A CLOSED-LOOP OTOLITH SYSTEM
ASSESSMENT PROCEDURE

By

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ABSTRACT

A test procedure that is sensitive to changes in the response of the human otolith system to linear accelerations has been developed. The test is a closed-loop test in which blindfolded subjects are given a sum of sinusoids velocity disturbance in the lateral direction and directed to null their subjective velocity using a joystick controller. The test procedure has been optimized to provide the best possible data for all test subjects. The testing was performed using the M.I.T. Man-Vehicle Laboratory Sled facility.

Classical control theory quasi-linear describing function analysis is used to analyze the test data. Frequency spectrum plots of the velocity and joystick signals, along with velocity and joystick RMS values, are used to measure the velocity nulling performance of the subject. Bode plots relating acceleration input to joystick velocity command output give the transfer function of the subject.

The Bode plots of four of the subjects tested show very good agreement. The one sigma deviations and data scatter are as low or lower than that of most human subject testing. A regression analysis was used to develop a transfer function model, G_{HO}. The model, with the values obtained from one subject, is

$$G_{HO} = \frac{2.02(j\omega)}{(j\omega + 1.42)(j\omega^2 + 2(0.144)(0.540)j\omega + (0.540)^2)}$$

This test procedure will be used in the pre-and post-flight testing of astronauts. Its purpose is to define how humans adapt to weightlessness. The results will help to more fully understand the causes of space motion sickness.

Thesis Supervisor: Dr. Laurence R. Young
Title: Professor of Aeronautics and Astronautics

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May the wind always be on your tail
and your visibility be unlimited.

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CHAPTER 1

INTRODUCTION

The purpose of this work is to develop a test procedure that is sensitive to changes in the response of the human otolith system to linear accelerations. The test is a closed-loop test in which blindfolded subjects are given a motion disturbance in the lateral direction and directed to null their subjective velocity using a joystick controller. This type of test avoids the magnitude estimation problem of open-loop testing. (Ref. 6) However, it also involves more non-linear effects caused by the human operator which will be elaborated upon throughout this work. The experimental hardware used was the M.I.T. Man-Vehicle Laboratory Sled facility which is described in Chapter 3. The test procedure is to be used in pre- and post-flight testing of astronauts. It is expected that the testing will show changes in the way otolith information is processed by the brain following exposure to a weightless environment. This information will then be used to more fully understand space motion sickness.

From previous work with human subjects, Ref. 5,6,7,8, it is known that the acceleration disturbance must not be predictable, as subjects can then learn the disturbance and respond accordingly. To avoid this a sum of sinusoids velocity disturbance is used. The current system used on the Sled has great flexibility in generating these velocity disturbance profiles. This flexibility involves varying the number of sinusoids, the frequency of each sinusoid, and the peak magnitude of the velocity or acceleration at each frequency. Other variables of the system are the gain of the joystick controller and the pole of the digital filter used to filter this joystick signal. The more specific problem, then, is to find the proper disturbance profile and joystick response by adjusting these parameters.

From previous work in defining otolith system response, Ref. 4,5,9, it was found that good response of the otolith system is obtained in the 0.05-0.5 Hz frequency range. This was the only range considered throughout the testing. The disturbance frequencies are determined by the prime numbers used to multiply a base frequency. The base frequency is determined by the desired period. This allows no harmonic multiples to interfere with the disturbance frequencies. The amplitudes of the disturbance frequencies can be found using many different techniques. These include defining the disturbance by a flat position, velocity, or acceleration amplitude, with or without scaling by a first, second or third order filter. This flexibility was heavily used in developing the final test procedure.

Very little previous work has been done on otolith testing exclusively. Meiry in 1965 attempted a closed-loop otolith test but quickly abandoned it because subjects could not stay within the physical limits of the track. (Ref. 5) This is because the otolith organs are sensitive to acceleration only, and also have an acceleration threshold of approximately 0.005 g's. Thus, constant velocity motion should be undetectable. These limitations make the closed-loop task very difficult as will be shown. Also, the works on human vestibular testing that the author is familiar with do not attempt to rationalize their disturbance time histories. With no known background in this specific area of otolith system testing the test procedure had to be developed from the fundamentals.

Classical control theory describing function techniques are used in the data analysis as the human operator (HO) response is considered to be quasi-linear. A block diagram of the system under consideration is shown in Fig. 1.01. The final criteria for determining if a particular test profile was acceptable was to look at the frequency response of various signals obtained from the Sled system. The outputs available are position, velocity, acceleration, commanded velocity, and joystick signal. The most important result is found in the transfer function of the HO which is the Bode plot relating acceleration input to joystick output. Of secondary importance, but valuable in qualitative terms, are frequency response plots of velocity amplitude (with and without HO control) and joystick amplitude. While the transfer function gives the overall response of the HO, the amplitude plots give information on individual control differences and qualitative indications of how well the HO performed the velocity nulling task.

The development of the final test procedure has proceeded using experimental techniques. Based on past experience with the Sled some initial velocity disturbance profiles were generated and tested on several subjects. Based on this experience new profiles were developed and tested. Computer simulations were not used in the development phase as most of the problems discovered in the first tests were non-linear and subjective with no previously known quantitative definition. Also, the basic model for the otolith system is linear and would not have shown the non-linear effects seen. Thus, the final procedure was determined based on actual test data from all previous tests. Its justification has been by statistical and qualitative reasoning, rather than by strict mathematical calculations. It is felt that this gives a fully developed profile, as it is based on actual real world experience.

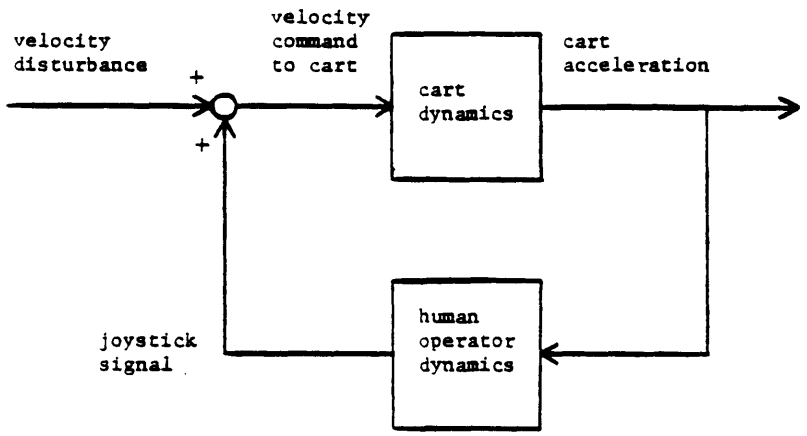


Figure 1.01 The Closed-Loop System

Thesis Organization

Chapter 2 discusses in more detail the space motion sickness problem and shows how the test procedure will be utilized. It also discusses previous work involving the analysis of the human otolith system. Chapter 3 discusses in detail the M.I.T. Sled facility hardware and software and the data reduction techniques used. Chapter 4 is a narrative discussion that reveals the steps taken to achieve the final test procedure. Chapters 5,6, and 7 discuss the final experimental method, the results, and the significant discoveries of this work.

For those interested in only the method and results, it is suggested that Chapters 1,5,6, and 7 be read. Those more interested in the full development process used to obtain the results should read Chapter 2 and 4 also. Those interested in the details of the test facility and the data reduction calculations should also read Chapter 3.

CHAPTER 2

BACKGROUND

2.1 Otolith System Testing for Spacelab

This work is part of the Scientific and Technical Proposal for Vestibular Experiments in Spacelab. (Ref. 1) Its purpose is to define how the human operator changes response to linear accelerations after adapting to weightlessness. This information will then be used to understand more fully the causes of space motion sickness. A brief description of the proposal and the scientific background follows.

The first step to achieve this result is to obtain baseline data in the normal 1 g environment of man. This will be done in the five to six month period before the Space Shuttle flight STS-9. Six test sessions will be held during this period as shown in Table 2.1.01. The tests will be conducted on a quick turnaround basis as the astronauts will be available for only a limited time during each test session. It is also desired for the test results to be obtained in a reasonable time. Baseline data will be obtained for each participating astronaut of the STS-9 mission.

Within eight hours of the astronauts return to earth the first post-flight testing will be done. Subsequent testing will be accomplished over the next two week period as also seen in Table 2.1.01. This testing will show how the HO response has changed due to the intervening weightlessness and will also show a readaptation pattern. In later experiments on the German D-1 Spacelab Mission some sled acceleration tests could be performed in orbit.

F07 timetable: Baseline Data Collection

F-180	18-20 April 1983	M.I.T. Sled	at	M.I.T.
F-90	28-30 June	U.S. Lab Sled	at	Dryden
F-60	21-22 July	"		"
F-30	31 Aug.-2 September	"		"
F-15	15-16 September	"		"
F-8	21-22 September	"		"
Flight	30 September-8 October			
L+0	8 October	"		"
L+1 to L+7	9-15 October	"		"
L+14	22-23 October	"		"

F = flight
L = landing

TABLE 2.1.01 Spacelab 1 Linear Acceleration Sled Test Timetable

The best theory currently available to define the causes of space motion sickness is the conflict model theory. (Ref.1,2,3) This theory states that upon encountering a weightless environment there is a conflict between visual, tactile, and semi-circular canal sensory perception, and otolith system sensory perception. This conflict is caused by the lack of a 1 g "bias" to the otolith organs. Since the otolith organ output and corresponding brain interpretation is based on millennia of development in a 1 g environment this conflict is easily conceptualized. It is felt that this specific conflict is the cause of space motion sickness.

There are two theories available to explain recovery from space motion sickness based on the conflict model. The primary theory states that since without a constant 1 g "bias" acting on the otolith organ the output is questionable, it is inhibited by the brain. More reliance is then placed on vision to determine orientation. The HO response to linear acceleration is therefore not based on the response of the otolith system and otolith system sensitivity to linear accelerations would be decreased. The secondary theory states that the brain can cancel the 1 g "bias" effects in its processing and concentrate on purely linear acceleration. This would cause an increase in otolith system sensitivity.

These theories must be considered in developing the test procedure to measure changes in the response of the otolith system. The procedure must be able to show an increase or a decrease in otolith system response. The required performance of the HO must not be maximized or minimized so that with varying otolith sensitivities the tests can be completed and precise results obtained.

2.2 The Otolith System Model

Work in defining the otolith system response is found in Ref. 2. This work has resulted in the Young and Meiry model shown in Fig. 2.2.01. The original data for this model was obtained using a system in which the subject was oscillated at one frequency and indicated the direction of the motion with a joystick. (Ref. 5) The test was therefore an open-loop process in which only phase information was desired. No amplitude information was obtained due to the magnitude estimation problem of open-loop testing. (As stated in Chapter 1, the closed-loop velocity nulling task was attempted but quickly abandoned due to the inability of subjects to stay within the track limits for more than 40 seconds). As expected the Bode plot shows good agreement with the phase data, but the amplitude information is meaningless. It is this amplitude estimation problem that the closed-loop task is expected to resolve.

It is noted that this otolith system transfer function is based on a velocity or acceleration input to the subject and a perceived output indicated by a hand operated joystick. Thus, it is a model for the complete path from the otolith organ output, through the processing of this information by the brain which outputs a signal to the muscles of the hand, and finally to the response of the hand itself. As such, this model can also be used as a basis for the closed-loop task. It is expected that the response of the subject in the closed-loop task will be similar to this complete otolith system model. Possible differences will be discussed in section 2.3.

As is seen from the plots of the otolith system model there is a sharp

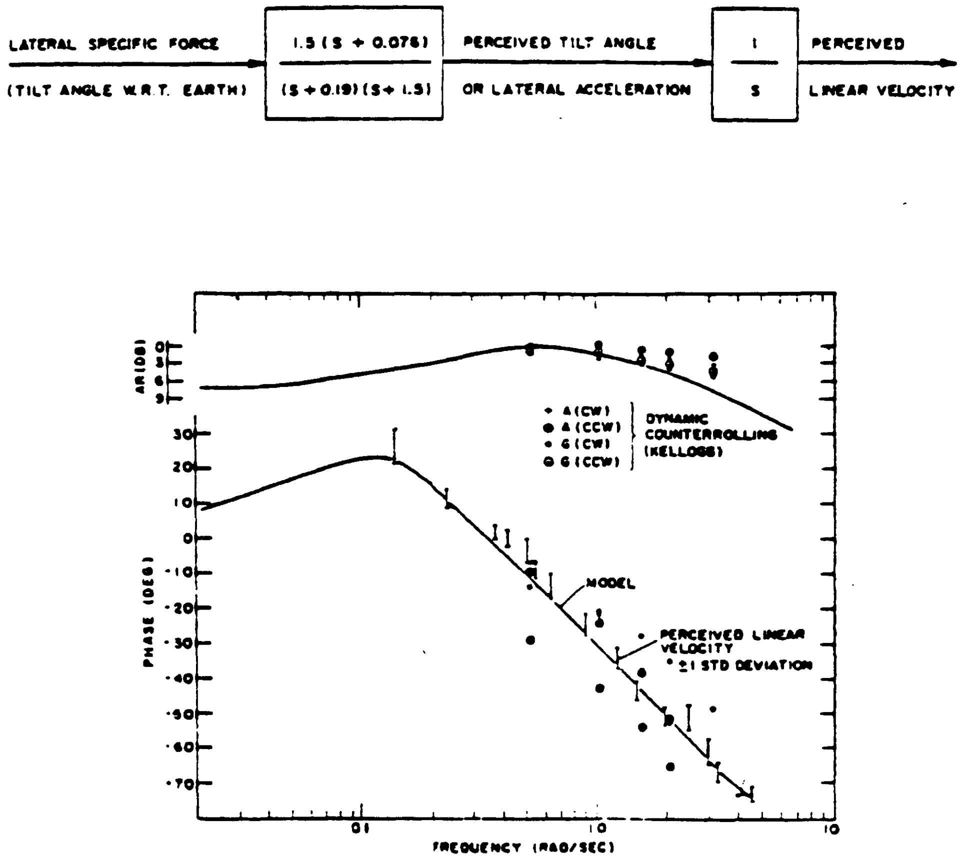


Figure 2.2.01 The Young & Meiry Model (from Ref. 1)

drop-off of the phase at higher frequencies. Assuming the amplitude follows this model it would also show a similar drop-off. This means very little response of the HO to disturbances at the high frequencies. To avoid possible control problems in the closed-loop task a frequency range of 0.05-0.5Hz was chosen. This allows a full octave range and also contains the break frequency of 0.22 Hz (1.5 rad/sec) of the model. Good HO response should be obtained over this frequency range and the break frequency should be indicated to enhance the results.

