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TITLE

VIBRATION MEASUREMENTS IN SELECTED ARMOURED VEHICLES

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VIBRATION MEASUREMENTS IN SELECTED ARMOURED VEHICLES

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ABSTRACT

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This study investigated the triaxial vibration environment in armoured vehicles to determine the characteristics of the vibration to which crewmen are exposed. Vehicles tested included the M113 Armoured Personnel Carrier, the M109 Self-propelled Howitzer, the M113½ Lynx, the Centurion Tank and the M548 Cargo Carrier, all travelling over snow-packed roads. A magnetic tape data acquisition system and a real-time method of analysis is described. The vibration spectra are compared to proposed I.S.O. vibration exposure standards to determine Fatigue and/or Decreased Proficiency Boundaries and Exposure Limits. Results indicate that the length of ride in these vehicles should be limited if the Fatigue Boundaries and Exposure Limits are not to be exceeded. Limitations of the present study are outlined and recommendations for future studies are made.

VIBRATION MEASUREMENTS IN SELECTED ARMOURED VEHICLES

INTRODUCTION

An increasing involvement in the human factors problems in armoured vehicles has led this Institute to become interested in the vibration environment of various armoured vehicles. In particular, this study deals with the triaxial acceleration to which personnel of the Canadian Armed Forces Land Element, riding in selected military vehicles, are subjected. In the past, work at the former Canadian Forces Institute of Environmental Medicine centered mainly around the effects of vibration upon aircrew, although much information is available in the literature relating to vibration research in various transportation systems(1). The study was undertaken to determine the reliability of a method of assessment of the vibration environment in Canadian Armed Forces armoured vehicles and to obtain basic data which can serve as a base of comparison for future vehicles. A long-term aim is to acquire sufficient data systematically in successive studies to permit vibration standards to be set for these and similar vehicles.

Vehicles tested included the M113 Armoured Personnel Carrier, the M109 Self-propelled Howitzer, the M113½ Lynx, the Centurion Tank and the M548 Cargo Carrier. The vibration measurements were carried out concurrently with other human factors studies(2) and consequently were restricted in scope.

Evaluation of vibration data is complicated by the lack of vibration exposure standards of demonstrated validity. Valid standards should reflect the effect of vibration on performance as well as on the physiological changes which occur in human beings in a vibration environment. Though several studies have attempted to determine the effects of vibration on human performance, e.g., tracking performance (3,4), few of the data can be reliably applied to other settings However, one standard for the evaluation of vibration effects on man is the International Organisation for Standardisation (I.S.O.) Proposed Standard(5) which attempts to facilitate the evaluation and comparison of data gained from continuing research on vibration, and also lays down guides concerning acceptable human exposure. This I.S.O. Proposed Standard was the one used in evaluating the data collected in this study.

OBJECTIVES

It was the object of this study to:

a. develop a method of measurement of triaxial vibration in armoured vehicles,

b. develop an accurate and reliable technique of analysis of vibration data,

c. ascertain relative vibration intensities in armoured vehicles, and,

d. obtain relative figures of vibration transmission to a man from an armoured vehicle in which he is riding.

DATA ACQUISITION

Equipment

The vibration measurement in armoured vehicles was accomplished with a magnetic tape data acquisition system which can be grouped into three sections:

1. *Transducers.* The transducers were two Statham A3–350 linear accelerometers which were excited by direct current. Their specified range was ±10G, although the signal conditioning equipment was designed for a full scale recording of ±5G. Their natural frequency was 110 Hz, well above the range of vibrations studied. Each accelerometer was the fully active strain gauge type and bridge imbalances, equivalent to G-loading, could be detected and amplified. Two accelerometers were mounted orthogonally on a specially constructed mount which could be attached to a moulded fibreglass seat pack strapped to a sitting subject or be mounted on the floor to measure vehicular vibrations.

The use of a seat pack was in accordance with one of the I.S.O. recommendations. This states that when a resilient element, such as a seat cushion, exists between the rigid structure (the seat) and the man, it is permissible to interpose a rigid transducer support between the man the resilient element, provided it does not significantly alter the transmission of vibration to the man, or otherwise introduce noise into the measurements(5). The exact extent to which the vibration transmission to the man was altered with the seat pack is not known, however, the advantage of such a design of seat pack is that the accelerometers will stay more accurately aligned over a long period of use and it is likely to be more comfortable on a hard seat(1).

Provision was made to rotate the accelerometers through ninety degrees in order to measure the acceleration in the third axis. The use of only two accelerometers at one time was dictated by the limitations of the electronic package and the availability of only two channels for simultaneous recording of data.

2. *Signal Conditioning Electronic Package.* The signal conditioning equipment was contained in a 4½" x 4½" x 2½" package excluding the batteries. It consisted of a precise direct current excitation supply for the transducers, a chopper calibration section and a three-channel multiplexer. A block diagram of the system is shown in Figure 1 and the complete schematics for the electronics pack as well as a description of the circuits is given in Appendix A.

Two of the three channels were used as data channels to record the vibration data from the two accelerometers while the third channel was used for coding via a manual code button. The third channel was also used to monitor the speed constancy of the tape recorder and thus ensure valid data. Since a fixed frequency was recorded on this channel, any deviation in frequency was the result of speed variations in the tape recorder. It was imperative to know of the existence and frequency of these unwanted variations since they would be present on the two data channels as well and would be similar to vibration data.

As shown in the block diagram in Figure 1, the signal from each accelerometer is amplified and then modulates the frequency of an audio oscillator which serves as carrier. Each carrier is at a standard IRIG frequency. The three carriers are then added electronically and the composite signal is recorded on magnetic tape. Calibration of the system was achieved by chopping a constant 1 G signal with a 5 Hz square wave. This square wave was required by the analysis equipment to calibrate the system.

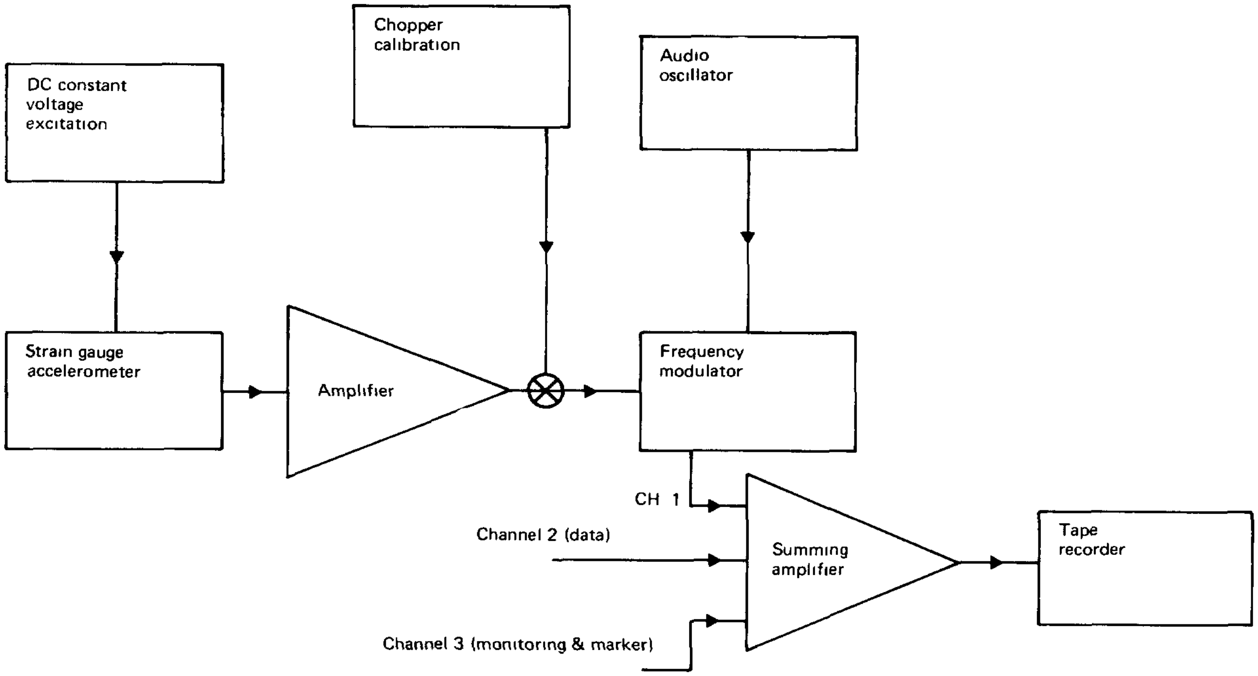

Figure 1. Block diagram of Data Acquisition System.

