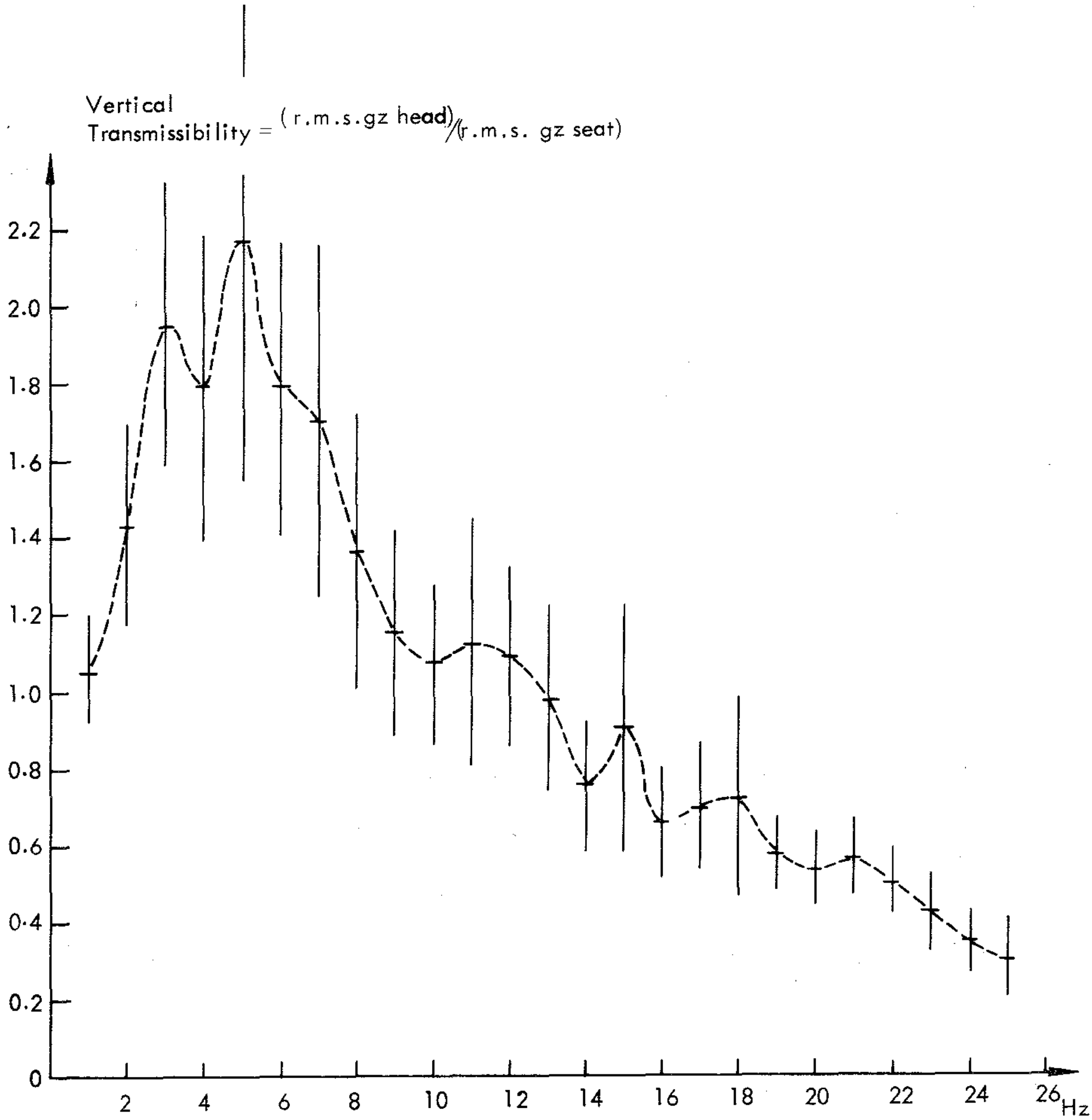


FIG 5·3 MEAN AND STANDARD DEVIATION OF TRANSMISSIBILITY OF EIGHT PILOTS IN SCOUT HELICOPTER

f	SEAT VIBRATION		HEAD VIBRATION		TRANSMISSIBILITY		TRIAL TWO
	MEAN g x 10^{-3}	S.D. g x 10^{-3}	MEAN g x 10^{-3}	S.D. g x 10^{-3}	MEAN	S.D.	MEAN VERT. HEAD VIB'N g x 10^{-3}
1	6.47	1.38	6.82	1.78	1.05	0.14	7.98
2	4.08	0.97	5.65	0.65	1.43	0.26	6.28
3	2.82	0.60	5.41	1.08	1.95	0.37	5.67
4	2.95	0.58	5.36	1.72	1.79	0.39	6.18
5	2.43	0.51	5.13	1.45	2.16	0.62	5.52
6	2.44	0.47	4.32	0.82	1.79	0.37	4.49
7	4.89	0.85	8.47	3.26	1.70	0.46	7.59
8	2.61	0.61	3.50	1.13	1.36	0.36	3.18
9	2.81	0.33	3.25	0.82	1.15	0.26	2.96
10	2.58	0.85	2.70	0.73	1.07	0.20	2.88
14	2.06	0.48	1.51	0.28	0.75	0.17	1.43
21	1.97	0.33	1.05	0.24	0.56	0.10	0.79
28	19.64	4.30	4.61	1.81	0.24	0.10	3.13
33	5.27	2.17	3.24	1.13	0.61	0.45	2.97
37	13.97	4.45	3.96	1.34	0.29	0.10	3.22

TABLE 5.1: Mean and Standard Deviation of Vertical Seat Vibration, Vertical Head Vibration and Transmissibility in Trial Three compared with Mean Vertical Head Vibration in Trial Two (8 pilots, Scout, hover).

F Hz	HEIGHT			WEIGHT			HIP CIRCUMFERENCE			LEG LENGTH			CHIN/BREGMA			FOREHEAD		
	Seat	Head	Trans	S	H	T	S	H	T	S	H	T	S	H	T	S	H	T
1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
5	-0.50 (.)	+0.18	+0.29	-0.32	+0.38	+0.54 (.)	-0.43 (.)	+0.18	+0.36	–	–	–	–	–	–	-0.38	+0.29	+0.50 (.)
6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
7	+0.50 (.)	+0.64 (...)	+0.43 (.)	+0.61 (..)	+0.25	+0.04	+0.71 (....)	+0.43 (.)	+0.07	+0.14	+0.29	+0.43 (.)	+0.43 (.)	0.00	-0.29	+0.46 (.)	+0.18	+0.11
8	-0.43 (.)	-0.14	+0.14	-0.32	-0.39	-0.25	–	–	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
14	-0.36	0.00	+0.43 (.)	-0.18	-0.14	+0.32	-0.21	0.00	+0.35	-0.39	+0.11	+0.50 (.)	-0.29	+0.14	+0.50 (.)	-0.54 (.)	-0.32	+0.11
21	-0.71 (....)	-0.50 (.)	–	-0.61 (..)	-0.54 (.)	–	-0.64 (...)	-0.43 (.)	–	-0.50 (.)	–	–	-0.14	+0.29	+0.43 (.)	–	–	–
28	-0.14	0.07	-0.11	-0.04	+0.04	+0.04	-0.21	0.00	+0.07	+0.25	+0.21	0.00	0.00	+0.57 (..)	+0.65 (...)	+0.25	+0.11	+0.04
33	+0.07	-0.50 (.)	-0.29	+0.11	-0.11	-0.4	-0.04	-0.21	-0.21	-0.21	-0.29	+0.07	-0.54 (.)	+0.50 (.)	+0.50 (.)	-0.18	+0.18	+0.11
37	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

. = $p < 0.1$; .. = $p < 0.05$; ... = $p < 0.02$, ... = $p < 0.01$.

