CoA/M/ASAE - 148

R 36351

A.S.A.E. Memo. No. 148

February, 1968

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- by -

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1.0 Introduction

In Appendix 1 of this report general procedures for the design and evaluation of vibration isolation systems are reviewed. It is shown that in general, a vibration isolation system is adequate only when it enables a human operator to meet the objectives of some system by performing a task well enough and for long enough. If the vibration intrudes too far upon the operator's performance and endurance the system of which he is a part will not meet its objectives. There still remain examples today where inadequate vibration isolators limit the performance of a system. The agricultural tractor is one of these. It is not uncommon to see a tractor driver supplementing the tractor tyre spring by using his own vibration isolators - his legs.

1.1 Road vehicle vibration isolation systems

In most passenger transport vehicles, particularly passenger cars, vibration isolation systems (suspension systems) have progressed to the point where vibration no longer intrudes upon the performance of the driving task. Passengers are now willing to ride for long periods of time in such vehicles. However, so long as it is commercially worth while development of such already acceptable suspension systems will continue.

1.2 Suspension improvement

Faced with the problem of improving an already satisfactory suspension system, a vibration engineer at present can be certain of only one thing. Namely that he has shown an improvement only when he has physically attenuated vibration of the vehicle at all frequencies in the RIDE SPECTRUM (2).

This truth emerges from the fact that human beings are frequency sensitive to vibration. A characteristic about which, at present, we cannot be precise for the case of random vibration.

At this point it should be emphasised that even when a reduction in vibration power has been achieved physically, at all frequencies, there remains the problem of Just Noticeable Difference (JND). One JND being the smallest difference in vibration characteristic capable of causing a change in the response of the human recipient (1). If there exists less than one JND in the reduction of vibration, the value of such a reduction to the human being will be nil.

1.3 Suspension design criterion - minimum discomfort spectrum (MDS).

The vibration engineer who finds that he cannot reduce vibration power at all frequencies in the Ride Spectrum could direct his efforts towards achieving the Minimum Discomfort Spectrim. The M.D.S. is here defined as that distribution of Power in the Vehicle Power Spectrum (2) (See also Fig. 13) that causes least discomfort to the recipient.

If the characteristics of human sensitivity to random vibration were precisely known it would be possible to apply the M.D.S. technique to suspension design. This would be achieved for a fixed total vibration power (area under the P.S.D. curve figure 13) by adjusting the position of the power peaks on the frequency axis to coincide with frequencies of minimum sensitivity. To apply the M.D.S. technique it is therefore necessary to know sensitivity characteristics for random vibration in terms of Power, frequency and Number and distribution of Spectral Power Peaks.

In vehicle vibration the spectral power peaks correspond to the dominant natural frequencies of the system (Fig. 13).

J.N.D. problems also arise for the M.D.S. technique. The Spectral peaks must be moved, in frequency, more than 1 JND for the adjustment to be considered of value to the vehicle occupant. Another approach towards the M.D.S. is to transfer the power from one spectral peak to another in a less sensitive frequency region. Again JND problems arise if this is achieved by contracting the bandwidth of the spectral peaks.

It seems necessary therefore to know human vibration sensitivity characteristics in terms of the JND centre frequency and bandwidth of a spectral peak. Information which, it seems credible, could be furnished from laboratory studies using narrow band random vibration starting with a random amplitude modulated sine wave.

1.4 Experimental evidence of human vibration sensitivity characteristics relevant to suspension design

Evidence concerning vibration intensity and frequency sensitivity has been available for more than 40 years. Reiher and Meister 1931 (3) determined subjectively the intensity and frequency characteristics of a large sample of people using sinusoidal vibration. Their curves showed an increase in sensitivity in the region 4 - 5 c/s. Later studies by Janeway (4), Goldman (5) and Dieckman (6) improved and fortified the Reiher and Meister Results. In particular Janeway reinterpreted the sensitivity curves in terms of derivatives of the motion splitting the frequency axis into regions of amplitude, velocity, acceleration and jerk dependence. Goldman added a scatterband to the sensitivity curves to accommodate individual difference. Dieckmans work which also stratified the frequency axis into motion derivatives led to the adoption of a German VDI standard (7) for human vibration sensitivity. However such sinusoidally derived frequency sensitivity curves, based upon subjective evaluation techniques have not found favour with the vibration engineer attempting to improve or evaluate an already satisfactory suspension system, Van-Eldik Thieme (8). Thus although the concept of a Minimum Discomfort Spectrum has been understood for a long time, Human Factor studies have so far failed to sensitise Research techniques that specify Human Vibration characteristics, in terms useful as design criterion for the vibration eingineer. Lack of application of sinusoidally derived sensitivity curves as design criterion for random vibration isolators

suggest that they may not be valid.

The advent of electrohydraulic vibrators capable of producing random vibration in the laboratory has made possible a review of Human Sensitivity characteristics. In particular JND's of vibration power, narrow power band centre frequency and width and the interaction between number and distribution of spectral peaks could be investigated.

Random Vibration Studies, such as these, if they are to succeed where the sinusoidal studies failed, require human vibration evaluation methods - Research techniques - more sensitive than the subjective techniques used hitherto.

It is to this aspect - evaluation - that the experiment reported here makes some contribution. Techniques for measuring the effects of vibration on human beings are reviewed. A technique which uses a psychological index of vibration effects is tested. The same index is used to check the validity of using electrohydraulic vibrators to simulate the random vibration experienced by the occupant of a passenger car.

The JND and other sensitivity characteristics mentioned above, although extremely important in suspension design, are not considered in this presentation. Indeed their omission sets a limit to the value of the reported experiment. For, even if a psychological index leads to the development of a yardstick for vibration effects, to be of value to the vibration engineer, a point must be located on the scale which represents 1 JND. The psychological index tested in this experiment is therefore seen only as a stepping stone to the determination of human vibration sensitivity characteristics and for use as a suspension evaluation technique. Knowledge of the vibration sensitivity characteristics would permit use of the MDS technique for suspension improvement.

1.5 Suspension evaluation

As a technique for evaluating a suspension system (ride evaluation) any index must be capable of detecting small differences which exist between similar suspensions. Often large differences are known to exist subjectively between suspensions but their quantitive effect upon human performance, mental capability and well being cannot be agreed because of the lack of a quantitative measurement technique. The present vogue towards energy transfer between degrees of freedom of passenger cars - from pitch motion to vertical motion (hydrolastic suspension) is one example of a claimed improvement which needs to be quantified. In this experiment a psychological index is tested to see whether it could form the basis of a quantitative technique for measuring the effects of vibration on car occupants.

2.0 Methods for evaluating low intensity vibration isolation systems - the measurement of human vibration sensitivity

Low intensity vibration has already been defined. It was said to be vibration whose characteristics intrude neither upon ability to perform the driving task nor upon willingness of persons to remain exposed to such vibration for long periods of time. The majority of passenger car vibration falls into this category.

By definition, therefore, the performance of a car suspension system cannot be evaluated in terms of the driving task or general feelings of well being. It would of course be possible to increase the severity of the vibration by driving the vehicle over abnormally rough surfaces until the vibration influenced driving performance and feelings of well being. However a validation problem would arise when extrapolating the rough surface results to more comfortable conditions. A more acceptable approach, which to some extent circumvents the above validation problem, would be to increase the difficulty of the driving task or to provide passengers with a difficult task to perform at comfortable levels of vibration. There is a tendency for a vehicle suspension system to perform best at its design point. A suspension system which provides the most adequate isolation on extremely rough surfaces is not necessarily the one which performs best on good surfaces, concluding therefore that an evaluation technique must apply in non-exaggerated vibration conditions. Driving performance and well being indices are rejected as evaluation techniques.

2.1 Subjective measures

Although, in general, low intensity vibration fails to cause intolerance. It is still very valid to ask a person which, for example, of two suspension systems he would prefer. Such opinions or subjective judgements are of fundamental importance, for if any objective evaluation technique is to succeed it must not disagree violently with what the person thinks. Any objective evaluation technique must immediately be abandoned if it disagrees violently with human judgement because it is less fundamental!

It is important to distinguish between human judgement which is 'honestly' right and 'honestly' wrong.* Human judgement in some ways can be looked upon as hypothesising. On the basis of experience of a suspension system a judge might hypothesise that one suspension system is better than another and then decide to accept or reject his hypothesis. If the hypothesis is in fact true in his judgement he decides to accept it, he is said to be honestly right - similarly if it is false and he decides to reject the hypothesis. If however, he makes a wrong decision and rejects a true hypothesis or accepts a false hypothesis he is said to be honestly wrong.

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* The prefix 'honestly' is used here to indicate that the subject is answering objectively, not maliciously.

Therefore, although more fundamental than more objective evaluation techniques, the objective technique should not be so weak that it cannot detect an honestly wrong decision.

Subjectively evaluation should where possible accompany the objective measures and vice versa. Semantic problems prevent accurate ranking of vibration sensation using subjective methods. Ranks such as intolerable, bearable, uncomfortable, acceptable and comfortable are often misunderstood and are generally insensitive.

Subjective scale measures have had their use. (Dieckman (6), Richer and Meister (3), Goldman (5) but have generally been superceeded by pair comparison methods. (M.I.R.A. (9)).

2.2 Cross modality

A semi subjective evaluation technique which overcomes the semantic problem is cross modality. In this technique sensations of vibration motion, touch and position, the kinaestatic and tactile senses are equated to the auditory or visual mode of sensation. Cross modality techniques have been described by Stevens, Ref. 1 and used in suspension evaluation studies by Versace (10). One technique is to equate the magnitude of vibration sensation with noise sensation. Random noise is applied to headphones whilst the subject undergoes the vibration. The subject selects that loudness of noise which generates a sensation in his ears, equal in magnitude to the vibration. Regression and Correlation of Cross Modality Variables have received attention for example in the two references quoted.

Cross Modality was considered as a possible evaluation technique in this study. It was however abandoned without rationale in favour of a more objective technique. It is still considered to be one of the more acceptable methods.

Because of the experimental design, subjective measures were not required in the primary evaluation study. They were however used to rate a motion simulator.

2.3 Classification of objective evaluation techniques

The objective techniques fall into two broad classes. Those which are based upon Central Nervous System functions and those on Cardiovascular Functions. Making three general classes together with the subjective methods.

2.3.1 Central nervous system functions

The CNS functions which were considered for use as an index of vibration effects include:

1. Neuropsychological indices of brain function, Electroencephalograms (E.E.G.).

2. Vigilance and attention.

3. Organisational factors, the effects of vibration on high level mental organisation processes.

4. Psychophysiological functions - Just Noticeable differences, reaction times, ability to maintain constant forces, changes in the accommodation time of the eye, changes in flicker fusion frequency.

5. Orientation function of vestibular apparatus.

6. Visual Acuity - Peripheral Vision changes

7. Tracking tasks.

2.3.2 Cardiovascular functions

1. Electrophysiological measures

   - Electromyogram (E.M.G.)
   - Electrocardiogram (E.C.G.)
   - Galvanic Skin Response (G.S.R.)

2. Metabolic functions.

Briefly, the physiological measures were rejected because of the general lack of effect on such measures of low intensity vibration. Electrophysiological and electroencephalographic were not used because of lack of expertise in measuring such quantities and because of lack of equipment. It is worth mentioning however that changes in the characteristics of the E.E.G. can be used to measure degree of wakefulness or arousal in a subject. If comfort is defined in terms of arousal, then the E.E.G. measures could form the basis of a powerful index. The most comfortable suspension system permitting the passenger to achieve a minimum level of arousal, i.e. sleep.

The psychophysiological measures were abandoned in favour of a more psychological measure in particular performance on a high level mental organisation task. Such tasks had been used very successfully in Aviation Medicine to study the effects of oxygen starvation on mental capability. A high level perceptual or mental organisation task was therefore chosen from amongst the set of alternatives because it was felt that this functional aspect of the brain was likely to break down first under the action of an external vibration stress. A belief which the I.A.M. studies tended to confirm. The high level mental organisation task used was continuous short term memory a description of which appears in section 5.0.

Although not studied here, it seems likely that some of the Cardiovascular functions could be used as value judgements for suspension systems. In particular it is quite possible that a certain amount of vibration is a good thing for blood circulation. Evidence for this is provided by relative willingness to sit for long periods of time in car seats compared to household armchairs. It is possible that 'vibro-message' reduces the need for postural

alterations.

3.0 Measurement and description of noise and vibration

3.1 Vibration measurement

The experiment described in section 5 required a vehicle to be driven over a rough road surface to generate a random vibration environment.

The measurement of vibration experienced by seated subjects was referred to the vibration entering the seat structure. A rigid platform was welded beneath the seat and accelerometers attached to this. Three accelerometers were originally used to measure seat structure vibration as shown in figures 6 and 7. The three accelerometers corresponding accurately to the x, y and z axes of the seat relative to the vehicle axes.

It may be argued that measurement of vibration at the seat structure is not a measurement of the vibration experienced by the occupant of the seat. Indeed this is true, but seat structure vibration is representative of the occupants vibration. The latter in any case can be found by multiplying the seat structure vibration by the transfer characteristics of the seat. The seat structure vibration was measured since it was convenient for the purpose of simulation and it overcame problems of accelerometer attachment to the subject or fabric of the seat surface.

In general it is true for the seat of the vehicle used that vibration experienced by the seated occupant is greater than the seat structure vibration

Preliminary measurement of the vehicle vibration under the test conditions of speed and weight with the tri-axial accelerometer configuration revealed that vertical vibration was very much greater than either fore and aft or transverse vibration. After the preliminary measurement the fore and aft and transverse accelerometers were abandoned. This decision agreed with the rating of the subjects who found it hard to detect motions other than vertical. This finding markedly simplified the simulation problem which was restricted to the vertical degree of freedom on the basis of this result.

Measurements of the vertical vibration of the seat structure were made and recorded on to magnetic tape. The vibration measurements were not recorded at the same time as the short term memory tests. However the experimental conditions were the same. Vehicle speed was 30 m.p.h. and the car carried one subject of average weight and two experimental controllers Fifteen of these measurements were made under severely wet driving rain conditions and sixteen under very dry hot conditions. This was done deliberately because it was not intended to restrict the road tests to a particular set of weather conditions. It was therefore necessary to measure vibration under the extremes of wet and dry because vehicle vibration tends to be different under these conditions. The difference arises from changes in the damping characteristics of the suspension system.

3.2 Noise measurement

The noise inside the vehicle and on the motion simulator was measured using a microphone placed adjacent to the subjects head, see Fig. 1. Ten measurements were made on the test track and ten on the motion simulator. Both sets of measurements were tape recorded. The sound level meter used for the noise measurement can be seen in figure 3 adjacent to the tape recorder.

3.3 Description of vibration measurements

The 31 records of seat structure vibration each 60 seconds in length were divided into 15 obtained under wet and 16 under dry conditions.

The description used for each record of vibration was r.m.s. acceleration level and acceleration power spectral density (2).

3.3.1 Procedure

Both descriptions were obtained from the Atuocorrelogram of the record and an ensemble average across the 31 records. The analysis procedure is shown in figure 10. Each vibration record was first conditioned by passing it through a Low Pass filter having an equivalent noise bandwidth of 19.56 c/s Figure II. The purpose of the low pass filter was to limit the frequency spectrum of the vibration record and to prevent aliasing (2) errors affecting the calculation of power spectral density. Vibration components above the filter cut-off frequency - 25 c/s, were not included in the description. Frequencies of vibration above 25 c/s do not reach the seated occupant.

The band limited vibration record was then passed through an Autocorrelation analyser. 128 points of the autocorrelogram were computed with time delay increments of 10 ms and 160 ms. An averaging time of 30 seconds was used. For each record the computation averaging commenced at the beginning of the test track as determined from a cue given by the speech track of the tape recorder. Each record was passed through the Correlation analyser twice once for each time delay increment.

From the Autocorrelogram's computed as

$$R(\tau) = \frac{1}{T}\int_{o}^{T} x(t)x(t+\tau)dt$$

the mean square value was determined at $\tau = 0$.

After normalising the Autocorrelograms to their value at $\tau = 0$, i.e.

$$\Gamma(\tau) = \frac{R(\tau)}{R(o)}$$

the autocorrelograms were Fourier Transformed to obtain a raw estimate of the Power Spectral density Gx(f) where

$$Gx(f) = 2h[Rx(o) + 2 \sum_{r=1}^{m-1} Rx(\tau)_r \cos(\frac{\pi rk}{m}) + (-1)^k Rx(\tau)_m]$$

where h is the sampling interval of the original record, $Rx(\tau)_r$ the value of $R(\tau)$ at the rth lag point and m the maximum number of correlation points, in this case 128, f in Gx(f) is given by

$$f = \frac{kf_c}{m} \text{ fork} = 0,1,2, \ldots, m.$$

The raw power spectral density estimates were then smoothed according to the Hamming relationship

$$G(fo) = 0.5\ Gx(fo)+0.5Gx(f_1)$$

$$G(f_k) = 0.25\ Gx(f_{k-1}) + 0.5Gx(f_k) + 0.25Gx(f_k+1)$$

$$\text{fork} = 1,2, \ldots, m-1$$

$$G(fm) = 0.5G_x(fm-1) + 0.5Gx(fm).$$

The results of this descriptive procedure are shown in figure 12 to 18. The overall average rms acceleration was found to be 0.1067g, Figure 12. The power spectral density curves revealed four distinct power peaks, figure 13. This indicated that the vibration as measured at the structure was compounded from four single degree of freedom generators. The first peak at 1.56 c/s corresponded to the whole body vibration of the vehicle on its road springs. The second peak at 4.88 c/s was the motion of the subject on the seat. The third peak at 11.1 c/s was the vibration generated by the unsprung mass of the suspension system vibrating on the tyre spring. The last peak at 16.4 c/s was the natural frequency of the floor structure of the vehicle.

The percentage of vibration contributed by each of the above identified sources was 23%, 9.2%, 17.3% and 50.5% as given by the area beneath each peak of the power spectrum, Fig. 13.

3.4 Description of noise measurements

The ten noise recordings from the car and motion simulator - each of 30 seconds in length were first A weighted. After A weighting, the records were passed individually through an rms detector and then the ensemble average for the two groups of ten obtained. The overall average rms noise level was

FOR CAR	83.52 db A
FOR MOTION SIMULATOR	68.93 db A

The power spectral density curves for the two noise recordings were obtained using a narrow band analyser. The results are shown in figure 19.

4.0 Vibration simulation experiment

4.1 Synthesis of the vehicle power spectral density curve

The motion simulator consisted of a flat platform driven by an electro-hydraulic jack. Control of this jack was based upon Jack displacement.

Initially attempts were made to reproduce the actual accelerometer recordings, of the car vibration, by integrating the signals twice to obtain a measure of displacement. The fidelity of reproduction using this method was found to be unacceptable. Attempts were made to control the platform using the seat structure accelerometer figure 7. This proved to be too big a development job.

On the basis of these difficulties it was decided to synthesise the P.S.D. curve rather than reproduce an acceleration time history record. In simulating the P.S.D. curve average properties only are reconstructed. In view of the integrating nature of human motion sensation the reconstruction of averages was assumed to be reasonably valid.

4.11 Synthesis procedure

An analogue computer was used to simulate four single degree of freedom filters (spring, mass, damper systems). The natural frequency of the filters was made equal to the centre frequencies of the spectral peaks in the vehicle ride spectrum, figure 13. Namely, 1.56, 4.88, 11.1 and 16.4 c/s. The Q of the filters i.e. the ratio of the centre frequency to the half power bandwidth, was made to equal those of the spectral peaks. To the four filters was applied random noise from a random noise generator. The output of the four filters was then summed and applied to the control system of the vibrator.

The acceleration power spectral density measured at the seat structure on the simulator platform is shown in figure 20. The rms acceleration (area under the P.S.D. curve) for the motion simulator was the same as that for the vehicle, 0.1067 rms.g.

The analogue computer programme used in the simulation is shown in figure 21. The motion simulator is shown in figures 8 and 9.

For the motion simulator experiment described below, the car seat and stimulus/response keyboard were fixed to the simulator to reproduce the postural conditions of the vehicle, figure 9. No attempt was made to mock-up a vehicle structure around the simulator. The experiment was performed as shown in figure 9 with the simulator surrounded by peripheral equipment. Noise level on the simulator was 69dbA, 13dbA less than in the vehicle.

4.2 Experiment with the motion simulator

An experiment was conducted to test the Research Hypothesis: of no difference between performance of a Short Term Memory task under real and simulated conditions.

This Research Hypothesis is one of validity. That vibration synthesised on a motion simulator is an adequate representation of that measured in the vehicle in terms of performance on the task.

4.2.1 Procedure

Under simulated vibration conditions, six subjects each performed the Short Term Memory task at the three behind level of task difficulty, in the same way that they had performed it earlier in the vehicle (see Section 5 for details). The three behind level of task difficulty was chosen because it seemed to fill but not flood the subjects channel capacity. Introspective reports concerning the fidelity of simulation were also collected.

4.3 Results of simulation tests

The results for individual subjects are shown in figures 22 - 27 in terms of Time, Error and Entropy (Contingent Uncertainty see 5.6.1 below) performance. The subject average performance on the simulator is shown in figures 28, 29 and 30.

4.4 Discussion of results

A Student 't' test was used to test the hypothesis of no difference between performance under real and simulated vibration conditions, Table 9. In all cases, Time, Error and Entropy in Table 9, the hypothesis was accepted at $p = 0.05$ level of significance. One concludes from this that the simulated vibration was an adequate representation of the real vehicle vibration. A conclusion which the subjective reports (NOT included) substantially confirmed.

5.0 An experiment to test the sensitivity of a psychological index to changes in low intensity random vibration

In this experiment the effect of low intensity vibration on a high level mental organisation task is studied.

5.1 The psychological index

A short term memory task described by Whitfield (12) was used as the high level mental organisation task. The task involved random numbers displayed on a tube one at a time. In the simplest case in Whitfield's experiment the subject merely pressed a push button in accordance with the number displayed. The numbers and push buttons ranged from 0 - 9.

In this straight transmission case the task difficulty is described as 0 - behind. To increase the severity of the task the subject is made to store numbers continuously in the short term memory. To achieve this the correct response to a number displayed on the tube is made by pressing the push button not according to the number displayed now, but by pressing the key according to the number displayed 1, 2, 3, 4 or 5, numbers ago. The task difficulty is therefore described in terms of the number of numbers which must continuously be memorised. It is described as 0, 1, 2, 3, 4 or 5 behind. Knowledge of results were given to the subject in the form of an auditory tone or a red light which came on when a wrong button was pressed. The light and tone vanished when the subject again made a correct response.

5.2 Research hypothesis

That performance on a short term memory task will be different at different levels of low intensity vibration. The direction of difference being predicted as a reduction in performance with an increase in vibration Intensity.