3. *Tape Recorder.* A NAGRA III portable tape recorder using one quarter inch tape was used to record the frequency modulated data. It was run at 15 ips since the higher speed gave a more constant tape speed with fewer signal artifacts on the two data channels. The tape recorder was shock mounted on several layers of foam rubber in a custom-built mount to maintain as constant a tape speed as possible in the vibration environment.

The vibration measurement system is completed by an external battery pack. The complete system (without the tape recorder) is shown in Figure 2.

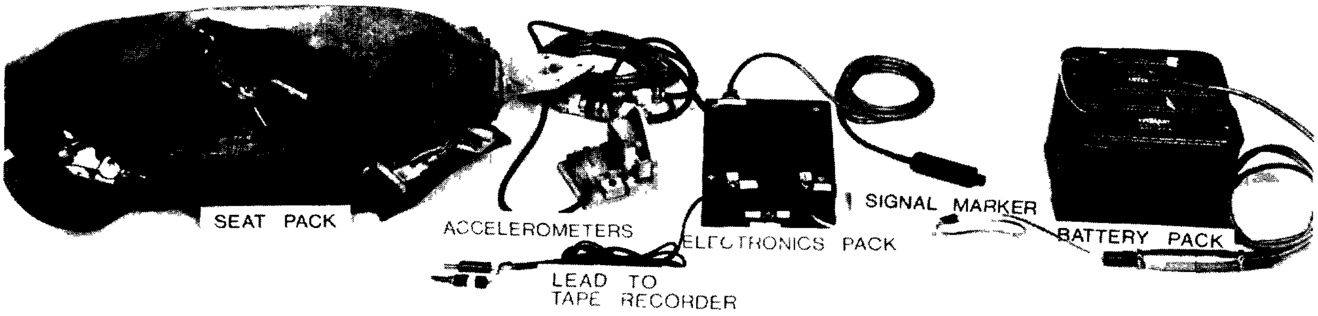

Figure 2. Vibration Data Acquisition System.

Procedure

To make measurements which would compare the levels of vibrations present at the floor of a vehicle to those actually transmitted through the seat to the man, the accelerometers were first mounted on the floor referenced to the same axes used in measuring vibrations at the man/seat interface. After a five minute run the accelarometers were rotated to measure vibrations in the third axis as only two axes could be measured at any one time. The run was repeated over the same stretch of road.

The accelerometers were then mounted on the seat pack strapped to the subject and the two five minute runs were repeated to record vibrations experienced by the subject travelling over the same road. The direction of rectilinear vibrations was measured in relation to an orthogonal co-ordinate system having its origin at the centre of the heart of the subject as shown in Figure 3. For all these measurements the accelerometers were first levelled by a spirit level to ensure proper alignment of the accelerometers in their respective axes.

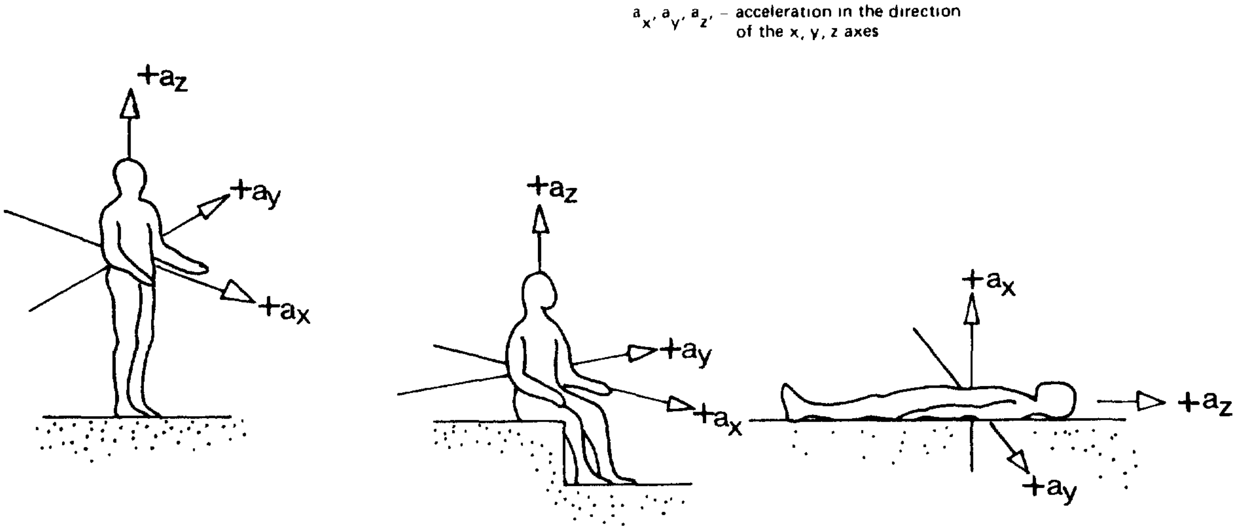

Figure 3. Coordinate system for mechanical vibrations influencing humans.

The above procedure was carried out in all vehicles travelling at 15 – 25 m.p.h. over hard packed snow. Due to time limitations no other types of terrain could be studied.

Whenever extremely rough road conditions were encountered the signal marker was used to code the third or marker channel in order to study the effect of the resulting increase in vibrations on the functioning of the recording equipment.

Details of the vehicles tested are given below·

Centurion Tank

The crew commander's seat, from which measurements were taken, consisted of a cushion-covered pan-type seat mounted on top of an adjustable pedestal. Difficulty in mounting the accelerometers on the floor below this seat necessitated mounting them at the base of the pedestal (directly to the interior of the turret). The turret was held stationary. A picture of the recording equipment inside the tank is shown in Figure 4.

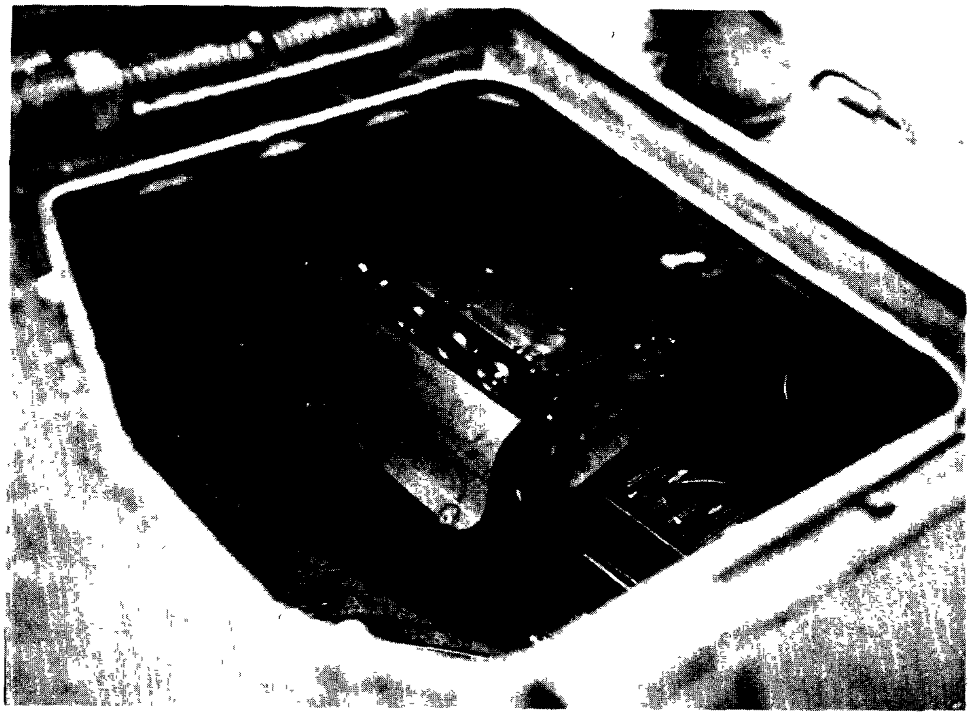

Figure 4. Installation of test equipment in Centurion Tank.

M109

Measurements were made directly on the floor of the vehicle and on the seated passenger facing sideways in the vehicle. The fold-out seat consisted of a square metal tubular frame with interwoven canvas straps.

M113

Measurements were made directly on the floor of the vehicle and on the seated passenger facing sideways in the vehicle sitting on a bench-type fold-down seat with integral cushion.

M113½

Measurements were made directly on the floor of the vehicle and on the seated driver sitting on a pan-type seat covered with a 2" thick cushion.

M548

Measurements were made on the floor of the vehicle and on the seated driver sitting on a bench-type seat with integral cushions.

ANALYSIS

Equipment

The vibration data recorded on magnetic type was analyzed by a system consisting of a decoder, a spectrum analyzer and a signal averaging computer. The final spectrum of root mean square – G (RMS–G) versus frequency was recorded on an X–Y plotter. A block diagram of the analysis system appears in Figure 5.