2.3 The Closed-Loop Task

As stated previously, the main reason for using the closed-loop task is to resolve the magnitude estimation problem. This hopefully will mean more correct magnitude response of the subject as well as correspondingly more correct phase information. However, the closed-loop task contains some additional effects which must be considered.

A block diagram for the closed-loop task is shown in Fig. 2.3.01. With the subject in the loop as shown, the task is not only motion estimation but manual control. As in other manual control tasks different control techniques can be used to achieve the same desired results. This technique, or control strategy, then becomes a part of the HO response. Also, the HO is not a linear system and so does not respond only to the disturbance. The HO will generate some extra response, or remnant, which cannot be linearly correlated with the disturbance. These aspects of the HO control are indicated in the block diagram of Fig. 2.3.02. The V=0 summing point indicates the velocity nulling task. The block diagram shows the complete HO system, as considered in this work.

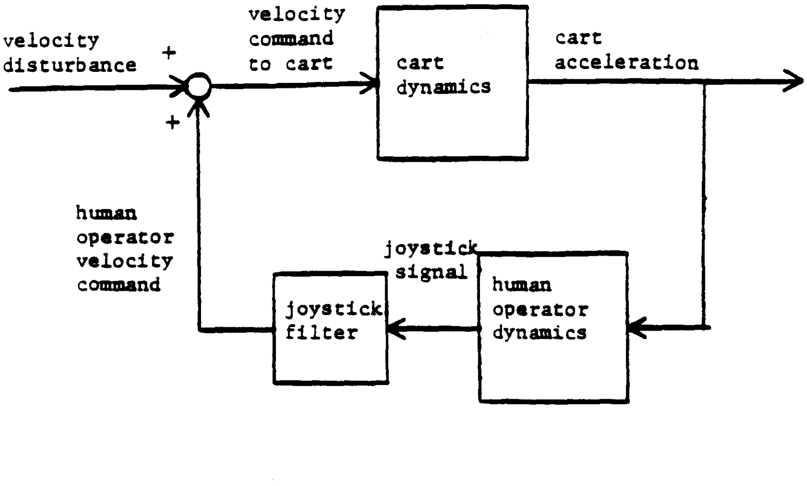


Figure 2.3.01 The Closed-Loop System

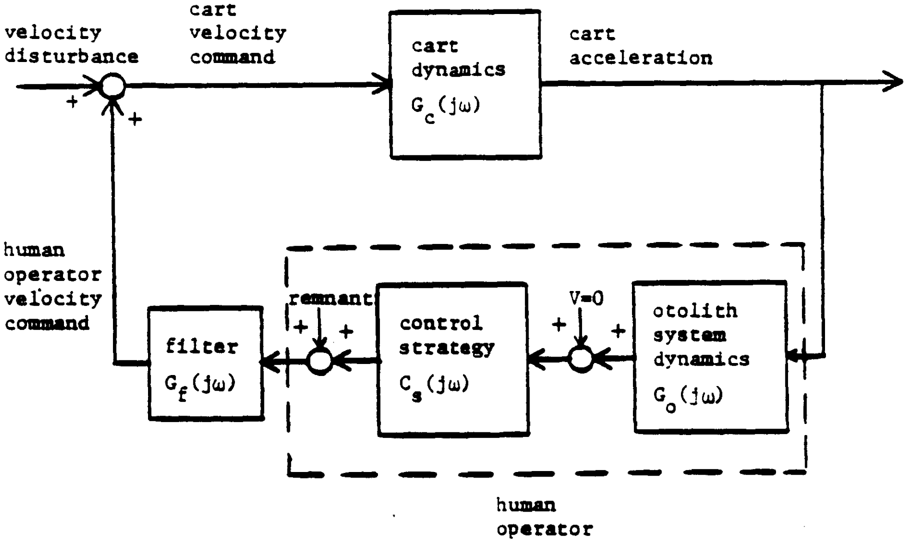


Figure 2.3.02 The Closed-Loop Block Diagram
with Details of the Human Operator

The transfer function for the HO is taken across the human operator block hown in Fig. 2.3.02. Thus, the transfer function is not that for the tolith system obtained by open-loop testing. The purpose of this thesis is ot to define the control strategy transfer function, but its effects are mportant and will be elaborated upon throughout this work. The transfer unction obtained in this thesis will contain the control strategy effects. his will not effect the desired result, which is to measure HO performance n the closed-loop task, but will effect the analysis and observations of he data.

Of more minor importance from a scientific standpoint but important in a ractical sense is the limited track length of the Sled. Because the tolith organs act as accelerometers only, no output will occur for onstant velocity motion. (Ref. 5,9) This will cause difficulties for the O in the closed-loop task. Without an acceleration input deciding on a ontrol input will then be accomplished by guessing. Also, as noted in Ref. , subjects often indicate the wrong direction of motion in the open-loop ask. For the closed-loop task, then, this could mean initially a wrong ontrol input, as the HO should sense the wrong direction and correct imself. This shows that there is ample opportunity for the HO to input mproper control and increase his motion instead of decreasing it. Also, ince the HO cannot exactly match the disturbance due to the limitations of he otolith organs, the HO will never stop his motion completely. All this eads to the HO possibly exceeding the limits of the Sled track and ending run before the disturbance profile is completed. This is of major mportance for the data analysis, since a full run is desired for traightforward data reduction, and is one of the major problems to overcome in developing a satisfactory test procedure.

2.4 Engineering Units

In Ref. 4,5 the otolith system transfer function is shown with velocity or acceleration input and corresponding perceived velocity or acceleration output. Therefore it is possible to construct transfer functions based on the velocity or acceleration disturbance. Since the otolith organs sense only acceleration it seems more correct from a physical viewpoint to use the acceleration input. Therefore, the acceleration input is used in this work.

The disturbance command to the Sled is a velocity command as will be described in Chapter 3. The control of the cart by the HO is added to that of the disturbance command in the feedback loop and is therefore a velocity control. The HO transfer function will have an acceleration input and velocity output. All signals from the Sled are converted to engineering units by the method of Chapter 3; acceleration in m/s^2 and velocity in m/s. In order to use the Young and Meiry model with this input and output it is necessary to add an integrator. This results in the transfer function and Bode plot shown in Fig. 2.4.01. This transfer function was used as a general guideline to verify the form of the Bode plots obtained from all testing.

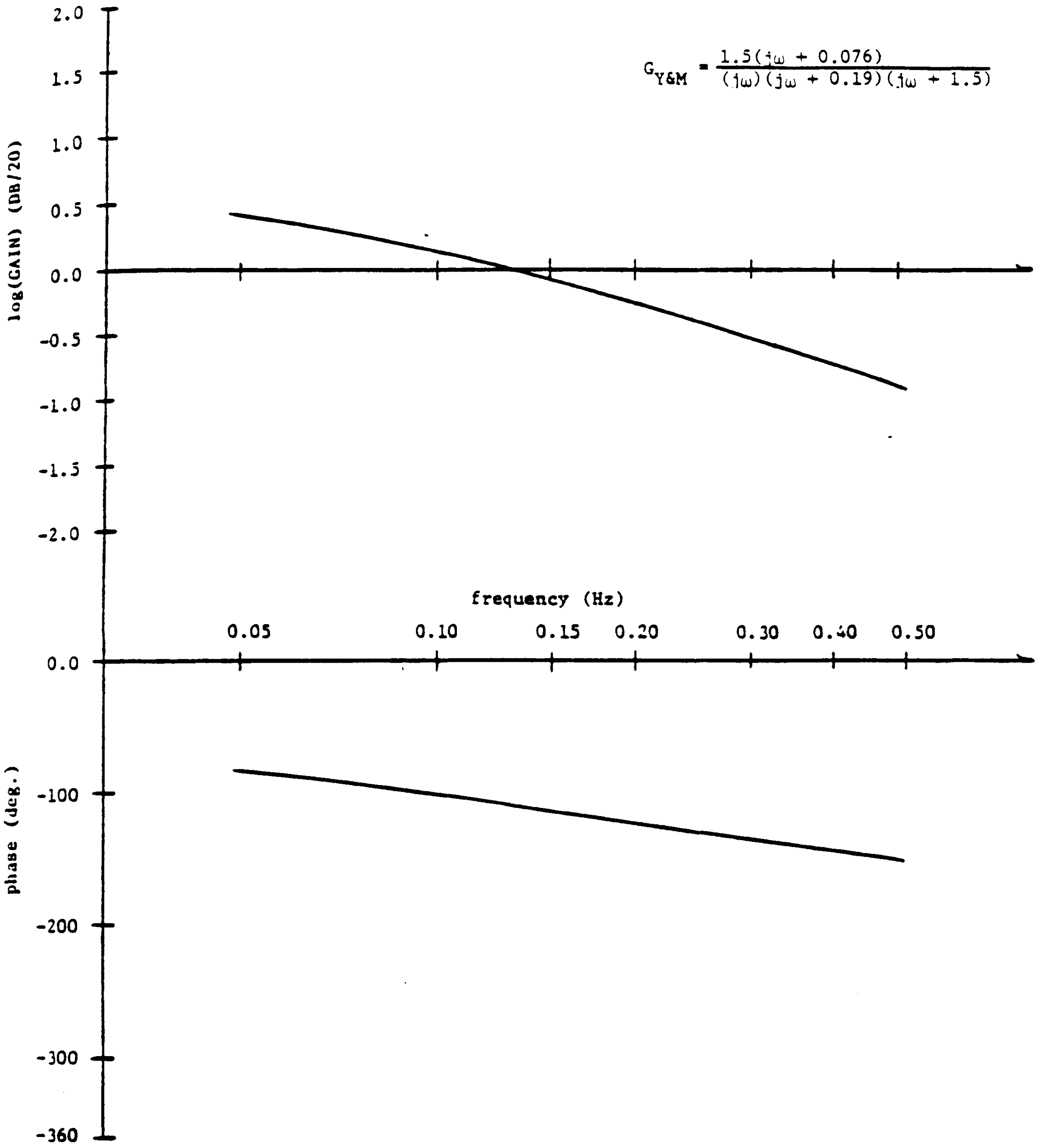


Figure 2.4.01 The Young & Meiry Model
Bode Plot, with Integrator

CHAPTER 3

THE EXPERIMENTAL SYSTEM

3.1 The M.I.T. Sled

The M.I.T. Sled is a rail mounted linear acceleration cart. Four pillow block bushings are mounted to the cart and slide along two circular rails. The cart is aligned for straightness along one rigidly fixed rail while the other rail is held loosely and aligned by the bushings. The total length of travel of the cart is 4.7 m.

A chair is mounted to the cart which can be put at different positions for testing along all three body axes. Lord vibration dampers, which attenuate frequencies below 40 Hz, insulate the chair from the cart frame. The chair is a modified automobile racing seat in which subjects are firmly supported. A lap belt and chest belt are attached to the chair and rigid foam pads are wedged between the shoulders of the subject and the outside chair supports. Two types of head restraints were used in the testing. Both contained foam padding to firmly support the sides and back of the head. One was open-faced, containing no structure in front of the face. This restraint was used in the initial development testing. The other head restraint contained an attachment which is used to take pictures of the subject's eyes in the occular torsion experiments. This attachment dropped down in front of the subject's face and effectively sealed it from wind generated by the cart motion. Speakers are mounted in both head restraints in which white noise is generated to mask some of the cart motion noise.

A cable attached to both sides of the cart is wound around a pulley at one end of the rail support structure and a winch drum at the other. The cable is held at 625 lbs. of tension to improve the dynamic response of the cart. The winch drum is driven by a 3.5 horsepower DC permanent magnet torque motor. (Fig. 3.1.01) The motor is controlled by an analog velocity controller. The controller is a PWM (Pulse Width Modulation) controller that uses tachometer feedback. The controller functions as a current generator allowing the velocity of the cart to be proportional to a low current voltage signal applied to the controller. With this controller the maximum acceleration of the cart is 10.0 m/s^2 and the bandwidth is 7 Hz. In addition to the tachometer utilized by the analog controller, a ten-turn position potentiometer is mounted on the motor shaft, and an accelerometer is mounted on the chair near the head of the subject. These transducers give the cart position, velocity, and acceleration signals which are then digitally stored.