TABLE 5.2: Values of the Kendall Rank Correlation Coefficient showing the Correlation between Body Size and Levels of (a) Vertical Vibration at the seat; (b) Vertical Vibration at the head; and (c) Body Transmissibility.

The only significant correlation between body size and transmissibility is a positive correlation ($p < 0.02$) between the chin to bregma measurement and transmissibility at 28 Hz. The transmissibility data at 14, 21 and 33 Hz also suggests ($p < 0.10$) that the ratio of head vibration to seat vibration is greatest for those pilots with the largest heads (as indicated by the chin/bregma measurement).

Returning our attention to the 7 Hz component, it is of interest to see that, while there is at this frequency a positive correlation between seat vibration and height, weight and hip circumference, there are negative correlations at frequencies above and below 7 Hz. The larger bodied pilots, who have the greatest vertical head vibration in the hover, also appear to have the greatest levels of vibration at the seat in this flight condition. Indeed the lack of significant correlations with transmissibility at 7 Hz suggests that the high levels of head vibration may well be due to increased seat vibration with these larger pilots at this frequency. Conversely, the data suggests that at 5 Hz and 8 Hz the seat vibration is greatest for the smaller pilots.

A possible explanation of the data presented here and in Section 4 may stem from the assumption that larger bodied pilots receive more vibration through the back portion of the seat and this contribution is of greatest significance when vertical vibration is relatively low. This source of 7 Hz vibration may thus be expected to have been important during the hover where there was little vertical vibration of this frequency. Large pilots would thus suffer greater transmission of vibration from the back of the seat during the hover and in consequence vibration of their bodies (at the head and horizontal pilot/seat interface) will be greater than that for smaller pilots. At frequencies either side of 7 Hz the vibration is of a random nature and greatest in the vertical direction. According to the hypothesis, the back portion of the seat is then less important and vertical transmission via the horizontal pilot/seat interface predominates and is less for the larger pilots. Similarly at the other peak frequencies and in other flight conditions, the vertical aircraft vibration levels are predominant in determining vertical vibration on the seat.

The above conjecture is merely one of many possible explanations. Consequently although it is in broad agreement with the observed data, it is largely unverified and cannot be offered as a finding of the study.

5.4.3 Effect of Seat Cushion on Vibration at the Pilot/Seat Interface

The mean levels of vertical vibration measured at the seat have been shown in Table 5.1. The transmissibility data indicate that over the frequency range 1 to 40 Hz the mean seat vibration varies between approximately one third and two times the vertical head vibration. The levels of vibration on the seat may be expected to be highly dependent upon the frequency response of the seat cushion. Unfortunately it was not practicable to record the vibration level below the seat cushion during each part of the present trial. However, an estimate of the seat transmissibility may be obtained by comparing the mean levels recorded on the seat during the trial with the corresponding peak levels recorded before and after the trial on the floor of the aircraft below the pilot's seat. Table 5.3 shows this data and it may be seen that at all of the frequencies the levels on the seat are a fairly large fraction of the levels measured at the floor. (The high value at 37 Hz is possibly associated with the high level of the fore-and-aft vibration at this frequency).

HOVER	7Hz	14Hz	28Hz	33Hz	37Hz
Ratio of peak seat acceleration to peak floor acceleration	0.84	0.25	0.46	0.27	0.72

TABLE 5.3: Ratio of Peak Levels of Mean Vertical Seat Vibration to Peak Levels of Vertical Floor Vibration during the Hover (vibration not measured simultaneously at the two points).

For the aircraft used in this experiment it is apparent that during the hover the 7 Hz vertical vibration of the pilot's heads was slightly greater than the magnitude of this component at the floor. On the other hand, the acceleration level of the 28 Hz component at the head was less than 10% of the level at the floor during the hover. The approximate ratios of vertical head acceleration to vertical floor acceleration (not measured simultaneously) for the 7 Hz and 28 Hz component in Trial Two are shown in Table 5.4.

	r.m.s. g head / r.m.s. g floor 7 Hz	r.m.s. g head / r.m.s. g floor 28 Hz
Ground	0.84	0.25
Hover	1.1	0.07
100 knots	0.70	0.05
115 knots	0.72	0.06

TABLE 5.4: Ratio of Peak Levels of Vertical Head Vibration to Peak Levels of Vertical Floor Vibration during Different Flight Conditions

The 7Hz (hover) and 28 Hz(ground) components appear to depart from the general trend. These are both low vibration conditions and the increased ratio of head to floor vibration may well be associated with a nonlinearity in transmission or the presence of non-vertical vibration.

6. DISCUSSION

It is not the intention to consider the possible effects of the measured levels of vibration in the present document. The following discussion is merely to place the data in the context of previous measurements and current vibration standards.

6.1 Previous Helicopter Vibration Measurements

The Scout helicopter is manufactured by Westland Aircraft Ltd. who have a contractual requirement to conduct limited vibration measurements on the floor of aircraft prior to delivery. Typical measurements of the 7 Hz vertical, and the 28 Hz and 56 Hz fore and aft, lateral and vertical components will be found in Westland Aircraft Test Report DI 50001/9. It would appear that the vibration levels presented in the above document are of a similar order of magnitude to those reported here. A direct comparison of the scatter of results is not practicable but it would appear that the manufacturers have also found considerable variations in the vibration levels between aircraft. The present experiments do not allow comment on the manufacturers statement that no IR (7 Hz) vibration "of any consequence" is present in the fore-and-aft and lateral axes of the aircraft.

Triaxial floor vibration at 28 Hz in two Scout helicopters during 100 kt forward flight have also been measured by Lovesey (1971). The levels reported in both aircraft and all three axes lie outside the ranges of comparable levels found in the present trials. The levels quoted by the above author are, in fact, average levels of the complete vibration waveform over some frequency range and are not, therefore, directly associated with the most predominant frequency. The floor vibration levels determined in the present study are broadly typical of those quoted for other helicopters (e.g. W.L. Jones (1970), R.W. Balke (1970), B. Rosenberg (1966), W.C.Hixson & J.I. Niven (1969)) although the precise spectra are, of course, highly particular to each aircraft type. (This may be seen from a comparison of the vibration spectra for the Scout (Figure 3.1) with the spectra obtained by the present author from a Sioux AH Mk.I during 80 knot forward flight and shown in Appendix 5).

The head vibration of helicopter pilots has been measured by Rosenberg (1966) and Seris and Auffret (1965). In both studies the measured levels of head vibration are greater than those presented here. This appears to be partly a consequence of higher levels of low frequency vibration at the seats of those aircraft studied by these authors. However, the excessive peak levels (approximately ± 0.3 g at 11 and 15 Hz) that are quoted in these reports raise doubts as to the validity of their methods of attaching the accelerometers to the head and helmet.