A photograph of the analysis equipment is shown in Figure 6.

1. *Decoder*

The decoder separates the three channel multiplexed signal into the two original data channels and the third monitoring channel by passing the signal through bandpass filters. The frequency modulated data is then demodulated producing the original waveform. A typical waveform is shown in Figure 7. A complete discussion of the circuitry is given in Appendix A.

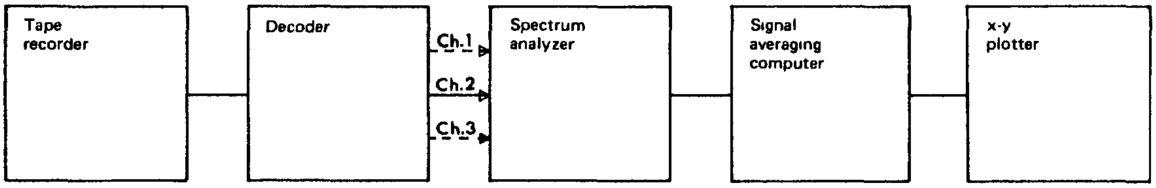

Figure 5. Block diagram of analysis equipment.

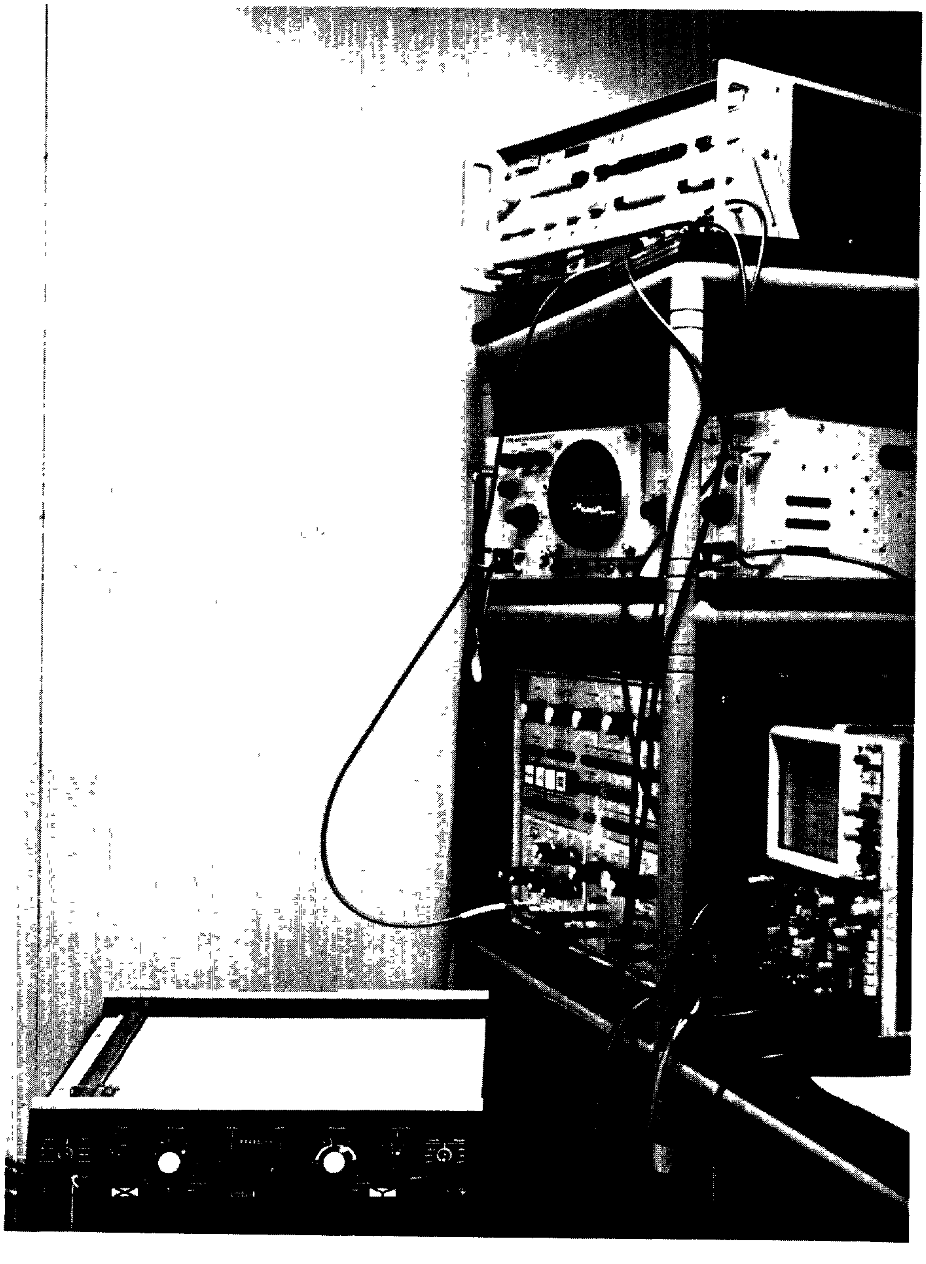

Figure 6. Analysis equipment.

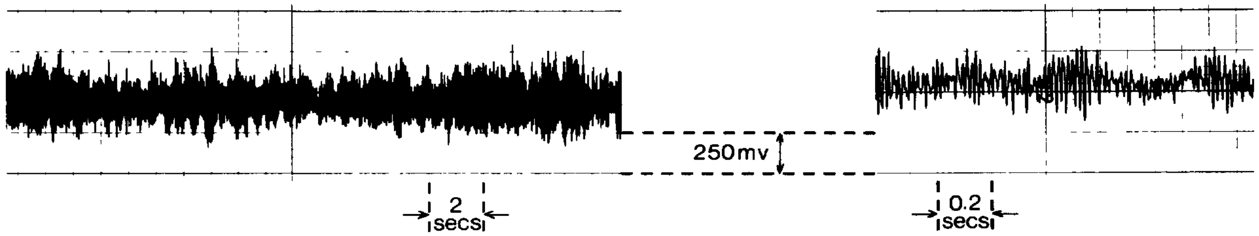

Figure 7. Typical vibration data (M 109 shown).

2. *Spectrum Analyzer*

Each channel was analyzed separately in real time by a Federal Scientific Ubiquitous Spectrum Analyzer, Model UA–10. The frequency range analyzed was from DC to 100 Hz with a constant 0.5 Hz filter bandwidth. A complete spectrum was produced every second. The self-generated frequency markers of the spectrum analyzer served to calibrate the frequency axis.

Electrical calibration of the Y–axis (RMS–G) was obtained by analysis of a 1 g peak-to-peak square wave produced by the electronic chopper in the instrumentation package. The amplitude of the first term of the Fourier expansion of such a waveform is $\frac{2G}{\pi}$. Thus the calibration peak produced by the spectrum analyzer from such a waveform is .637 G RMS and was used to calibrate the Y–axis.

3. *Signal Averaging Computer*

The linear spectrum produced by the spectrum analyzer was averaged sixty-four times on a Fabritek Model 1074, Instrumentation Computer. The averaged vibration spectrum was then plotted by an X–Y plotter. A typical spectrum is shown in Figure 8.

Procedure

All magnetic tapes were examined to ensure recording of proper data and freedom from electronic failures. A five minute sample of vibration in each acceleration axis in each vehicle had been recorded and was broken down into four averaged vibration spectra. Each linear spectrum plotted was the average of sixty-four individual spectra produced every second by the spectrum analyzer. The average of sixty-four individual spectra served to enhance the signal in the presence of noise and to produce a statistically valid spectrum.

The four spectra thus produced were then broken down into the standard one-third octave bands in compliance with the proposed I.S.O. Standard on Vibration Exposure Limits and the mean RMS vibration amplitude for each band was calculated. The Limiting Fatigue and/or Decreased Proficiency Boundary was then determined from the I.S.O. Standards.

Since the results obtained were calibrated in RMS–g, the RMS–acceleration of the I.S.O. boundaries, given in m/sec^2, was adjusted using the constant $1\ g = 9.80665$ m/sec^2.

A spectrum of the tape speed monitoring channel was also obtained for each tape recording. Peaks in these spectra, which were the result of tape speed variations due to mechanical vibrations transmitted to the tape recorder, also appeared as peaks in the vibration spectra of the data channels and were deleted from the spectra as artifacts.