5.3 The experiment

In this experiment the dependent variable was time and error performance on the short term memory task. The primary independent variables were vibration intensity, task difficulty and subjects. Other independent variables in the experiment which affected either the vibration environment or the subjects are listed in table 1. An indication of whether or not steps were taken to control the variables listed is also included in table 1.

5.3.1 Design of the experiment

Six subjects were used in the experiment each subject acting as his or her own control. That is each subject performed the Memory task under all experimental conditions. Namely at two levels of vibration and five levels of task difficulty.

For each subject the order of presentation of the conditions were as follows:

1. Vibration level 1 at task level 1 followed by task difficulty 2 up to 5.

2. Vibration level 2 at task level 1 up to 5.

3. Motion Simulator at vibration level 2 and task level 3.

In an original design a balanced design was planned where two groups of matched subjects would perform the task in reverse order with respect to the two vibration conditions. The merit of this design is that it takes into account the Welford, Brown, Gabbe effect (13). The balanced design which used twelve subjects was abandoned in favour of the 6 subject design because of pressure of time.

5.3.2 Choice of the vibration scale points

Two vibration intensities were chosen from the scale of low intensity (as defined) vibration so that they were a maximum distance apart. The philosophy being that the psychological index must first be proven with large differences. For, if it failed to discriminate large vibration differences it would be unlikely to discriminate small differences. The lower limit of vibration corresponding to vibration conditional was taken as zero. In this condition the subject performed the task in a stationary vehicle. The second scale point, vibration condition 2, was determined by driving a test vehicle over a moderately rough road surface at 30 m.p.h. At this speed the vibration interferred neither with the driving task or the willingness of the subjects to sustain the vibration. Although as revealed in discussion with the subjects it did influence manipulation of the response keyboard.

Since the points on the vibration scale were fixed by the requirements of the experiment the vibration variable was considered fixed for the purpose of analysis of variance of the results.

5.3.3 Choice of task difficulties

In a previous study Whitfield (12) using the same apparatus and task in a Study of short term memory had deduced the performance task difficulty relationship shown in figure 34.

The 'tick' phenomenon in Whitfield's findings suggested that subjects found the task easier performing 1 back than 0 back. Reasons for which are given in reference 12. In order to construct a scale of increasing task difficulty the 0 back task was not used. The task difficulty in this experiment therefore was minimum at 1 back, maximum at 5 back, with even steps in between.

5.3.4 Subjects

Six subjects were used, four male, 2 female. All subjects were members of The College of Aeronautics Staff, except 1 who was a student. Their occupations were: two shorthand typists, two draughtsmen, 1 postgraduate student, 1 apprentice.

Subject attitude towards the experiment was initially controlled by using a standardised briefing sheet Appendix II. The briefing sheet also formed the basis of the training scheme. However attitude of the subjects went out of control due to a lengthy lag between testing under vibration conditions 1 and 2.

5.4 Apparatus and conduct of the experiment

Conduct of the short term memory task. In both the zero vibration condition and the road vibration condition the subject performed the task seated in the front passenger seat of a small passenger car, a Morris 1100.

Figure 1. Keyboard and display, which were integral were placed before the subject as shown in figure 1. The keyboard was adjustable for angle, height, and distance from the subject. The subjects were allowed to choose their own keyboard position. The keys were arranged to fit the position of the fingers, figure 1. The key position was adjustable and subjects were given the option of adjustment if they found the key position difficult. The display is shown hooded in figure 1, it consisted of a neon tube. The hood was necessary to provide sufficient contrast in daylight.

5.5 Training

Before proceeding with either of the experimental conditions, the subjects were given time to practice the use of the keyboard as indicated in Appendix II. Having mastered and fully learned the keyboard the subjects were then allowed to proceed to the actual tests when their performance was recorded.

As a result of lag after the 1st test condition most subjects suffered a loss of skill and had to be retrained before proceeding to the second vibration condition.

The apparatus used to generate the task consisted of a tape reader and D.I.M.P., Random numbers used for the stimulus were stored on punched tape as shown in figure 2. D.I.M.P. figure 5 (Dynamic Immediate Memory Probe after an experiment of the same name by Whitfield (12)), functioned as a display generator. In its memory it stored the numbers that had been used and dependent upon the 'number back' of the task difficulty compared these numbers with the number of the key pressed. Each response of the subject gave rise to a Binary coded pulse. The pulses were fed directly to a S.E.T.A.R. transcription unit which generated a punch tape bearing in coded form whether the response was correct or incorrect and stating the time interval between responses. In the second vibration condition, the response information from the subject generated by D.I.M.P. was tape recorded and played back into S.E.T.A.R. after test. The tape recorder and its electrical equipment can be seen in figures 3 and 4. The experimental controller for the task sat in the rear of the test car - figure 2.

Vibration condition 2 was generated by driving the test car at 30 m.p.h. over a test track. The test track was in fact a delapidated section of perimeter track belonging to The College of Aeronautics Airfield. The length of the test surface was such that a vehicle speed of 30 m.p.h. 30-40 responses by the subject were sufficient to cover the length of the test track. For this reason, the 600 stimuli were split into 20 groups of 30. Each condition of task difficulty at vibration level 2 required 20 repeated test runs. In all each subject performed 100 times on the test track.

5.6 Results.

5.6.1 Description of raw data

Three descriptions were applied to each set of 600 responses.

1. Average Response Time (seconds).

2. Total Number of Errors in 400 responses.

3. Average Rate of Contingent Uncertainty between stimulus and response for 400 responses (Bits/sec.).

For each experimental condition, the subjects made 600, responses (20 trials in groups of 30) only 20 of the 30 responses in a group were used to calculate the above values. The twenty responses in each group were taken after ignoring the number of numbers corresponding to the task difficulty - the number back.

Contingent Uncertainty was calculated because it afforded a means of combining time and error. It was hoped that this description would give a measure of 'trade off' by the subject between time and error. It is a direct measure of the 'transmission inefficiency' or 'unpredictability of response' of the subject, based on information content of stimulus and response.

The contingent uncertainty (20) was calculated for each response as:-

$$H(x:y) = H(x) + H(y) - H(x,y),$$

where H(x) is the stimulus uncertainty, H(y) the response uncertainty and H(x,y) the joint uncertainty between stimulus and response. The stimulus uncertainty that is the uncertainty associated with the appearance of a number in the range 0 - 9 was calculated from the actual relative frequency of each number. It was not assumed that each number was equi probable with $p = 1/10$. This was done because the same set of random numbers were used for each experimental condition. Each subject therefore observed the set of random numbers 11 times. All subjects agreed after the experiment that they had developed a strong sense of probability towards the numbers. They all knew for example that the probability of an 8 was zero.

The digital computer programme used to describe subject perfomance is shown in Appendix 3. The programme used to Fourier Transform the Vibration Autocorrelograms was R.A.E. Pegasus Program 02.01.09.

5.7 Discussion of Results

5.7.1 Hypothesis tests

The Null hypothesis of no difference between Short term memory under vibration conditions 1 and 2 was tested by analysis of variance. A Three factor test was used the model for which is shown in Appendix IV. The Three factors were Vibration, Task difficulty and Subjects. Expected value for mean squares and 'F' ratios in the analysis of variance test were calculated according to rules suggested by Winer (14). The results of the analysis of variance test is shown in tables 5, 6 and 7. The test was applied

to Time, Error and Entropy.

Level of Significance was taken as p = 0.05. The decision is made as follows:

Ho: $V_1 = V_2$	Accept	Reject
Time		√
Error		√
Entropy	√	

In all cases variation in the results was due to a high contribution from individual difference as expected. The variation due to task difficulty is high for Time and Error but low for entropy.

Selected 't' tests were also applied to the time, error and entropy results with subjects and task difficulty averaged out. The results are shown in Table 8. In none of the six tests selected, could the Null hypothesis $H_o : V_1 = V_2$ be rejected at p = .05. This finding really adds nothing to the interpretation of the results except that it demonstrates the merit of subtracting out variation or differences due to other factors, such as individual difference between subjects and task difficulty.

In conclusion, it may be said that although the Null hypothesis $H_o: V_1 = V_2$ was not unanimously rejected in terms of Time, Error and Entropy, the rejection for time and error does indicate that short term memory may be useful as an index of vibration effects.

5.7.2 Graphical presentation of data

Twelve graphs are presented in figures 22-33. Six are individual subject results for Time, Error and Entropy performance, three Averages with respect to subjects and three scattergrams plotted for all subjects.

Two facts emerge from the graphs:

1. That the speed of response was better under vibration conditions at all levels of task difficulty. The response time showing a progressive increase with task difficulty which varied little between the two vibration conditions figure 28. A high degree of coherence in the response time pattern was found between subjects, figure 31.

2. That a reversal effect in number of errors occured between 1 and 2 behind. Individual difference in error score figure 32 being too great to permit an interpretation of the average figure 29.

The reversal effect in error is demonstrated more clearly in the Entropy result, figure 30.

Clearly, the only really consistent difference between the two vibration results is the time difference. That the direction of this difference was unexpected is demonstrated by the Research Hypothesis. The justification for improvement in response time resides either in learning effects or cortical arousal. The latter explanation appears to be more acceptable if one compares the results of subjects SH and EM with the others. SH and EM were both high speed typists, familiar with the manipulation of keyboards and highly practiced in continuous short term memory. Even they showed improvement under conditions of vibration.

Mediating against an improvement in response time in the vibration condition was the keyboard task. With the keyboard and hand vibrating the keyboard task was more difficult. Evidence of the keyboard effects could have been checked by making the subjects respond in the two vibration conditions without transmitting information, e.g. by keying the numbers 0 to 9 chronologically.

If the arousal theory is correct and vibration does improve cortical activation the change might be better detected using E.E.G. measures (14).

Regarding the effects of noise in this experiment which were very different for the two vibration conditions the Motion Simulator results are thought to offer an explanation. The motion simulator noise 69dbA compared to 83dbA for the vehicle on the road, was closer to the zero vibration condition then to the vehicle vibration condition. The good agreement between the motion simulator result and vehicle vibration result figures 28-30 which was fairly consistent between subjects figures 22-27 suggests that noise was not a significant factor.

In pure psychological terms the result obtained in figure 28 confirms the Whitfield 1964 finding (12). Namely that Short Term Memory exhibits a 'tick' phenomenon for response time versus memory span. The toe of the tick is of course missing in figure 28 because the 0 behind condition was not investigated.

5.8 In conclusion

0.1067 rms g is a lot of vibration. The psychological index test in this experiment has not entirely demonstrated that it is sufficiently sensitive to quantify the human effects of such a large difference in vibration. In its present form, the short term memory task is unlikely to discriminate accurately between small differences which exist between similar vehicle suspensions. As an evaluation technique and aid to the vibration engineer it is not yet proven. The best stability in the index appears to be response time, a measure which appears to be relatively insensitive to the difficulty of the short term memory task. If a scale of sensitivity were contemplated in terms of this task, response time would undoubtedly provide the best scale. It is possible, in view of the results obtained, that the slope of a contingent Uncertainty line between task levels 1 and 2 could also be used to form a scale.

The experiment proves the validity of using motion simulation to synthesise a vehicle ride spectrum as a laboratory representation of a real vehicle ride environment.

5.9 Recommendation for further work

1. The objective psychological index of random vibration effects on man, used in this experiment should not be abandoned until the experiment has been repeated with an improved experimental design. By changing the design so that the subjects perform first in the no vibration condition, second in the vibration condition, and third again in the no vibration condition, changes in performance of the short term memory task in the vibration condition can be normalised to learning effects.

2. Having demonstrated the validity of the motion simulator more use should be made of its simulation capabilities. Further tests using Short term memory could easily include more vibration scale points.

Studies such as those mentioned in section 1.3 which might lead to a more precise definition of the Minimum Discomfort Spectrum could be tackled with the Short term memory and Motion Simulator techniques.

3. In terms of cardiovascular (blood circulation) function it is by no means clear what kind of vibration characteristics constitute a health benefit or hazard. Again this is a study which a physiologist could tackle with the aid of a motion simulator.

TABLE 1

TABLE OF INDEPENDENT VARIABLES

Subject Variables	Controlled?	Remarks
Motivation	No	
Altitude	Yes	Each subject briefed using same briefing instructions
Training	Yes	Each subject trained to a predetermined level of skill
Time of day	Yes	
Posture	No	
Position of Keyboard	No	
Movement	No	
Environmental Variables		
Noise	No	Measurement inside the vehicle and on the motion simulator
Heat/Ventilation	No	
Other environmental factors	No	
F ctors which affect the vehicle vibration		
Speed of Vehicle	Yes	To within the limits attainable by a driver
Tyre Pressure	Yes	
Weight - fuel	No	
subject	No	
Road Surface	Yes	Vibration measured under extremes of wet and dry
General Weather	No	
External variables		
Traffic	Yes	Test performed on a test track

TABLE 1

Information (Inductive and Deductive) Required by the Vibration Engineer To Design and Evaluate a Vibration Isolation System

D = DEDUCTIVE I = INDUCTIVE

SYSTEM TO BE ISOLATED

Stage	Hardware	Human
1. (D)	Required life. Performance Maintenance Frequency Probability Statements binding these demands.	Acceptable Probability of Injury. Required Endurance and Performance. Fatique Frequency.
2. (D)	Degree of freedom of the system. Description of Representative Vibration Characteristics. In terms of Amp Prob. Freq. and Time for each degree of freedom.	Same
3. (D)	Validity of accelerated and real time laboratory tests.	Simulation Techniques Validity of Simulation
(I)	(Design) Test Specification for High Fidelity accelerated on real time test.	(Design) Real Time Test Specifications
4. (D)	Levels and characteristics of vibration which impair the life, performance and increase the maintenance frequency, of the instrument to be isolated.	Levels and characteristics of vibration which effect permanent injury and which affect endurance, performance and fatigue.
5. (I)	Statement of the levels and characteristics of vibration that the isolation system must exclude from the Hardware Unit.	Same - for the human being.
6.	Statement of the Physical Properties, Mass, Moments of Inertia, Centres of Gravity, Elasticities and damping - of the hardware unit.	Same
7.	Statement of the Dynamic Properties. Transfer Function Frequency Response Function - Mechanical Impedance - Cross Coupling effects etc.	Same

8.	Design of Isolation System	Same - except consider human isolation system - legs and tissue.
9.	Production Information - Cost/Value	"
10.	Design of attachment device	Design of support restraint system.
11.	Does the isolation system meet the system requirements of the hardware unit. When exposed to the vibration described in Stage 2 and under operational conditions. Does the Isolation System Transmit Vibration with levels and characteristics that should have been excluded according to Stage 5.	Design for Human Being - Evaluate in terms of system requirements - endurance - performance - time to fatigue and in terms of the undesirable vibration transmitted and the energy absorbed by the human being. When exposed to the remnant vibration not isolated. Finally does the H.O. find the isolation system acceptable.

TABLE II PERFORMANCE ON SHORT TERM MEMORY TASK-SUBJECT DATA

Time - secs. $.10^3$

Vibration Level	Subject	Task Difficulty				
		1	2	3	4	5
0	D.J.	849	932	1590	1758	1877
1	D.J.	760	945	942	1444	1810
0	D.R.	745	1025	1915	1429	1612
1	D.R.	580	686	1398	985	1196
0	P.K.	884	885	1160	1269	1465
1	P.K.	766	772	902	1008	1389
0	C.C.	803	1042	1530	2361	2508
1	C.C.	749	939	1770	1948	1712
0	S.H.	667	1023	1221	1389	2157
1	S.H.	460	652	941	1269	1801
0	E.M.	625	822	1068	1074	1379
1	E.M.	538	930	967	991	1182

Vibration Level

0 = No vibration

1 = 0.1067 RMS g

TABLE III NUMBER OF ERRORS

Vibration Level	Subject	Task Difficulty				
		1	2	3	4	5
0	D.J.	10	18	54	161	196
1	D.J.	48	32	20	183	132
0	D.R.	12	52	63	42	48
1	D.R.	10	12	107	21	47
0	P.K.	26	17	17	3	24
1	P.K.	10	6	25	13	12
0	C.C.	18	52	166	35	134
1	C.C.	23	32	38	60	201
0	S.H.	0	7	0	19	17
1	S.H.	11	8	12	7	16
0	E.M.	11	32	16	13	22
1	E.M.	13	11	9	7	16

Vibration Level

0 = No vibration

1 = 0.1067 RMS g

TABLE IV ENTROPY (CONTINGENT UNCERTAINTY) BITS/SEC x 10^3

Vibration Level	Subject	Memory Delay				
		1	2	3	4	5
0	D.J.	50	104	135	176	170
1	D.J.	276	140	109	237	188
0	D.R.	120	168	132	150	148
1	D.R.	106	106	207	119	170
0	P.K.	180	143	102	18	83
1	P.K.	91	50	167	100	54
0	C.C.	140	189	219	72	117
1	C.C.	189	160	96	110	175
0	S.H.	0	35	0	92	41
1	S.H.	142	100	81	38	60
0	E.M.	113	197	107	88	82
1	E.M.	158	71	51	43	79

Vibration Level

0 = No vibration

1 = 0.1067 RMS g

TABLE V ANALYSIS OF VARIANCE OF ERROR

SOURCE	SS	D. of F.	M.S.	F (S)	F	F (Th)	SIGNIFICANCE
C - Subjects	55038,95	5	11007.79	C/within cell	203	3.02	>> 99%
B - Memory	23590.767	4	5847.692	B/BC	2.04	1.46 (75)	75%
A - Vibration	340.817	1	340.817	A/AC	7.83	6.61 (95)	95
CB	57211.633	20	2860.582	BC/within cell	52.77	1.88	>> 99%
CA	217.483	5	43.497	AC/within cell	0.800	1.33 (75)	None
BA	1243.433	4	310.858	AB/ABC	0.396	1.46 (75)	None
ABC	15669.767	20	783.488	ABC/within cell	14.4	1.88	99%
WITHIN CELL	61780.00	1140	54.2				

TABLE VI ANALYSIS OF VARIANCE - TIME

SOURCE	SS	D. of F.	M.S.	F (S)	F	F (Th)	SIGNIFICANCE
C - Subjects	2057091	5	411418.297	C/within cell	263.7	3.02	>> 99%
B - Memory	7450574	4	1862643	B/BC	19	4.43	>> 99%
A - Vibration	734162	1	734162	A/AC	28.28	16.3	>> 99%
BC	1920601	20	96030	BC/within cell	6.15	1.88	99%
CA	129782	5	25956	AC/within cell	16.63	3.02	99%
BA	94315	4	23578	AB/ABC	1.02	1.45 (75)	None
ABC	458762	20	22938	ABC/within cell	14	1.88	99%
WITHIN CELL	37360.100	23940	1560				

TABLE VII ANALYSIS OF ENTROPY VARIANCE

SOURCE	SS	D. of F.	M.S.	F (S)	F	F (Th)	SIGNIFICANCE
C - Subjects	73049	5	14609	C/within cell	25.94	3.02	99%
B - Memory	4767	4	1191	B/BC	0.609	1.46	None
A - Vibration	1500	1	1500	A/AC	0.401	1.69 (75)	None
BC	39107	20	1955	BC/within cell	3.472	1.88	99
CA	18673	5	3734	AC/within cell	6.63	3.02	99
BA	13601	4	3400	AB/ABC	1.24	1.46	None
ABC	54649	20	2732	ABC/within cell	4.85	1.88	99
WITHIN CELL	642029	1140	563				

TABLE VIII SELECTED t TEST FOR DIFFERENCE IN MEAN BETWEEN STATIC AND 0.1 RMS g VIBRATION ENVIRONMENT

MEASURE	MEMORY DELAY	t	$t_{.95}$	NULL HYPOTHESIS
TIME	4 Behind	1.12	1.81	Accept
ERROR	3 Behind	0.61	1.81	Accept
ENTROPY	1 Behind	1.575	1.37	Reject at P = .90
ENTROPY	2 Behind	1.161	1.81	Accept
ENTROPY	3 Behind	0.025	1.81	Accept
ENTROPY	5 Behind	0.44	1.81	Accept

TABLE IX DIFFERENCE IN MEANS BETWEEN REAL AND SIMULATED ENVIRONMENT; 't' TEST

MEASURE	D. of F.	't'	$t_{.95}$
Time	11 - 2	0.25	1.83
Error	11 - 2	0.17	1.83
Entropy	11 - 2	0.54	1.83

Null hypothesis cannot be rejected for any of the measures

Appendix I

Vibration Isolation Systems - Identification of the Human Factor Problems

A vibration engineer who has to isolate a delicate instrument from damaging high frequency vibration would almost certainly consult the instrument engineer. He would enquire about the dynamic and static characteristics of the instrument and about its tolerance to vibration. In most cases the instrument engineer is likely to be able to furnish the information required to design a satisfactory vibration isolator.

If the delicate object to be isolated from vibration is a human being, what information does the vibration engineer require? and what advice can he expect to get from a Human Factor Specialist? By contrasting the information required to design and evaluate a hardware isolation system and a human isolation system some pockets of human factor ignorance can be identified.

The stages in the design, development and evaluation of an isolation system are shown in figure 35. The information required at each stage for the case of both hardware and human isolation is outlined in the accompanying table. In most cases the differences which arise between the design for hardware and human beings is not procedural or in terms of the information required. The difference arises in the methods of acquiring the information.

In particular, the human factor specialist could be expected to assist stages 1, 3, 4, 6, 7, 10 and 11.

Evidence for stage 1 is provided by the allocation of function procedures in system design (15). Stages 3 and 4 cannot proceed without some insurance for the well being of the human being. Studies of tolerance to vibration have been studied by Coermann (16) and the health hazard by Matthews (17). Information on the physical and dynamic characteristics of the human body as a complex elastic body stages 6 and 7 can be obtained from (18) (16). The vibration isolation properties of the legs Stage 8 have been studied by Hornick (19).

Since human beings cannot be integrated with an isolation system using nuts and bolts, a support and restraint system must be specified. Information that can assist stage 10 may be found in (20).

Methods of evaluating the efficiency of an isolation system include checks to see that the human component in the system, as a result of the suspension, can adequately perform his function. If he cannot the system will not meet its objectives.

If it is not possible to evaluate the suspension system in terms of human performance on the primary task, artificial tasks of greater severity can be substituted. In the design and development of car suspension systems, few techniques have been devised for suspension evaluation.

None of the human factor areas mentioned above in the design stages of a vibration isolation system have been fully explored by human factor specialists. Least of all, techniques for evaluating the effects of vibration and the efficiency of an isolation systems in human terms. At present a human factor specialist would find it hard to completely satisfy the vibration engineer in terms of the quantitative information he needs

Appendix II

Vibration Project

1st Test Series (Immediate Memory)

Experimental instructions to be read to subject without variation.

Practice session

In this experiment we are trying to see if small amounts of vibration have any effect on people's ability to do mental work. The way we will do this will be essentially to get you to do mental work in this room first of all and then compare your efforts with those you produce on the same task when you are a passenger in a car.