Two types of joysticks were used by subjects to control the velocity of the cart. The first joystick consists of a toothed wheel with the axis mounted horizontally and aligned towards the subject. A one turn position potentiometer was mounted to this wheel which gives an output of ±0.54 volts with full rotation of the wheel. (The ±15 volt system power supply is used to power the joystick.) This joystick was used in the initial testing only. The joystick used for most of the testing is a standard two-axis joystick similar to the type found on radio control transmitters. The centering spring was removed from the axis used for control allowing no joystick position cue to influence the subject. The output of this joystick with full stick deflection was ±0.17 volts. This voltage is important as it is used to generate the controller gain. Both joysticks were mounted on

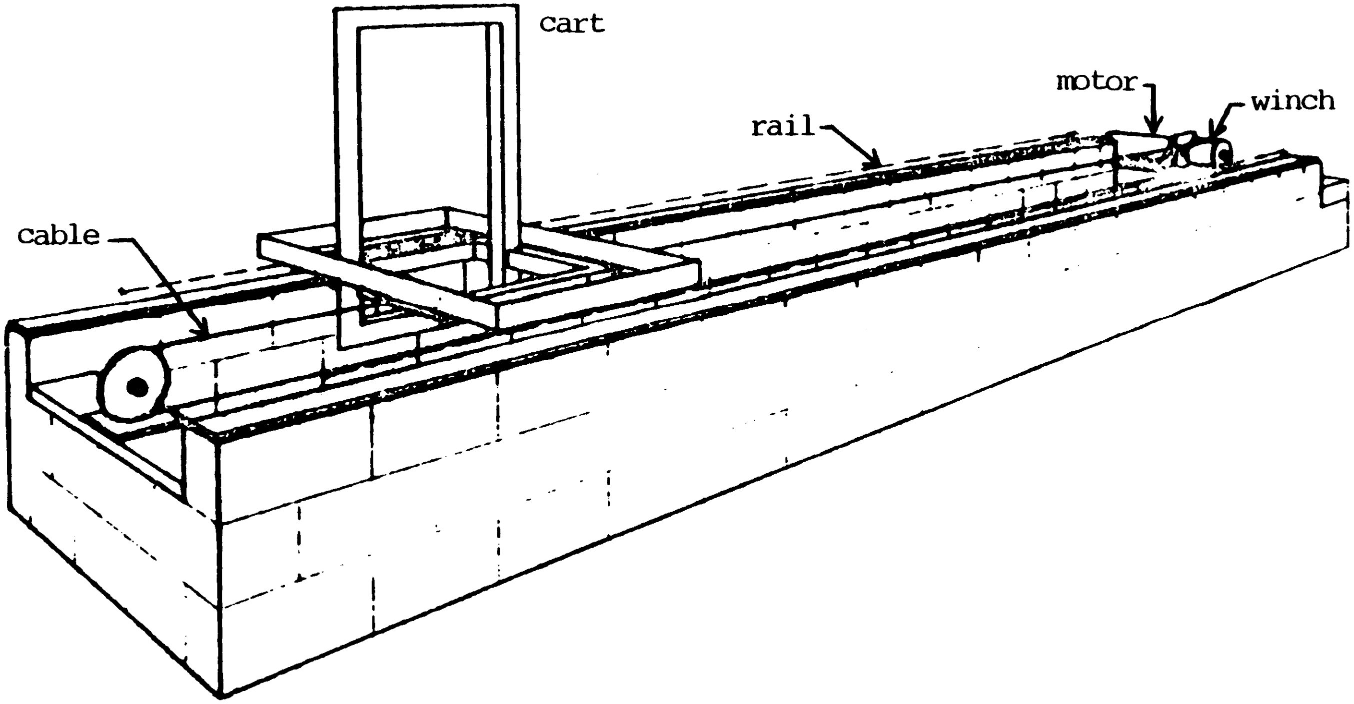


Fig. 3.1.01 The M.I.T. Sled Components

boards which were placed between the cart supports in front of the subject. This allowed the joysticks to be firmly attached to the cart frame. A support for the arm or hand was also mounted to the boards in a convenient position. The joystick output voltage was also recorded. (Appendix A contains pictures of the Sled hardware.)

The hardware safety features on the Sled are numerous. Limit switches are mounted on the Sled support structures near the rail ends. These switches are activated by a probe on the cart frame which stops the system. Shock cords are mounted near the rail ends which contain the cart to the available track when the limit switch is activated. Subjects are given a "panic button" thumb switch which also stops the system and can be activated at any time during a run. The test conductor also has access to two switches which can stop the system.

The Sled system is controlled by a remotely stationed Digital PDP 11/34 minicomputer and a Digital Laboratory Peripheral System (LPS). A fortran program is used to calculate the velocity commands to the cart, which is discussed in section 3.2. These digital commands are stored in a data file and accessed by the test conductor to run the cart. A digital-to-analog converter is used to generate the analog voltage velocity command to the cart controller. If the joystick is used its output is scaled and added to the stored velocity command to determine the final cart velocity command. Analog-to-digital converters are used to convert the analog output signals before they are recorded.

The sled system is controlled by a Sled control panel mounted in the same room as the sled. This panel interacts with the minicomputer. This allows the test conductor to run any stored velocity command file, set the joystick and data storage to be enabled or disabled, check the digital value of any signal output, and do other operations. The system can also be stopped at any time from this panel. This gives the test conductor full control of the system during the tests.

3.1.1 Calibrations

The D/A converters used in the sled system have 12 bits and a range of ±10.0 volts. The A/D converters have 12 bits and a range of ±1.0 volts which gives a gain of 2048 counts/volt. Voltage dividers of 0.1 volts/volt are used to scale the output signals before they are converted by the A/D. This value and the calibrations of the individual transducers have resulted in the following calibrations used to convert the stored digital values to engineering units:

Acceleration	0.01 m/s^2/count
Velocity	0.002722 m/s/count
Position	0.001895 m/count
Commanded Velocity	0.003998 m/s/count
Joystick Velocity Command	0.003998/JSCALE m/s/count

The position calibration was found directly by a system calibration of the position potentiometer. The acceleration calibration was found using the accelerometer calibration. The velocity calibration was found by measuring the tachometer output and the motor RPM. Knowing the drum diameter, in m, the theoretical cart velocity, in m/s, can then be found by

$$\text{velocity}=(\text{RPM})(\pi)(\text{diameter})(1/60)$$

to give the required calibration data. The command calibration was found by injecting a known voltage signal into the controller and measuring the tachometer output. Using the velocity calibration the velocity was found and then the command calibration data could be found. The velocity commanded by the joystick follows this same path as it is also a commanded velocity. The count values of the joystick signal are stored before they are filtered and scaled and added to the stored velocity command. The calibration is therefore the same except for the software scale factor, JSCALE, which is explained in section 3.2. (As noted in section 3.2 the break frequency of the digital joystick filter is 10.54 rad/sec. This is sufficiently far from the maximum disturbance frequency of 3.14 rad/sec so that the filter is not a factor in the calibration.) The A/D and D/A calibrations were used as required to find the final calibrations in engineering units/count.

In order to determine the proper JSCALE value it was decided to scale the maximum commanded velocity to some percentage of the maximum commanded joystick velocity, as described in section 4.5. Using the previously defined calibrations, the following equation was used to find the correct JSCALE:

$$\mathrm{JSCALE}=(\mathrm{Volt}_{\mathrm{jmax}})(P\ \%)(2048)(0.003998)/(V_{\mathrm{max}})$$

where $\mathrm{Volt}_{\mathrm{jmax}}$ is the maximum output of the joystick: and V_{max} is the maximum commanded velocity of the profile in m/s. This results in the maximum commanded velocity being equal to the desired percentage, P, of the maximum joystick commanded velocity.

3.1.2 Cart Transfer Function

The cart system dynamics have been described in Ref. 12. The model developed in this reference was found using bond graph techniques and an assumed cart mass. In order to verify the model, data was taken for a few runs without HO control. The final test profile was used. One run with no subject and one run with a 140 lb. subject were considered. The standard data reduction techniques described in section 3.3 were used with the velocity command as the input and the cart acceleration as the output. A Bode plot of the results is shown in Fig. 3.1.2.01.

This plot shows that the cart transfer function can be approximated by a simple differentiator with a gain of 1.12. Although there is some scatter in the data at the low frequencies it is felt that the more simplified model for the system is more useful for any further work. This plot and model were used as required in all further work. It is also seen that the additional mass of the subject had little effect on the results. This gives assurances that the analog controller is performing satisfactorily with the varying subject mass. It is noted that this model differs from that of Ref. 12.

3.2 Sled System Software

All functions of the Sled are controlled by a single program called CART. Individual functions are accessed from the CART program by two letter codes. The hierarchy of the CART program is explained in Ref. 13,14 and will only be described as necessary here. It is noted that the software has been designed to be "user friendly" and has great flexibility in its current capability and potential for future growth. All program parameters, which are used extensively in the software descriptions, are denoted by

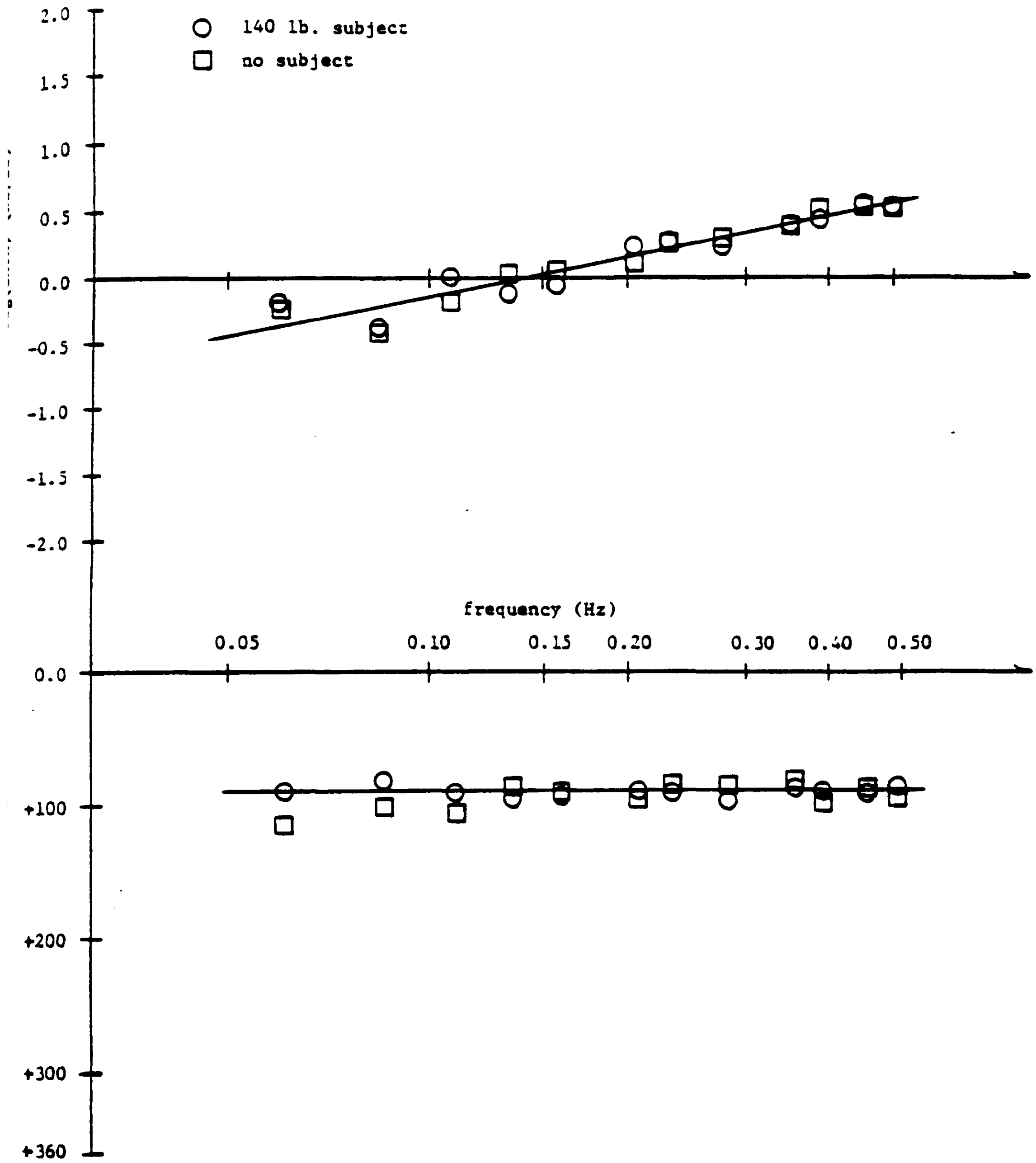


Figure 3.1.2.01 The Cart Transfer Function Bode Plot

capital letters.

Safety features have also been incorporated in the cart system software. Limit checks are made on the commanded velocity to prevent an overvoltage to the controller. The cart position and velocity are checked at every sample to determine if the cart could reach the track limits. If so the software decelerates and stops the cart. The deceleration is limited, however, so often the hardware switches are reached before the cart is stopped. These are the principle software safety features.

3.2.1 Disturbance Profile Generation

In order to drive the cart with a sum of sinusoids velocity signal two files have to be created. The first file contains the discrete velocity commands as determined by the sum of sines. These files are generally called velocity command profiles, or profiles, and their generation is described in the next section. Each profile is defined by a different set of parameters. Groups of these profiles are then assigned to files called protocol files. Each protocol file is made up of a series of profiles. A profile is run by accessing it from the protocol file using the Sled control panel described in section 3.1. Ref. 13,14 further describe the file system.

All profiles used to run the cart in this work are sum of sinusoids velocity commands. These profiles are defined by

$$v(t) = \Sigma A_i \sin(\omega_i nT+\varphi_i)$$

where v(t) is the velocity time history in m/s: A_i is the peak amplitude at the i^{th} disturbance frequency, ω_i, in rad/sec : T is the sampling rate in seconds/sample; n is the consecutive sample number: and t is time = nT.

The program used to generate a sum of sinusoids profile is accessed by the SO command. Ten parameters are needed to generate a sum of sines profile. The profile run time, in seconds, is input as variable TRUN. It is used to determine the fundamental or base frequency in rad/sec by

$$\omega_b = 2\pi/\mathrm{TRUN}$$

The fundamental frequency is also input in Hz. This is used by the test conductor for illustrative purposes. The number of sinusoids used in the profile is input as variable NSINES. The disturbance frequencies used in the profile are determined by the h_i numbers stored in a data file. Prime numbers and one even number, if desired, can be used without having the harmonics of the frequencies affect each other. The disturbance frequencies are determined by

$$\omega_i = h_i \omega_b$$

The FLAT input parameter sets the peak amplitudes at the disturbance frequencies of either position, velocity, or acceleration constant. For a constant velocity profile the velocity amplitudes, A_i, are set to

$$A_i = 1.0$$

For a constant position profile the velocity amplitudes are set to

$$A_i = \omega_i$$

For a constant acceleration profile the velocity amplitudes are set to

$$A_i = 1.0/\omega_i$$

The FILTER and FPOLE input parameters can also be used to further scale the amplitudes before the limit checks are made. This will be discussed in section 3.2.2.