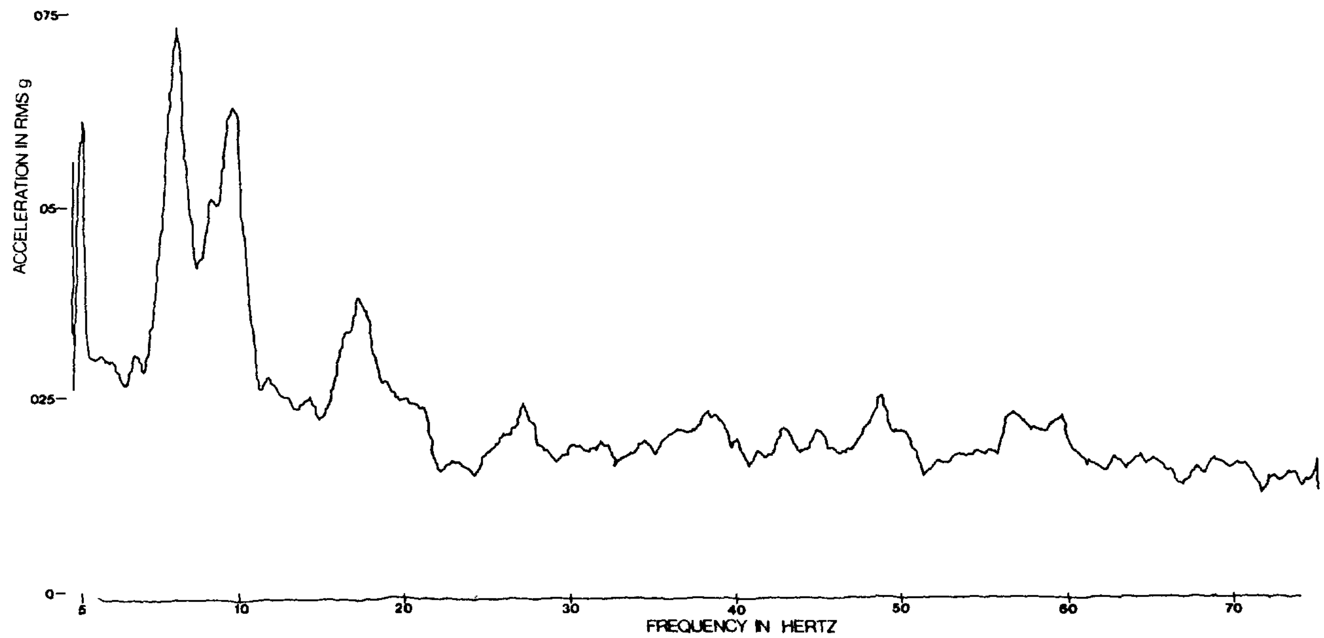

Figure 8. Typical spectrum generated.

RESULTS

Table I is a summary of the vehicles tested. Shown are the intensity and frequency of the critical vibrations which determine the limiting boundaries. Also shown are the Fatigue and/or Decreased Proficiency Boundaries (below which human working efficiency is preserved), and the Exposure Limits (below which human health and safety are preserved), both expressed in hours.

The complete averaged spectra for each axis, broken into the standard 1/3 octave bands, as well as the standard deviation for each averaged vibration intensity, are given in Appendix B, Figures 1 to 4. The applicable Decreased Proficiency Boundaries are also shown on these graphs.

TABLE I

Vehicle	Position In Vehicle	Axix	Boundary Determining Freq (HZ)	Intensity (RMSg)	Decreased Proficiency Boundary (HRS)	Exposure Limit (HRS)
M109 SP HOWITZER	Floor	X	2	.053	2½	Approx 6*
		Y	1 to 5	.021	8	24
		Z	2	.094	2½	Approx 7
	Passenger Seat	X	2.5	.029	8	Approx 14
		Y	5	.026	16	24
		Z	2.5	.100	Approx 2*	Approx 6*
CENTURION TANK	Base of Crew Commander Seat	X	1 to 2	.024	Approx 7	16
		Y	Not	available		
		Z	5	.056	Approx 3½*	Approx 10*
	Crew Commander Seat	X	3.5	.024	Approx 11	24
		Y	5	.030	16	24
		Z		.064	Approx 3*	8*
M113 APC	Floor		Not	available		
	Passenger Seat	X	Not	available		
		Y	4	.048	Approx 7½	Approx 16
		Z	3.15	.094	Approx 2*	Approx 6*
M113½ LYNX	Floor		Not	Available		
	Driver's Seat	X	4	.074	4	Approx 11
		Y	3.15	.047	Approx 6	Approx 12
		Z	5.0	.102	Approx 1½*	4*
M548			Not	available		

* The lowest value in any set of limits for a vehicle is the one which must be referred to in limiting the length of ride.

DISCUSSION

In all vehicles tested, the Decreased Proficiency Boundary tends to occur after only a few hours (as short a time as 1½ hours in M113½ Lynx), with the Exposure Limit being reached after only a few hours more (4 hours in the case of M113½ Lynx). These results should be viewed critically, however, because of the shortcomings of this initial study outlined below. As well, only approximate limits for man's safety and performance under field conditions can be given, since the exact physical mode of action of the environment varies with man's unpredicatable position and motion, and since biological variations with respect to physical, physiological, and psychological reactions make such limits statistical in nature (6).

For the two vehicles in which data was obtained for both the floor and man/seat interface it appears that the seat does not offer any vibration isolation, in fact, the limiting boundaries are reached earlier at the man/seat interface. This does not appear unreasonable since the subjects were not restrained and within themselves form a complex resonant system which tends to accentuate certain vibrations to which they are subjected. It has been reported(6) that in ordinary passenger seats, the seat cushion does not alter the resonant frequency of the man-seat system significantly, so that no isolation is achieved in the frequency range below 5 Hertz. Sometimes amplification is unavoidable and for severe low-frequency vibration and shock conditions, such as are prevalent in military vehicles, suspension of the whole seat is superior to the simple seat cushion (7). These special seats and restraints can be employed to provide maximum body support in all critical directions for the subject in the most advantageous position. Further research in this aspect of the vehicle vibration environment is required.

Limitations of this initial study were numerous and included the following: (1) temporary electronic equipment failures which caused loss of some data (most seriously, complete loss of data on M548), (2) tape recorder speed variations due to inability to completely isolate the tape recorder from the vibration environment (causing artifacts in the data), (3) the bulky size of the accelerometers, which may have influenced the accuracy of the recorded data and made their installation in confined spaces difficult, and (4) the validity of the assumption that the fibreglass seat pan does not alter the vibration transmission characteristics of the man/seat system, is not known.

CONCLUSIONS

1. A method of measurement of triaxial vibration in armoured vehicles has been found to be feasible with the limitations outlined in this report.

2. An acceptable technique of analysis of vibration data has been established, with resultant data which is comparable to an existing arbitrary standard.

3. Levels of vibration in armoured vehicles, travelling over gravel roads covered with hard-packed snow, are of sufficient intensity to warrant consideration of applying limitations on acceptable length of rides in some vehicles, according to present standards.

4. The present seating systems in the M109 and Centurion Tank, appear to have little effect on modifying the vibration experienced by unrestrained subjects.

RECOMMENDATIONS

1. An improved vibration data acquisition system should be developed to overcome the limitations of the existing system.

2. An extensive vibration study of all armoured vehicles should be undertaken in order to obtain more data on the vibration environment under all conditions encountered in the field.

3. The seating and restraint systems in armoured vehicles should be investigated to determine their suitability in high vibration environments encountered in military vehicles.

4. Vibration measurement and analysis should become a standard practice prior to vehicle procurement for the Canadian Forces.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. R. Howat and the staff of the Electronics Workshop for their help in the design and construction of the electronics package as well as MWO R. Harris for his help in the construction of the seat pack.

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APPENDIX A

INSTRUMENTATION

General

The electronic package includes a small accelerometer amplifier, multiplexer, battery pack, coding switch, and a precision portable tape recorder. Three channels are available in the multiplexer, two measure "G" forces in two planes, and the third records a constant frequency which indicates tape speed, thus ensuring accurate records. After amplification the accelerometer voltages frequency-modulate audio oscillators which are subsequently added and the composite signal is recorded on the tape recorder. A separate decoder using bandpass filters is used to decipher this signal for spectral analysis.