The mental work we are going to ask you to do is something similar to what is involved in looking up and dialling a telephone number and makes use of what is called your 'immediate memory'. You will see a number appearing on this display (indicate): now you will have to remember it while you press the key here (indicate) with the number on it corresponding to the number which appeared on the display before this present one. Press the key and a new number will appear while you of course hold in your memory while you press the key corresponding to this present one; and so on for 30 digits. On some trials you will have to hold 2 or perhaps 3 numbers in your head in this way while you operate the keyboard. For convenience we say you are operating '1-behind', '2-behind' or '3 behind'.

You will see it is quite like dialling a telephone number where you may first of all look up the number in the book and then you hold a decreasing number of digits in your immediate memory as you proceed with dialling. However, we will explain all this in more detail at later sessions. On this first occasion all you are required to do is practice the keyboard. You will not really have to use your memory faculties. You will simply press the key which corresponds to the number on the display.

I will bring the first number up for you and then you proceed pressing the keys. Each new number will come up and you press the appropriate key.

Experimental Sessions

(Experimenter: use the first digits of the first trials to demonstrate then always rest the tape to begin the first trial proper).

(i) 'One-behind'.

This time we start the trial proper.

First of all I will present the first number to you on the display by means of this button (indicate 'start' button on D.I.M.P.)

1. You must remember this number which is ....
2. Press the zero key to bring up the next number which is ....
3. Press the key .... (1) which will bring up a new number ....
4. Press the key .... (2) and so on for 30 digits.

Thus you are pressing the key appropriate not to the number on the display at the moment, but the one which appeared just previously, i.e. playing 'one-behind'.

(ii) 'Two-behind'.

This time the task is a little more difficult. We want you to try and hold two numbers in your memory while you deal with a third. Again I will bring the first number up on the display by means of this button (indicate 'start' button on D.I.M.P.)

1. You must remember the number which is ....
2. Press the zero key to bring up the next number which is ....
3. Press the zero <u>again</u> to bring up the next number which is ....
4. Press the key .... (1) which will bring up a new number ....
5. Press the key .... (2) and so on for 30 digits.

Thus you are pressing the key appropriate not to the number on the display at the moment but one which appeared two previously - playing 'two-behind'.

(iii) 'Three-behind'.

Again the task is a little more difficult. Three numbers have to be held in the memory while you deal with a further. Again I will bring the first number up on the display by means of the button.

1. You must remember the number which is ....
2. Press the zero key to bring up the next number which is ....
3. Press the zero key <u>again</u> to bring up the next number which is ....
4. Press the zero key again to bring up the next number which is ....
5. Press the key .... (1) which will bring up a new number ....
6. Press the key .... (2) which will bring up a new number ....
7. Press the key .... (3) which will bring up a new number ....
   and so on for 30 digits.

Thus you are pressing the key appropriate not to the number on the display at the moment but one which appeared three previously - playing 'three-behind'.

APPENDIX III

Data analysis Program (Ferranti Pegasus Code).
For calculation of Average Response Time, Number of Errors and Contingent Uncertainty in D.I.M.P. Keyboard Task.

```
J1.0
n1=1
STOP
30)→M2080
v0=v100
v0=v0/20
v0=v0X0.01
v1=n50
v2=n59
v3=n51
v4=n60
v5=n52
v6=n61
v7=n53
v8=n62
v9=n54
v10=n63
v11=n55
v12=n64
v13=n56
v14=n65
v15=n57
v16=n66
v17=n58
v18=n67
→20,n1≠1
→21,n49=1
→22,n49=2
→23,n49=3
→24,n49=4
→25,n49=5
STOP
21)TEXT1BEHIND

→20
22)TEXT2 BEHIND

→20
23)TEXT3 BEHIND

→20
24)TEXT4 BEHIND

→20
25)TEXT5 BEHIND

20)n2=21
n3=1
n4=2
1)vn2=vn3+vn4
vn2=vn2/20
n2=n2+1
n3=n3+2
n4=n4+2
→1,20>n4
n5=31
n2=21
2)n0=20
→31,vn2=*0
2)vn5=LOGvn2
→33
31)vn5=0
32)v30=LOG2.0
vn5=vn5/v30
v30=LOG2.0
→33
31)vn5=0
32)vn5=vn5/v30
vn5=vn5Xvn2
n5=n5+1
n2=n2+1
→2,30>n2
v40=0
n5=31
3)v40=v40+vn5
n5=n5+1
→3,40>n5
v40=-v40
v41=0
n6=2
4)v41=v41+vn6
n6=n6+2
→4,20>n6
v41=v41/20
n0=20
→5,v41=v0
v42=LOGv41
v42=v42/v30
v43=v42Xv41
v44=0
n7=1
6)v44=v44+vn7
n7=n7+2
→6,19>n7
v44=v44/20
v45=LOGv44
v46=v45/v30
v47=v44Xv46
v48=v43÷v47
v48=-v48
n8=51
n2=1
7)vn8=vn2/20
n8XX=n8+1
n2=n2+1
→7,19>n2
n9=71
n8=51
9)n0=20
→10,vn8=*0
vn9=LOGvn8
vn9=vn9/v30
vn9=vn9Xvn8
→11
10)vn9=0
11)n9=n9+1
n8=n8+1
→9,69>n8
v70=0
n10=71
12)v70=v70+vn10
n10=n10+1
→13,89>n10
v70=-v70
v90=v40+v48
v90=v90-v70
v92=v90/v0
Xn0=n0
→13
5)v92=0
13)n11=2
v94=0
14)v94=v94+vn11
n11=n11+2
→14,20>n11
→15,n1≠1
v95=0
15)v95=v95+v94
→16,n1≠1
v96=0
16)v97=v94Xv94
v96=v96+v97
→17,n1≠1
v103=0
17)v103=v103+v101
v104=v92X1000
v105=v104Xv104
→18,n1≠1
v106=0
v107=0
18)v106=v106+v104
v107=v107+v105
→19,n1≠1
v108=0
19)v108=v108+v100
n1=n1+1
→30,21>n1

PRINTv95,3122
v109=v95xv95
PRINTv109,3122
PRINTv96,3122
PRINTv108,3122
v111=v108xv108
PRINTv111,3306
PRINTv103,3306
v110=v108/400
PRINTv110,3126
PRINTv106,3126
v113=v106xv106
PRINTv113,3306
PRINTv107,3306
v112=v106/20
PRINTv112,3306
v114=v112/1000
PRINTv114,3052
Xn0=n0
STOP
(→0)
******2*
```

Machine Code Data Entry Program.

```
T128.0
119 0000.
0
127 4000.
0
300 -000.
0

Jr2**********6.2
A3

T260.0

0.7 200
  0 100
 35 201
  0 0712
0.1 267
 12 5712
 12 6712
  1 074
 17 600
0.4 660
 17 600
 17 600
 16 300
1.0 060
125 -10
18

 16 400
  5 140
  9 343
1.3+360
  1 140
  5 341
1.6 361
  1 443
1.4 461
0
 2.5 060
0
  3 341
1.6+361
0
  2 140

 2.5 460
  3 140
  8 443
 2.5 460
  4 140
  1 443
 2.5 460
0
 2.4 060
0
 0.7 200
 25 152
  0 0712
  0 1401
0
0

 16 600
 16 643
3.0 660
 16 641
3.4+160
  5 640
  6 120
 16 600
3.3+767
3.7 100
  4 0721
0.0 060
+0
260 -00
0

0
  6 1721
  7 2721
  8 3721
  9 4721
0
 20 240
 10 5721
  0 074
 16 300
 13 343
0.4+361
  1 074
0
  5 0721
0.1 060

  1 074
 16 600
  0 700
  3 340
0.3 100
0.4+060
260 -00
0
 16 600
 16 644
1.0 662
 12 641
1.0 663
0
2.0 060
0

  1 341
 16 000
1.0+367
  0 074
  3 340
 16 000
1.2+367
0
0.0 060
0
+0
+0
+0

 25 652
2.4 0606
2.3 720
  5 701
0.4 367
4.0 060
+10
  6 540**
2.1 060
1.0 060
0
  0 540
2.1 060
  2 540
2.1 060
  3 540
2.1 060
1.0 060
0
  7 540
2.1 060
  4 540
2.1 060
  5 540
2.1 060
  8 540
2.1 060
  9 540
2.1 060
  1 540
2.1 060

 16 600
 16 500
  1 543
1.1+561
4.3+661
4.6 300
4.5 060
  8 643
5.0 661
4.7 300
 11 4721
4.0 060
125 -10
0
126 -20
0

  7 641
1.1+661
125 740
  3 752
  1 500
4.6 300
 14 7703
  7 101
 14 7713
  7 720
 15 0703
  7 101
 15 0713
0.0 261
 12 0725
0.0 060

  0 074
 16 600
 10 643
4.1+662
 10 641
 25 652
  6 301
  1 500
  0 0703
 35 101
  0 0713
 16 000
 16 000
  1 243
  9 4725
5.2+060

  1 074
 17 100
0.5+160
  4 240
 16 000
0.2 267
  0 074
  3 240
 16 000
0.4 267
0.0 060
 16 100
**** 0 074
 16 200
  1 201
 13 1725

 30 243
1.1+260
  0 077
  2 240
 14 7703
  1 600
1.7 100
  0 700
 38 156
1.6 603
 14 2725
2.0 060
-256
+294

 12 156
2.7 605
  6 101
 14 7713
 35 301
1.2 267
  0 074
0
  0 772
2.5 110
+0
+0
-512

Z
**********
```

Appendix IV

Analysis of variance

1. General model

$$Xijkn = \ldots + \alpha_i \ldots + \beta_j \ldots + \gamma_k \ldots + \alpha\beta_{ij} \ldots + \alpha\gamma_{ik} \ldots + \beta\gamma_{jk} \ldots + \alpha\beta\gamma_{ijk} + \epsilon_{ijkn}$$

2. Factors - 3

Factor	Variable	Levels	Operator
Vibration	Fixed	p = 2	Dp = 0
Memory	Fixed	q = 5	Dq = 0
Subjects	Random	r = 6	Dr = 1

3. Mean Square Expectancy

	p	q	r		
FACTOR	i	j	k	n	Expected value of M.S.
αi	Dp	q	r	n	$Dn\sigma_e^2 + nDqDr\sigma^2_{\alpha\beta\gamma} + nqDr\sigma^2_{\alpha\gamma} + nrDq\sigma^2_{\alpha\beta} + nqr\sigma^2_{\alpha}$
βj	p	Dq	r	n	$Dn\sigma_e^2 + nDpDr\sigma^2_{\alpha\beta\gamma} + npDr\sigma^2_{\beta\gamma} + nrDp\sigma^2_{\alpha\beta} + npr\sigma^2_{\beta}$
γk	p	q	Dr	n	$Dn\sigma_e^2 + nDpDq\sigma^2_{\alpha\beta\gamma} + npDq\sigma^2_{\beta\gamma} + nqDp\sigma^2_{\alpha\beta} + npq\sigma^2_{\gamma}$
$\alpha\beta ij$	Dp	Dq	r	n	$Dn\sigma_e^2 + nDr\sigma^2_{\alpha\beta\gamma} + nr\sigma^2_{\alpha\beta}$
$\alpha\gamma ik$	Dp	q	Dr	n	$Dn\sigma_e^2 + nDq\sigma^2_{\alpha\beta\gamma} + nq\sigma^2_{\alpha\gamma}$
$\beta\gamma jk$	p	Dq	Dr	n	$Dn\sigma_e^2 + nDp\sigma^2_{\alpha\beta\gamma} + np\sigma^2_{\beta\gamma}$
$\alpha\beta\gamma ijk$	Dp	Dq	Dr	n	$Dn\sigma_e^2 + n\sigma^2_{\alpha\beta\gamma}$
E(ijk)n	1	1	1	Dn	σ_e^2

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Figure 1: Display and keyboard mounted in test vehicle.
Sound level pick-up is above subjects head.

Figure 2: Random numbers on tape provided number source.
DIMP computer provided stimulus, checked response
and provided a pulse coded record of response.

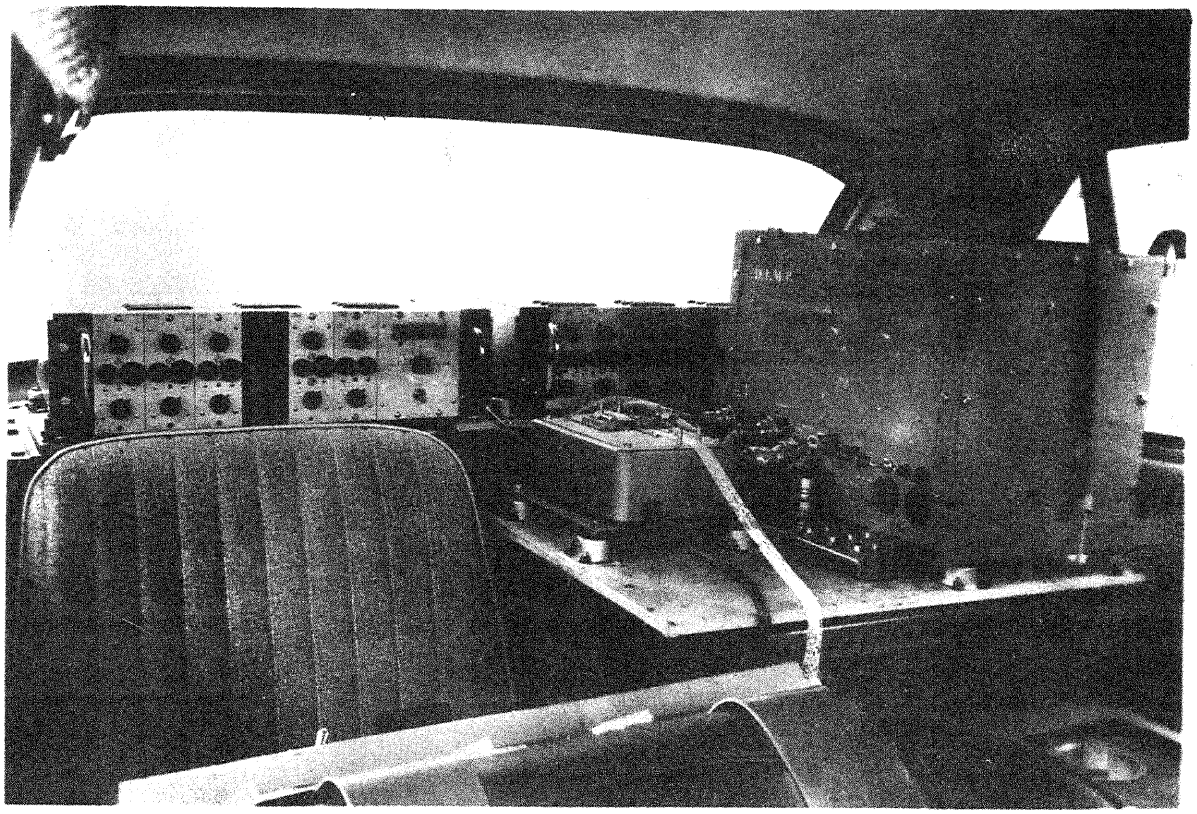

Figure 3: Shows the magnetic tape recorder and sound level meter housed in the rear of the test vehicle.

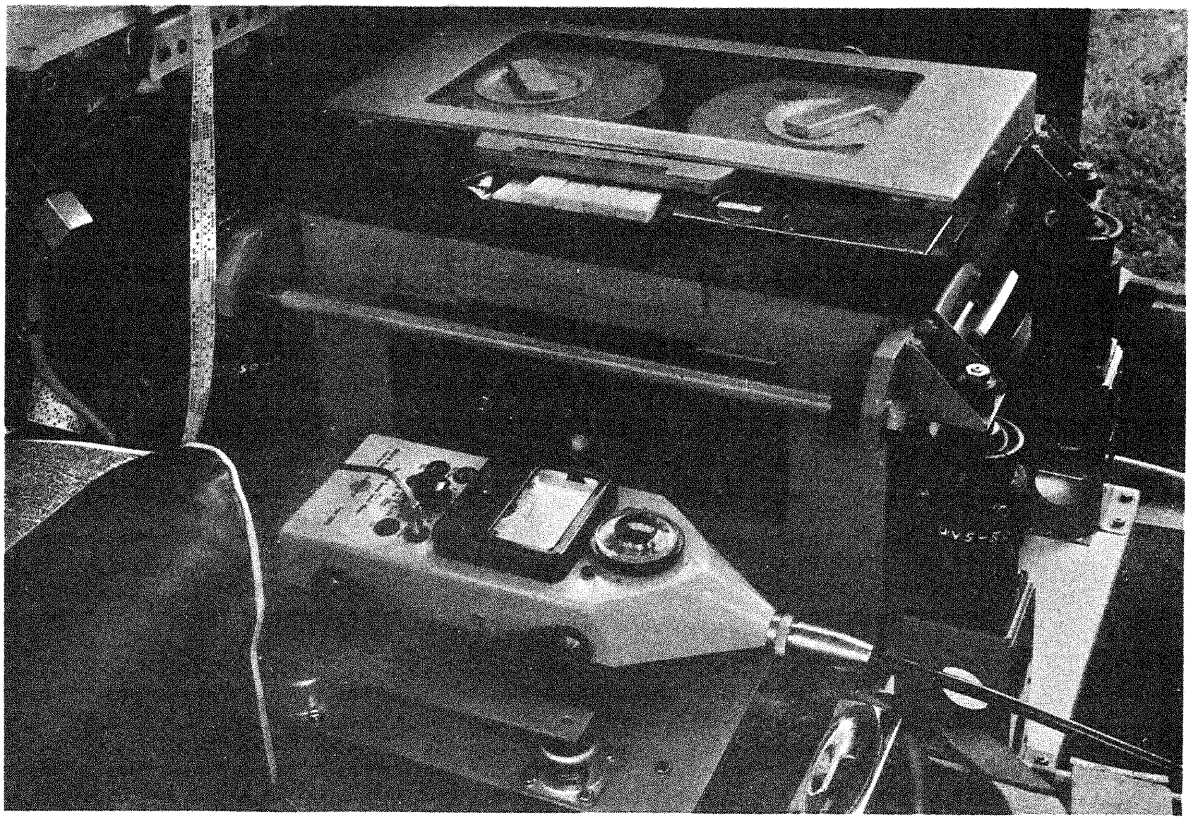

Figure 4: Illustrates the amount of equipment that was required to generate & store subject & vibration data. Picture shows vehicle boot.

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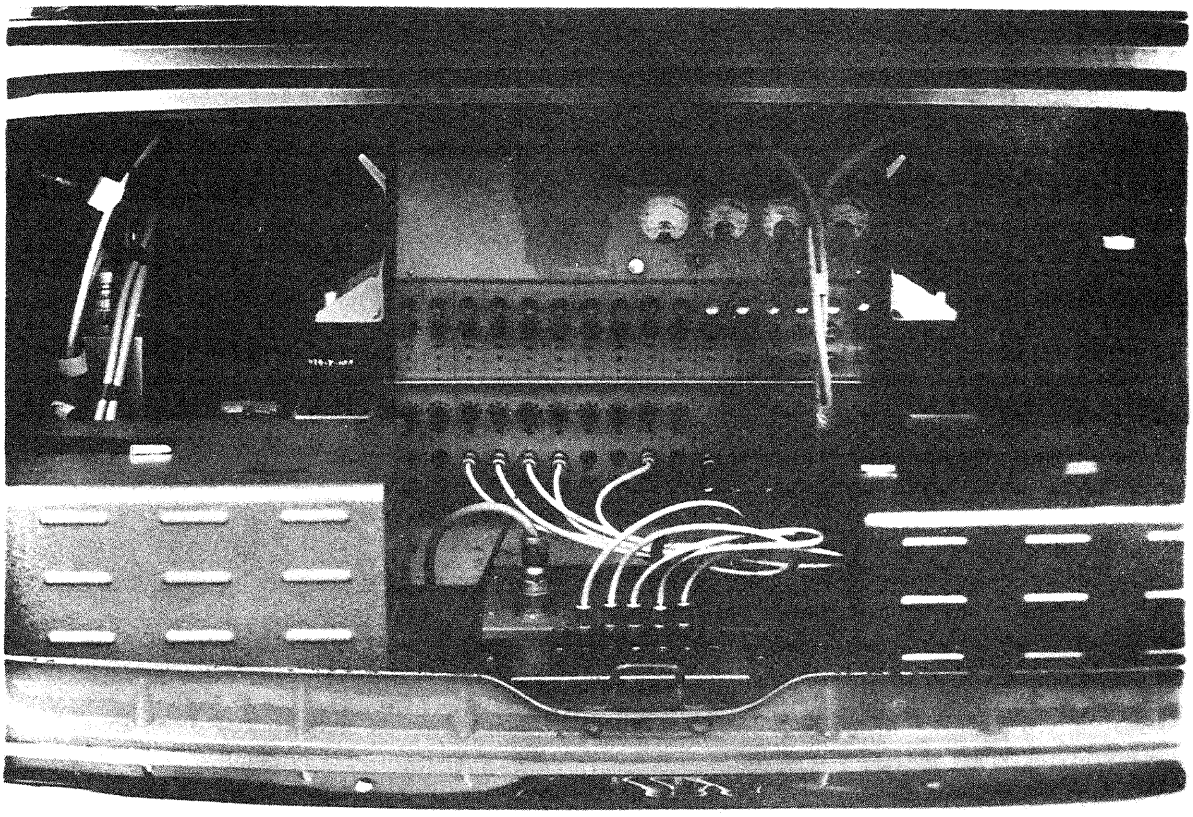

Figure 5: The Dynamic Immediate Memory Probe Computer.