6.2 Aircraft Vibration Standards

The current United Kingdom vibration standards for rotor craft and all fixed wing aircraft are specified in volume 3 of AvP 970. A curve is given which defines the "threshold of unpleasant vertical vibration" above 9 Hz and is reproduced in Figure 6.1. It has been suggested by Jones (1965) that, since extrapolation of this curve to zero frequency is to specify a limit unlikely to be achieved, a compromise is necessary. He suggests the level be fixed at 0.1 g (presumably ± 0.1 g) up to a frequency of 20 Hz and thereafter the curve of AvP 970 should be followed. In practice the AvP 970 limits appear to have more impact on the design of helicopter instrumentation than the provision of a suitable working environment for the crew. The present and previous studies have shown that AvP 970 is exceeded by the Scout helicopter at 28 Hz.

In a recent review, Gabel et al (1971) have observed that the United States joint military flying qualities specification (MIL-H-8501A) is well into the discomfort region at all frequencies. This is a constant acceleration limit of ± 0.15 g for flight conditions up to cruising speed (± 0.20 g at higher speeds) and would appear to reflect the state of helicopter engineering rather than human response to vibration. The U.S. Navy Aeronautical Requirements specification (AR-56) is a modification of MIL-H-8501A such that below 10 Hz the level should not exceed ± 0.05 g.

It has been shown by Jackson and Grimster (1971) that the vibration of helicopters straight from the production line is accepted by test pilots when at no frequencies are there components greater than about ± 0.7 inches per second. This vibration level is that recorded on some rigid structure within the cockpit so that actual levels experienced by the pilot will differ from ± 0.7 ins/sec as a consequence of the frequency response of the seating, etc. Cooper (1957) proposed a pilot opinion rating system that is now occasionally employed during the production testing of aircraft. The nine or ten point scale is based on the following table :

	Adjective Rating	Numerical Rating	Description	Primary Mission Accomplished?	Can be Landed
Normal Operation	Satisfactory	1	Excellent, includes optimum	Yes	Yes
		2	Good, pleasant to fly	Yes	Yes
		3	Satisfactory, but with some mildly unpleasant characteristics	Yes	Yes
Emergency Operation	Unsatisfactory	4	Acceptable, but with unpleasant characteristics	Yes	Yes
		5	Unacceptable for normal operation	Doubtful	Yes
		6	Acceptable for emergency condition only	Doubtful	Yes
No Operation	Unacceptable	7	Unacceptable even for emergency condition	No	Doubtful
		8	Unacceptable - dangerous.	No	No
		9	Unacceptable - uncontrollable	No	No
	Unprintable	10	*!*!*!*!*! Did not get back to report	What mission?	

TABLE 6.1: Pilot Opinion Rating System (proposed by G.E. Cooper 1957)

There are no known satisfactory attempts to correlate these ratings with vibration levels recorded in helicopters.

The proposals of the International Organisation for Standardisation (1968) are likely to be considered as a basis for the specification of aircraft vibration limits. These proposals are necessarily based on meagre and diffuse information but at least attempt to consider the human response to the vibration environment. The vibration levels are those at the point of entry to the body, but, for example, do not allow for vibration at points other than the horizontal surface of the seat of a sitting person. If the many deficiencies of the I.S.O. proposals are overlooked, it would be reasonable to arbitrarily select the 4-hour fatigue decreased proficiency levels as the limiting condition for many helicopters.

The vibration levels of the peak in the frequency spectrum at the floor of the eight aircraft in Experiment One did not exceed the 8-hour fatigue decreased proficiency curves in either the fore-and-aft or lateral axes during any flight condition. (Indeed the levels were generally below the 8-hour reduced comfort boundary). In the vertical axis the mean levels of the 7 Hz and 28 Hz components are near or above the corresponding 8-hour F.D.P. levels during all forward flight conditions and a few aircraft exceed the 28 Hz 4-hour F.D.P. level during 100 knot and 115 knot forward flight. However, there is some degree of isolation provided by the seat so that the levels experienced by the pilot do not exceed the 4-hour F.D.P.

The I.S.O. curves have been seen to be time-dependent. However, it must be emphasised that there is as yet little research data to support the nature of the time dependency. Indeed, many of the flying tasks are unlikely to be time-dependent in the manner specified by the I.S.O. proposals and the curves in their present form cannot therefore be used to predict time dependency of general flying performance. Furthermore, the very general nature of the relevant criteria (fatigue decreased proficiency) cannot be directly applied to predict proficiency at any particular task.