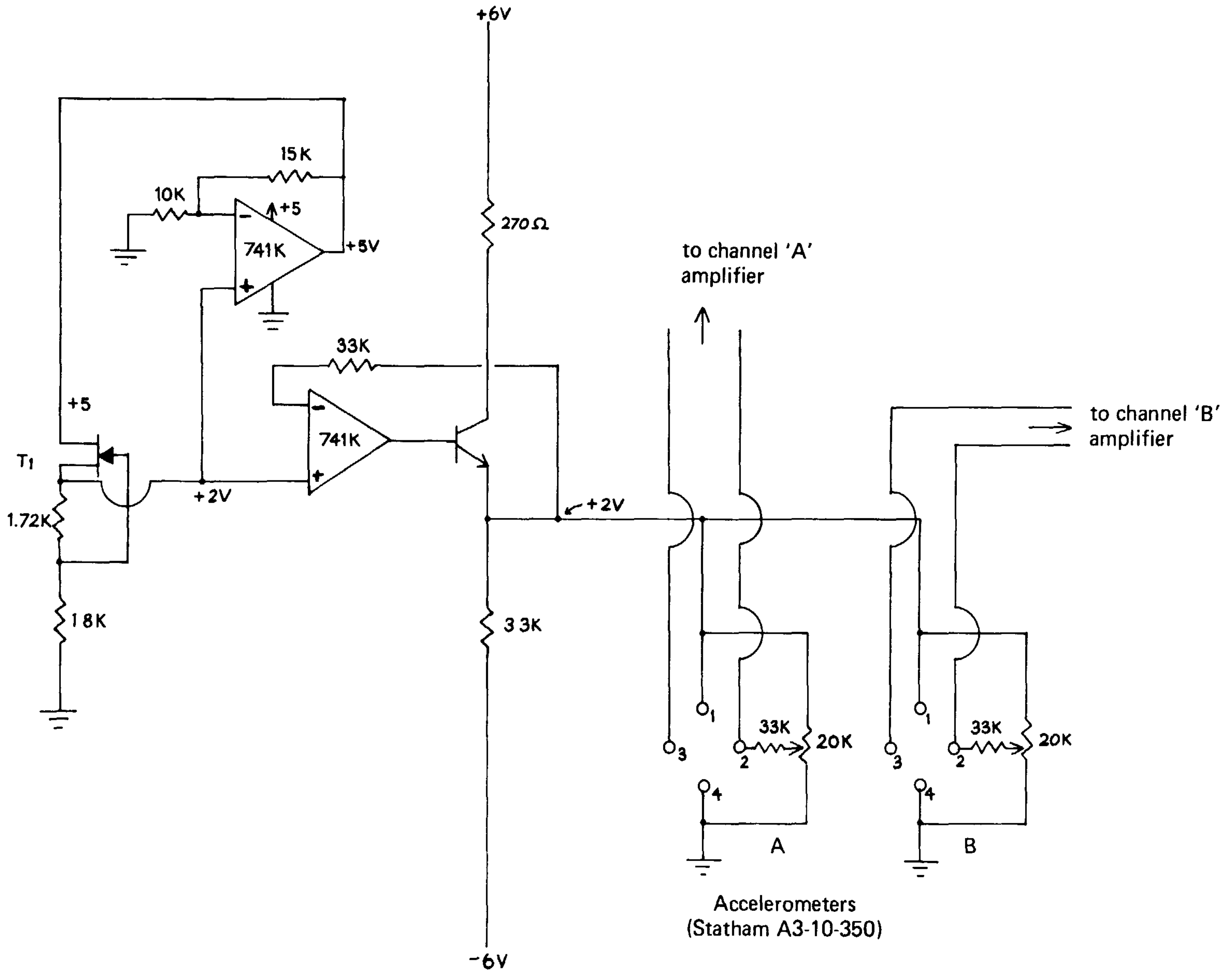
Circuit Details

A detailed diagram of the accelerometer excitation circuit is shown in Figure 1. Care is taken to ensure that the F.E.T. constant current generator (T1) is operating at its zero temperature coefficient current. This circuit ensures that the voltage applied to the accelerometers is constant regardless of temperature or supply voltage variation.

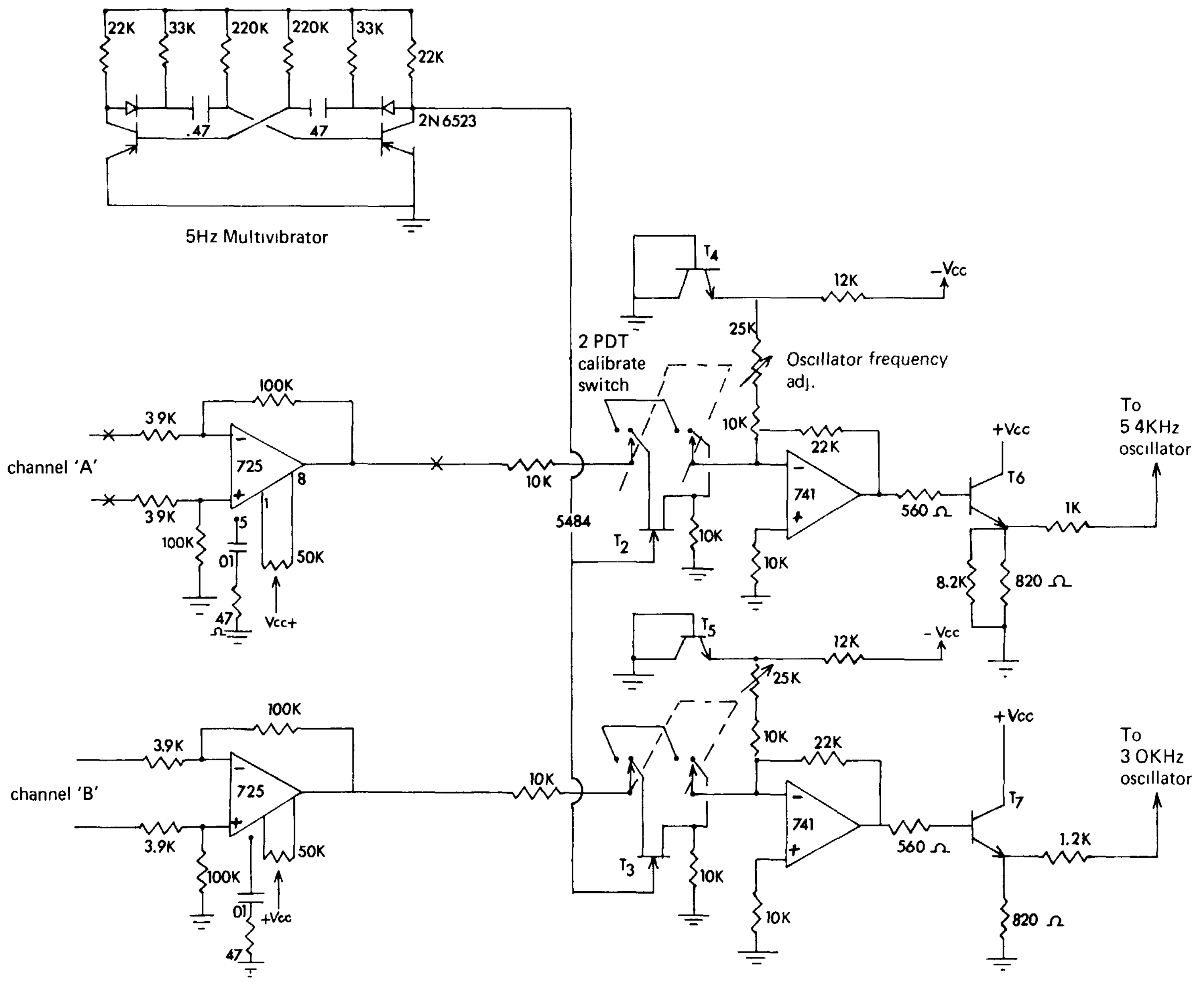
Details of the accelerometer amplifier are shown in Figure 2. One of the unique features of this circuit is the method of injecting a plus or minus 1 G calibration signal. Each channel can be switched to "calibrate" whereby a FET switch chops the incoming signal to ground at a 5 Hertz rate (T2–3). In this condition, the accelerometers are positioned to measure a plus one "G" force and then a minus one "G" force. This system also measures any input offset which might be present in the input preamplifiers. T6 and T7 are used as voltage-to-resistance converters, and T4 and T5 are voltage sources to allow the output of the operational amplifier to be varied. This offset voltage is only enough to overcome to the base emitter drop of T6 and T7.

The channel oscillators are similar to those described by Zweizing(8). Standard IRIG channels are used with centre frequencies of 1.3, 3.0, and 5.4 K Hz. The sine wave oscillators consist of twin T filters and operational amplifiers, with the gain of the amplifier set slightly higher than the attenuation of the filter. Modulation of the oscillators is achieved by changing the resonant frequency of the T filters via R3b (Figure 3). A summing amplifier is used to add the three oscillator signals, and this voltage is recorded on the portable tape recorder.