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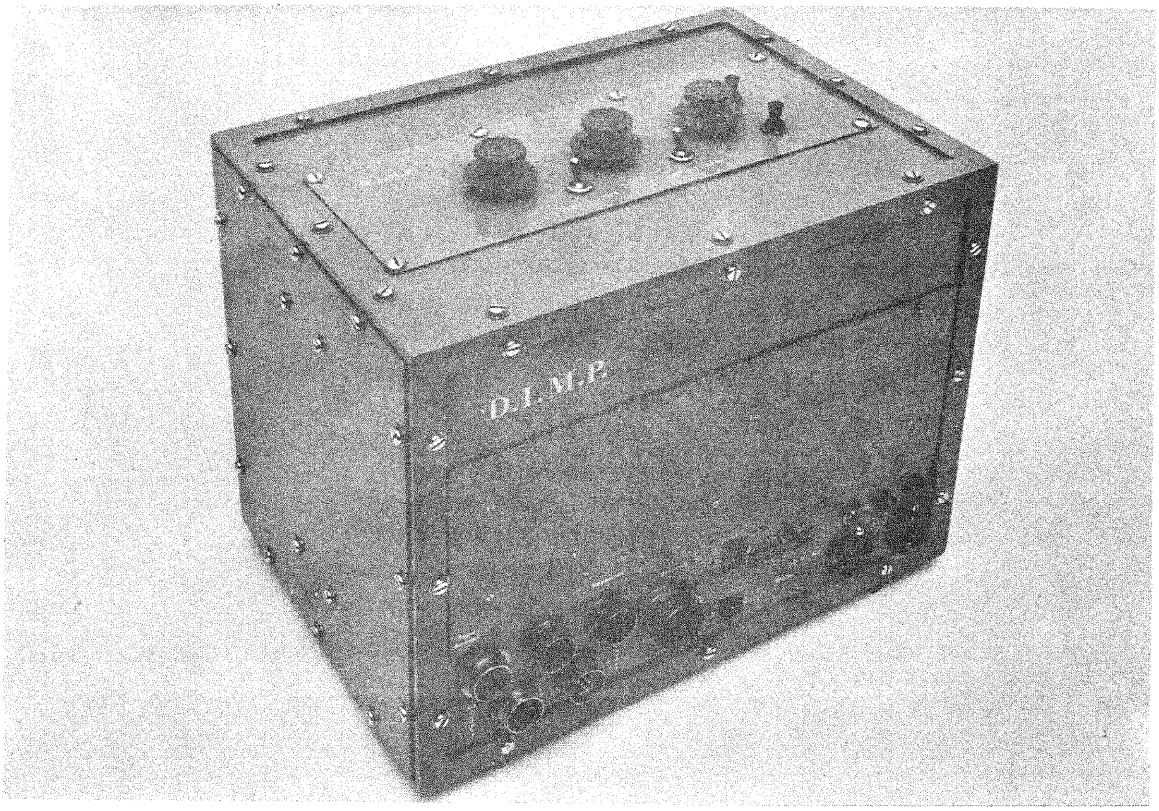

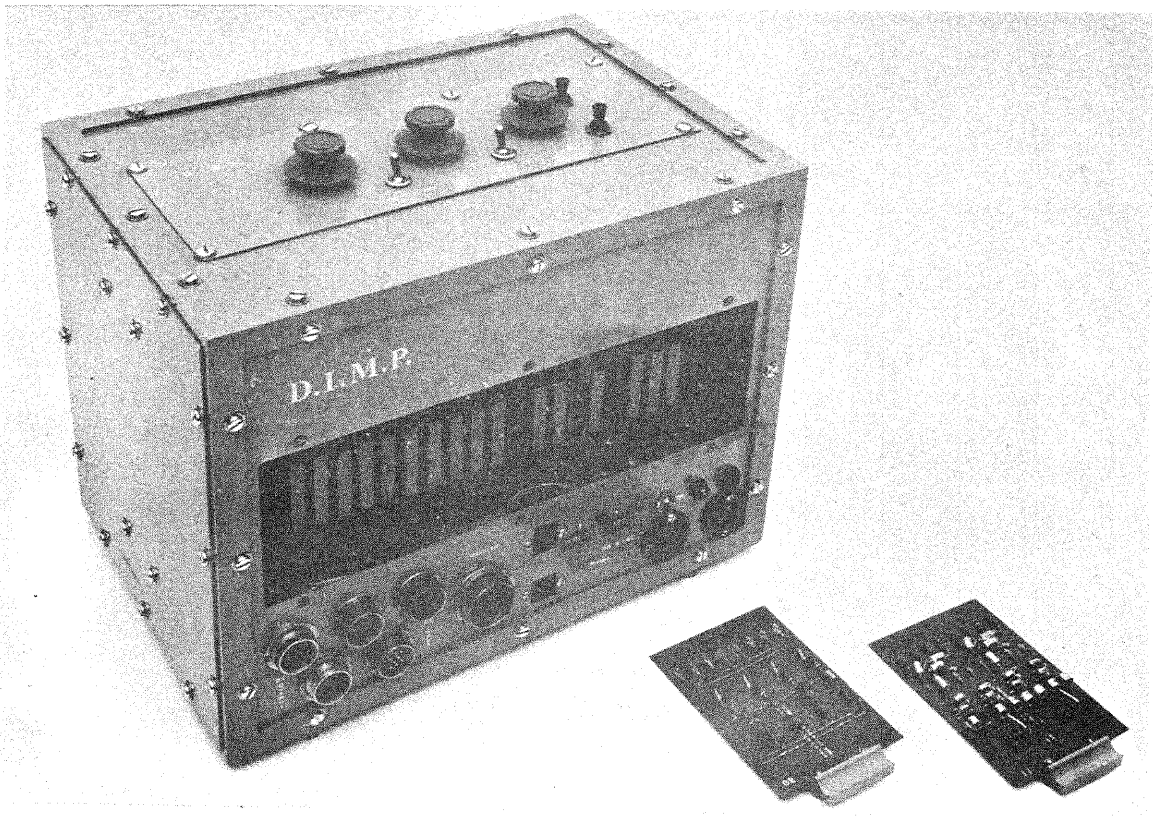

Figure 6: A rigid platform was attached to the underside of the seat structure for attachment of accelerometers.

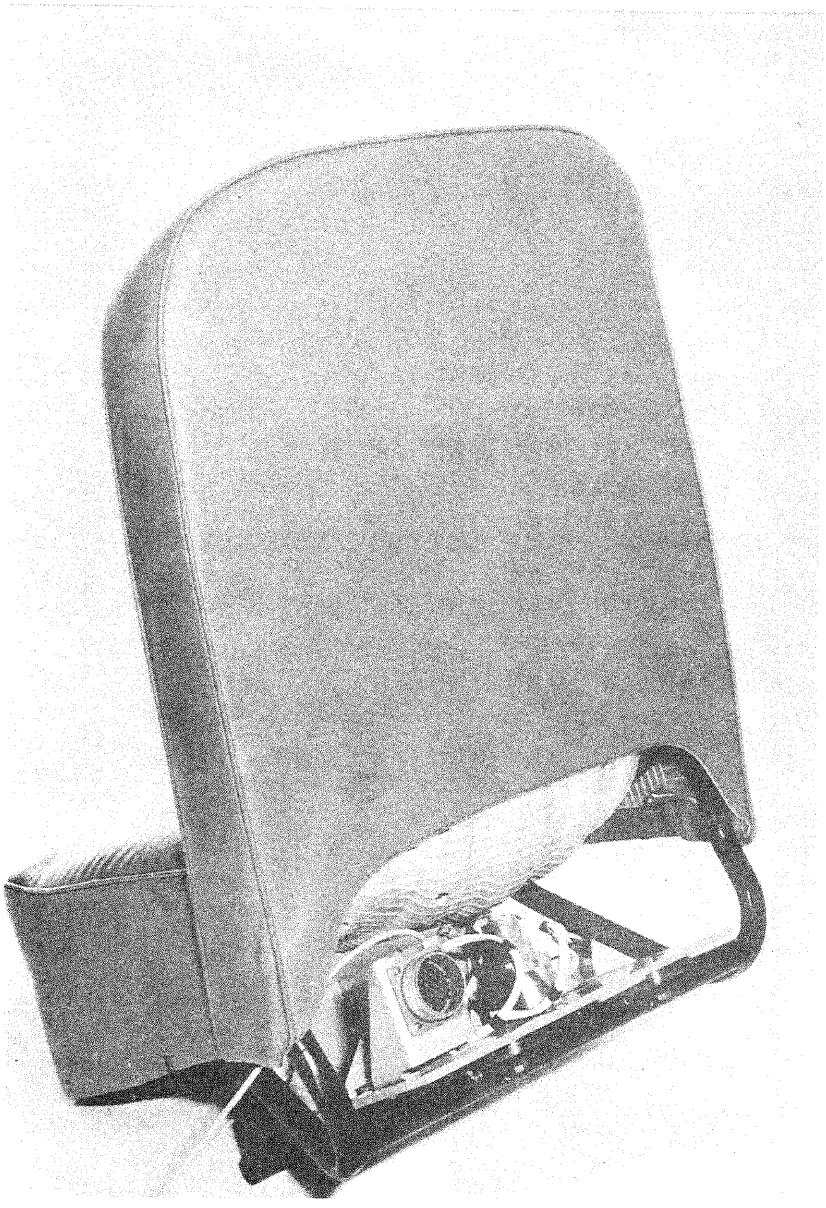

Figure 7: Close-up of the tri-axial accelerometer configuration used to measure seat structure vibration.

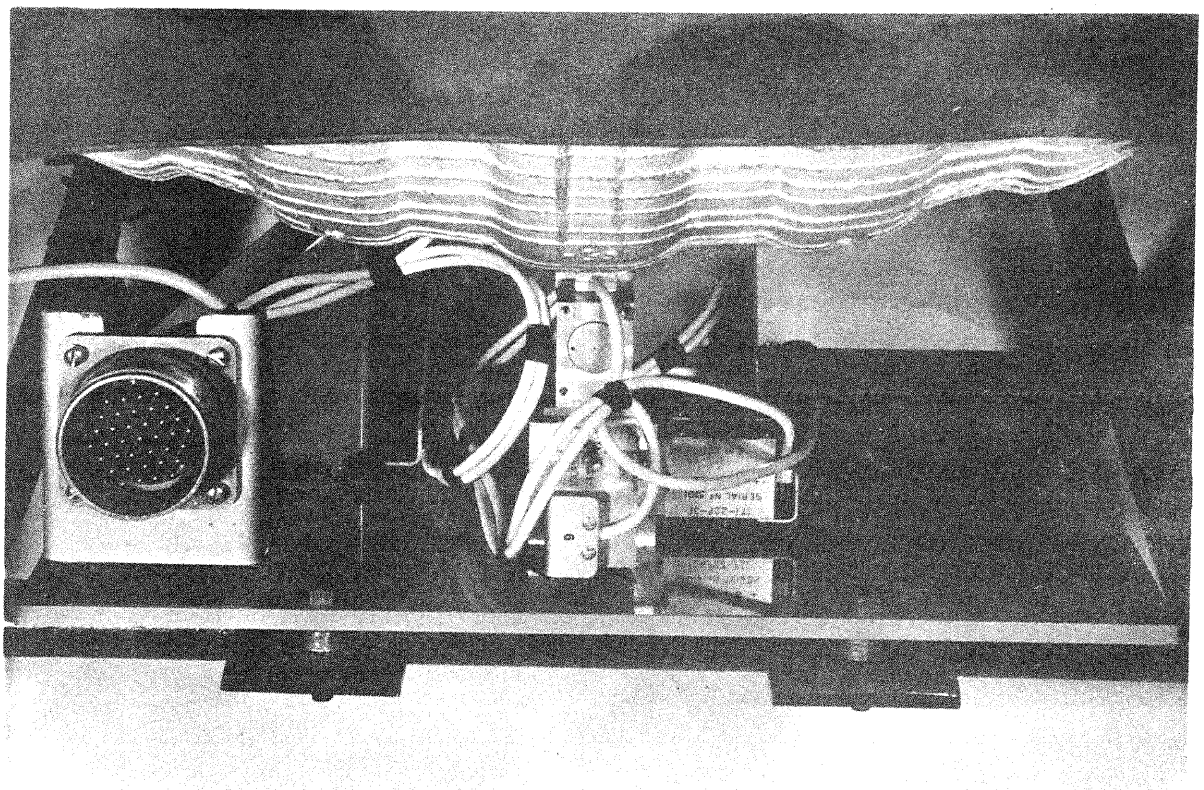

Figure 8: The motion simulator – electro-hydraulic jack & vibration platform.

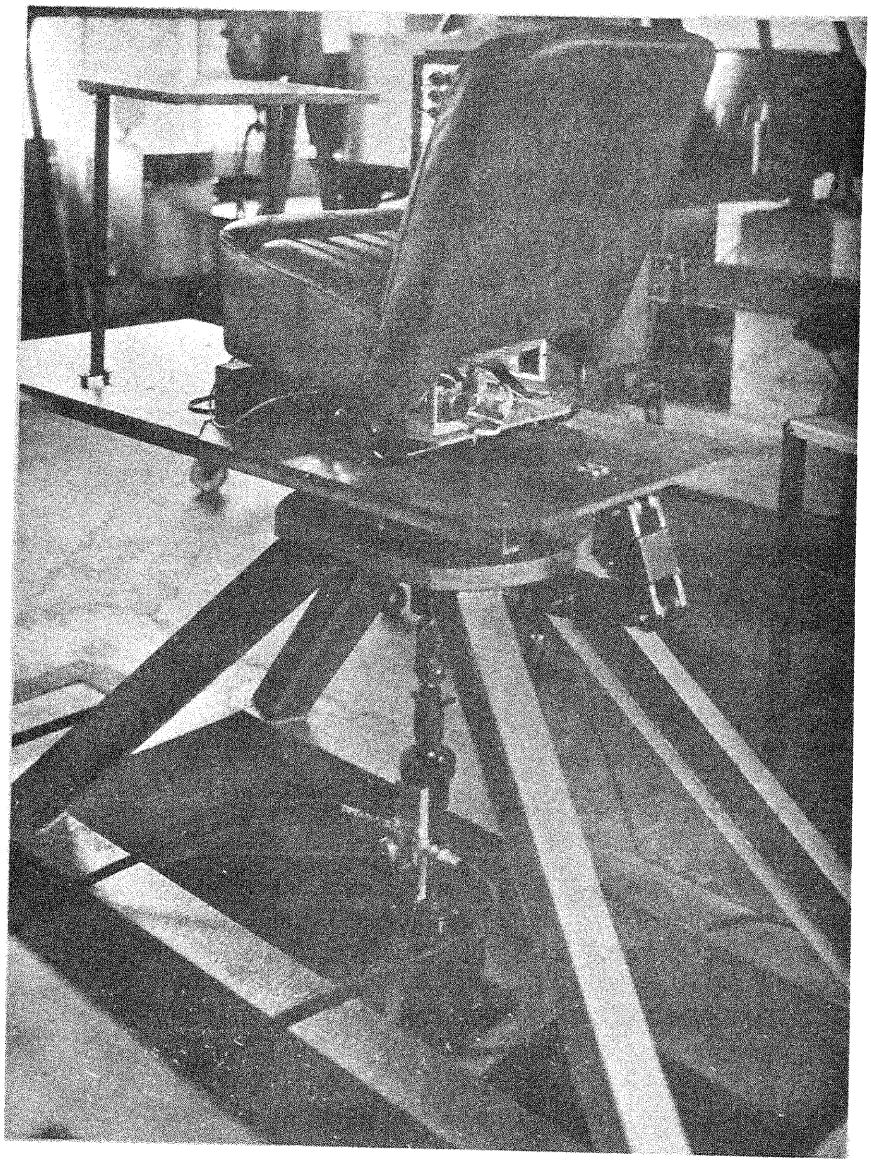

Figure 9: Shows the conditions under which the simulator tests were conducted. The analogue computer used to synthesise the vehicle spectrum is in the centre.

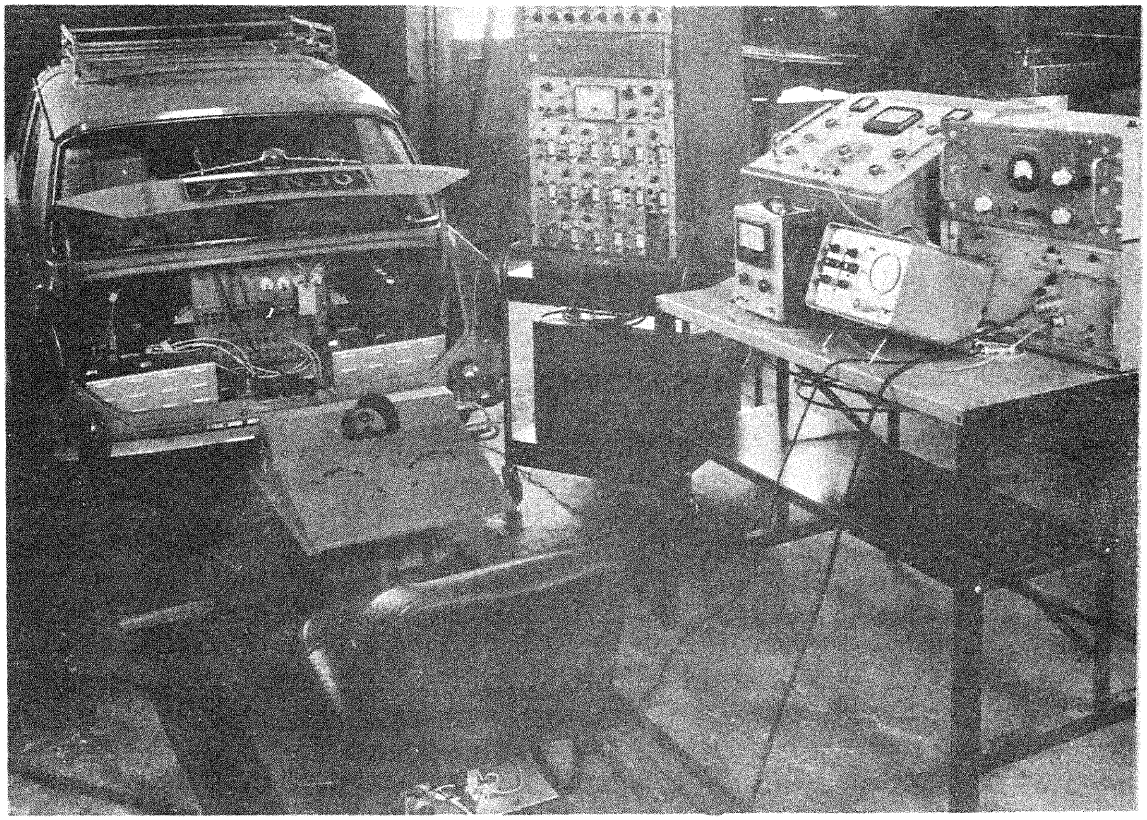

Figure 10: Analysis procedure for obtaining the Power Spectral Density Function.

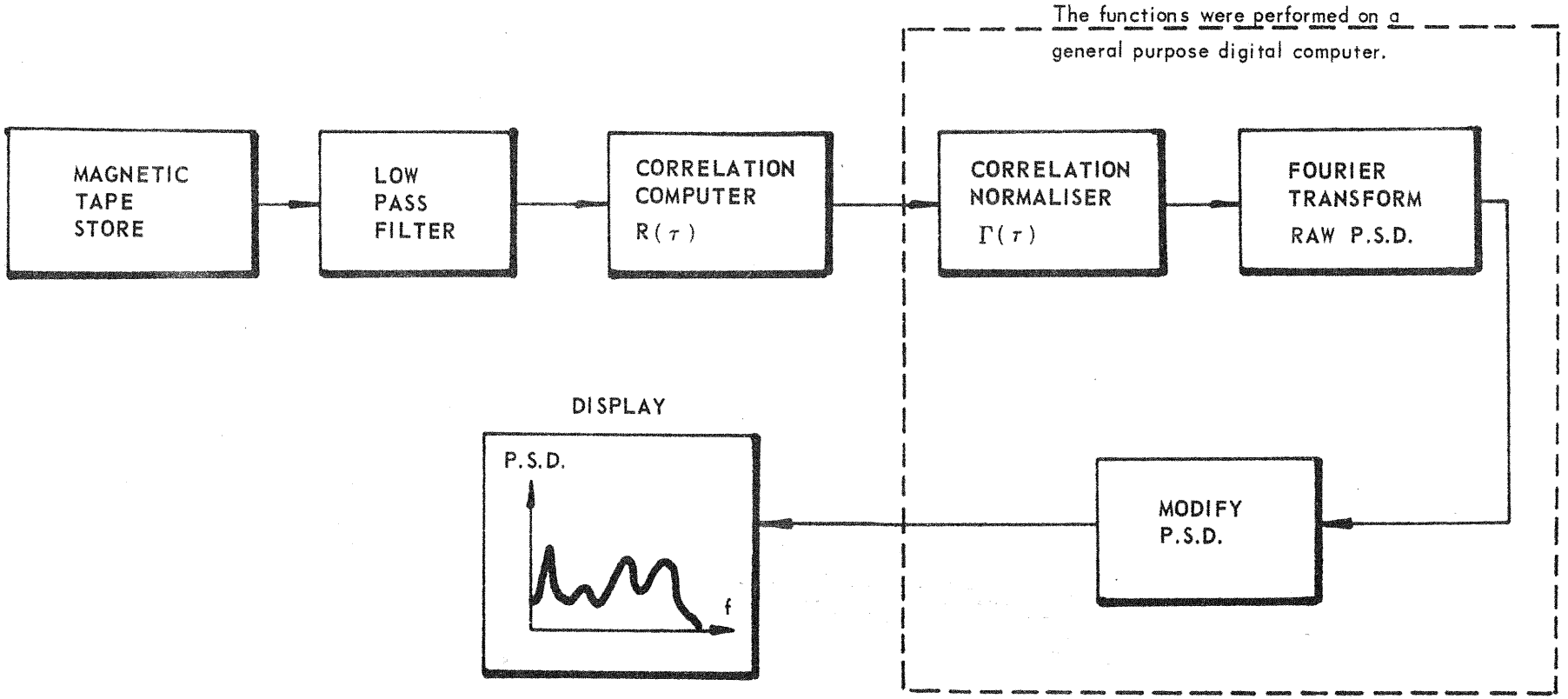

Figure 11: Frequency Response of Low Pass Filter

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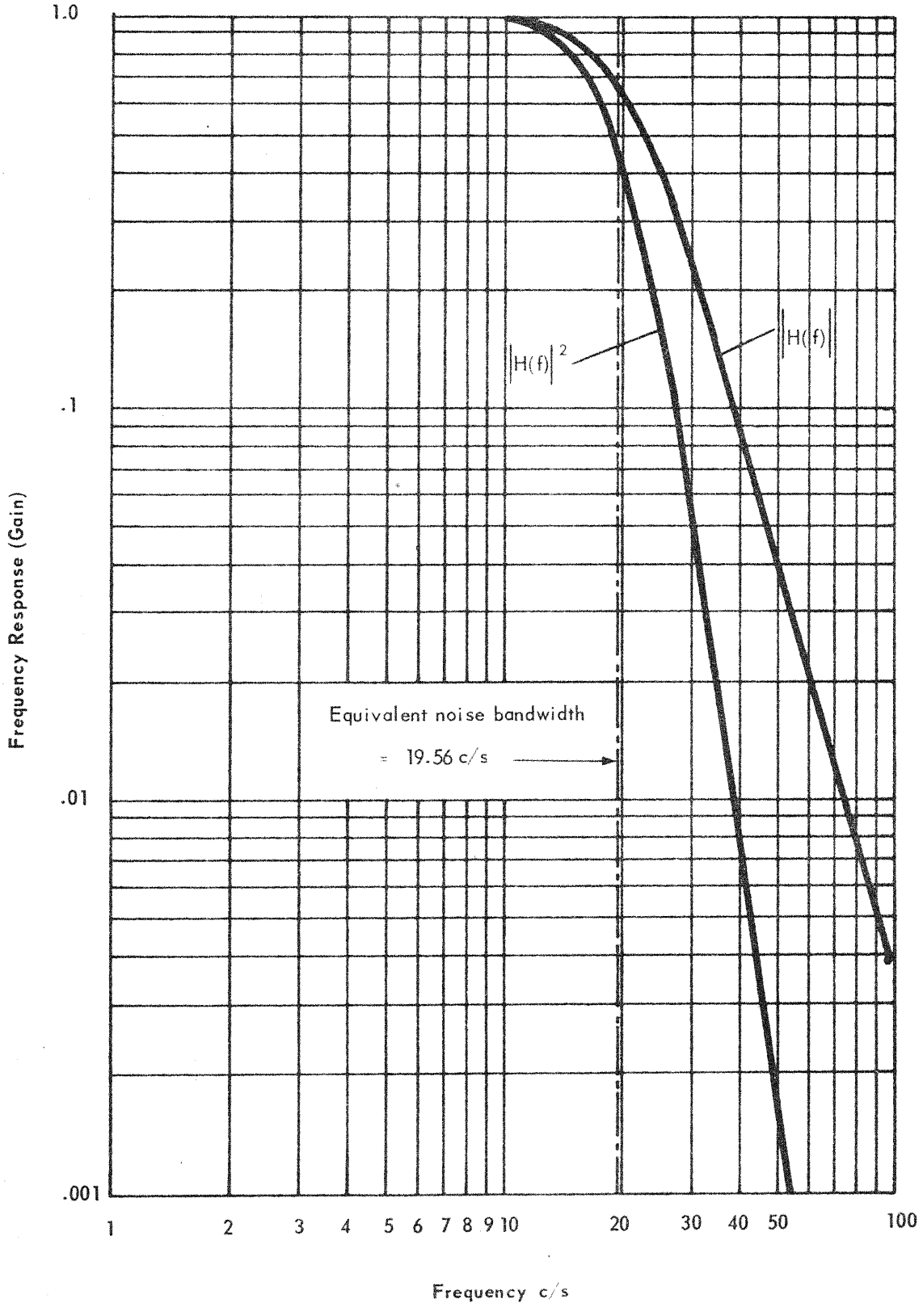

Figure 12: Autocorrelation function of vibration measured at the seat structure.