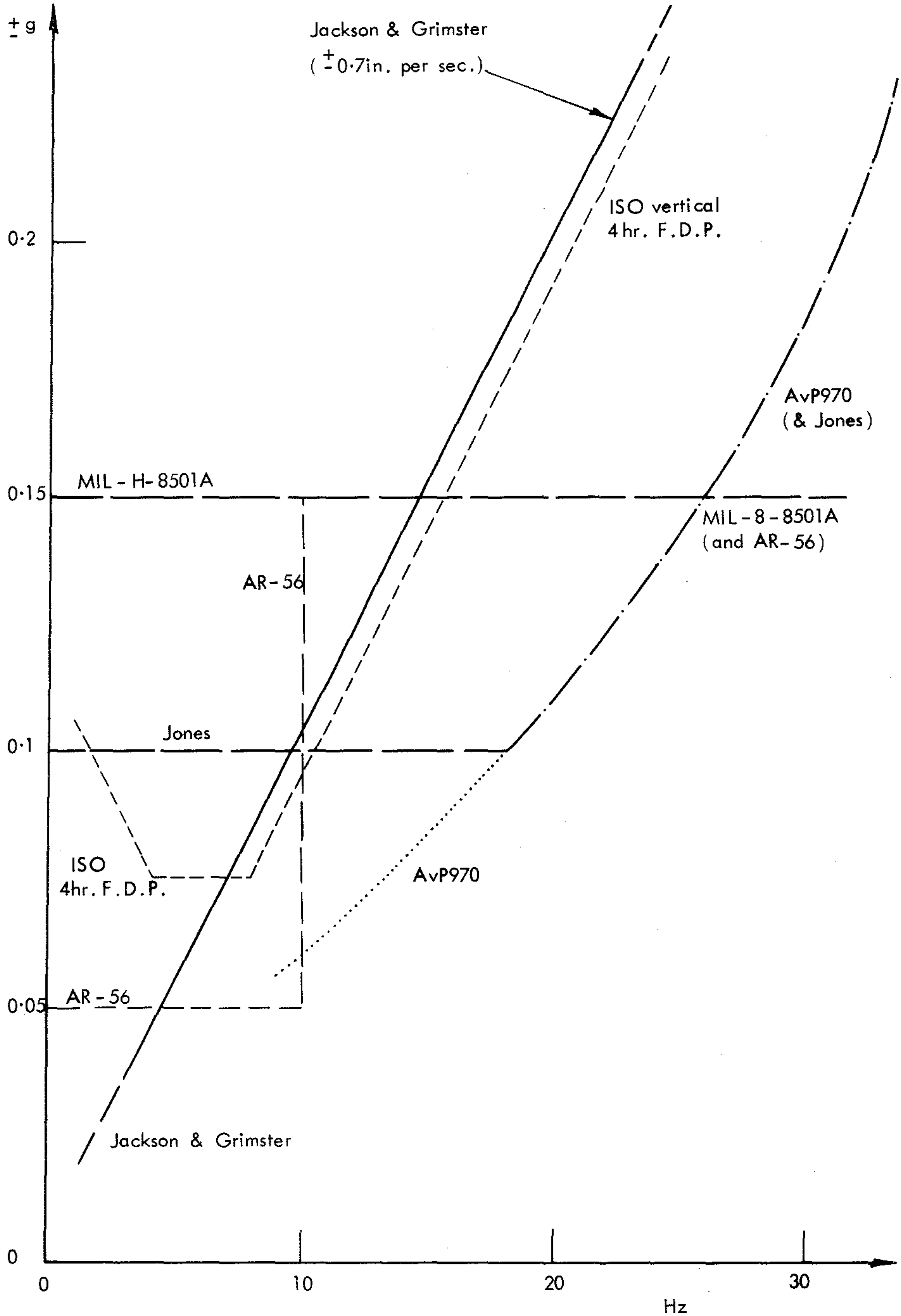


FIG. 6.1 SOME CURRENT (AND PROPOSED) AIRCRAFT VIBRATION LIMITS.

7. CONCLUSIONS

7.1 Scout Helicopter Vibration

1. Levels of triaxial floor vibration in the Scout helicopter are shown in Appendix 2.
2. The helicopter vibration is predominantly associated with the frequencies of the rotary mechanised parts although these are not the only motions present. Other low frequency vibration was also present and may be of greater significance during adverse weather conditions.
3. The vibration levels associated with certain frequencies change according to flight condition and the direction of change is similar for most of the aircraft tested.
4. Vibration levels associated with the main rotor frequencies (7, 14, 28 and 56 Hz) are greatest in the vertical axis. Except at 28 Hz, they are least in the lateral axis.
5. The levels associated with the tail rotor frequency (33 Hz) are greatest in the fore-and-aft axis and least in the lateral axis.
6. The relative levels of vibration in the three axes are similar in most flight conditions.
7. There is a relation between the levels of lateral and fore-and-aft vibration, but not vertical vibration, at the main rotor frequency (7 Hz).
8. There appears to be little relation between the magnitudes of any one of the main rotor frequencies (7, 14, 28 and 56) and any of the other main rotor frequencies.
9. The peak levels have been found to exceed those specified in Av.P 970.

7.2 Pilot Vibration

1. Levels of triaxial vibration of pilots in the Scout helicopter are shown in Table 4.3.
2. Levels of vertical seat vibration and vertical vibration transmissibility are shown in Table 5.1.
3. The level of head vibration at a single frequency did not exceed 0.03 g r.m.s. in any axis.
4. Lateral head vibration is less than vertical and horizontal vibration at almost all frequencies.
5. Fore-and-aft head motion is of a similar magnitude to vertical motion.

6. There is no evidence that head vibration in one axis is related to the levels of vibration at the same frequency in another axis.

7. In forward flight at 115 knots 7 Hz vertical head vibration was significantly less ($p < 0.005$) for pilots with the largest measures of hip circumference.

8. In the hover, 7 Hz head vibration was significantly greater ($p < 0.02$) for pilots with the largest measures of hip circumference.

9. Vertical head vibration is greater than vertical seat vibration at frequencies between about 2 and 10 Hz.

10. Pilots with larger heads had significantly greater ($p < 0.02$) levels of transmissibility of 28 Hz vertical vibration to the head.

11. The 7 Hz vibration level at the pilot/seat interface during the hover was significantly greater ($p < 0.01$) for those pilots with a large hip circumference.

12. Pilots were not, in general, good judges of the relative amounts of vibration in different flight conditions.

8. RECOMMENDATIONS

1. More knowledge of the environment within helicopters will aid the application of research data on human response to environmental stress to the helicopter situation. (Such information will also contribute to our knowledge of human response). It is recommended that comprehensive data should be obtained during the production testing of aircraft. The information collected over a period of time will be of use to both aircraft engineers and research workers. Such data may, for example, help determine the vibration conditions acceptable to pilots and thereby establish design limits. (This has been attempted by Jackson and Grimster (1971)).

2. Aircraft vibration levels, as they affect the pilot and crew, should be studied early in the life of an aircraft and consideration should be given to possible improvements to the pilot's vibration environment.

3. In addition to normal flight conditions, the characteristics of helicopter vibration during adverse weather conditions and during the transition and other transient stages of flight should be determined.

4. Consideration should be given to the design of easy-to-use vibration measuring equipment which would indicate the vibration level of the principal frequencies for a particular aircraft.

5. There are a number of other factors likely to affect the levels of vibration on pilots. These include the seat harness and helmets. (The helmet type worn in the present experiments has a mass approximately one-third of the mass of the pilots' heads). The effects of the design of such equipment upon the vibration situation should be considered.

6. More research is needed to be able to predict the dynamic response of the body from a knowledge of the vibration input. In particular there is a need to know the 6-axis motion of the head consequent upon selected vibration inputs to the body.

7. A study should be made of the angular head motions of pilots during flight. For some frequencies of vibration these motions are likely to be associated with vestibular and visual disturbance yet there is little knowledge of their characteristics.

8. There is little knowledge of the manner in which seat design affects the acceptability of vibration. It is recommended that the transmission of vibration to pilots from real seats be studied with a view to the design of improved seating. The occurrence of pilot backache should also be considered in relation to seat design. (In relation to the possible isolation of pilots from vibration the comments by Randle (1957) regarding the utilisation of vibration cues should be considered).

9. The present study suggests that pilots may not be efficient detectors of abnormal levels of vibration. If the acceptability of vibration in operational aircraft is to be largely determined by subjective methods, it would be desirable to compare such methods with the merits of alternative objective measuring systems.

10. New systems introduced to the helicopter often require the pilot to perform complex visual operations. While it is possible to perform such tasks adequately as a static simulation, they can easily become quite incompatible with the in-flight helicopter environment. The direct effects of vibration on performance should be given particular consideration when devising artificial pilot aids.

11. Helicopter vibration has been shown to be a multiaxis and multiple frequency motion. Currently available research data is too inadequate for any extrapolation of the limited knowledge on human response to vertical sinusoidal motion to human response when subjected to realistic helicopter vibration. Research on human response to multiaxis vibration with complex waveforms (non-sinusoidal) is greatly needed.

12. The time dependent effects of helicopter vibration (and vibration in general) deserve detailed study. It is recommended that a study should be made of the interaction between the duration of vibration exposure and performance at a simulated pilot task. A visual search task is one which appears suitable and has particular relevance to many flying situations. Such studies should also consider the separate effects of other environmental conditions and the possibility of interactions between stresses.

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APPENDIX ONE

PERFORMANCE OF VIBRATION RECORDING SYSTEM

1. Accelerometers

Three Endevco 2265-20 strain gauge accelerometers were used. These each have a mass of 6 grams, transverse sensitivity of less than 5% and thermal sensitivity change less than 2% of output per 10 degree Centrigrade temperature change.