The frequency variation of each sinusoid is adjusted by the DEL input phase angle. This is done to give more flexibility and allow each sinusiod to have a different starting point. The phase angle for each sine is found by

$$\varphi_i = i*DEL \quad i=0,1,....NSINES-1$$

DEL is chosen so that no phase angle is duplicated.

With all these parameters chosen the sines are completely defined. The amplitudes can now be further adjusted by the input track length limit, FPOS, in m, and the input acceleration limit, FACC, in g's. The track length limit is checked first. The sum of sines velocity is integrated to give the position. With the input sampling time, T, the maximum and minimum position of the run are found using

$$\text{position}(t) = \Sigma(A_i/\omega_i)\sin(\omega_i nT+\varphi_i-\pi)$$

If the maximum position excursion exceeds the FPOS limit then the amplitudes are scaled by

$$A_i = A_i(FPOS/(pos_{max} - pos_{min}))$$

Using these newly defined amplitudes the maximum absolute acceleration, in g's, is found by

$$\text{acceleration}(t) = \Sigma A_i\omega_i\sin(\omega_i nT+\varphi_i+\pi)/9.81$$

If this acceleration exceeds the FACC limit the amplitudes are further scaled by

$$A_i = A_i(\text{FACC}/|acc_{max}|)$$

At this point the profile is completely defined. The velocity is then checked to find the first zero crossing, at a time t_0. The phase angles are then adjusted so the profile will start at this point. This insures that the first velocity commanded by the profile is small. The starting position is then calculated by finding the position at t_0 and then finding

$$\text{starting position} = pos(t_0) - (pos_{max} - pos_{min})/2.0$$

This centers the profile within the cart travel limits.

This completes the profile generation phase. Two more steps are then used to store the profile in a data file, and assign this data file to a protocol file. When these steps are complete the profile can then be used to run the cart.

The profile generation program has been programmed on two different computers. Appendix B contains the program listings and a brief explanation of their use. Only the VAX output calculates the maximum commanded velocity and the histogram values. The histogram data is found by calculating each nT acceleration command value using the equation previously defined. The values of these points are then filed into ranges of multiples of 0.005 g and counted. The maximum value of each 0.005 g range and the number of points in each range is then determined.

3.2.2 Profile Amplitude Scaling

As stated in the previous section the amplitudes of the disturbance frequencies can be scaled by using the FILTER and FPOLE variables. These parameters define the order and pole location of a low pass filter. The method used to define this scaling will now be developed.

The velocity command is written as

$$v(t) = \Sigma A_i \sin(\omega_i nT+\phi_i)$$

When filtering is used the amplitudes, Ai, are adjusted so that the power spectral density of the velocity is scaled according to

$$\int_{\omega_{imin}}^{\omega_{imax}} \Phi_{vv}(\omega) d\omega = (K/(FPOLE+j\omega)^{FILTER})^2$$

The amplitudes at each frequency are then chosen to be

$$1/2A_i^2 = A_i^2 \int_{\omega_{imin}}^{\omega_{imax}} \Phi_{vv}(\omega) d\omega = A_i^2(g(\omega_{imax}) - g(\omega_{imin}))$$

where $g(\omega)$ is the indefinite integral of $\int \Phi_{vv}(\omega) d\omega$ and the ω_{imax} and ω_{imin} are chosen to be the geometric means between the disturbance frequencies. For interior points between disturbance frequencies these frequencies are found by

$$\omega_{imax} = (\omega_i \omega_{i+1})^{0.5}, \text{ and}$$

$$\omega_{imin} = (\omega_i \omega_{i-1})^{0.5}$$

The lowest ω_{imin} frequency, ω_0, is found by assuming that the lowest disturbance frequency, ω_1, is the geometric mean of the lowest ω_0 and the next lowest disturbance frequency, ω_2. Thusly , ω_1 can be found by

$$\omega_1 = (\omega_0 \omega_2)^{0.5}$$

Solving for ω_0 then gives

$$\omega_0 = \omega_1^2/\omega_2$$

Similarly the highest ω_{imax} frequency, $\omega_{NSINES+1}$, is found by

$$\omega_{NSINES+1} = \omega_{NSINES}^2/\omega_{NSINES-1}$$

The K value is chosen by specifying the variance of the velocity amplitudes, from 0.0, to be 1.0. This gives:

$$\sigma_d^2 = 1.0 = \Sigma 1/2A_i^2 = \int_{\omega_{1min}}^{\omega_{1max}} \varphi_{vv}(\omega)d\omega + .. + \int_{\omega_{NSINESmin}}^{\omega_{NSINESmax}} \Phi_{vv}(\omega)d\omega = K\int_{\omega_{1min}}^{\omega_{NSINESmax}} \phi_{vv}(\omega)d\omega$$

so

$$K=1.0/\int_{\omega_{1min}}^{\omega_{NSINESmax}} \Phi_{vv}(\omega)d\omega = 1.0/[g(\omega_{NSINES+1}) - g(\omega_0)]$$

The final equation for the filtered amplitudes can now be written as

$$A_i = A_i\left[2\frac{g(\omega_{imax}) - g(\omega_{imin})}{g(\omega_{NSINES+1}) - g(\omega_0)}\right]$$

The indefinite integrals are readily calculated and will not be elaborated upon here.

3.2.3 The Digital Joystick Filter

As stated in section 3.1 the joystick signal is filtered before it is added to the stored velocity command. A digital first order low pass filter is used. The software implementation of this digital filter is

$$Y(n) = (1-\alpha)Y(n-1)+(\alpha/JSCALE)U(n)$$

where Y(n) is the filtered output: U(n) is the filter input, or raw joystick signal: and n is the sample number. JSCALE and α can be varied by using the JO command in the CART program. In analog form this filter is represented by

$$Y(s) = (K/(1.0/\tau+s))U(s)$$

where τ is the time constant. Comparing the two forms gives

$$K = 1.0/JSCALE, \qquad \tau = T/\ln(1.0-\alpha)$$

As is seen the JSCALE variable is used to vary the gain of the filter and the α variable is used to vary the pole of the filter. As is shown in Chapter 4, JSCALE is an important parameter in determining the success of a profile. α was set at $\alpha=0.1$ and never varied throughout the profile development.

With $\alpha=0.1$ the equivalent time constant is $\tau=0.095$ sec. From the stripcharts of the cart velocity during full deflection tests of the joystick it was seen that the cart response had no visible delay and no overshoot. To increase the time constant would lower this response time which would be easily noticed by the HO. Also, the human sensory system operates with a 0.20 sec time constant which gives a sufficient safety margin compared to $\tau=0.095$ sec. It would not be desirable to increase τ as this would decrease the safety margin and possibly cause resonance effects similar to pilot induced oscillations. There is no reason to decrease τ, as the response of the cart is quite acceptable. For these reasons α was not varied.

3.3 Data Reduction

A data file is created for every run during which the data storage flag is enabled. The A/D's used to convert the output signals have 8 channels. The 5 outputs available for this work are found in channels 1,2,3,4, and 6. The data points are grouped into blocks of 256 points which gives 32 samples of each channel per block. The PDP 11/34 minicomputer is used to process the data directly from the stored data files.

To reduce this data each channel is accessed individually and stored in a file. This is done by storing every 8th + desired channel # point of the original data file. The data is then concatenated to produce 1024 points to be used to run the Fast Fourier Transform (FFT) algorithm.

The total number of data points of each output of each run is found by

$$\text{run time/sampling rate} = TRUN/0.01$$

The number of points for each concatenation is then found by

$$N = TRUN/(0.01)/(1024)$$

From the ensemble of N points an average and standard deviation are determined. Any of the N points which are more than two standard deviations from the average are discarded and a new average is determined. The percentage of the discarded points is printed out as REJECT. This new average is then stored in an array of 1024 points. When all 1024 points are found the average, AVG, square root of the mean squared error, RMS, and the standard deviation, STD, are calculated.

With the concatenation of all channels complete, an FFT is used to find the frequency distribution. A simple fortran FFT program obtained from Ref. 15 was coded into the PDP-11/34 minicomputer. This allows the data to be processed directly from the stored data files obtained during the test runs. Two programs are run sequentially to obtain the final results.

The first amplitude and phase obtained from the FFT are the bias values. The subsequent values are associated with a frequency, f, defined by

$$f(I) = (I-1/1024)*(1.0/TRUN)$$

where I is the array position. The I-1 factor is needed since the first array values are the bias values as stated. The run time, TRUN, is specified to be a multiple of 1024 times the sampling rate. This insures that the disturbance frequencies can be exactly reproduced by the FFT. The remnant frequencies and values are found by averaging the amplitudes, phases, and frequencies of all the points between the disturbance frequencies. Although this is not precisely correct, the real and imaginary parts should be averaged and then the amplitude and phase determined, Ref. 8 shows that there is a negligible difference between the two methods of computation. The log(GAIN) and phases of the transfer function are then determined by

$$\log(\mathrm{GAIN(N)}) = \log\left[\frac{\mathrm{AMPJ(N+1)}}{\mathrm{AMPA(N+1)}}\right], \quad \mathrm{phase(N)} = \mathrm{PHASEJ(N+1)} - \mathrm{PHASEA(N+1)} + 180$$

where AMPJ is the joystick amplitude: AMPA is the acceleration amplitude: PHASEJ is the joystick phase angle: PHASEA is the acceleration phase angle. The 180 deg. correction is added since the subject opposes the cart motion. All count values are converted to engineering units with the calibrations of section 3.1 before entering the FFT program. The desired plots are then created with this data. An explanation of the plots is contained in Appendix E.

It is noted that the FFT does not correct for the run time used. This means that the ouput is not scaled in a meaningful way. This results in the high amplitude values seen in the frequency spectrum plots. To keep this in mind when looking at these plots, the designation FFT has been placed in with the engineering units notation. This only affects the frequency plot data as the scaling factors are canceled when the amplitude ratios are taken for the GAIN and phase data.

For runs that are not completed; (i.e. the subject did not stay within the track limits for the full run time) no FFT information was obtained. Since it was desired to work with only completed runs for the procedure little effort was expended on analyzing incomplete runs. A program was written to calculate the RMS, AVG, and STD values of all data points for a run, however. This was used for the initial testing since most of these runs were incomplete. The RMS, AVG, and STD values were computed from only the concatenated 1024 points for all further runs. There is a few precentage points of error between the two methods of computation but it is not of significance for this work.

Listings of all the programs used to reduce data in this work are provided in Appendix C. Brief descriptions of their use, along with input and output samples, are included.

CHAPTER 4

TEST PROCEDURE DEVELOPMENT

4.1 General Concepts

The background of the pre- and post-flight closed-loop otolith system testing has been developed in Chapters 1 and 2. One key factor of this test is that it is to be used on all participating astronauts. Therefore, there could be some variation of otolith sensitivity among the subjects. Also, as stated in Chapter 1, it is expected that adapting to weightlessness will cause a decrease in otolith sensitivity. This increases the range of otolith sensitivity at the less sensitive end. Any test procedure must then have two major goals:

1) yielding an accurate description of the HO response,
2) yielding this description for a wide range of otolith sensitivities.

As mentioned in Chapter 2 the test period will be of limited duration and data analysis needs to be performed without delay. Because of this it is felt that the test procedure should offer good chances for completing runs with little practice. This also means that some margin for error in control will be available, which should be helpful for subjects with varying otolith sensitivities. Further, it means that the test is not so difficult that results might be in question due to short runs. Finally it gives confidence in the procedure itself.

The data analysis can also be performed in a more straightforward manner with a standard FFT routine when runs are completed. This eliminates the problems of FFT analysis with incomplete runs and gives more consistent results. The run completion rate is therefore of major practical importance in developing a test procedure.

Initially a computer simulation of the closed-loop system was desired to help determine the general ranges of the system parameters. With the first testing, however, this idea was abandoned. The effects seen were very non-linear and so would not have been evident in a linear simulation. The main thrust of the development was then based on experimental results. Lessons learned from one set of tests were applied to determine the next profiles. This was continued until a profile was found that fit the previous criteria. A description of this development now follows.

4.2 The DHPR02.PRO Series, Part 1, and High Amplitude Problems

As stated previously the authors initial experience with the closed-loop nulling task was as a subject in the tests of Ref. 8. The parameters used to generate this profile are shown in Fig. 4.2.01. This initial experience suggested that a smaller track length be used to help subjects remain within the track limits. Also, it was felt that a run time of 184.32 sec. was too long as in the author's experience fatigue became a factor after about 120 sec.