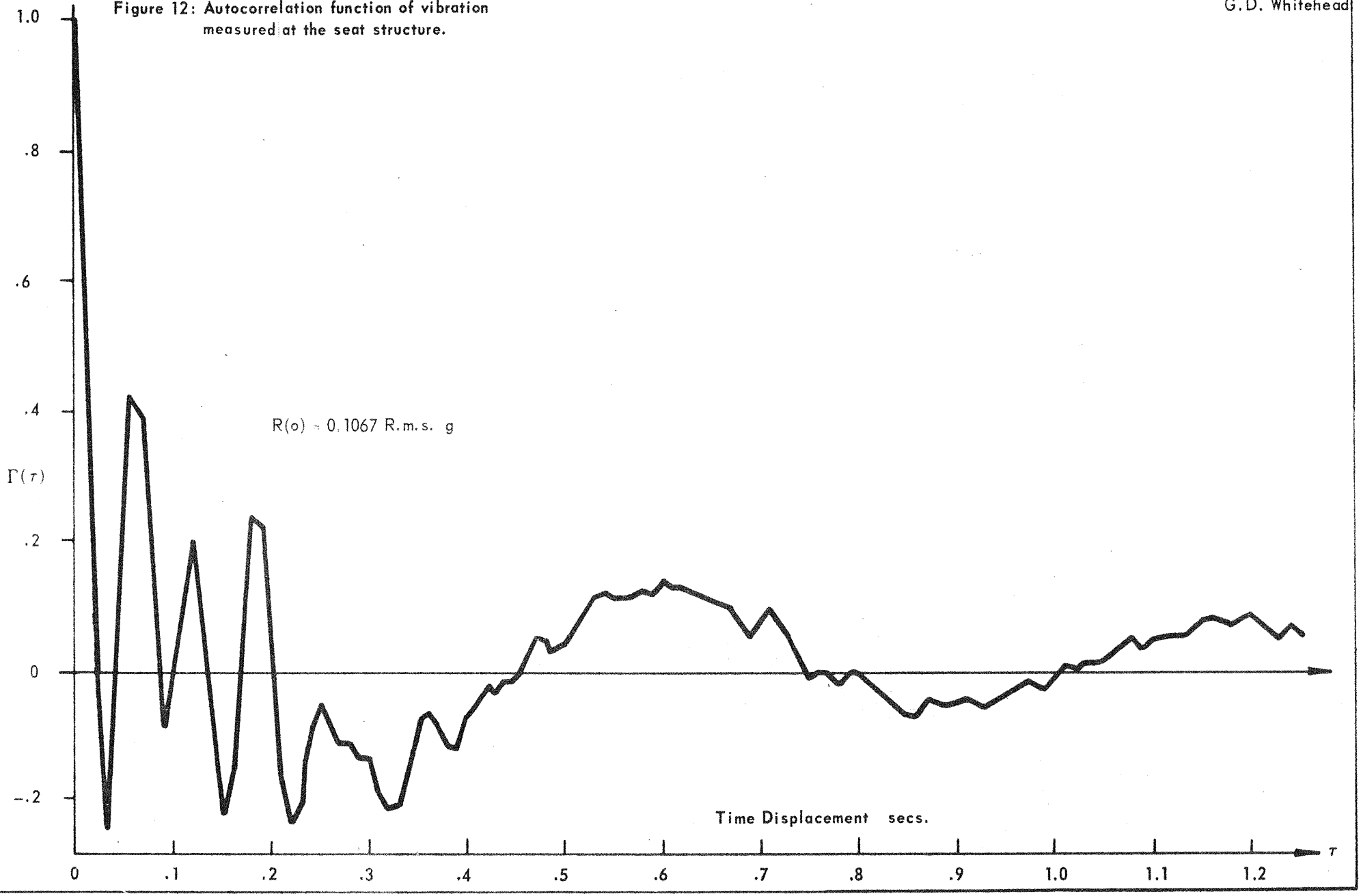

Figure 13: Acceleration Power Spectral Density of Vehicle Seat Structure – overall average.

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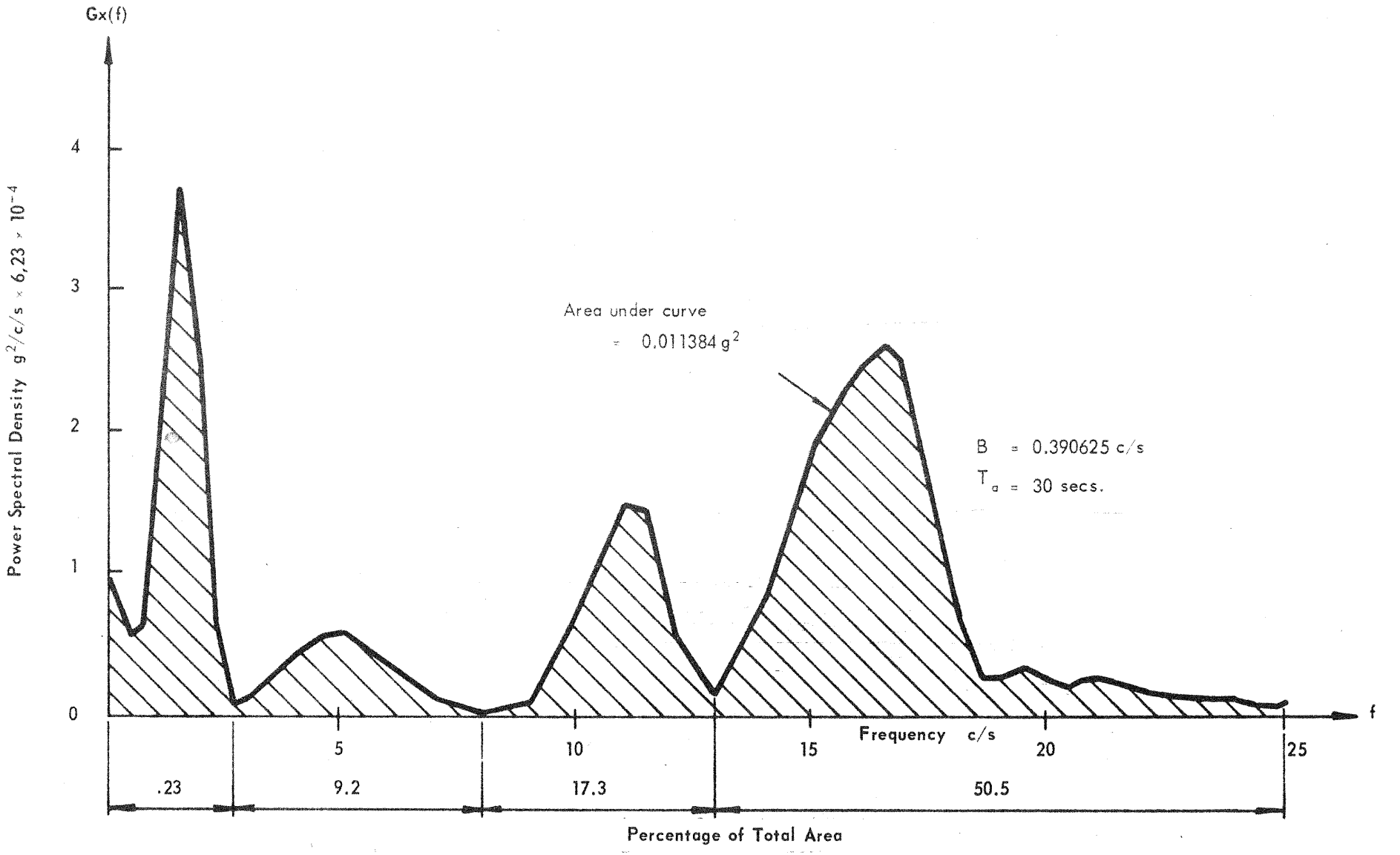

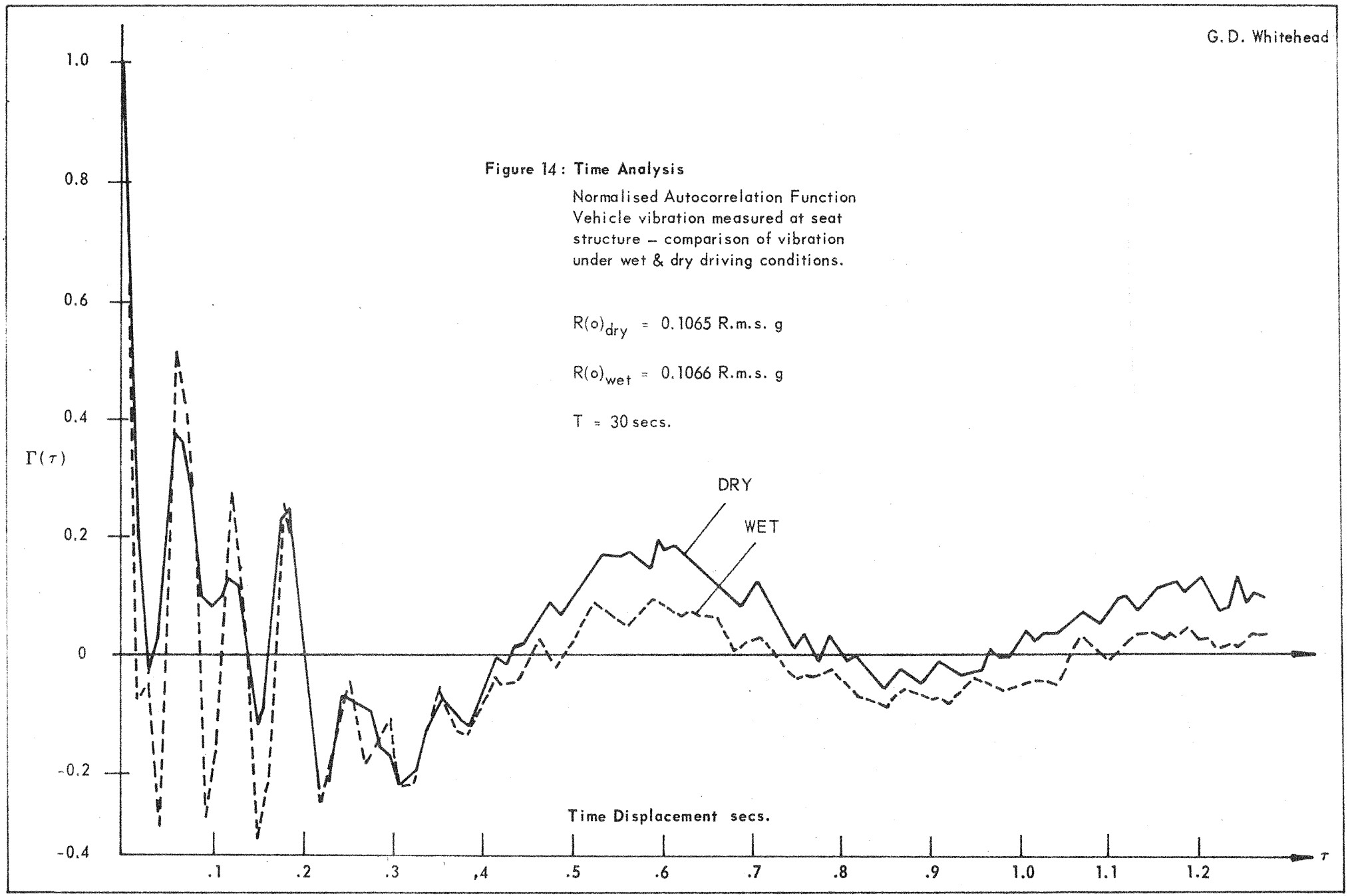

Figure 14 : Time Analysis

Normalised Autocorrelation Function
Vehicle vibration measured at seat structure – comparison of vibration under wet & dry driving conditions.

$R(o)_{dry}$ = 0.1065 R.m.s. g

$R(o)_{wet}$ = 0.1066 R.m.s. g

T = 30 secs.

Figure 15: Acceleration Power Spectral Density of Seat Structure vibration measured under wet & dry road conditions.

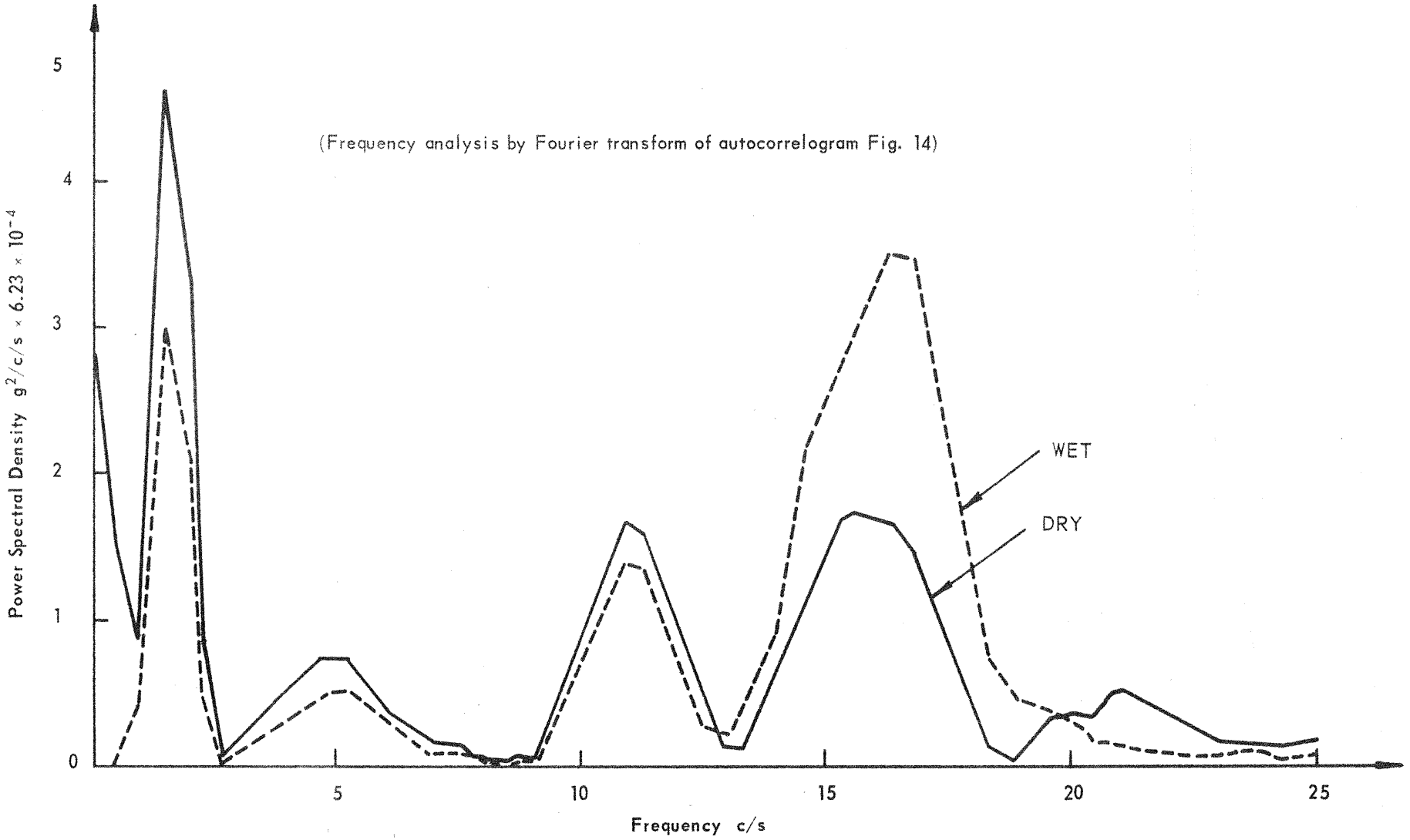

Figure 16: Autocorrelogram & Power Spectral Density curves for vehicle driven on dry road.
P.S.D. expands the 1.56 c/s peak in Fig. 13.

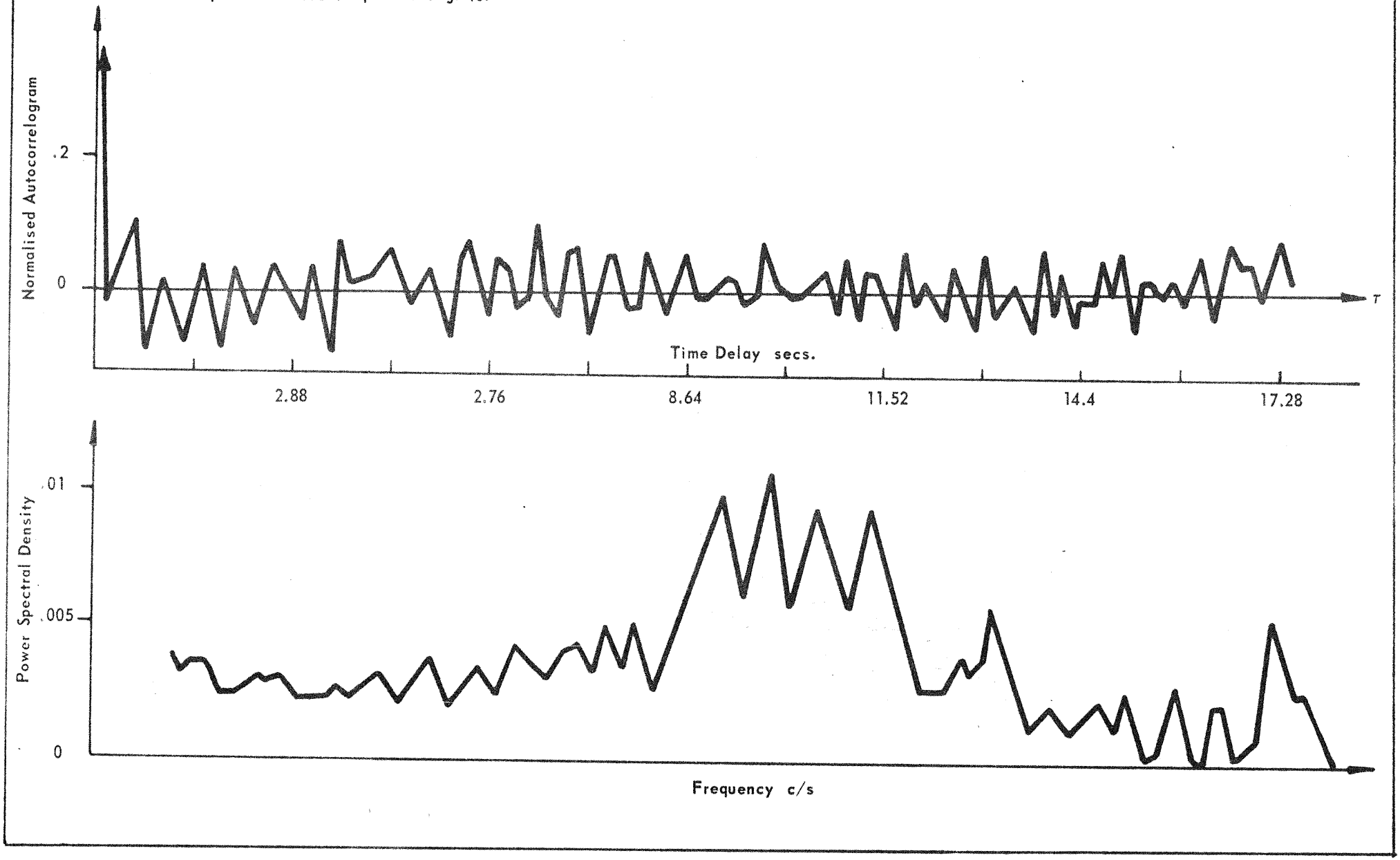

Figure 17: Autocorrelation & Power Spectral Density curve for vehicle driven on wet road.
P.S.D. expands the 1.56 c/s peak in Fig. 13.