2. Amplifiers

Each of the accelerometers formed part of a resistance bridge across the input of a D.C. amplifier. Each channel incorporated an optional high pass filter (3 dB at 0.03 Hz) and a fixed low pass filter (3 dB at 400 Hz).

3. Frequency Multiplex System

The outputs from the amplifiers were converted to three frequency modulated signals with different centre frequencies (3125 Hz, 5000 Hz and 6875 Hz) and then multiplexed with a constant frequency reference (12000 Hz) by means of a Dynatel Data System encoding package type DAE/3/T/O. The resulting single channel of information was recorded on a Sony TC 800A direct tape recorder for later decoding. The system incorporated low pass filters (nominally 3 dB at 100 Hz). The response was investigated in more detail and is summarised in the following table :

TABLE A.1

	-3dB POINT	RESPONSE TO 75 Hz
Channel 1	118 Hz	± 0.6 dB
Channel 2	100 Hz	± 0.5 dB
Channel 3	100 Hz	± 0.4 dB

4. Frequency Response of Accelerometer-Amplifier System

The response of the accelerometer-amplifier system was largely determined by the 400Hz low pass filter. Calibration over the range 5 to 400 Hz by sinusoidal vibration at a level of 0.7 g r.m.s. indicated a response of -0.8 dB at 80 Hz and -1.2 dB at 120 Hz and -3 dB at 400 Hz.

5. System Linearity

The accelerometer-amplifier system was tested for linearity by means of 20 Hz sinusoidal vibration over the range ± 0.05 g to ± 2.0 g. Non-linearity was found to be better than 5%.

The linearity of the frequency modulation system was determined by the application of d.c. voltages over the range ± 1 volt. All three channels were found to amplify positive signals more than negative signals with a consequent discontinuity at zero volts. The maximum deviation (for any channel) from the best fit straight line through the origin reflects an error of less than 10%.

6. Phase

The relative phase between channels of the accelerometer-preamplifier system was determined over the frequency range 1.4 Hz to 150 Hz. Maximum phase differences were 8 degrees below 5 Hz and 4 degrees from 5 Hz to 150 Hz. The maximum phase difference between channels of the multiplex unit in the range 0 to 100 Hz was 11 degrees.

APPENDIX TWO

TRIAL ONE - SCOUT FLOOR VIBRATION LEVELS

(See Section 3.4.1)

FORE AND AFT VIBRATION

		7 Hz	14 Hz	28 Hz	33 Hz	37 Hz	54 Hz	66 Hz
HOVER	Av.P(g^2x10^{-6})	108	11	429	1573	272	188	367
	S.D.P.	57	6	220	1687	559	154	303
	Mean 'g'	0.010	0.004	0.021	0.040	0.017	0.014	0.019
	Max g	0.015	0.005	0.027	0.065	0.041	0.023	0.029
	Min g	0.008	0.002	0.013	0.011	0.004	0.008	0.008
100 knots	Av.P.	75	33	2747	1114	263	206	1143
	S.D.P.	32	15	1700	979	352	80	831
	Mean 'g'	0.009	0.006	0.052	0.033	0.016	0.014	0.039
	Max g	0.012	0.007	0.074	0.050	0.036	0.019	0.052
	Min g	0.007	0.003	0.032	0.015	0.010	0.012	0.011
60 knots	Av.P.	74	32	2373	1102	218	397	234
	S.D.P.	35	31	2448	1071	340	176	121
	Mean 'g'	0.009	0.006	0.049	0.033	0.015	0.020	0.015
	Max g	0.011	0.010	0.088	0.052	0.032	0.026	0.021
	Min g.	0.005	0.002	0.021	0.012	0.006	0.011	0.009
115 knots	Av.P.	94	64	5978	1260	228	370	2064
	S.D.P.	53	12	2728	1160	249	130	1343
	Mean 'g'	0.010	0.009	0.078	0.036	0.015	0.019	0.045
	Max g	0.015	0.009	0.110	0.055	0.029	0.024	0.066
	Min g	0.007	0.007	0.057	0.016	0.010	0.016	0.018
30^{o} turn	Av.P.	74	42	3154	1032	239	331	569
	S.D.P.	50	26	1831	1046	356	153	288
	Mean 'g'	0.009	0.006	0.056	0.032	0.016	0.018	0.029
	Max g	0.013	0.010	0.077	0.052	0.033	0.024	0.030
	Min g	0.003	0.003	0.010	0.012	0.007	0.013	0.013
AUTO.	Av.P.	91	52	1694	958	250	1159	128
	S.D.P.	121	58	1253	860	279	524	31
	Mean 'g'	0.010	0.007	0.041	0.031	0.016	0.034	0.011
	Max g	0.020	0.012	0.063	0.050	0.029	0.044	0.013
	Min g	0.003	0.003	0.023	0.012	0.007	0.024	0.009
GROUND	Av.P.	355	32	133	1066	246	179	138
	S.D.P.	497	58	94	1060	295	83	90
	Mean 'g'	0.019	0.006	0.016	0.033	0.016	0.013	0.012
	Max g	0.034	0.013	0.017	0.052	0.030	0.017	0.018
	Min g	0.005	0.002	0.004	0.009	0.005	0.009	0.006