Using this experience seven profiles were created. The flat velocity calculation was used to scale the amplitudes as this lessened the number of variables required to generate the profiles. The track length was lowered to a range of 1.97-2.38 m while the corresponding maximum accelerations ranged from 0.120-0.204 g. Various numbers and distributions of frequencies

```
==================================================
 SUM OF SINES PROFILE

    1. DURATION OF PROFILE:    184.32 SEC
 PARAMETERS OF SINUSOIDS:
    2. NUMBER OF SINUSOIDS:      25
    3. FUNDAMENTAL FREQUENCY:   0.0054 HZ
    4. EQUAL AMPLITUDE DOMAIN:    0 (-1,P;0,V;+1,A)
    5. SUCCESSIVE PHASE ANGLE:  247.   DEG
 PARAMETERS OF SHAPING FUNCTION:
    6. ORDER OF FILTER:           2
    7. POLE:                      0.28 HZ
 PHYSICAL CONSTRAINTS:
    8. LENGTH OF TRACK            3.60 M
    9. ALLOWED ACCELERATION       0.41 G
   10. TIME INCREMENT:           0.015 SEC


 RESULTING IN THE SUM OF SINUSOIDS:
      FREQ        AMP       ACCEL AMP     PHASE
      [HZ]       [M/S]         [G]        [DEG]
     0.016        0.08       0.001          0.
     0.027        0.09       0.002        247.
     0.038        0.11       0.003        134.
     0.060        0.11       0.004         21.
     0.071        0.10       0.005        268.
     0.092        0.10       0.006        156.
     0.103        0.10       0.006         43.
     0.125        0.12       0.009        290.
     0.157        0.10       0.010        177.
     0.168        0.09       0.010         64.
     0.201        0.10       0.012        311.
     0.222        0.07       0.010        198.
     0.233        0.06       0.010         85.
     0.255        0.08       0.013        332.
     0.288        0.08       0.015        220.
     0.331        0.08       0.018        107.
     0.396        0.07       0.018        355.
     0.450        0.06       0.019        242.
     0.548        0.05       0.019        130.
     0.613        0.04       0.018         17.
     0.743        0.04       0.017        265.
     0.808        0.02       0.013        153.
     0.884        0.02       0.013         40.
     0.982        0.02       0.013        288.
     1.080        0.02       0.012        176.

MAXIMUM ACCELERATION IN SIGNAL:  0.140 G
PERCENT USAGE OF TRACK: 100.00%
STARTING POSITION:   0.00
==================================================
```

Figure 4.2.01 Profile Parameters of Ref. 8

```
INPUT PARAMETERS

     TRUN= 102.400
     NSINES= 11
     FFREQ= 0.009766
     FLAT= 0
     DEL= 247.000
     FILTER=  0
     FPOLE=   0.310
     FPOS=  3.50
     FACC= 0.300
     TLOOP= 0.010

ROFILE DESCRIPTION

     MAX ACCEL= 0.204
     VELMAX=  1.1460
     % USEAGE OF TRACK= 57.50
     STARTING POSITION=-0.363
     SCALE= 0.1881

FREQ.  (HZ)    AMP1  (M/S)    AMP2  (G)    PHASE (DEG)
      0.0488          0.13          0.004            0.
      0.1074          0.13          0.009          247.
      0.1660          0.13          0.014          134.
      0.1855          0.13          0.015           21.
      0.2246          0.13          0.019          268.
      0.2832          0.13          0.024          155.
      0.3027          0.13          0.025           43.
      0.3613          0.13          0.030          290.
      0.4004          0.13          0.033          177.
      0.4590          0.13          0.038           64.
      0.5176          0.13          0.043          311.
```

Figure 4.2.02 DHPR02.PRO Profile #6 Parameters were used to test the effects of these variables. The same DEL=247 was used to eliminate the effects of varying this value. One of the profiles is shown in Fig. 4.2.02. Five subjects were tested. The open-faced head restraint was used and subjects were asked to close their eyes during the runs. A blindfold was not used.

The results of these tests were most illuminating qualitatively. Very few runs were completed. The main effects seen were as follows:

1) Subjects often lost track of their direction of motion and it was common to make the initial control in the wrong direction. Often this ended a run. This was probably caused by the vibration of the cart giving a velocity cue without an acceleration cue during approximate constant velocity motion.

2) There was no tendency to end all runs at the same end of the track. It is noted in Ref. 5 that for angular motion this is not the case.

3) Control was sensitive and HO induced oscillations were not uncommon. Often high frequency oscillations were injected by the subject to decrease their response time and to attempt to find the zero input range of the joystick. Also, the high input accelerations at the higher frequencies probably contributed to the HO induced oscillations.

Bode plots were found for each completed run. A typical plot is shown in Fig. 4.2.03. (Appendix E contains a discussion of the plot formats.) The plot shows the general trends expected by the Young and Meiry model. The drop in gain with higher frequencies is clear, but the phase remains relatively flat. There is much data scatter, especially in phase, which signifies a large number of direction reversals. This corresponds with the large amount of HO induced oscillations observed during test runs. This activity generally means a high joystick remnant and little velocity nulling as will be shown. With this high remnant the Bode plots should tend toward the inverse plant dynamics as suggested in Chapter 6. The nearness of some of these gain plots to a slope of -1 (log(GAIN)/log(freq.,rad/sec)) and the flatness of the phase with frequency suggests this tendency. However, the Young and Meiry model is also close to the inverse plant dynamics so it is not clear which transfer function the data is following. No attempt was made to further investigate this problem at this time.

Since very few runs were completed more effort was placed in analyzing the time history data. It was desired to have a time domain measurement of HO performance and RMS data was used for this. The RMS errors of command (or error, since the stored command value is that of the disturbance plus joystick signals), acceleration, velocity, position, and joystick signals were calculated. These were then divided by the corresponding value of the no subject case, except for those of the joystick. The resulting ratios for one subject are shown in Table 4.2.01.

It is difficult to corelate the different ratios for each run. The position and acceleration ratios show the most scatter and indicated no general trends. The error and velocity ratios seem to corelate with each other and with completed runs. There is not as much corelation with run time as expected. This indicates that an HO reaching the track limits is not necessarily caused by poor control during the entire run, but by a few crucial mistakes. The overall poor control is suggested by the ratios being near 1.0, the neutral velocity nulling value. Since little corelation of the RMS errors was seen, consistency among the individual runs of each subject was checked as repeatability is a requirement for the procedure. It

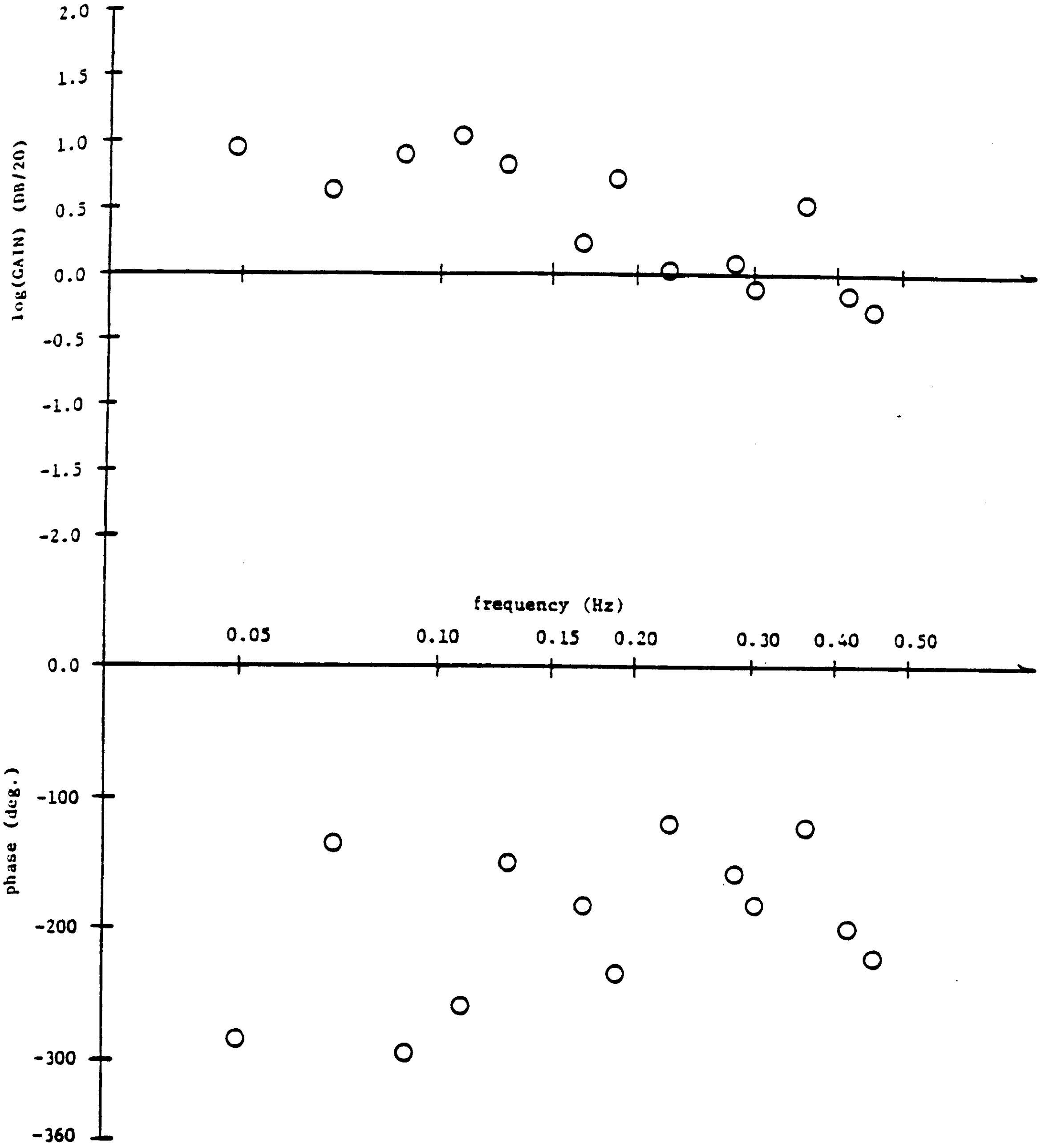


Figure 4.2.03 Bode Plot. Subject JL
DHPRO2.PRO Profile #7

DATA FILE	PR FILE	COMMAND RMS RATIO	POSITION RMS RATIO	VELOCITY RMS RATIO	ACC. RMS RATIO	DURATION (sec.)
005	1	0.911	1.43	1.03	3.19	30.72
006	1	0.70	1.39	0.89	1.78	15.36
007	1	0.77	0.73	0.82	2.08	10.24
010	1	0.98	2.52	1.09	2.60	15.36
008	2	1.12	1.05	0.97	2.25	33.28
009	2	1.10	0.80	1.00	2.60	74.29
011	3	1.29	1.24	1.15	2.67	23.04
012	3	1.22	0.48	0.85	2.88	15.36
013	4	1.24	0.66	1.38	2.70	38.40
014	4	1.52	0.98	1.19	3.30	15.36
015	5	1.30	1.31	0.78	2.50	10.24
016	5	1.26	0.65	1.33	2.33	2.56
017	5	1.86	1.05	1.08	3.47	10.24
018	5	1.52	1.14	1.04	2.33	23.04
019	6	1.45	1.99	0.98	2.84	33.28
021	6	1.32	1.61	0.93	2.51	43.52
022	7	1.41	1.22	0.88	2.61	79.36
023	7	1.44	1.13	0.79	2.57	38.40
024	7	1.34	1.09	0.80	2.22	81.92

TABLE 4.2.01 RMS Ratios. Subject DH, DHPRO2.PRO.

was found that runs 2,6,5 ,and 7 were the most consistent, based on the values of all the ratios. The general lack of consistency and corelation with subject performance will be shown to improve with the lower amplitude profiles.

4.2.1 Summary

Although few runs were completed with this testing some useful information was obtained. During all but one of the test sessions the runs were given to the subject in numerical order. Often the first run was given five or more times until the subject gained some familiarity with the system. Since profiles #6 and #7 were the most consistent and were usually given last it is felt that practice was the main factor for the consistency of these runs. Profiles #2 and #5 were probably consistent due to their low maximum acceleration and corresponding velocity which were the lowest of all the profiles. One of the main reasons for the generally poor run completion rate was disturbance amplitudes that were too large. Another major factor was the gain of the joystick. The JSCALE=2.0 gave a maximum velocity of 1.53 m/s. This allowed total control of the largest maximum velocity of any profile but was much higher than needed for the lower velocity profiles. This high sensitivity caused increased difficulty with the already difficult profiles and contributed to the poor performance.

This initial testing experience also pointed out the many non-otolith cues of the system. The cart motion could always be sensed through the cart noise and vibration which did not hamper the subjects performance but were perceptible. The white noise could not mask all of the cart noise. Wind over the hands and face could also be sensed, especially at the higher velocities. Subjects were required to wear long sleeves to eliminate this cue as much as possible. Accelerations could also be sensed by tactile cues which were clear since the subjects were firmly strapped to the chair. This points out some of the problems of this type of testing. It is not possible to eliminate all non-otolith cues from the subject. Nevertheless, it is felt that the otolith system provides the predominant motion sensing response.

A list of qualified results follows:

1)Subjects needed to be proficient with the joystick and have knowledge of the disturbance before successful runs could be expected. This means more practice is needed.

2) Profiles needed to be of lower amplitude and use less track length if subjects were expected to stay within the track limits.

3) The joystick gain was too sensitive to precisely control the disturbance.

4) The maximum number of disturbance frequencies within the frequency range desired should be used as this gives the largest number of data points in the frequency spectrum.

5) The ability of subjects to complete runs was less than expected. This suggested that in future testing more information about the profiles would be needed to determine a successful profile.

4.3 The DHPR02.PRO Series, Part II, and Low Amplitude Problems

With the knowledge gained from the first profiles a second set of profiles was created. Shorter run times were used to reduce possibilities for subject fatigue, which some subjects had noticed. The maximum possible number of frequencies were used for each profile, which varied with run time. The track length was lowered to a 1.01-1.26 m range, maximum acceleration to 0.102 g, and maximum velocity to a 0.456-0.534 m/s range. A JSCALE of 3.3 was used which gave a maximum joystick commanded velocity of 0.928 m/s. A typical profile is shown in Fig. 4.3.01.

Four subjects were tested. Again the open-faced head restraint was used and no blindfolds were used but subjects were asked to close their eyes during the runs. Masking noise was set to the highest level the subject could bear. All subjects were given null profile and practice runs with one of these profiles before data was taken. The order the profiles were given in was varied.