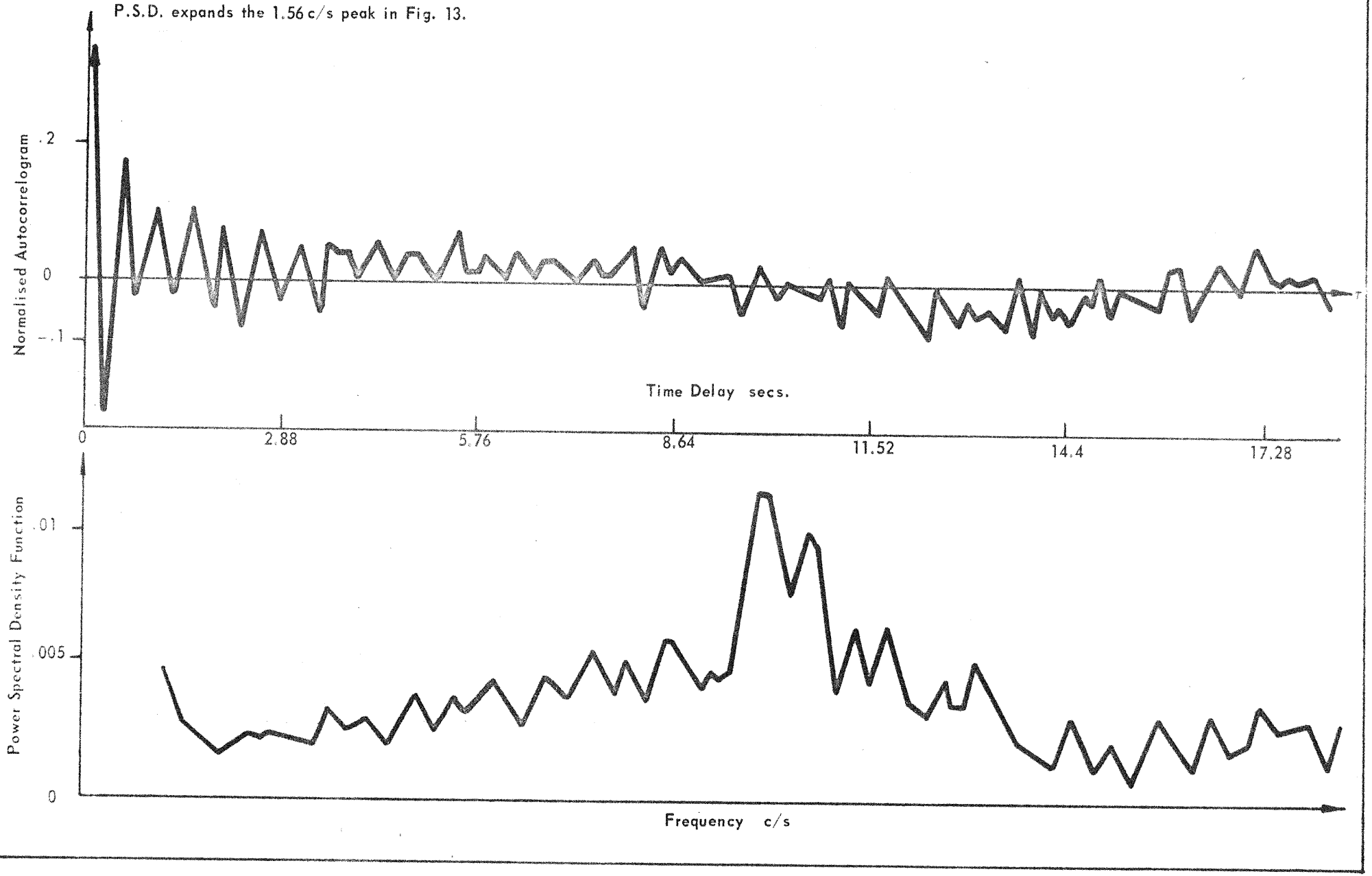

Figure 18: Overall average Power Spectral Density for $\Delta\tau$ = 160 ms.
Graph shows Fourier transform pairs.

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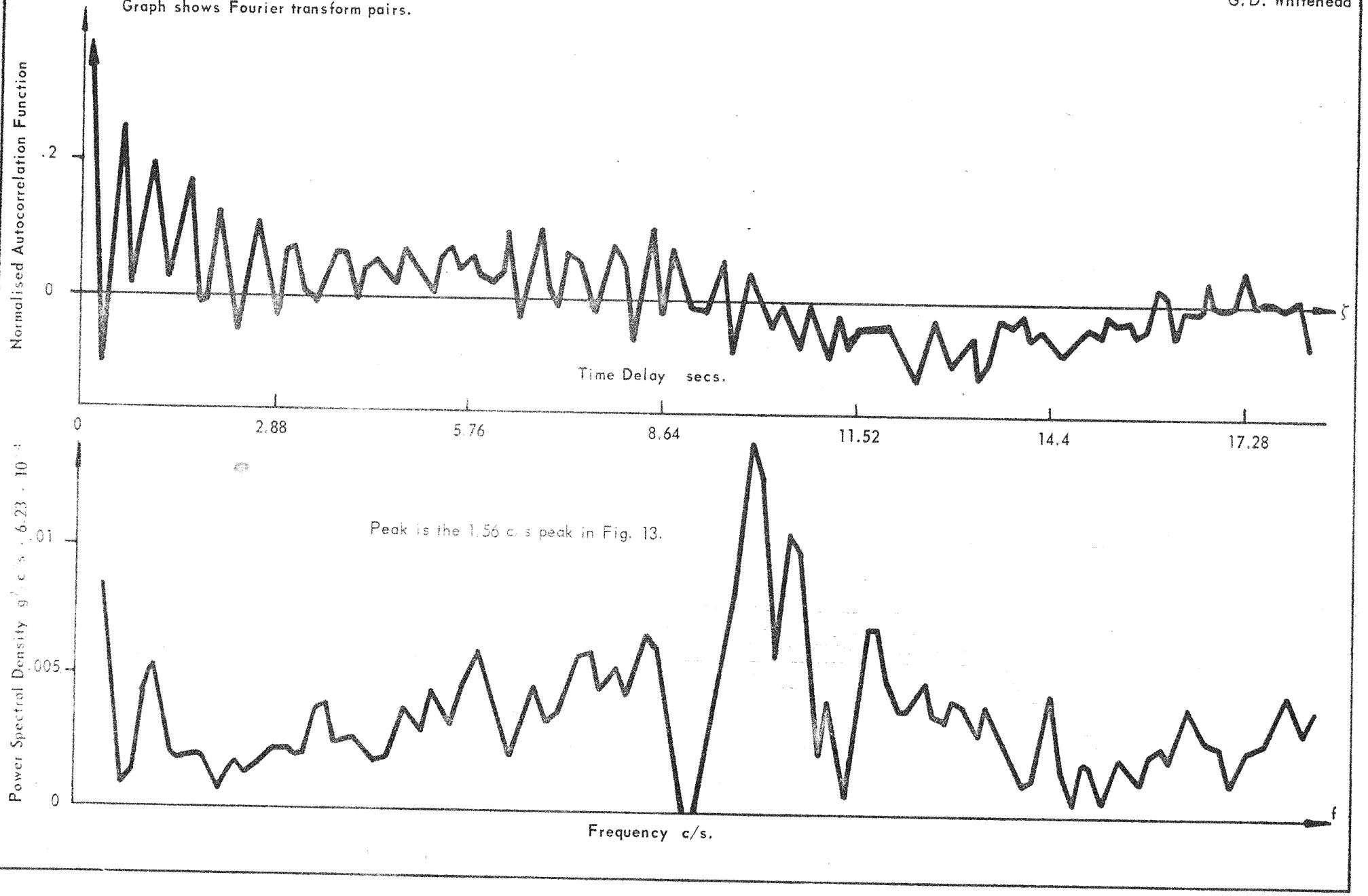

Figure 19 : Analysis of noise in the vehicle & on the Motion Simulator.

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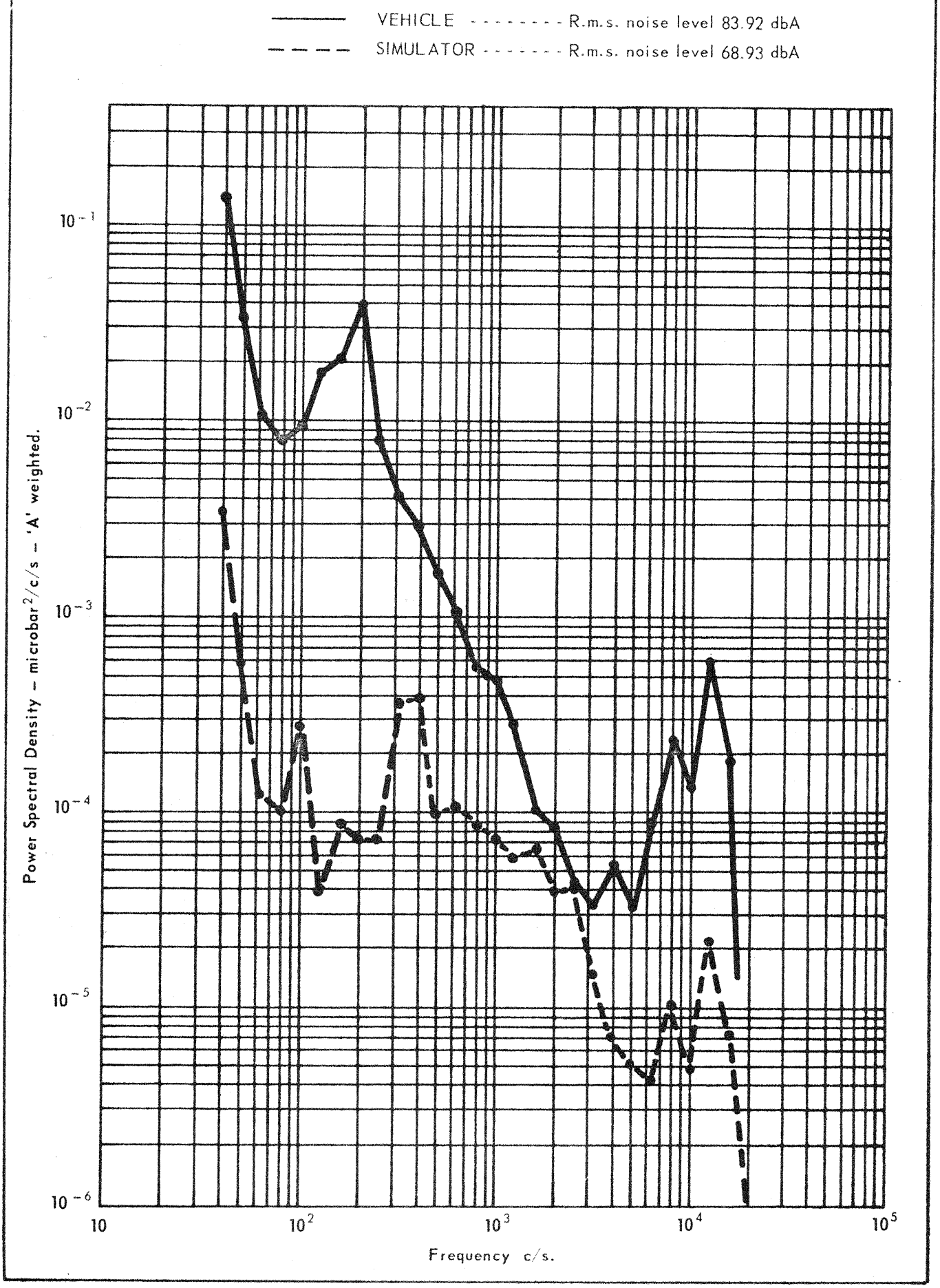

Figure 20: Power Spectral Density synthesised on the Motion Simulator.

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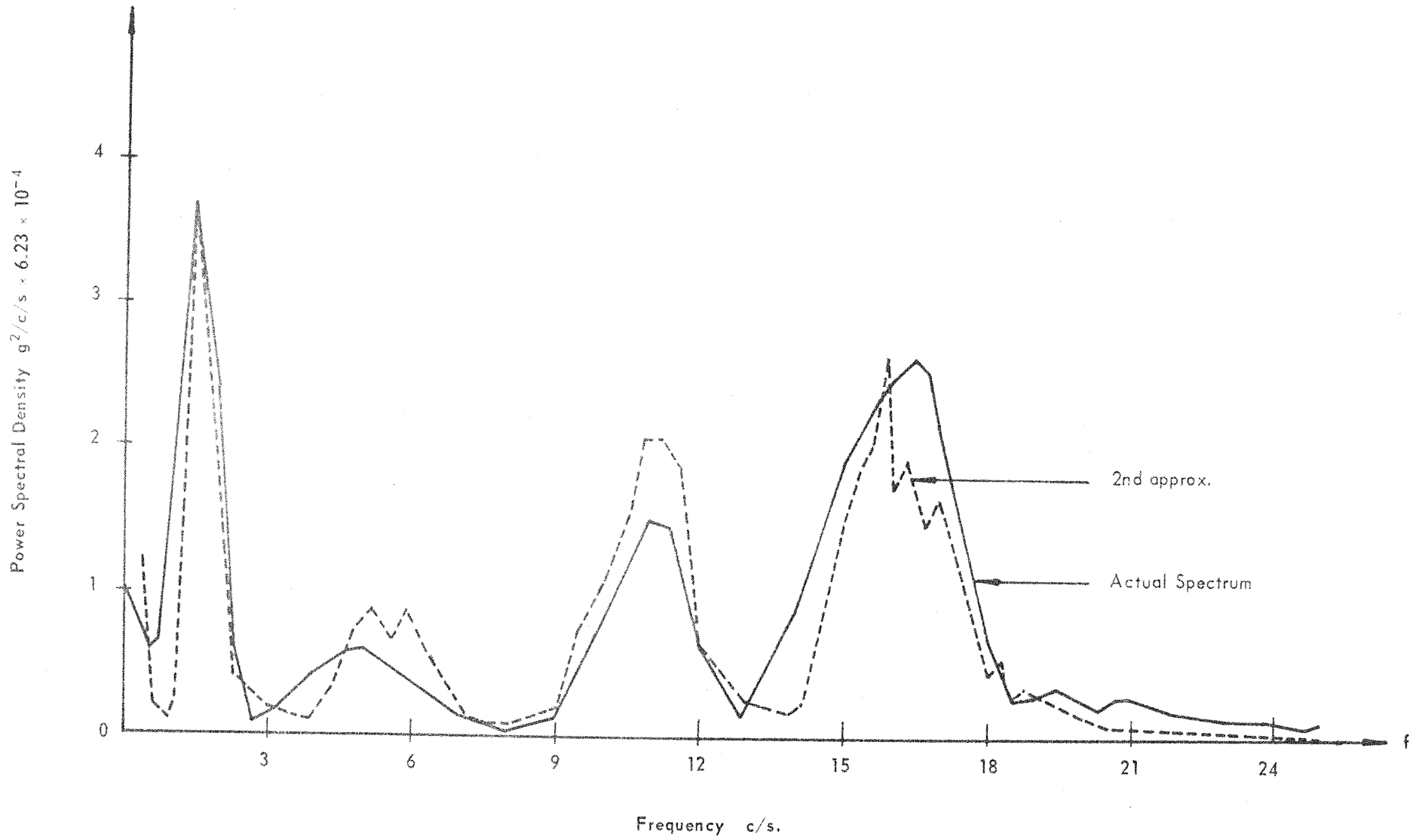

Figure 21: Analogue Computer Program for Vibration Synthesis.

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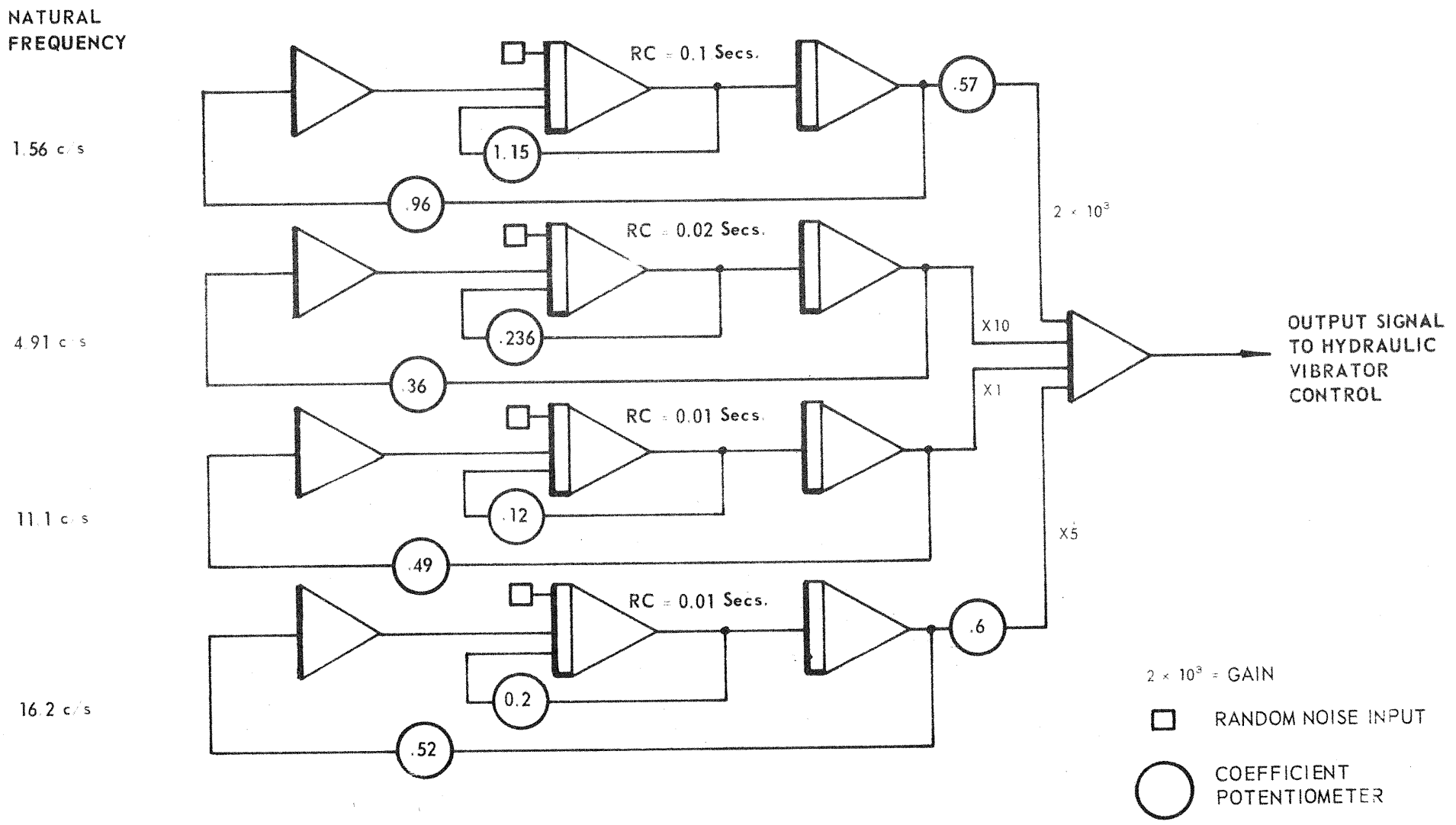


Figure 22: Performance on short term memory task.
SUBJECT D.J.

G.D. Whitehead

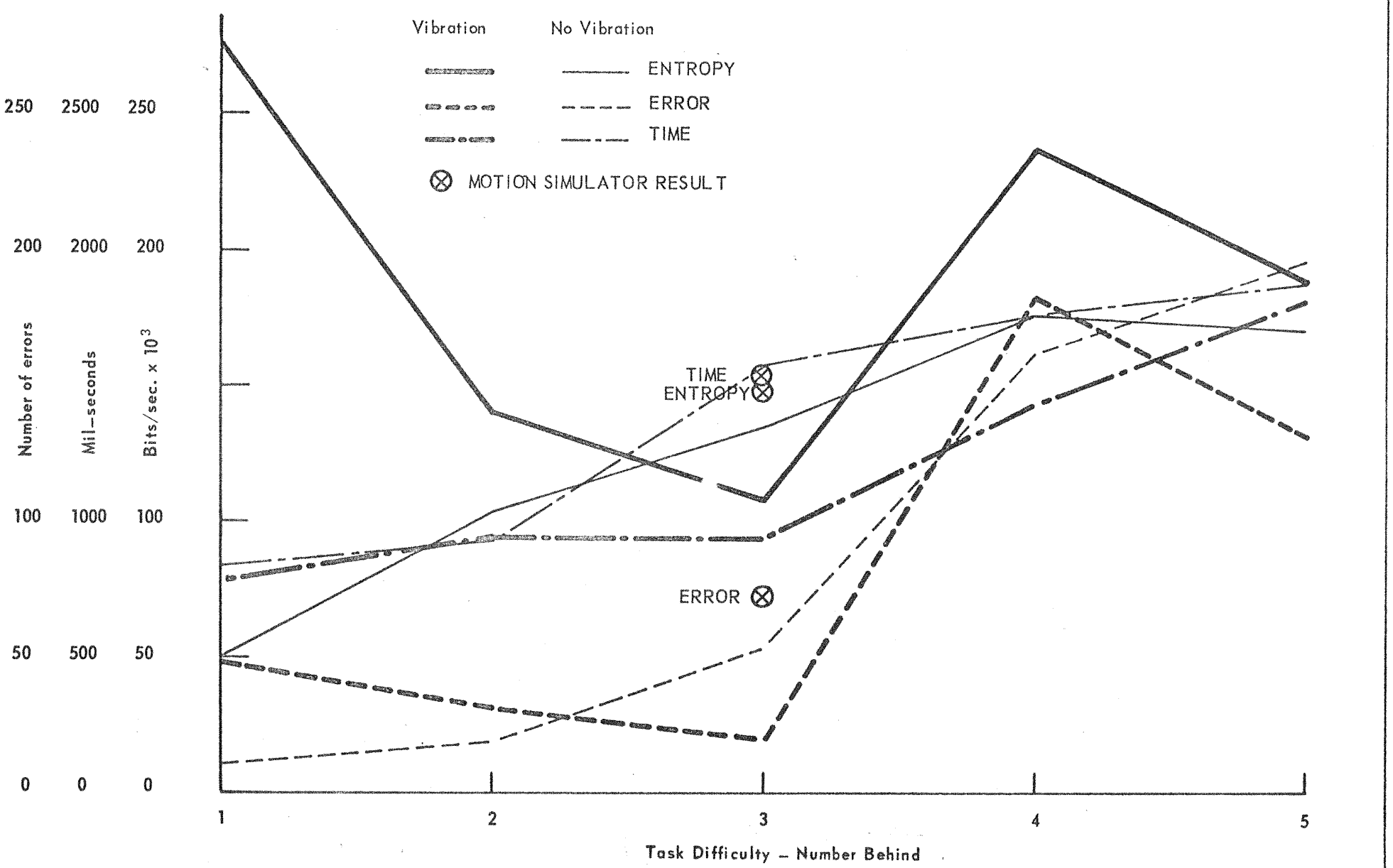


Figure 23: Performance on short term memory task.
SUBJECT D.R.