TABLE A.2a

LATERAL VIBRATION

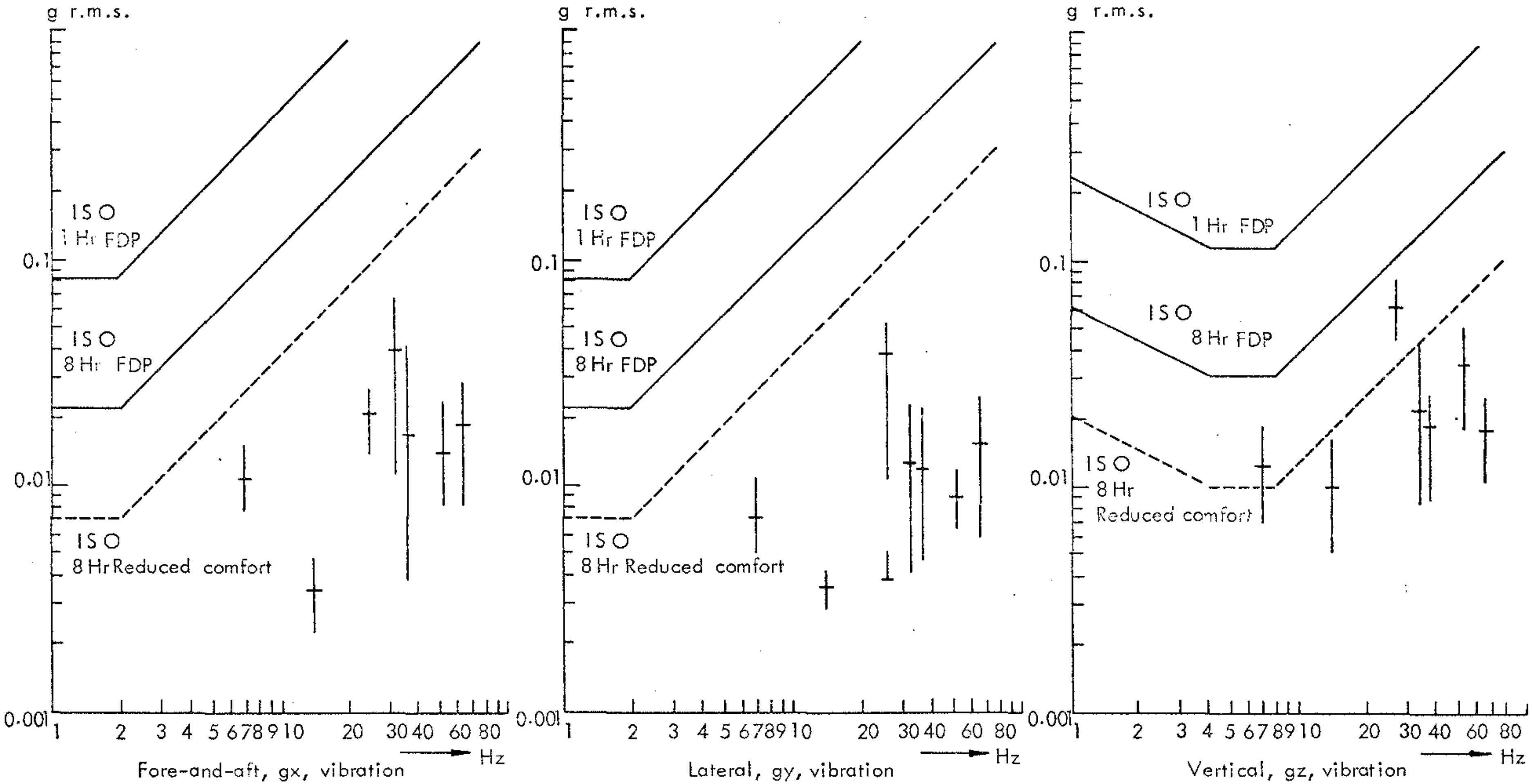
		7 Hz	14 Hz	28 Hz	33 Hz	37 Hz	54 Hz	66 Hz
HOVER	Av.P. ($g^2 x 10^{-6}$)	51	13	1439	148	141	78	231
	S.D.P.	31	4	870	178	151	33	190
	Mean 'g'	0.007	0.004	0.038	0.012	0.012	0.009	0.015
	Max g	0.011	0.004	0.051	0.028	0.021	0.016	0.024
	Min g.	0.005	0.003	0.010	0.004	0.005	0.006	0.006
100 knots	Av.P.	79	27	7964	204	197	203	1382
	S.D.P.	21	8	3063	161	131	84	1729
	Mean 'g'	0.009	0.005	0.089	0.014	0.014	0.014	0.037
	Max g	0.011	0.006	0.108	0.022	0.019	0.020	0.074
	Min g	0.007	0.004	0.046	0.009	0.007	0.012	0.014
60 knots	Av.P.	36	15	2392	143	199	264	299
	S.D.P.	15	10	840	164	177	226	309
	Mean 'g'	0.006	0.004	0.049	0.012	0.014	0.016	0.017
	Max g	0.008	0.006	0.059	0.020	0.026	0.026	0.031
	Min g	0.005	0.002	0.038	0.005	0.006	0.008	0.007
115 knots	Av.P.	88	70	15387	296	182	413	4886
	S.D.P.	13	30	5252	174	132	130	4906
	Mean 'g'	0.009	0.008	0.124	0.017	0.014	0.020	0.070
	Max g	0.011	0.012	0.156	0.024	0.021	0.025	0.129
	Min g	0.009	0.006	0.098	0.007	0.008	0.014	0.029
30° turn	Av.P.	77	29	8716	177	188	229	440
	S.D.P.	34	13	2213	167	145	95	847
	Mean 'g'	0.009	0.005	0.093	0.013	0.014	0.015	0.021
	Max g	0.012	0.007	0.117	0.022	0.020	0.021	0.050
	Min g	0.007	0.004	0.081	0.005	0.008	0.012	0.008
AUTO.	Av.P.	65	23	2624	131	254	177	95
	S.D.P.	33	9	1097	130	266	85	54
	Mean 'g'	0.008	0.005	0.051	0.016	0.016	0.013	0.010
	Max g	0.011	0.006	0.066	0.021	0.027	0.018	0.013
	Min g	0.005	0.004	0.035	0.006	0.005	0.008	0.005
GROUND	Av.P.	199	40	300	136	329	37	156
	S.D.P.	170	48	308	128	370	7	115
	Mean 'g'	0.014	0.006	0.017	0.012	0.018	0.006	0.013
	Max g	0.024	0.012	0.029	0.020	0.034	0.007	0.020
	Min g	0.006	0.002	0.005	0.005	0.006	0.005	0.007