The run completion rates were greatly increased. This was mainly due to the lower amplitudes and range of motion of the profiles. It was also felt that the lower amplitude of the disturbance caused the subject to concentrate more on his internal otolith cues rather than his tactile and external cues as a higher level of concentration was required to detect the disturbance. Control was generally better than the first profile set but it was noticed that subjects would often drift along the track with a high frequency motion while trying to find the zero position of the wheel joystick. This "walking" motion was done in an attempt to search out the low disturbance and is the first sign of the control injection control strategy described in section 4.5. The RMS velocity ratios seemed to indicate better control since most values were below 1.0. (Table 4.3.01)

Bode plots of the finished runs were similar to those of the first profile set. Fig. 4.3.02 shows a typical plot. The plot shows the expected

```
INPUT PARAMETERS

    TRUN   81.920
    NSINES= 12
    FFREQ= 0.012210
    FLAT= 0
    DEL= 247.000
    FILTER=  0
    FPOLE=   0.310
    FPOS=  2.00
    FACC= 0.150
    TLOOP= 0.010

ROFILE DESCRIPTION

    MAX ACCEL= 0.102
    VELMAX=  0.4900
    % USEAGE OF TRACK= 63.19
    STARTING POSITION=-0.163
    SCALE= 0.1124

FREQ.  (HZ)    AMP1  (M/S)    AMP2  (G)     PHASE (DEG)
     0.0610           0.08           0.003            0.
     0.0854           0.08           0.004          247.
     0.1099           0.08           0.006          135.
     0.1343           0.08           0.007           22.
     0.1587           0.08           0.008          269.
     0.2075           0.08           0.011          156.
     0.2319           0.08           0.012           43.
     0.2808           0.08           0.014          290.
     0.3540           0.08           0.018          178.
     0.3784           0.08           0.019           65.
     0.4517           0.08           0.023          312.
     0.5005           0.08           0.026          199.
```

Figure 4.3.01 DHPR02.PRO Proflie #12 Parameters trends and the data scatter is not significantly less than previously seen. This was unexpected, as it showed that completed runs and low velocity RMS ratios did not always give consistent data. This is a problem of low amplitude profiles.

A possible cause of part of the data scatter was felt to lie in the wheel joystick. Without any zero reference subjects tended to put in high frequency control to help sense their motion. This extra motion caused more scatter in the data and a higher remnant. The lack of positive control caused by the wide range of rotation of the wheel was also a factor.

Because of these problems another joystick was developed for use on the Sled. This joystick is shown in Appendix A and is the type found in model aircraft radio control transmitters. The zeroing spring was removed so this extra control cue would not influence the HO. Subjects generally have better knowledge of the input position when using this joystick but not exact knowledge. It is felt that this gives a more effective control without adding additional motion cues. The range of joystick deflection is 40 degrees. The controller for the U.S. Laboratory Sled, which will be used for most of the pre- and post-flight testing, is also a joystick with a 41 degree range. This further supports use of this joystick instead of the wheel. It is felt that this is the best type of joystick to use in this testing.

The joystick voltage output was less than that of the wheel joystick so it was necessary to change JSCALE. The new value found was based on JSCALE=3.3 for the wheel. Comparing voltage ranges gave JSCALE=1.5. Full deflection of the joystick then resulted in the same velocity as full

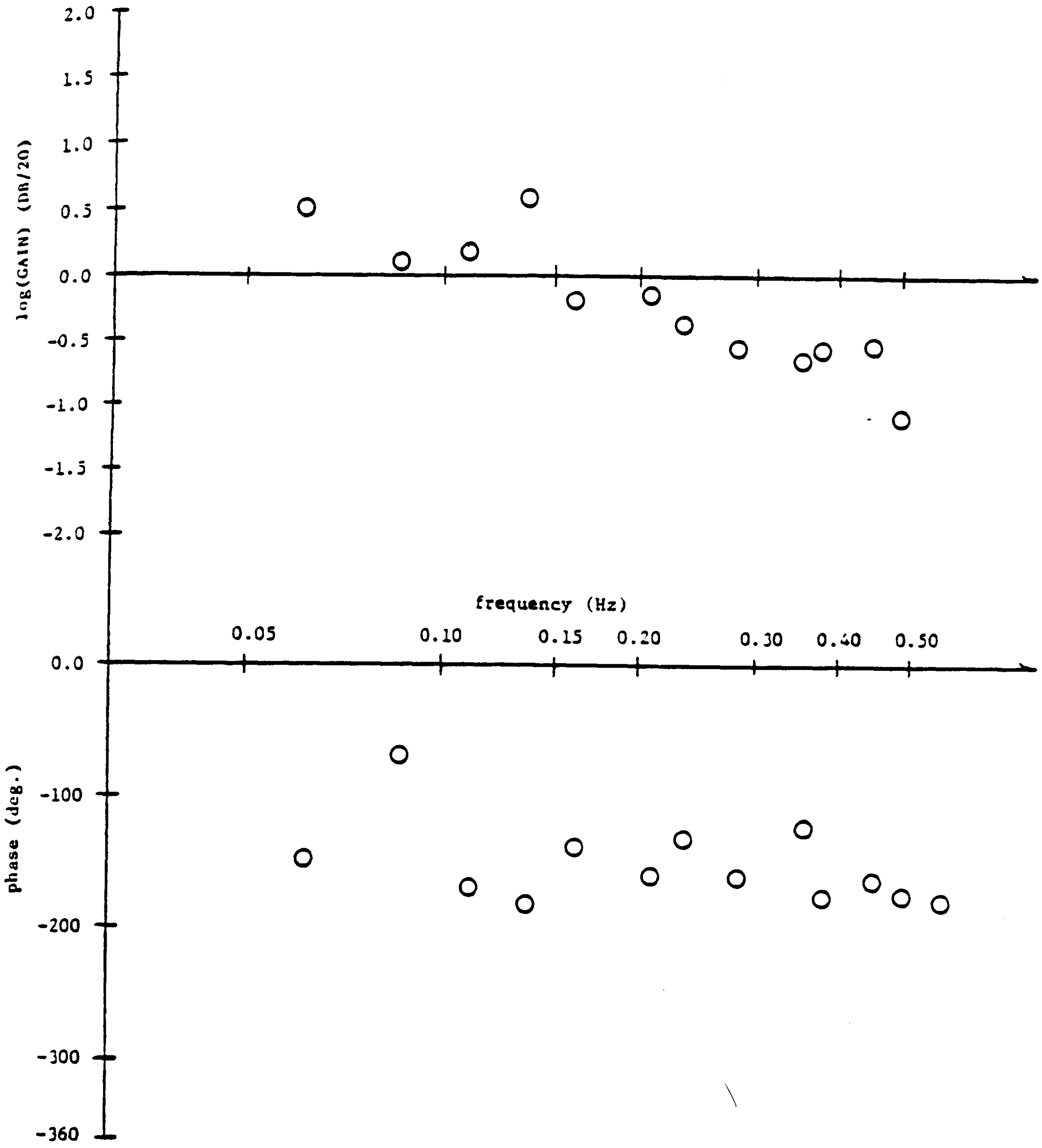


Figure 4.3.02 Bode Plot. Subject DH
DHPRO2.PRO Profile #12

DATA FILE	PR FILE	COMMAND RMS RATIO	POSITION RMS RATIO	VELOCITY RMS RATIO	ACCELERATION RMS RATIO	DURATION (sec.)
03	11	1.08	0.886	0.795	0.863	74.24
04	11	1.40	1.29	0.780	0.779	20.48
06	11	1.07	1.77	0.675	0.759	43.52
16	11	1.05	1.53	0.605	0.659	48.64
07	12	1.08	1.36	0.682	0.890	*81.92
08	12	1.06	1.07	0.723	0.994	*81.92
09	13	1.02	1.15	0.700	0.872	*71.68
10	13	1.73	0.747	0.546	1.063	7.68
11	13	1.02	1.35	0.711	0.900	*71.68
12	14	1.08	1.45	0.790	0.890	51.20
13	14	1.16	0.844	0.811	0.992	*61.44
14	14	1.29	1.65	0.768	0.914	23.04
15	14	1.05	2.35	0.682	0.805	*61.44

* Completed runs.

TABLE 4.3.01 RMS Ratios. Subject DH, DHPRO2.PRO.

deflection of the wheel.

At this time a change in philosophy for further testing occurred. Profile #12 had some success in run completion and was a good compromise between run time and number of disturbance frequencies. Because of this it was decided to concentrate on this profile in further testing. More practice would also be given using some of the other profiles. The author would be the principle subject and large population studies would not be done until a successful profile had been found.

The results of testing with these new ideas was indifferent. The run completion rate was similar to that when using the wheel joystick. Individual Bode plots showed similar scatter to previous plots. However, since all the completed runs were of profile #12 they could be averaged and variances and one sigma deviations determined. The resulting Bode plot clearly showed the form of the Young and Meiry model and the average points showed relatively little scatter. The deviations (plotted) were comparable to those seen in the results of the testing of Ref. 3,5,6,7,8.

The subject felt that the joystick gave better control, but that the control was too sensitive. It was easy to put in so much control that the disturbance was masked. This caused more directional activity and more scatter in the phase data. It was then decided to adjust the gain based on the maximum velocity of this specific profile. With this velocity known, the equation of section 3.1.1 was used with P=90% to find JSCALE. This would give the HO the least sensitive control possible while still giving full control over any part of the disturbance with some margin for calibration and system shifts in joystick voltage output. It was hoped that this would result in better control and much less data scatter.

Tests on the author were encouraging. After 5 practice runs the next 3 runs were completed. Control was comfortable as the input by the subject did not mask the disturbance and it was easier to input velocity commands near zero.

Data analysis was also encouraging, however, the RMS velocity ratios were greater than 1.0 which caused some concern. (Table 4.3.02) To see if the HO was actually performing the nulling task, frequency spectrum plots of velocity and joystick were made for the three completed runs. A typical plot is shown in Fig. 4.3.04. This type of plot is discussed in Appendix E. The joystick plot shows clearly that the joystick remnant was low indicating that the HO was responding to the disturbance with little control injection. This suggests that the Bode plot data will be precise. The velocity plot shows that there is some velocity nulling, although it is somewhat erratic. This shows that the RMS velocity ratio is not an accurate indicator of the velocity nulling performance. It is rather an indication of the overall velocity activity level, as it includes the remnant effects. The individual Bode plots show less scatter than for most of the previous data. The average Bode plot of the three runs shows phase variances lower than those of the previous test. Fig. 4.3.03 shows this plot. The gain variances are similar but the average points are less scattered as may be expected from the low joystick remnants. Also, there is a flatness in the gain at the low frequencies and some low phase at low frequencies which is suggested in the Young and Meiry model. These results are a major indicator of the better data obtained with the lower joystick gain derived with the P=90% criteria.

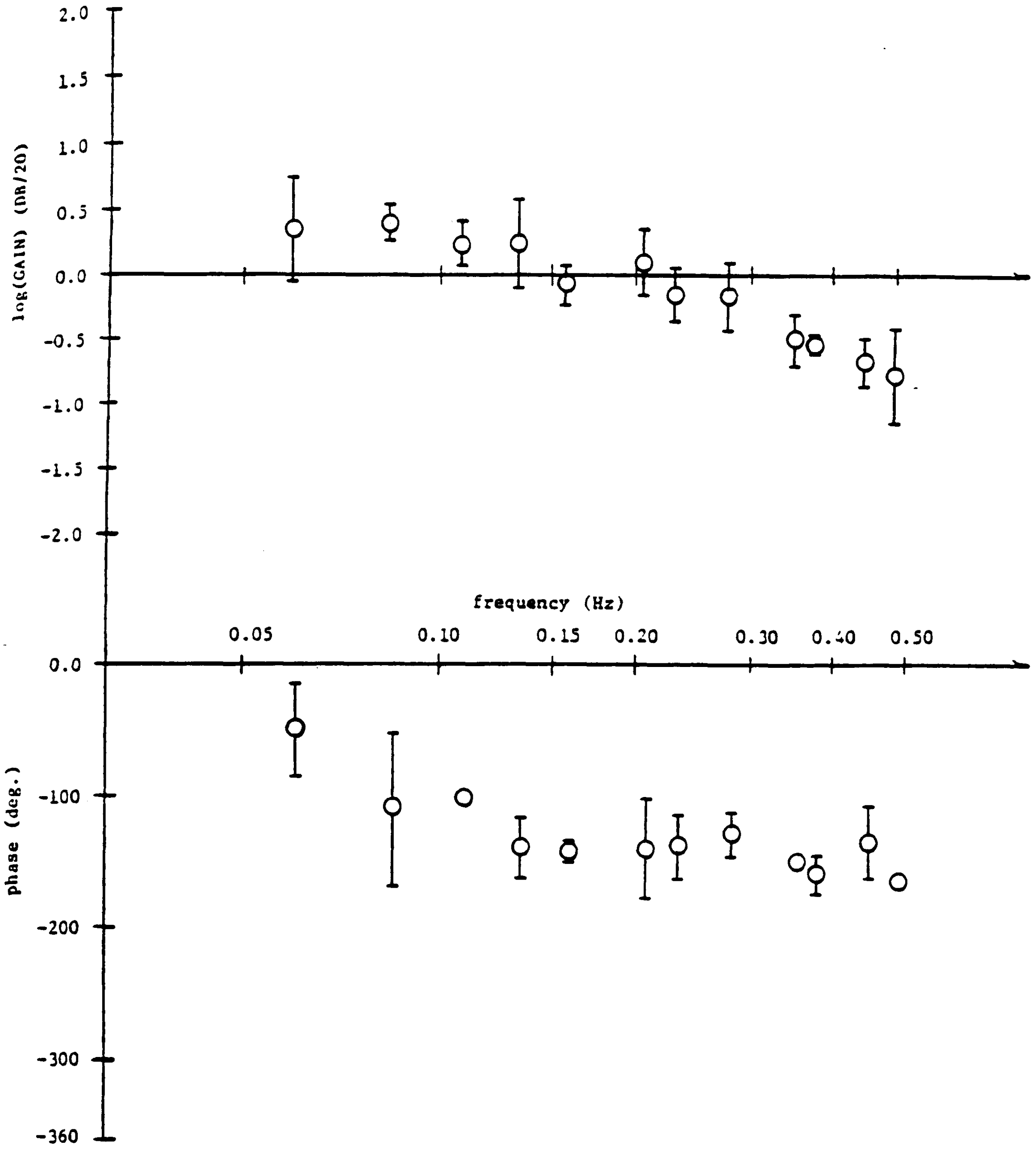
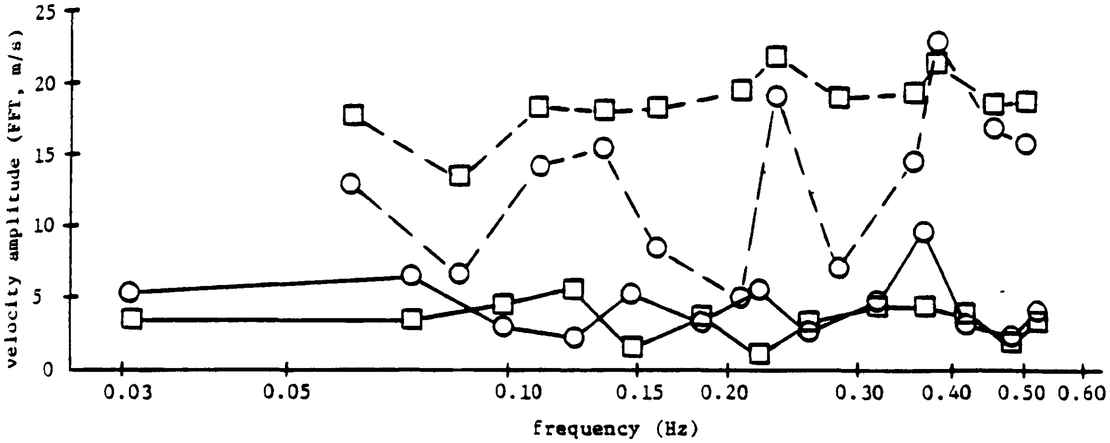