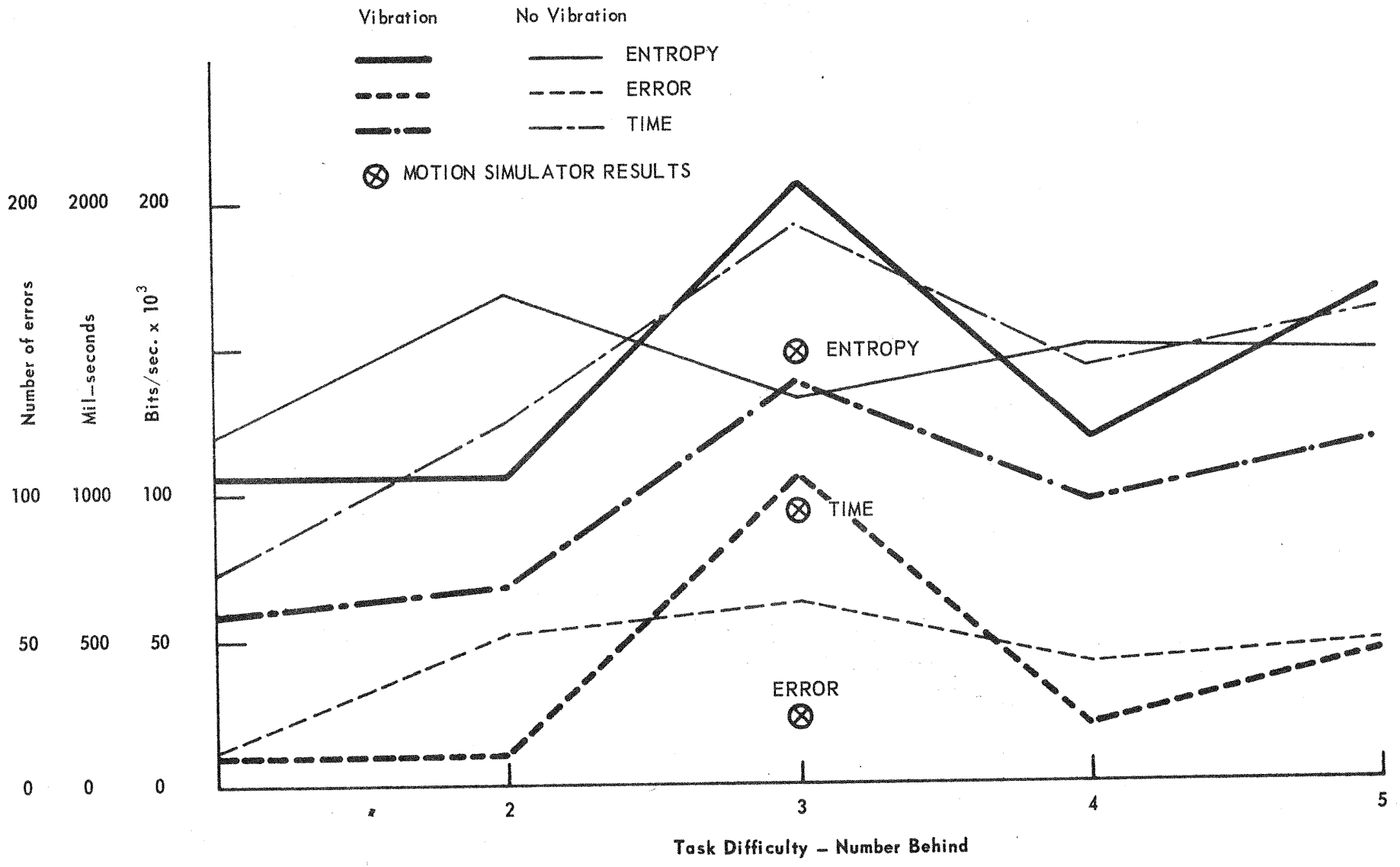


Figure 24: Performance on short term memory task.
SUBJECT P. K.

G.D. Whitehead

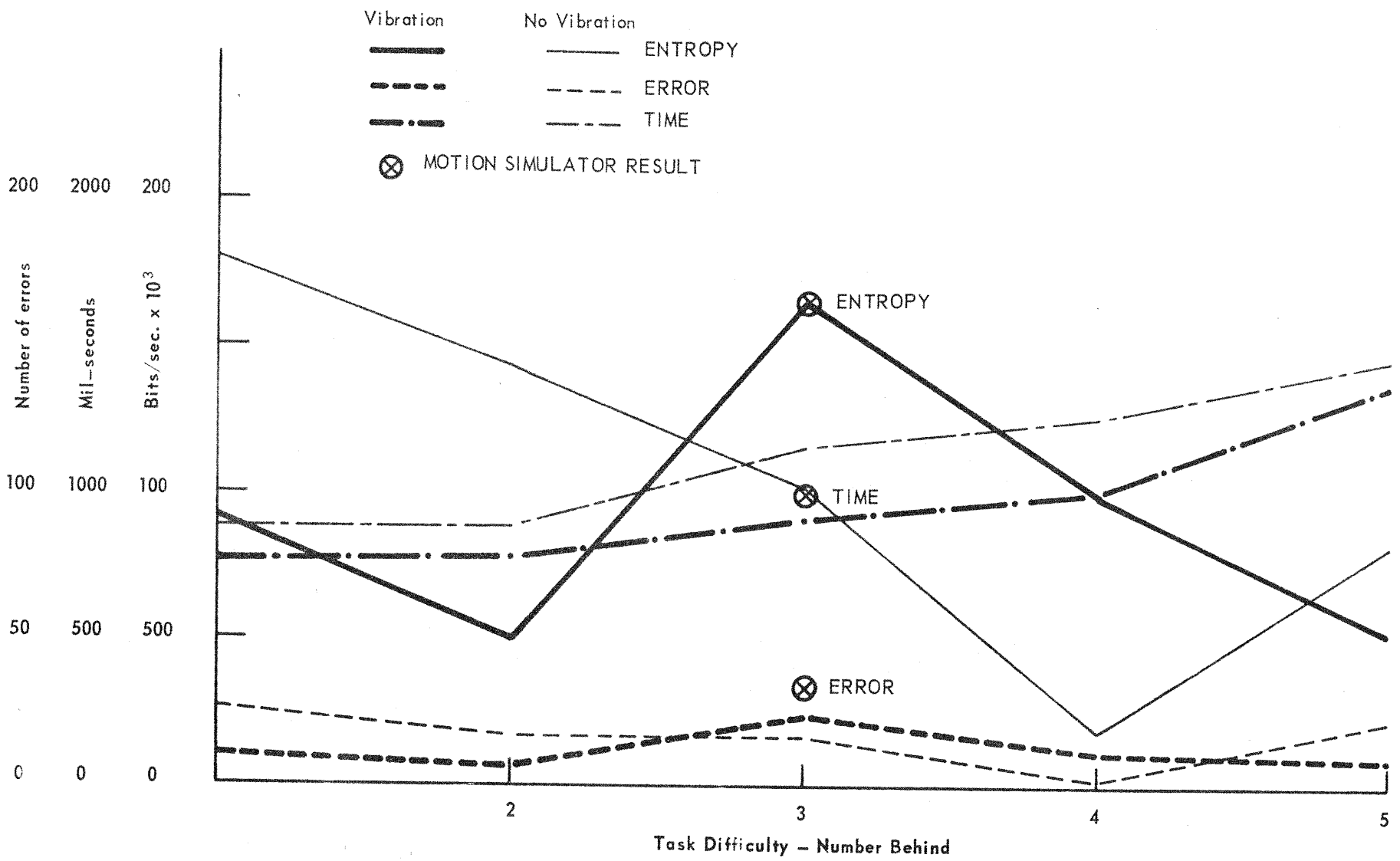


Figure 26: Performance on short term memory task.
SUBJECT S.H.

G.D. Whitehead

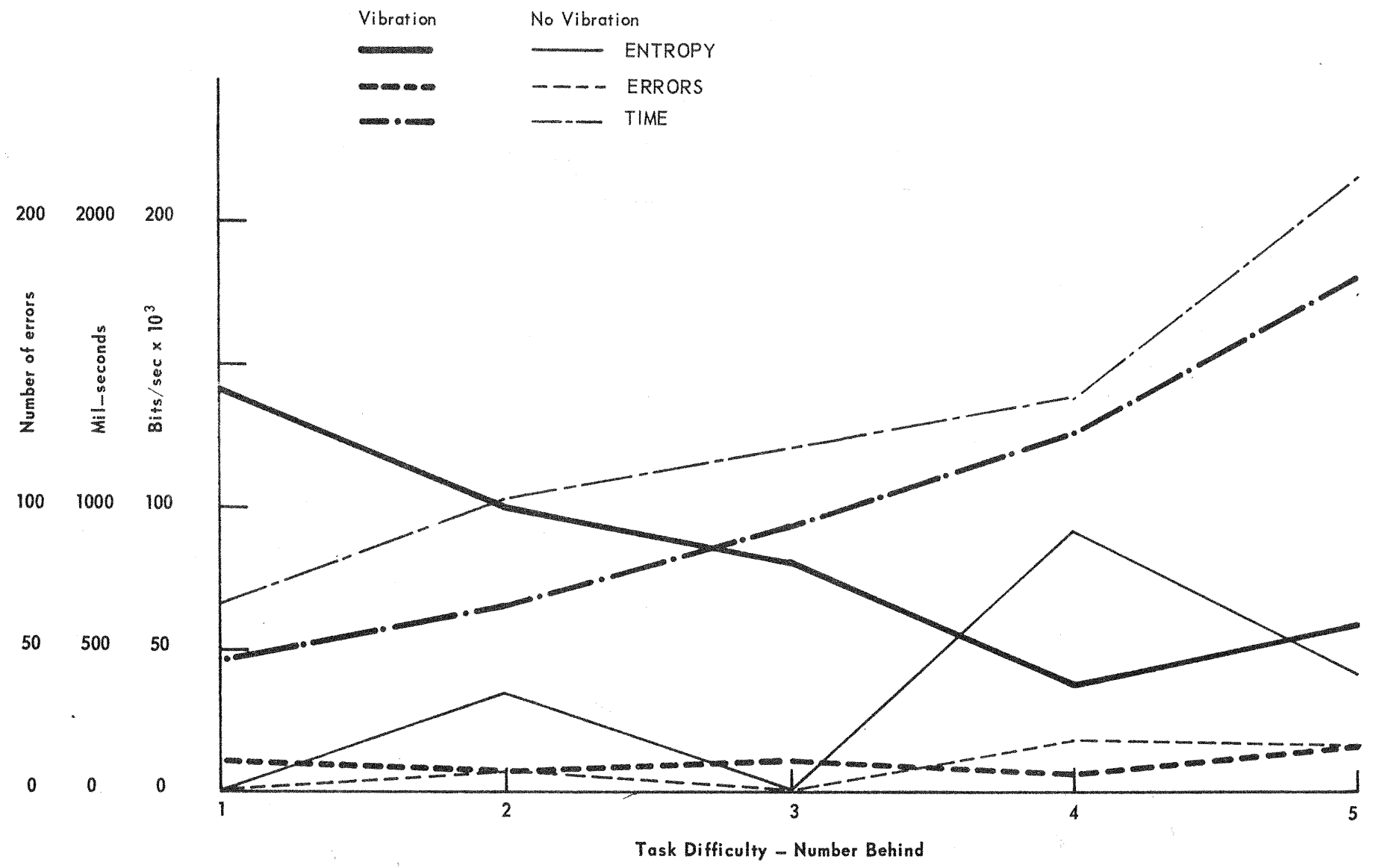


Figure 27: Performance on short term memory task.
SUBJECT E.M.

G.D. Whitehead

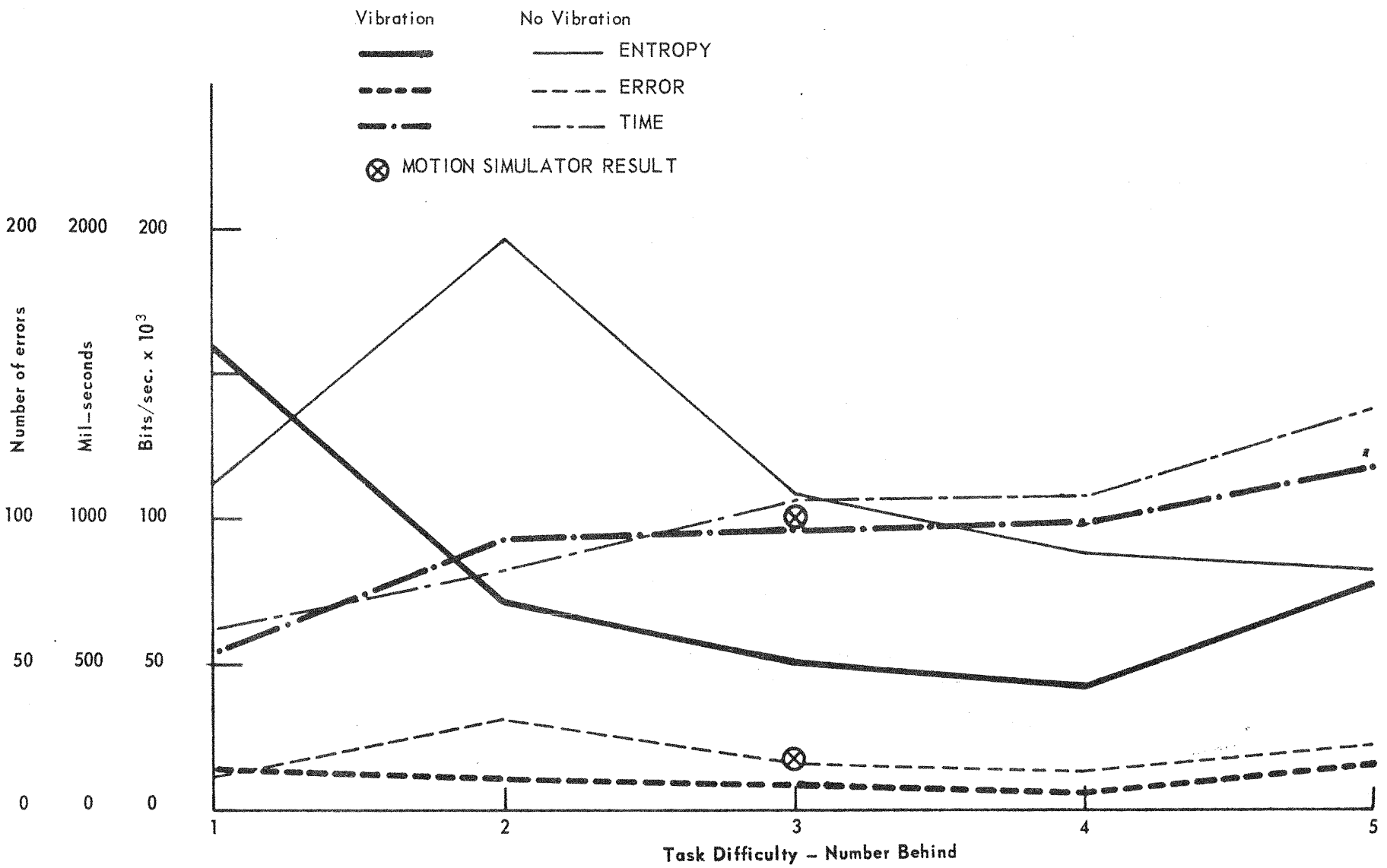


Figure 28: Average performance of subjects on short term memory task. In terms of time.

G.D. Whitehead

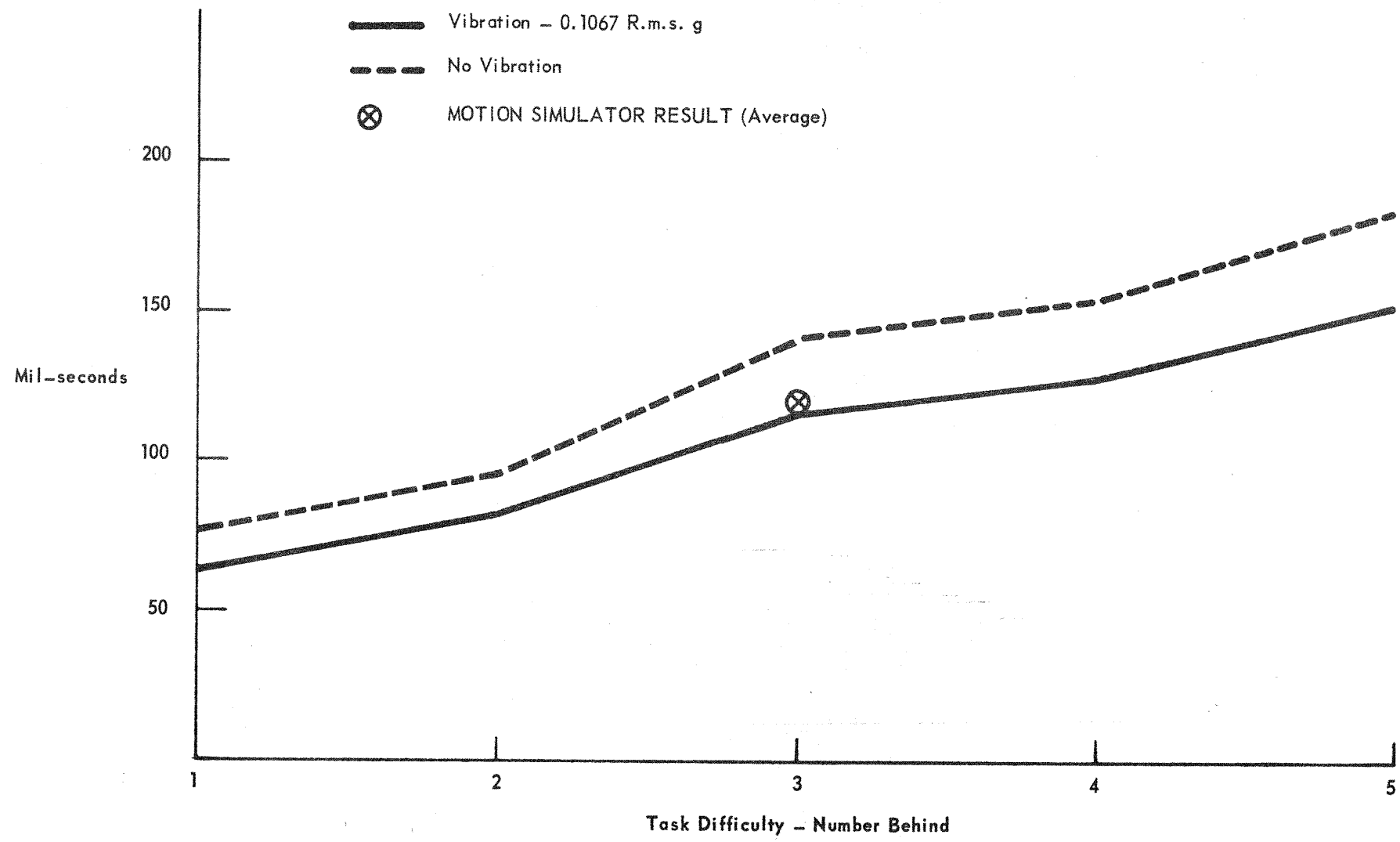


Figure 29: Average performance of subjects on short term memory task. In terms of error.

G.D. Whitehead

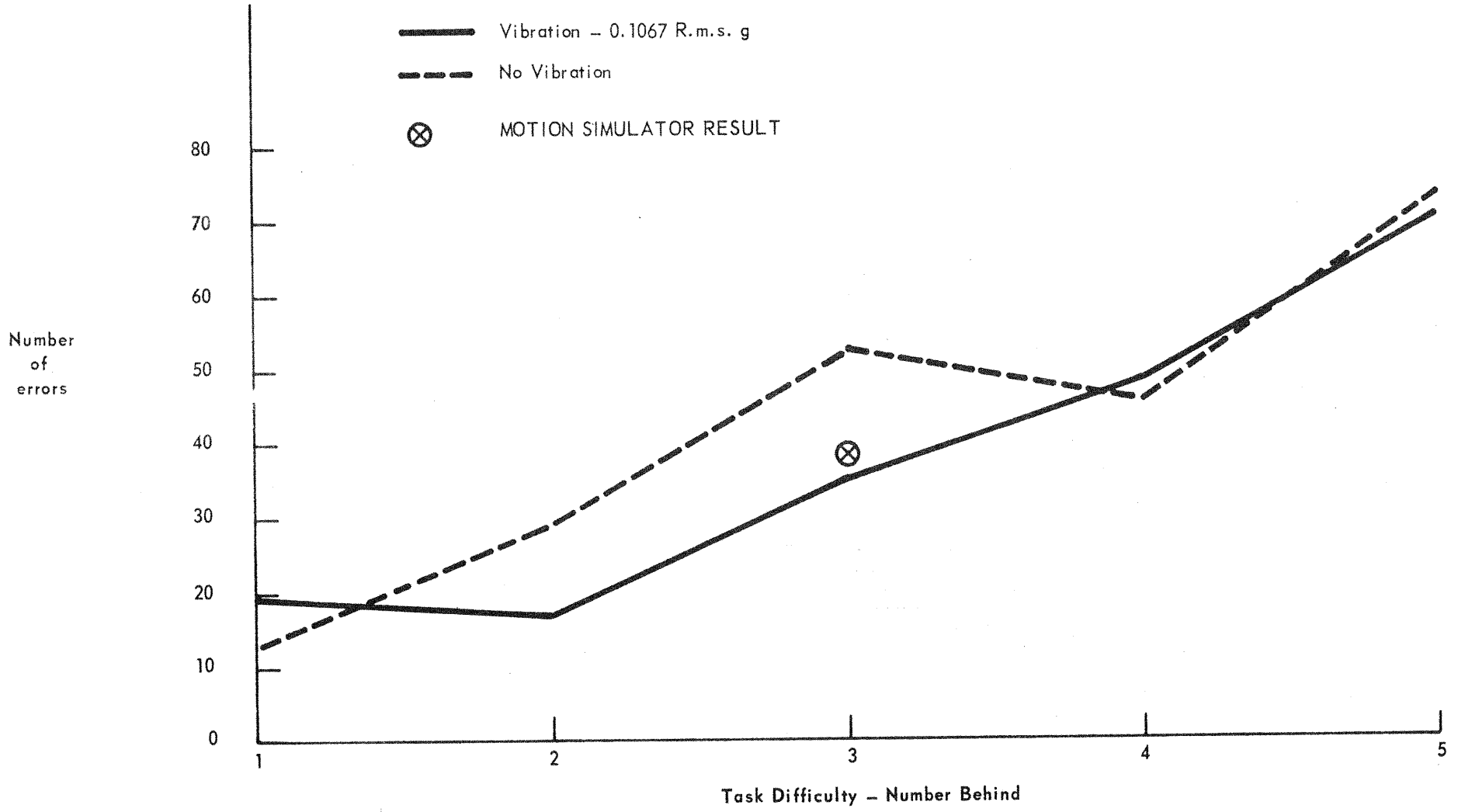


Figure 30: Average performance of subjects on short term memory task. In terms of entropy (contingent uncertainty).