TABLE A.2b

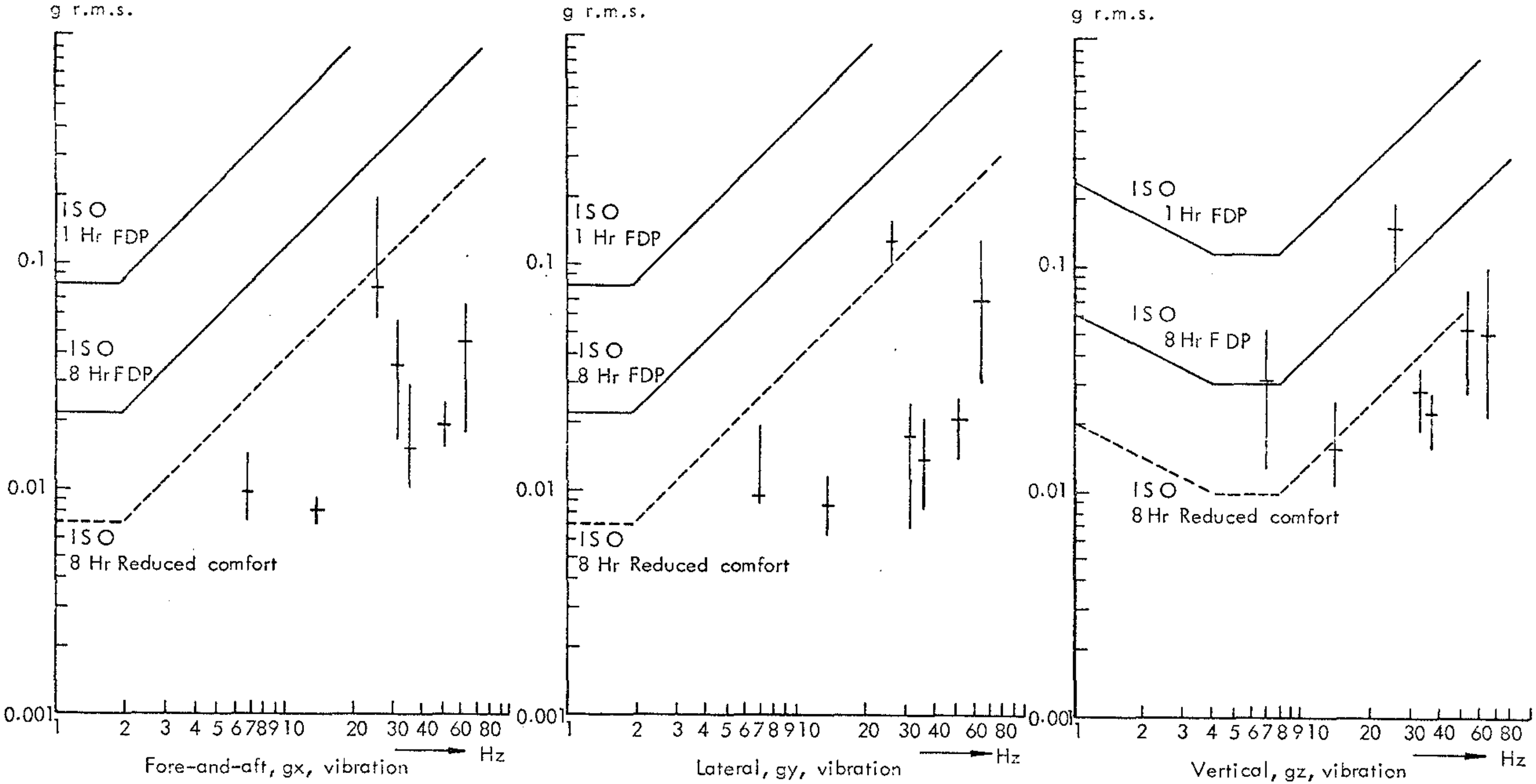
VERTICAL VIBRATION

		7 Hz	14 Hz	28 Hz	33 Hz	37 Hz	54 Hz	66 Hz
HOVER	Av.P. ($g^2 x 10^{-6}$)	159	103	4117	520	384	1301	337
	S.D.P.	107	82	1696	642	212	811	216
	Mean 'g'	0.013	0.010	0.064	0.023	0.020	0.036	0.018
	Max g	0.019	0.017	0.086	0.044	0.026	0.052	0.025
	Min g	0.007	0.005	0.045	0.009	0.009	0.018	0.011
100 knots	Av.P.	775	202	16059	732	590	3450	1856
	S.D.P.	627	170	8634	511	406	1736	1910
	Mean 'g'	0.028	0.014	0.0127	0.027	0.024	0.057	0.043
	Max g	0.044	0.025	0.180	0.042	0.038	0.077	0.070
	Min g	0.009	0.010	0.088	0.014	0.013	0.034	0.020
60 knots	Av.P.	311	185	7944	552	584	4760	432
	S.D.P.	258	193	5253	353	332	3326	501
	Mean 'g'	0.018	0.014	0.089	0.024	0.024	0.069	0.021
	Max g	0.028	0.025	0.122	0.034	0.034	0.102	0.036
	Min g	0.008	0.006	0.055	0.011	0.009	0.021	0.009
115 knots	Av.P.	1009	263	23780	852	549	3026	2761
	S.D.P.	856	190	11821	400	188	1778	3317
	Mean 'g'	0.032	0.016	0.154	0.029	0.023	0.055	0.053
	Max g	0.055	0.026	0.201	0.037	0.029	0.082	0.102
	Min g	0.013	0.011	0.101	0.019	0.017	0.029	0.023
30° turn	Av.P.	817	236	16076	599	528	5669	808
	S.D.P.	868	287	9344	439	254	2881	548
	Mean 'g'	0.029	0.015	0.127	0.025	0.023	0.075	0.028
	Max g	0.053	0.030	0.170	0.039	0.031	0.102	0.042
	Min g	0.012	0.006	0.076	0.012	0.010	0.046	0.016
AUTO.	Av.P.	852	173	6776	660	675	3052	230
	S.D.P.	828	186	2381	624	457	921	108
	Mean 'g'	0.029	0.013	0.082	0.026	0.026	0.055	0.015
	Max g	0.050	0.025	0.104	0.042	0.039	0.072	0.020
	Min g	0.010	0.006	0.051	0.010	0.013	0.047	0.009
GROUND	Av.P.	261	67	610	496	618	1205	184
	S.D.P.	272	43	553	771	408	903	95
	Mean 'g'	0.016	0.008	0.025	0.022	0.025	0.035	0.014
	Max g	0.026	0.012	0.039	0.048	0.036	0.055	0.019
	Min g	0.005	0.004	0.008	0.007	0.012	0.020	0.008

TABLE A.2c



APPENDIX 2: MEANS AND RANGES OF R.M.S. ACCELERATION LEVELS AT THE FLOOR OF EIGHT SCOUT HELICOPTERS DURING THE HOVER



APPENDIX 2 : MEANS AND RANGES OF R.M.S. ACCELERATION LEVELS AT THE FLOOR OF EIGHT SCOUT HELICOPTERS DURING 115 KNOT FORWARD FLIGHT

APPENDIX THREE

FURTHER ANALYSIS OF VIBRATION WAVEFORM

1. Phase

A brief attempt was made to determine the phase relation

(a) between harmonics within each vibration axis, and

(b) between identical frequencies in different axes.

The data obtained for vibration of the floor was found to be inconsistent and, since phase was only of incidental interest, the attempt was eventually discontinued.

2. Triaxial Nature of Vibration

It is possible that vibration could have been recorded in each of the three independent axes without the vibration being truly triaxial. This would require that a single component could be resolved into the three triaxial components found in these trials. Consideration of the spectra which have been presented will reveal that this is not possible.

3. Lissajous Figures

Since the vibration is of a triaxial nature, it is of interest to consider the shape of the Lissajous figures formed by combining the motion in two perpendicular axes. However, the suggestion that there is no simple phase relation between axes or harmonics will mean that the form of such Lissajous figures will be continuously changing. This has been shown for both floor and head vibration and at this stage it is considered that it would be misleading to show Lissajous figures which refer to just one instant of time.

4. Statistical Data

For all inputs of the vibration acceleration data to the Myriad computer various statistical values were computed. These include the values of the positive and negative peaks, the standard deviation, skewness and kurtosis of the signal. In part this information provided a simple check on the fidelity of the input signal and there is no virtue in reproducing the data here. In addition, however, the values may be used, for example, in the calculation of crest factors.

5. Crest Factor

The crest factor is defined as the ratio of the peak value to the r.m.s. value of a signal. For a single sinusoid the crest factor is thus approximately 1.4. The crest factors for the vertical seat vibration and vertical head vibration recorded in Trial Three are shown in Table A.3.

Pilot Number	P1	P2	P3	P4	P5	P6	P7	P8
Vertical Seat Vibration	2.7	2.5	2.3	2.4	3.0	2.8	2.6	2.9
Vertical Head Vibration	3.2	3.1	3.0	2.8	2.9	2.6	2.9	3.0

TABLE A.3: Crest Factors for Vertical Vibration at the Seat and Head (from Trial Three)

At both the head and the seat the crest factor is generally between 2.5 and 3.0.

APPENDIX FOUR

PROCEDURE AND QUESTIONNAIRE FOR TRIAL TWO

This is part of a series of experiments studying the effects of vibration upon helicopter aircrew. The present trial is to determine the levels of vibration transmitted to pilots during flight.

You will be asked to pilot the aircraft for one minute periods in each of the following conditions :

On the ground; hover at 10 ft; forward flight at 100 knots; forward flight at 115 knots.

Please fly the aircraft as accurately as possible during the one minute recording sessions.