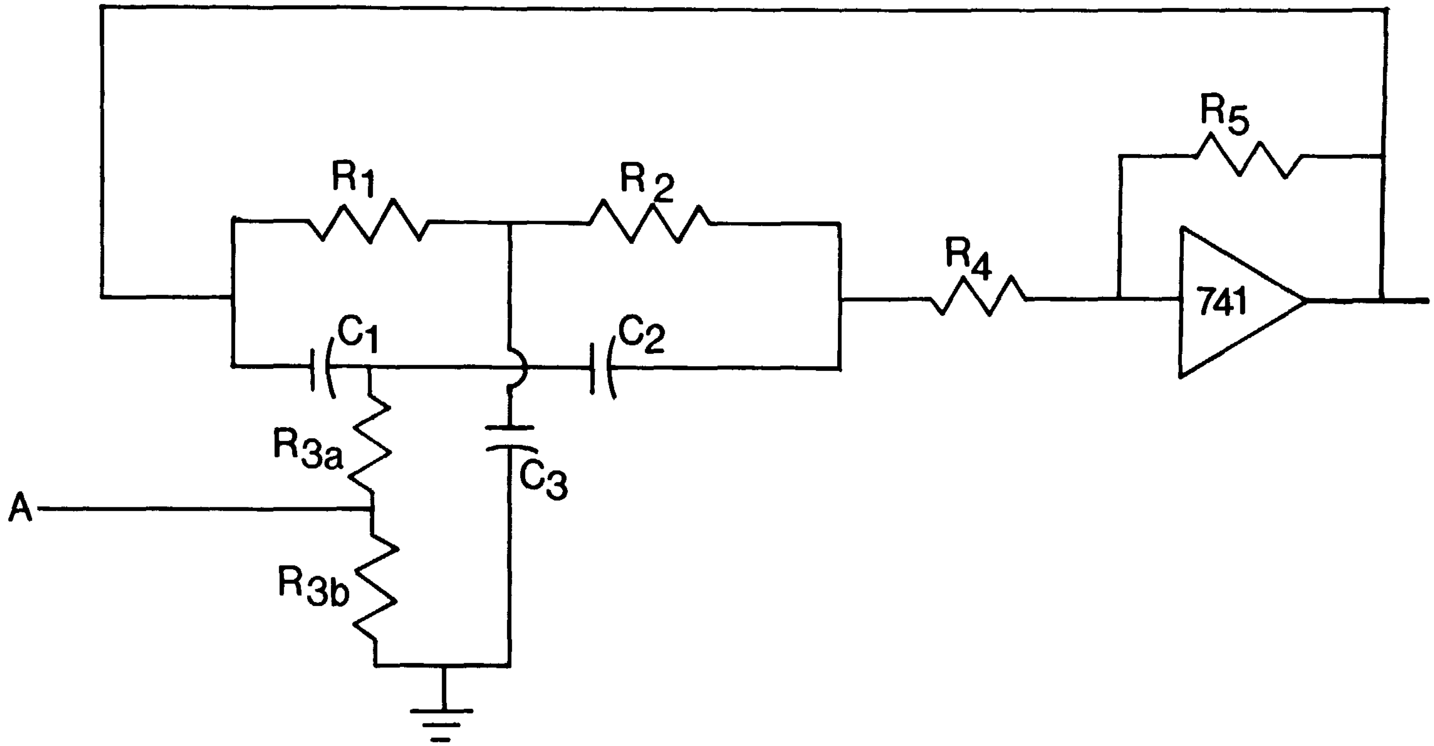
The Decoder (Figure 4) separates the three frequencies by using Band Pass Filters and then squares the output voltage, thus minimizing amplitude variation effects. After squaring, monostable flip-flops are triggered and the output signal is integrated. Differential operational amplifiers are used to minimize offset voltages and the output signal is then recorded.



APPENDIX A Figure 1 ACCELEROMETER EXCITATION CIRCUIT



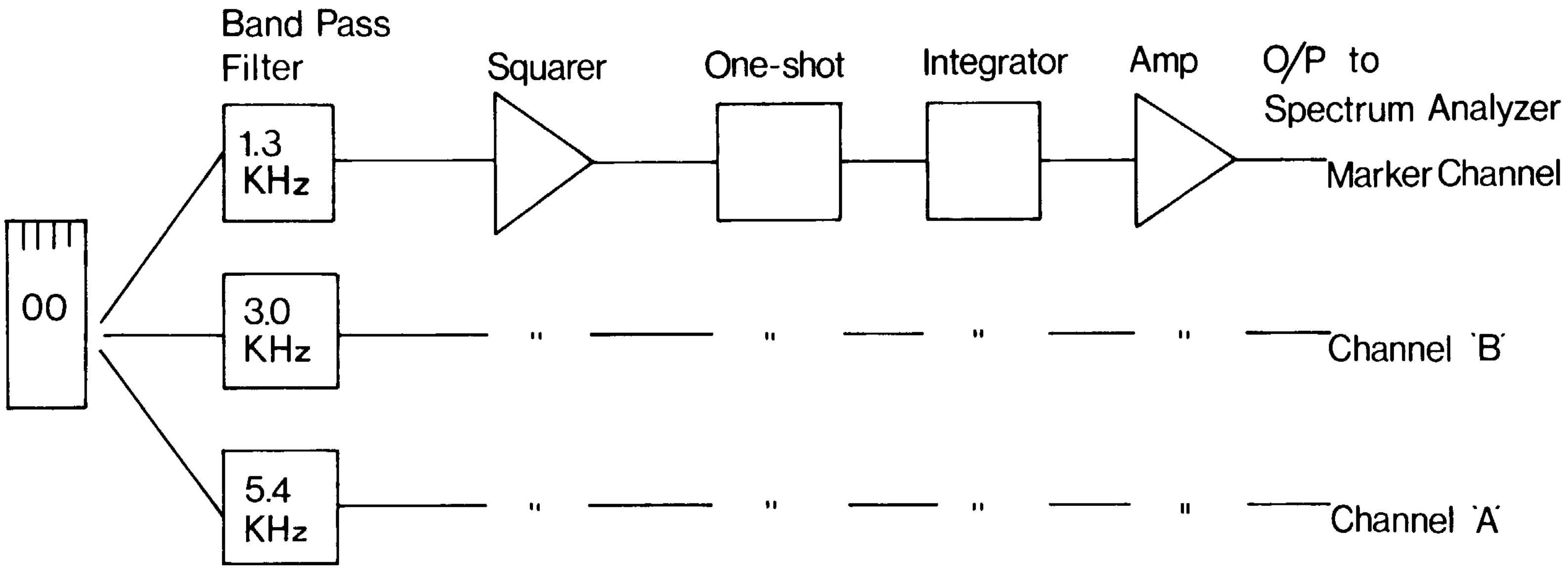
APPENDIX A Fig 2 ACCELEROMETER AMPLIFIERS



Values used in the oscillator T filter

	R_1	R_2	R_{3a}	R_{3a}	C_1	C_2	C_3	R_4	R_5
1.3 KHz	15 K	15 K	1K	1·2K	·01	·01	·047	47K	680K
3.0 KHz	15 K	15 K	1K	1·2K	·005	·005	·0144	47K	560K
5.4 KHz	12 K	12 K	Total 1·64 K		·003	·003	·01	47K	560K