Figure 4.3.03 Bode Plot. Subject DH,
DHPRO2.PRO Profile #12, JSCALE=2.56



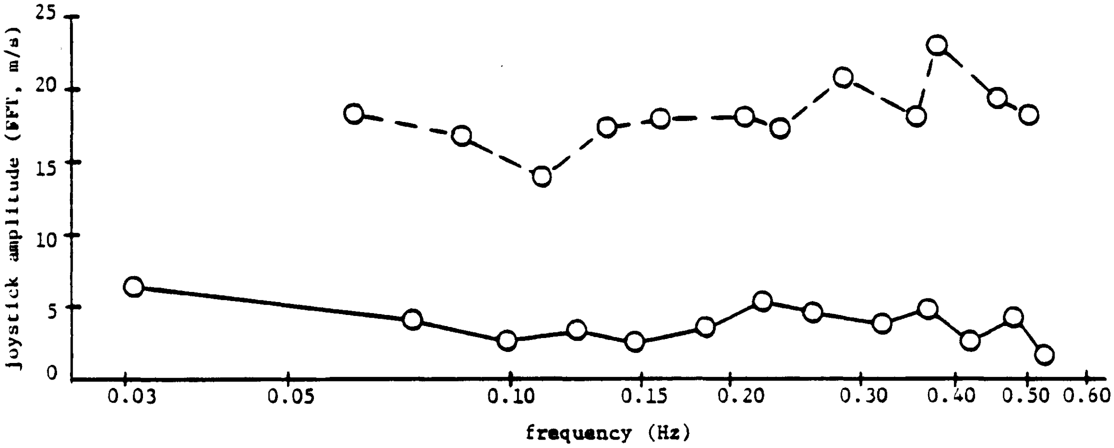


Figure 4.3.04 Frequency Spectrum. Subject DH, DHPRO2.PRO Profile #12, JSCALE=2.56

JSCALE = 1.5

DATA FILE	RMS VELOCITY RATIO	RMS JOYSTICK
11	1.26	0.201
16	1.34	0.164
11	1.34	0.162
18	0.685	0.162
23	0.730	0.162

JSCALE = 2.56

DATA FILE	RMS VELOCITY RATIO	RMS JOYSTICK
01	1.64	0.176
02	1.63	0.212
03	1.57	0.164

TABLE 4.3.02 RMS Data. Subject DH, DHPR02.PRO
Profile #12

since the RMS velocity ratios were also greater than 1.0 for the previous test, (Table 4.3.02), frequency spectrum plots were made for three of these completed runs. These plots showed that the joystick remnant was much higher and the velocity nulling was less than that for the JSCALE=2.56 case. The average Bode plot data was scattered as a result. It also suggests that the joystick gain was too high for precise control which caused the high joystick remnant. This data helps confirm the use of the p=90% criterium for finding JSCALE.

4.3.1 Summary

The results obtained for profile #12 were the type of results desired for the final test procedure. However, it was felt that the requirements of the HO were too low to fulfill the test procedure requirements. It would be difficult to see an increase in performance with the low disturbance amplitudes used. The acceleration amplitudes were already so low that to show an increase in performance the HO would have to have more precise control by many orders of magnitude. Also, if an HO's sensitivity were decreased, as expected, it would be very difficult to sense the already low disturbance. This would result in low control input amplitudes which would be difficult to separate from the remnant.

Another problem with this profile is seen by looking at the magnitudes of the acceleration inputs at the disturbance frequencies. Many of these accelerations are below the known threshold of 0.005 g. Thus, it is difficult to justify the result of the transfer function data with an input that the HO is supposedly not able to sense. (It should be noted that the dynamics of the hardware used to determine this threshold were probably not as good as the Sled dynamics, since it is a more modern system. Also, the threshold for an acceleration disturbance of a sinusoid form, or that of an additional acceleration form, would probably be different. However, it was felt that it would be less controversial to avoid these possible intricacies and assume the 0.005 g threshold as valid.) It was felt that higher amplitudes on the order of 0.015 g at all frequencies should be used to avoid any problems with the threshold. This was the next direction taken.

While these profiles were deemed unusable for the test procedure requirements they were very educational. Some major points discovered were:

1) Lower amplitudes of the disturbance result in more complete runs, as expected. They also cause the HO to concentrate more which should help insure that the otolith system is the major contributor to the HO response.

2) RMS velocity ratios are an overall activity measure and not necessarily a measure of the velocity nulling task.

3) The velocity frequency spectrum gives a clear view of the performance of the velocity nulling task. The joystick frequency spectrum gives a clear view of the control remnant which should be low for precise results. (See section 6.4)

4) It is desired to have about 3 complete runs to use in the data analysis. This helps show the subject's consistency.

4.4 The H1PR04.PRO Series and Profile Design Problems.

As stated in the last section the amplitudes of profile #12 were low and it was felt that the data was questionable due to this. It was therefore desired that the acceleration at all amplitudes be about 0.015 g. To design a profile to meet these conditions the profile generation program on the VAX computer was used. This was necessary as the PDP-11/34 minicomputer was too slow to be used effectively in the trial and error design mode that was utilized. The run times of 81.92 and 92.16 seconds were primarily used with only a few 102.4 second runs checked. The main outputs of interest used to determine if a profile was suitable were the velocity and acceleration amplitudes at each disturbance frequency, and the track length, maximum velocity, and maximum acceleration.

The technique used to search for a profile was straightforward. First the desired run time and frequency distribution was determined. Then, limits were set on track length and maximum acceleration, usually starting with 2.0 and 0.15 respectively, since past profiles had shown these values to be in the proper range. Next the scaling was chosen. Flat velocity, with or without first or second order filtering, and flat acceleration scaling were the types used most often. With these parameters decided upon the only other variable was the DEL frequency. The program was set up to cycle through varying values of DEL and output all the profile parameters. Usually these values were DEL=37 or 33 to DEL=337 or 333 by steps of 30 degrees. The profile that gave the minimum velocity with the desired acceleration or velocity amplitudes was then considered to be the best possible for the frequency range, distribution, and scaling used. Often the DEL variation was restricted and the step decreased to fine tune a promising profile, as changes in the output parameters varied greatly with DEL. The input variables were then adjusted as necessary until the desired output parameters were found.

The five profiles of this series that yielded the most useful information will now be examined. Fig. 4.4.01-.08 show the profiles and the associated histogram data, as well as the time histories of velocity and acceleration taken from runs with no subject.

4.4.1 Profile #1

Profile #1 was developed in an attempt to obtain a profile that had 0.015 g at each disturbance frequency. The flat amplitude scaling was used. A 0.015 g profile was not set up since it was felt that the maximum velocity of this profile was already too high and it would be significantly higher for the 0.015 g case.

The run completion rate of this profile was discouraging. The causes can be seen in the histogram data and the profile time history plots. The time history plots show that there is a part of the profile at the 50-55 second time period where there is a slow change in velocity with an associated low acceleration activity. This lack of acceleration causes confusion for the HO since he can sense the velocity through the cart vibration but not sense its direction. Subjects then tend to apply some low amplitude control input which causes them to drift away and reach the track limits. Also, the low number of velocity and acceleration reversals of the profile do not give enough acceleration input to the subject which makes control more difficult. The histogram data suggests this result as 17% of the profile acceleration command points are below the 0.005 g threshold.

This profile has too much emphasis on the low frequency end of the spectrum in both velocity and acceleration amplitudes. The high maximum

```
INPUT PARAMETERS

     TRUN   92.160
     NSINES= 12
     FFREQ= 0.010850
     FLAT= 1
     DEL= 107.000
     FILTER   0
     FPOLE=   0.080
     FPOS=  2.50
     FACC= 0.200
     TLOOP= 0.010

PROFILE DESCRIPTION

     MAX ACCEL= 0.140
     VELMAX   0.8095
     % USEAGE OF TRACK=100.00
     STARTING POSITION= 0.734
     SCALE= 0.1333

FREQ.  (HZ)    AMP1  (M/S)    AMP2  (G)     PHASE (DEG)
      0.0651          0.33           0.014           3.
      0.1194          0.18           0.014         113.
      0.1411          0.15           0.014         221.
      0.1845          0.11           0.014         330.
      0.2062          0.10           0.014          78.
      0.2496          0.08           0.014         188.
      0.3147          0.07           0.014         298.
      0.3364          0.06           0.014          46.
      0.4015          0.05           0.014         156.
      0.4449          0.05           0.014         265.
      0.4666          0.05           0.014         373.
      0.5100          0.04           0.014         123.

HISTOGRAM DATA

     ACC BIN= 0.005      # ACC POINTS=  1742
     ACC BIN= 0.010      # ACC POINTS=  1327
     ACC BIN= 0.015      # ACC POINTS=  1196
     ACC BIN= 0.020      # ACC POINTS=  1024
     ACC BIN= 0.025      # ACC POINTS=   831
     ACC BIN= 0.030      # ACC POINTS=   600
     ACC BIN= 0.035      # ACC POINTS=   455
     ACC BIN= 0.040      # ACC POINTS=   373
     ACC BIN= 0.045      # ACC POINTS=   286
     ACC BIN= 0.050      # ACC POINTS=   176
     ACC BIN= 0.055      # ACC POINTS=   208
     ACC BIN= 0.060      # ACC POINTS=   168
     ACC BIN= 0.065      # ACC POINTS=   141
     ACC BIN= 0.070      # ACC POINTS=   179
     ACC BIN= 0.075      # ACC POINTS=   133
     ACC BIN= 0.080      # ACC POINTS=    78
     ACC BIN= 0.085      # ACC POINTS=    59
     ACC BIN= 0.090      # ACC POINTS=    49
     ACC BIN= 0.095      # ACC POINTS=    27
     ACC BIN= 0.100      # ACC POINTS=    43
     ACC BIN= 0.105      # ACC POINTS=    15
     ACC BIN= 0.110      # ACC POINTS=    19
     ACC BIN  0.115      # ACC POINTS=    27
     ACC BIN= 0.120      # ACC POINTS=     6
     ACC BIN= 0.125      # ACC POINTS=     8
     ACC BIN= 0.130      # ACC POINTS=     8
     ACC BIN= 0.135      # ACC POINTS=    11
     ACC BIN= 0.140      # ACC POINTS=    22
     ACC BIN= 0.145      # ACC POINTS=     5
     ACC BIN= 0.150      # ACC POINTS=     0
```