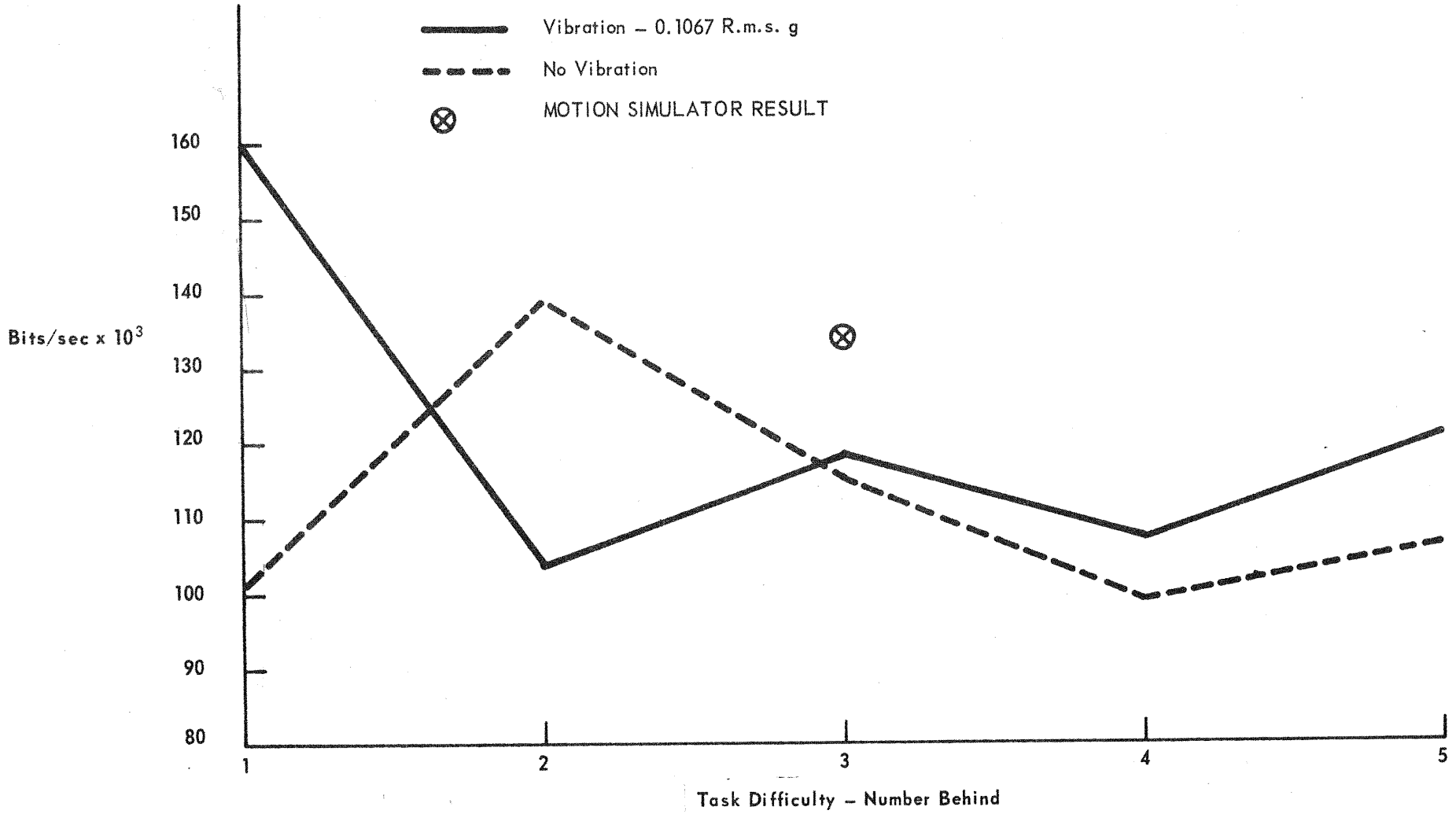


Figure 31: Scattergram of subject performance on short term memory task. – Time.

G.D. Whitehead

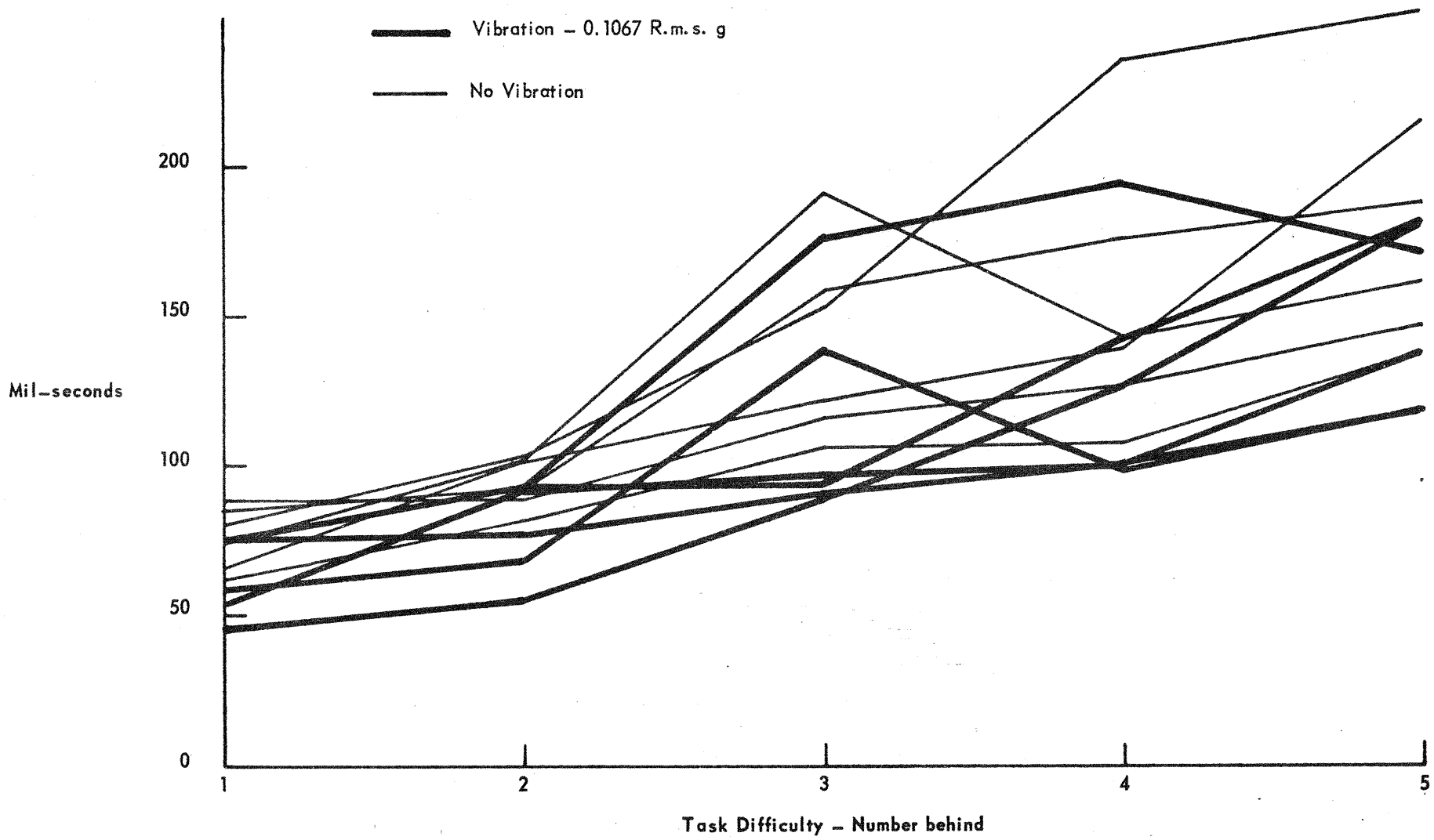


Figure 32: Scattergram of subject performance on short term memory task. – Error.

G. D. Whitehead

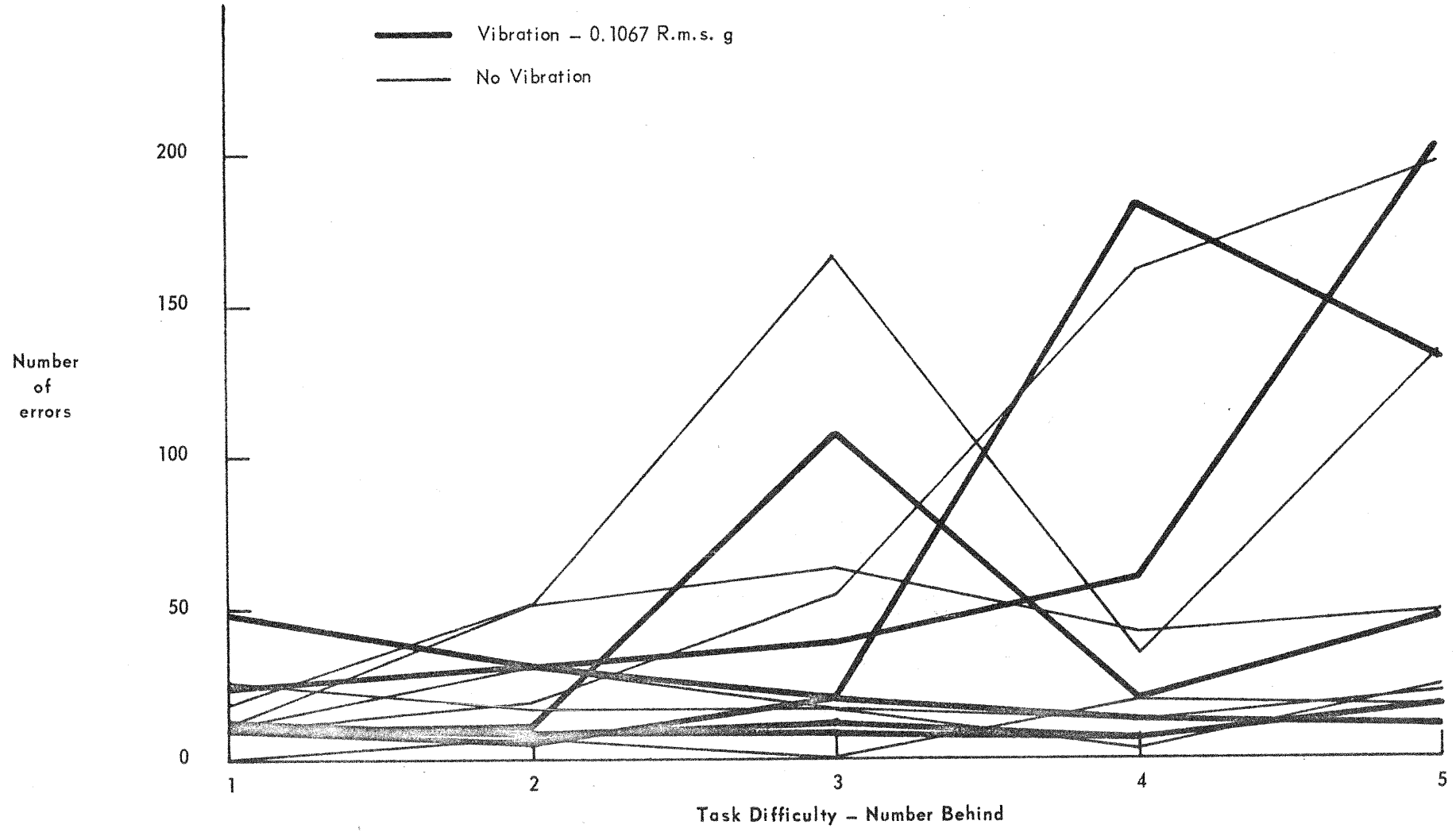


Figure 33: Scattergram of subject performance on short term memory task. – Entropy.

G. D. Whitehead

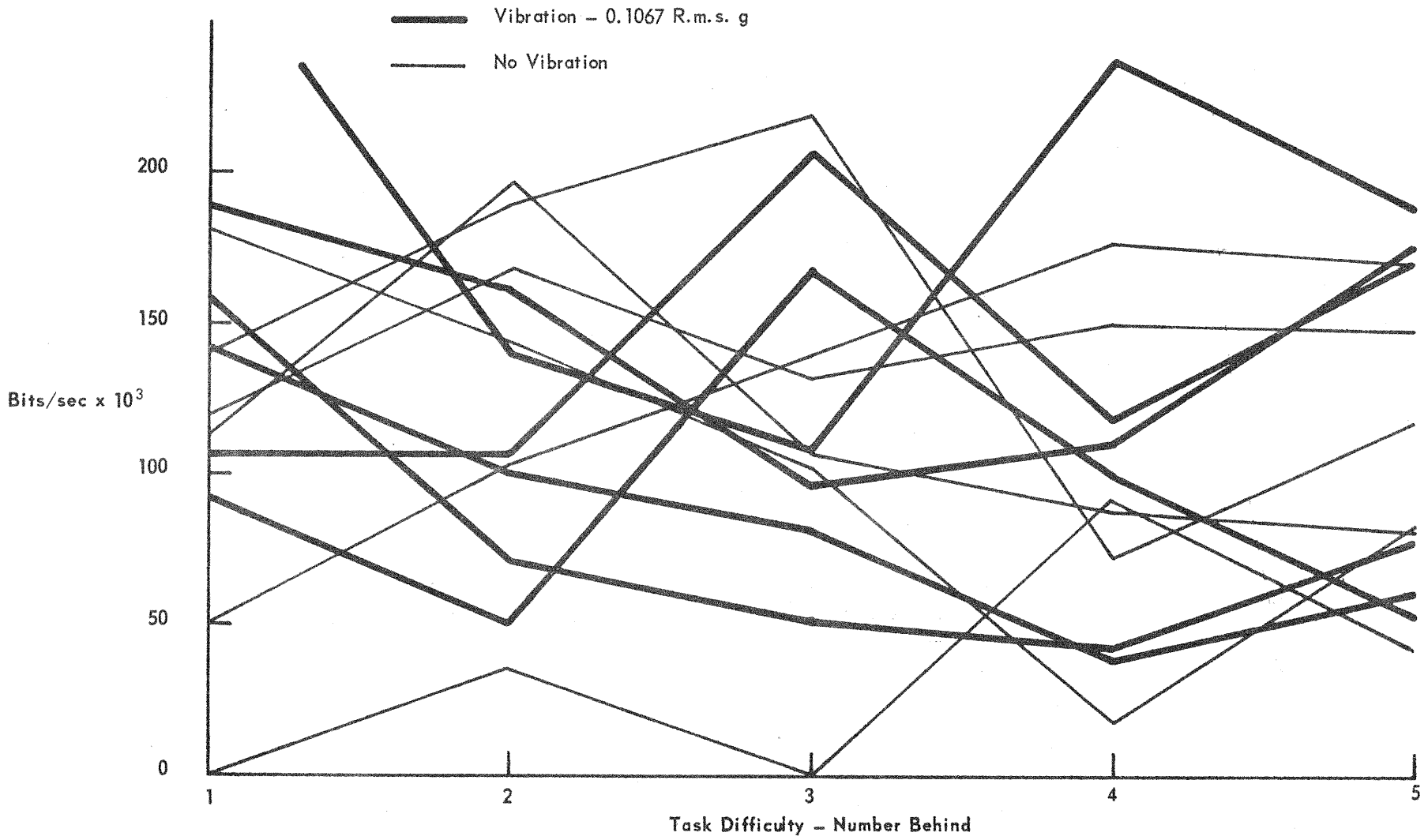


Figure 34: The Whitfield Tick Phenomonon in Dynamic Short Term Memory

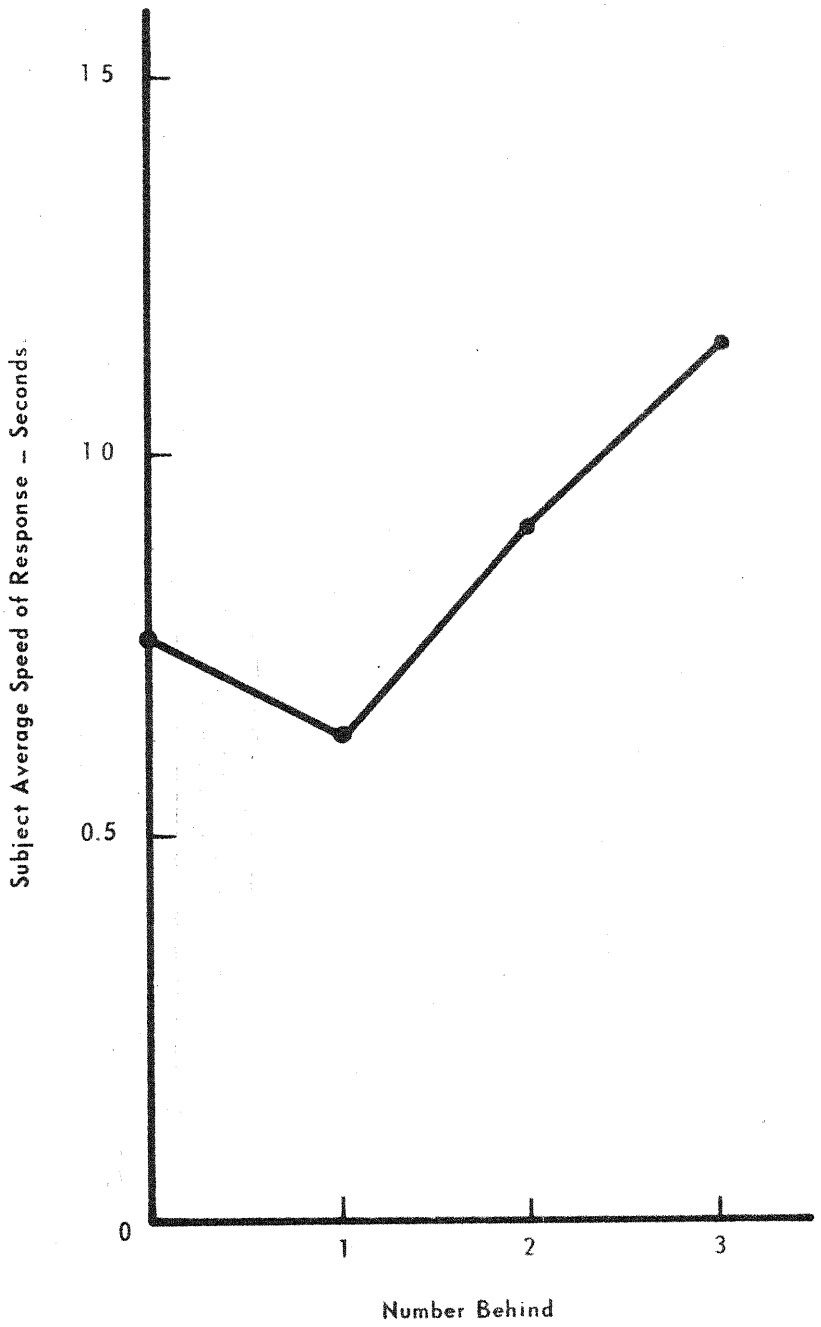
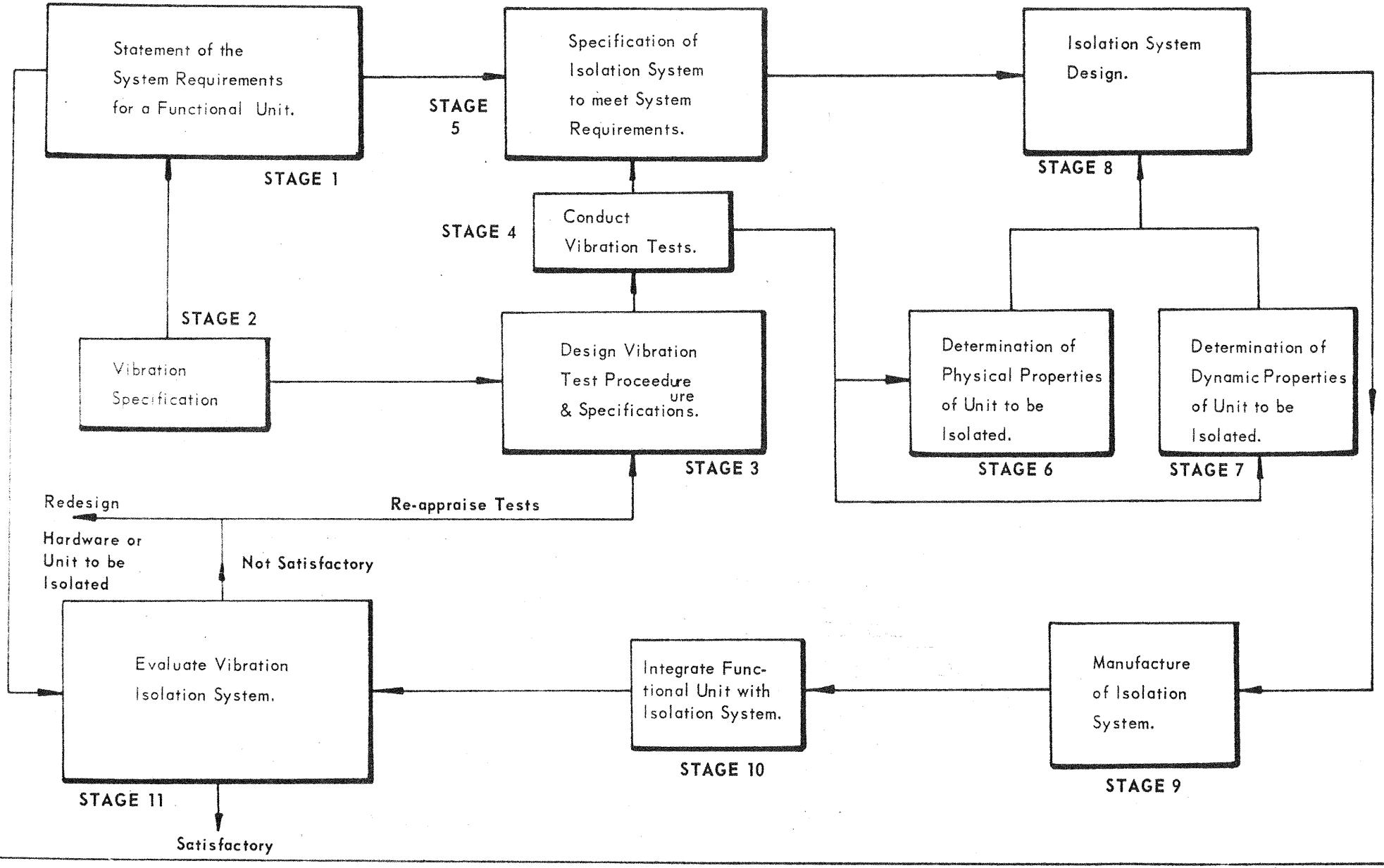


Figure 35: **Proceedural Structure for the Design & Evaluation of Vibration Isolation Systems.**

G. D. Whitehead