Appendix A Fig. 3 Oscillator



Appendix A Fig.4 Decoder

APPENDIX B

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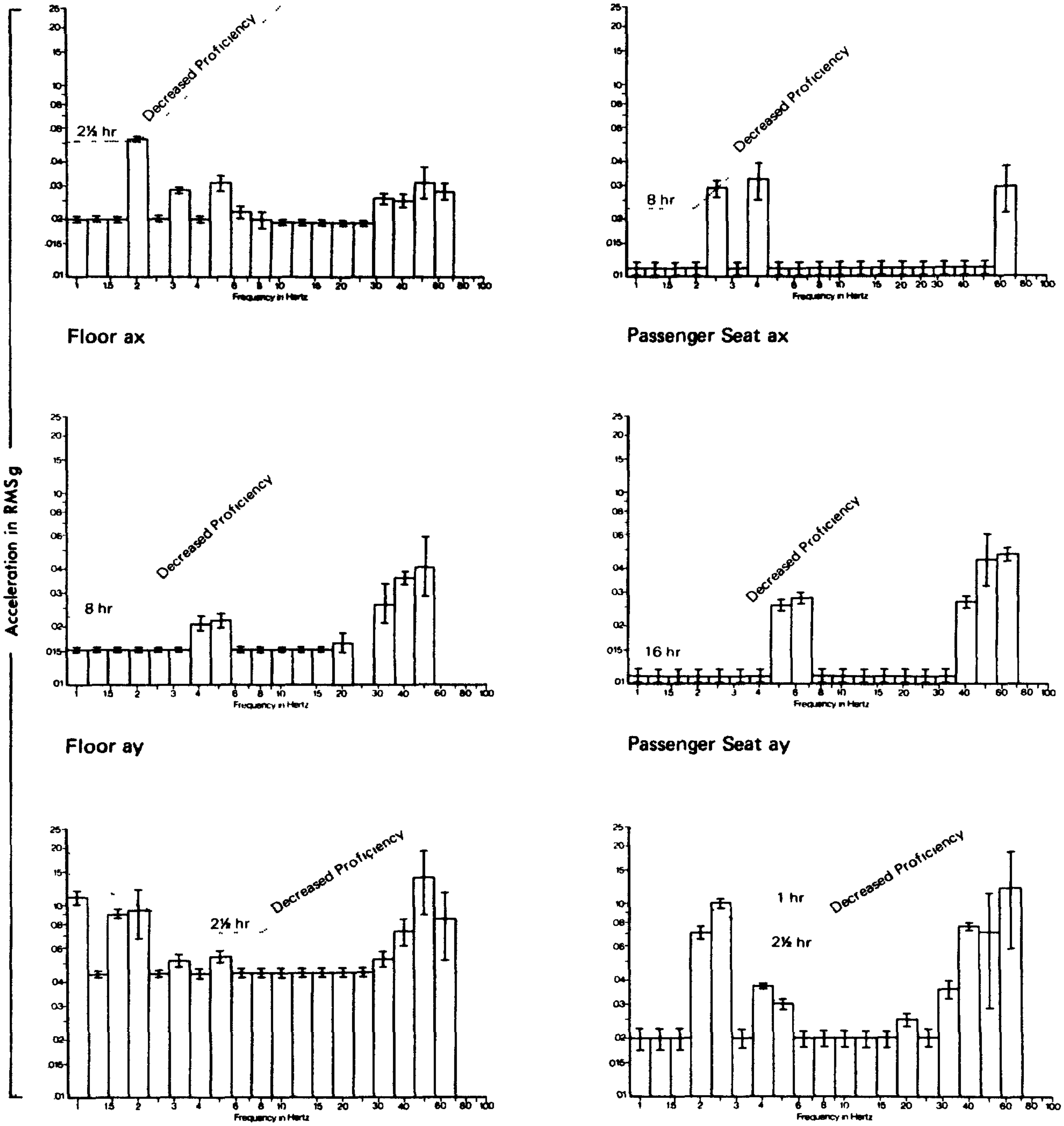