For each of the four flight conditions the vibration of your head will be recorded by means of a bite-bar held between your teeth. Please position this bar so that it is firmly held and comfortable before each recording session and hand it to the experimenter after the session. (The sensors on the bite-bar are very delicate, so please handle them carefully). Following these four runs, there will be a five minute pause while some changes are made and a sensor is placed on the floor, on your seat and on the bite-bar. You will then be asked to hover the aircraft for a further minute.

During the recording sessions it would be helpful if you would make as few head movements as practicable - although at all times and in all ways the safe operation of the aircraft should be the first priority.

Are there any questions?

After the flight you will be asked to complete the following.

Please number the four flight conditions in order of the amount of vibration in each, numbering the least as '1' and the most as '4'.

On the ground ______

Hover ______

100 knots ______

115 knots ______

Name: ____________________ Age: ________ years

Approx. flying experience: fixed wing ____ hrs; rotary wing ____ hrs.

Height: ________________ Weight: ______________

Head size: chin/bregma ________ Forehead: ____________

Leg length: __________ Hip circumference: __________

Are you physically fit? Unfit/average fitness/fairly fit/very fit.

Do you take any physical exercise? Never/occasionally/frequently/very frequently

How would you describe the vibration during this experiment? ________________

____

APPENDIX FOUR

PILOT CHARACTERISTICS

(Trials Two and Three)

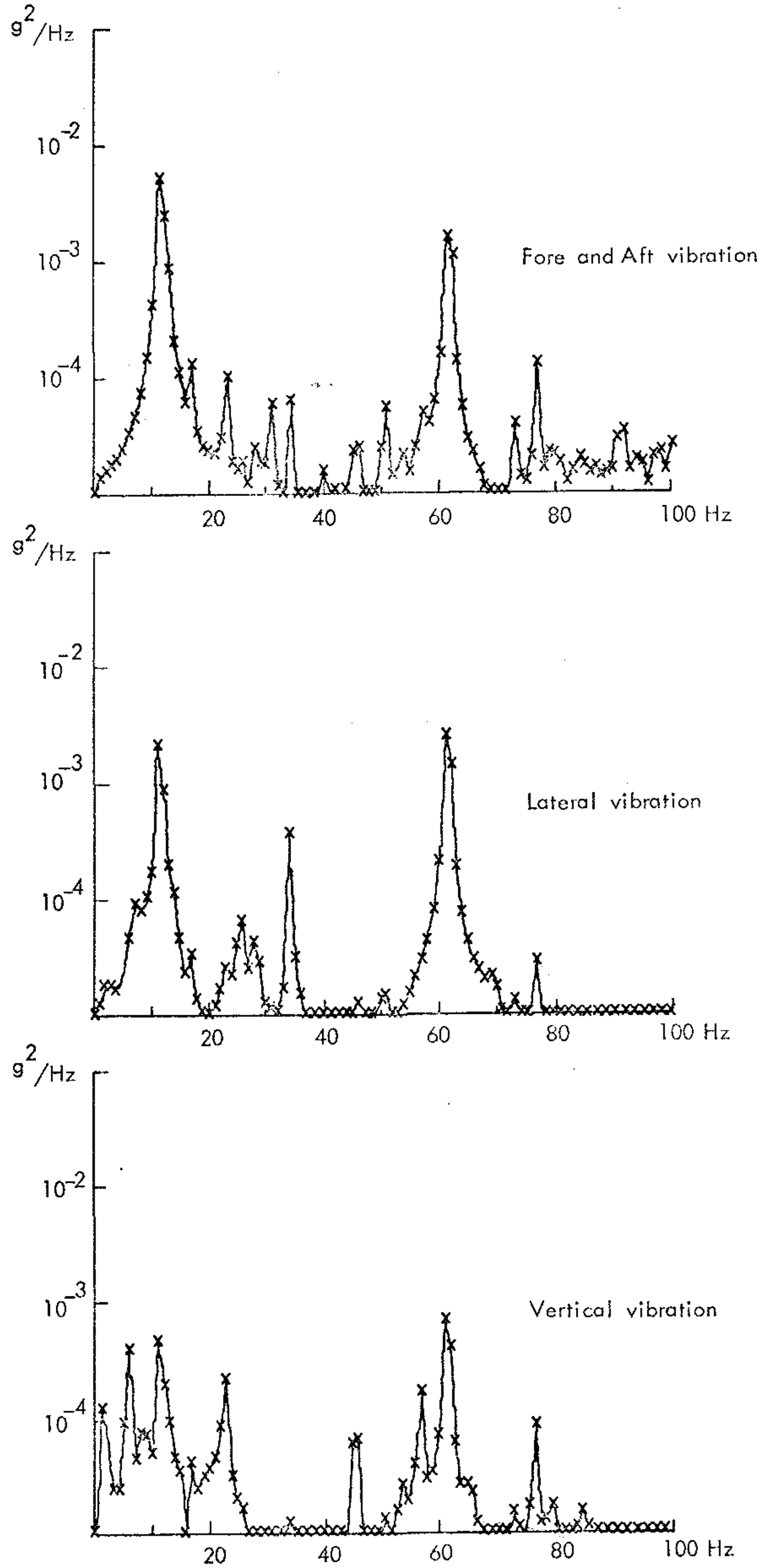
TABLE A.4

	P1	P2	P3	P4	P5	P6	P7	P8
Age (years)	28	31	43	29	30	36	31	32
Rotary Wing (hrs)	1600	1100	1000	1100	1200	360	2000	1140
Height (ft-ins)	6'0"	5'6"	6'1"	6'0"	6'0"	6'0"	6'3½"	5'10"
Weight (lb)	175	165	200	190	170	161	192	170
Chin/bregma (ins)	27"	26½"	26"	27½"	25"	26½"	27½"	27½"
Forehead (ins)	22½"	22½"	22½"	22"	21½"	22¼"	23½"	23"
Leg Length (ins)	33"	29½"	32"	32"	31"	35"	33"	29"
Hip circum.(ins)	40"	38"	42"	40½"	40"	29½"	42"	40"
Fitness	Av.	Fairly fit	Av.	Av.	Av.	Av.	Fairly fit	Fairly fit
Exercise	Freq.	Freq	Occas	Freq	Occas	Occas	Freq	Occas

Av = average

Freq = frequently

Occas = occasionally



APPENDIX 5: VIBRATION ACCELERATION SPECTRA AT THE FLOOR OF A SIOUX HELICOPTER DURING 80kt FORWARD FLIGHT

APPENDIX SIX

OUTLINE DESCRIPTION OF THE SCOUT AH MkI HELICOPTER

Aircraft type	Scout AH MkI
Manufacturer	Westland
Derivation	Saunders Roe
No. of main rotor blades	Four
Diameter of main rotor blades	32 ft 3 in
Construction of main rotor blades	All metal
Diameter of tail rotor	7 ft 6 in
Height to top of rotor hub	8 ft 11 in
Overall length (rotors turning)	40 ft 4 in
Undercarriage	Tubular skids
Unladen weight	3,232 lb
Engine	Bristol Siddeley Nimbus shaft turbine
Throttle control	Automatic
Cruising speed	122 m.p.h. (economy)
Max. rate of climb (in forward flight)	1,670 ft/min
Range with standard tanks	315 miles (four passengers)
Accommodation	Five seats
Max.take-off weight	5,300 lb
General description	5 seat general purpose helicopter.