Floor ax

Passenger Seat ax

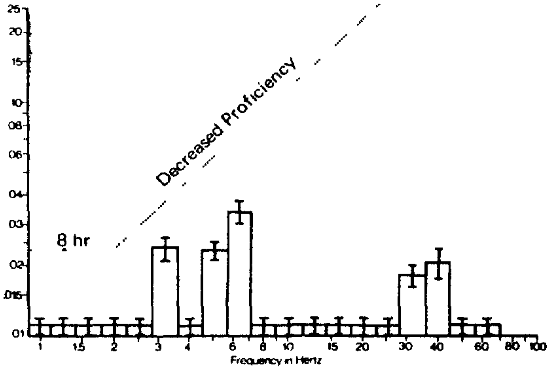
Floor ay

Passenger Seat ay

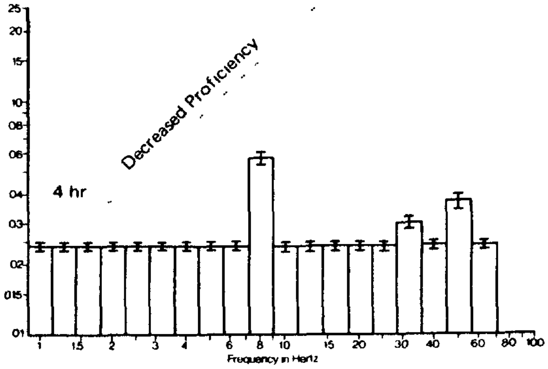
Floor az

Passenger Seat az

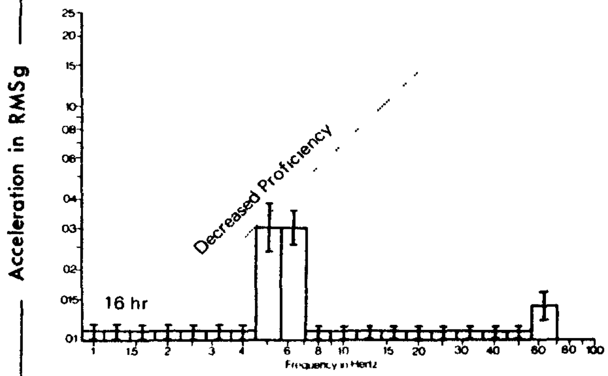
Appendix B Fig.1



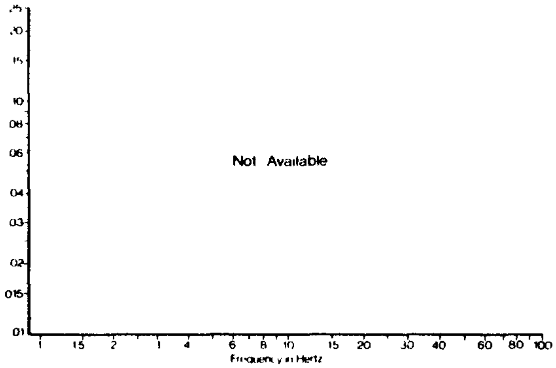
Crew Commander Seat ax

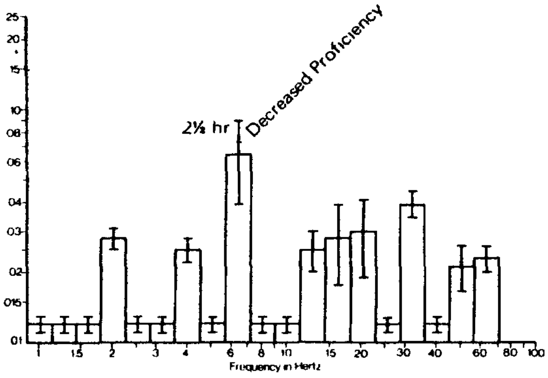


Base of Crew Commander Seat ax

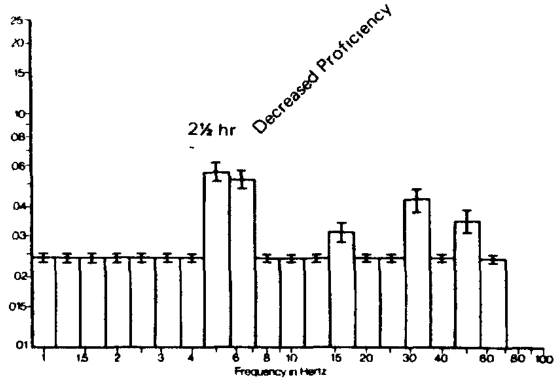


Crew Commander Seat ay



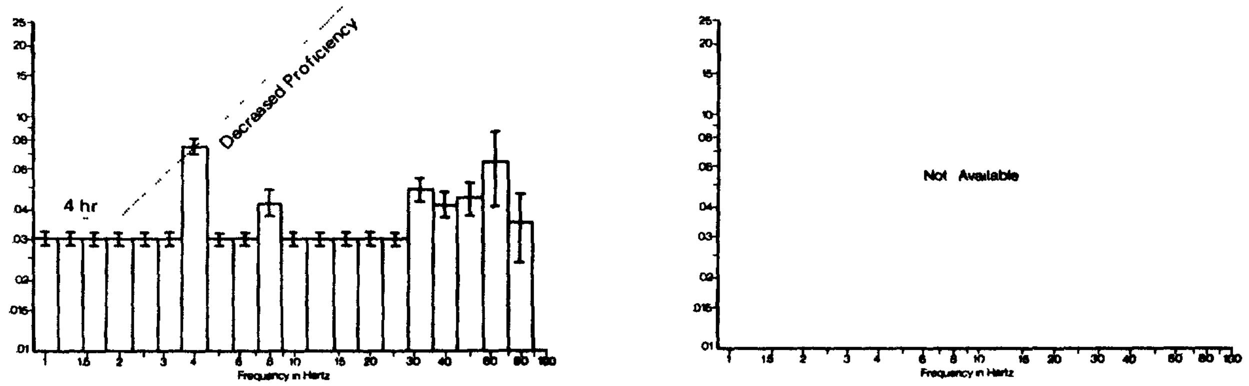


Crew Commander Seat az

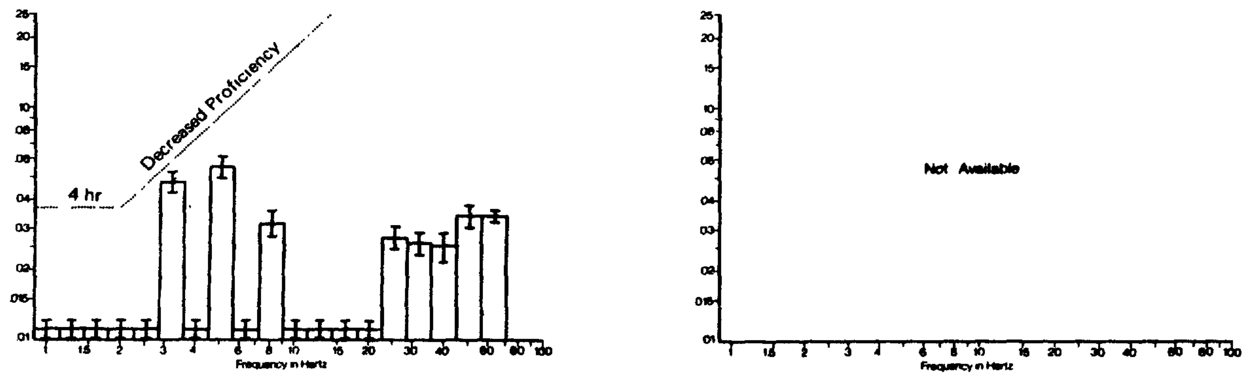


Base of Crew Commander Seat az

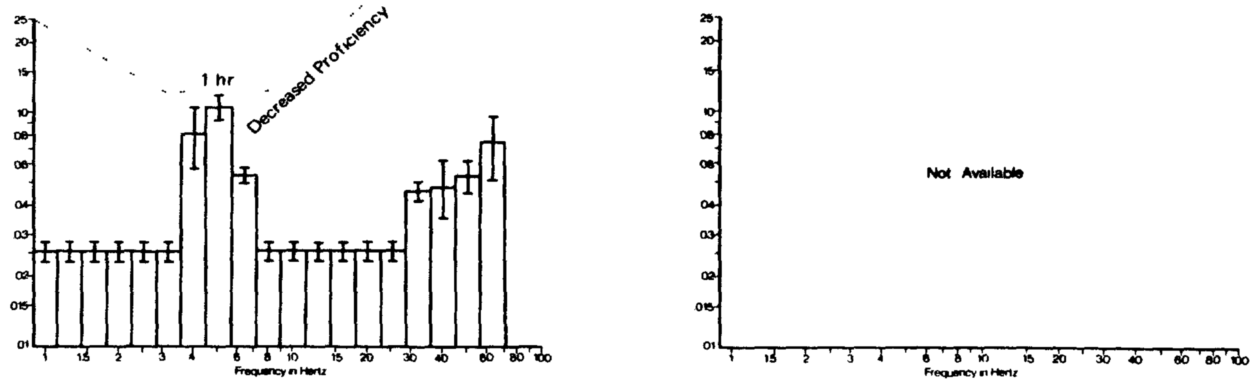
Appendix B Fig.2 Centurian Tank



Driver Seat ax



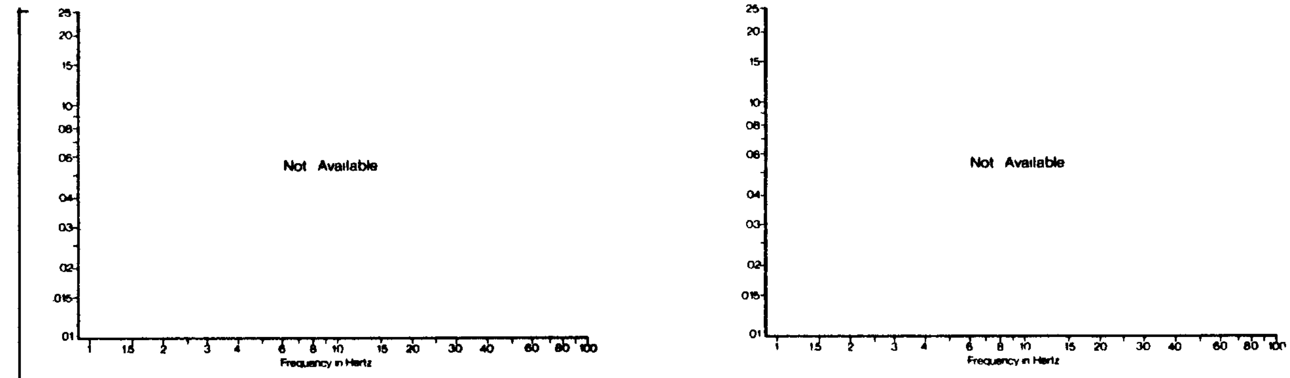
Driver Seat ay

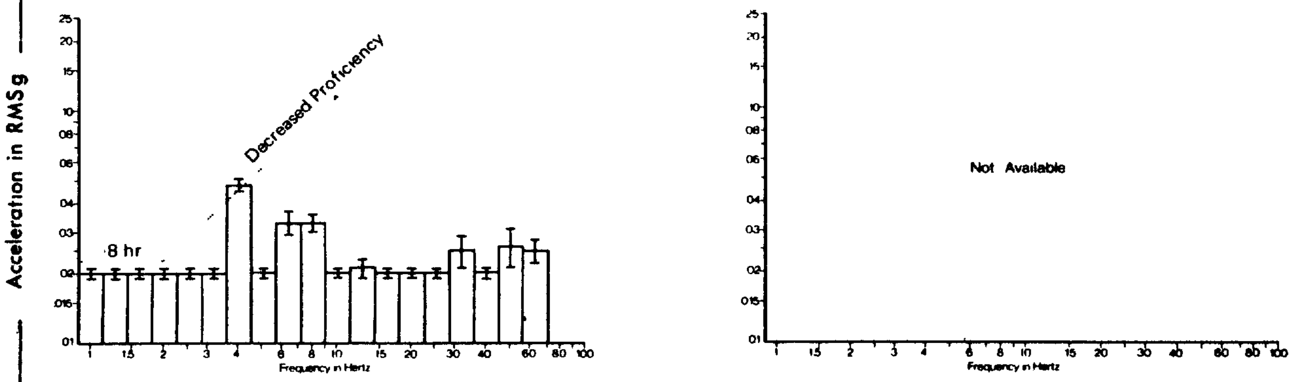


Driver Seat az

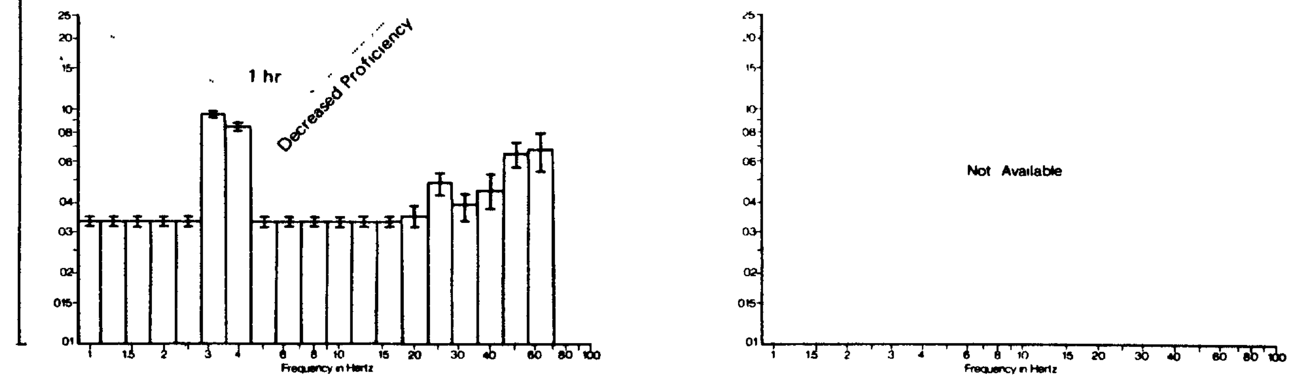
Appendix B Fig.3

M 113½ Lynx





Passenger Seat ay



Passenger Seat az

Appendix B Fig.4

M 113 APC

4101 U
4102 U
4103 U

42 U

0201 DCIEM
0202 406986

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This study investigated the triaxial vibration environment in armoured vehicles to determine the characteristics of the vibration to which crewmen are exposed. Vehicles tested included the M113 Armoured Personnel Carrier, the M109 Self-propelled Howitzer, the M113½ Lynx, the Centurion Tank and the M548 Cargo Carrier, all travelling over snow-packed roads. A magnetic tape data acquisition system and a real-time method of analysis is described. The vibration spectra are compared to proposed I.S.O. vibration exposure standards to determine Fatigue and/or Decreased Proficiency Boundaries and Exposure Limits. Results indicate that the length of ride in these vhicles should be limited if the Fatigue Boundaries and Exposure Limits are not to be exceeded. Limitations of the present study are outlined and recommendations for future studies are made.

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KEY WORDS

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