Figure 4.4.01 H1PRO4.PRO PRofile #1 Parameters

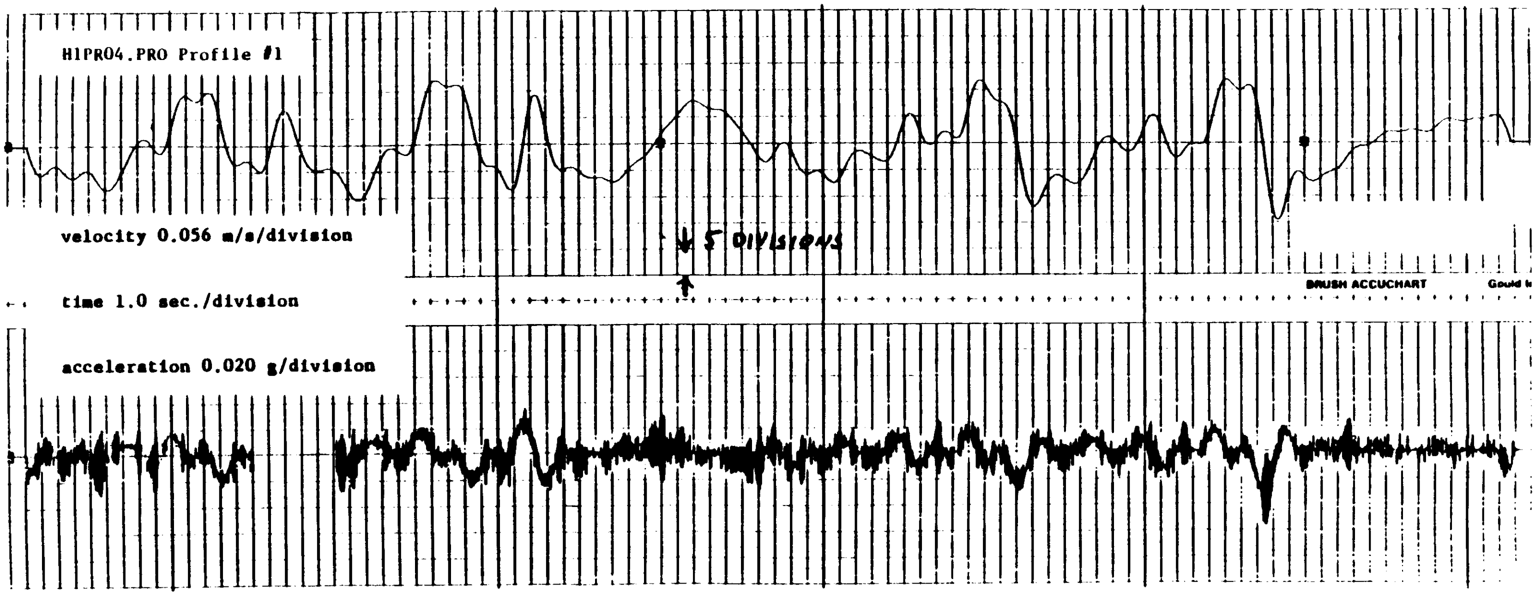


Figure 4.4.02 H1PRO4.PRO Profile #1 Time History

```
INPUT PARAMETERS

    TRUN=  92.160
    NSINES= 12
    FFREQ= 0.010850
    FLAT= 0
    DEL  113.000
    FILTER=  1
    FPOLE=    0.050
    FPOS=  2.50
    FACC= 0.200
    TLOOP= 0.010

PROFILE DESCRIPTION

    MAX ACCEL= 0.156
    VELMAX=  0.7847
    % USEAGE OF TRACK=100.00
    STARTING POSITION= 0.696
    SCALE  0.3279

FREQ.  (HZ)    AMP1  (M/S)    AMP2  (G)     PHASE (DEG)
     0.0651           0.30          0.012           3.
     0.1194           0.21          0.016         119.
     0.1411           0.14          0.013         233.
     0.1845           0.12          0.014         348.
     0.2062           0.10          0.013         102.
     0.2496           0.11          0.018         217.
     0.3147           0.09          0.017         334.
     0.3364           0.07          0.016          88.
     0.4015           0.07          0.019         204.
     0.4449           0.05          0.014         319.
     0.4666           0.05          0.014          73.
     0.5100           0.05          0.017         188.

HISTOGRAM DATA

    ACC BIN= 0.005      # ACC POINTS=  1109
    ACC BIN= 0.010      # ACC POINTS=  1436
    ACC BIN= 0.015      # ACC POINTS=  1141
    ACC BIN= 0.020      # ACC POINTS=  1017
    ACC BIN= 0.025      # ACC POINTS=   782
    ACC BIN= 0.030      # ACC POINTS=   670
    ACC BIN= 0.035      # ACC POINTS=   459
    ACC BIN= 0.040      # ACC POINTS=   462
    ACC BIN= 0.045      # ACC POINTS=   407
    ACC BIN  0.050      # ACC POINTS=   248
    ACC BIN= 0.055      # ACC POINTS=   230
    ACC BIN= 0.060      # ACC POINTS=   210
    ACC BIN= 0.065      # ACC POINTS=   192
    ACC BIN= 0.070      # ACC POINTS=   102
    ACC BIN= 0.075      # ACC POINTS=   141
    ACC BIN= 0.080      # ACC POINTS=   148
    ACC BIN= 0.085      # ACC POINTS=   120
    ACC BIN= 0.090      # ACC POINTS=    84
    ACC BIN= 0.095      # ACC POINTS=    35
    ACC BIN= 0.100      # ACC POINTS=    38
    ACC BIN= 0.105      # ACC POINTS=    29
    ACC BIN= 0.110      # ACC POINTS=    26
    ACC BIN= 0.115      # ACC POINTS=    13
    ACC BIN= 0.120      # ACC POINTS=    12
    ACC BIN= 0.125      # ACC POINTS=    15
    ACC BIN= 0.130      # ACC POINTS     20
    ACC BIN= 0.135      # ACC POINTS=    19
    ACC BIN= 0.140      # ACC POINTS=     6
    ACC BIN= 0.145      # ACC POINTS=     8
    ACC BIN= 0.150      # ACC POINTS=    10
    ACC BIN= 0.155      # ACC POINTS=    16
    ACC BIN= 0.160      # ACC POINTS=    11
    ACC BIN= 0.165      # ACC POINTS=     0
    ACC BIN= 0.170      # ACC POINTS=     0
```

Figure 4.4.03 H1PR04.PRO Profile #3 Parameters

```
INPUT PARAMETERS

     TRUN=  92.160
     NSINES= 12
     FFREQ= 0.010850
     FLAT= 0
     DEL= 247.000
     FILTER=  1
     FPOLE=    0.100
     FPOS=  1.80
     FACC= 0.200
     TLOOP= 0.010

PROFILE DESCRIPTION

     MAX ACCEL= 0.134
     VELMAX=  0.6698
     % USEAGE OF TRACK=100.00
     STARTING POSITION=-0.364
     SCALE=  0.2488

FREQ.  (HZ)    AMP1  (M/S)    AMP2  (G)     PHASE (DEG)
     0.0651           0.19          0.008             1.
     0.1194           0.16          0.012           248.
     0.1411           0.12          0.010           135.
     0.1845           0.10          0.012            23.
     0.2062           0.09          0.012           270.
     0.2496           0.10          0.016           157.
     0.3147           0.08          0.015            45.
     0.3364           0.07          0.014           292.
     0.4015           0.07          0.017           179.
     0.4449           0.05          0.013            67.
     0.4666           0.04          0.013           314.
     0.5100           0.05          0.015           201.

HISTOGRAM DATA

    ACC BIN= 0.005      # ACC POINTS=  1377
    ACC BIN= 0.010      # ACC POINTS=  1424
    ACC BIN= 0.015      # ACC POINTS=  1243
    ACC BIN= 0.020      # ACC POINTS=  1110
    ACC BIN= 0.025      # ACC POINTS=   871
    ACC BIN= 0.030      # ACC POINTS=   558
    ACC BIN= 0.035      # ACC POINTS=   515
    ACC BIN= 0.040      # ACC POINTS=   433
    ACC BIN= 0.045      # ACC POINTS=   300
    ACC BIN= 0.050      # ACC POINTS=   245
    ACC BIN= 0.055      # ACC POINTS=   243
    ACC BIN= 0.060      # ACC POINTS=   133
    ACC BIN= 0.065      # ACC POINTS=   150
    ACC BIN= 0.070      # ACC POINTS=   146
    ACC BIN= 0.075      # ACC POINTS=   170
    ACC BIN= 0.080      # ACC POINTS=    53
    ACC BIN= 0.085      # ACC POINTS=    42
    ACC BIN= 0.090      # ACC POINTS=    59
    ACC BIN= 0.095      # ACC POINTS=    12
    ACC BIN= 0.100      # ACC POINTS=    12
    ACC BIN= 0.105      # ACC POINTS=    13
    ACC BIN= 0.110      # ACC POINTS=    16
    ACC BIN= 0.115      # ACC POINTS=    19
    ACC BIN= 0.120      # ACC POINTS=    28
    ACC BIN= 0.125      # ACC POINTS=     9
    ACC BIN= 0.130      # ACC POINTS=    12
    ACC BIN= 0.135      # ACC POINTS=    23
    ACC BIN= 0.140      # ACC POINTS=     0
    ACC BIN= 0.145      # ACC POINTS=     0
    ACC BIN= 0.150      # ACC POINTS=     0
```

Figure 4.4.04 H1PRO4.PRO Profile #6 Parameters

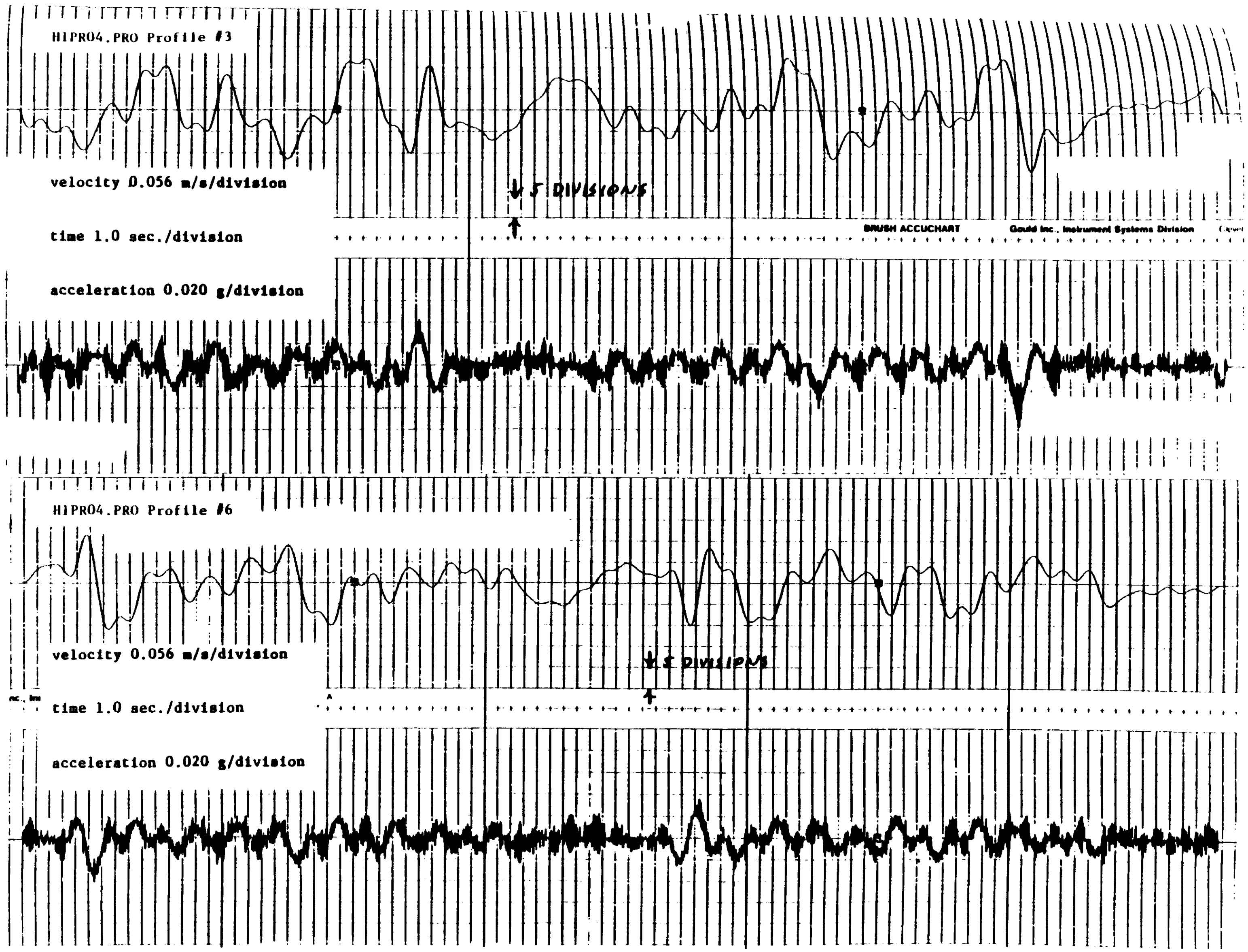


Figure 4.4.05 HIPRO4.PRO Profile #3 and #6 Time Histories

```
INPUT PARAMETERS

    TRUN= 81.920
    NSINES= 12
    FFREQ= 0.012210
    FLAT= 0
    VEL= 104.000
    FILTER= 1
    FPOLE=   0.200
    FPOS=  2.00
    FACC= 0.200
    TLOOP= 0.010

PROFILE DESCRIPTION

    MAX ACCEL= 0.123
    VELMAX=  0.6339
    % USEAGE OF TRACK=100.00
    STARTING POSITION= 0.044
    SCALE= 0.2582

FREQ.  (HZ)    AMP1  (M/S)    AMP2  (G)     PHASE (DEG)
     0.0610           0.11           0.004            1.
     0.0854           0.12           0.007          105.
     0.1099           0.11           0.008          208.
     0.1343           0.11           0.009          312.
     0.1587           0.12           0.012           55.
     0.2075           0.11           0.015          159.
     0.2319           0.10           0.015          263.
     0.2808           0.12           0.021            7.
     0.3540           0.10           0.022          111.
     0.3784           0.08           0.020          215.
     0.4517           0.09           0.025          319.
     0.5005           0.07           0.023           63.

HISTOGRAM DATA

    ACC BIN= 0.005     # ACC POINTS=   809
    ACC BIN= 0.010     # ACC POINTS=   882
    ACC BIN= 0.015     # ACC POINTS=  1029
    ACC BIN= 0.020     # ACC POINTS=  1191
    ACC BIN= 0.025     # ACC POINTS=   654
    ACC BIN= 0.030     # ACC POINTS=   378
    ACC BIN= 0.035     # ACC POINTS=   360
    ACC BIN= 0.040     # ACC POINTS=   387
    ACC BIN= 0.045     # ACC POINTS=   383
    ACC BIN= 0.050     # ACC POINTS=   272
    ACC BIN= 0.055     # ACC POINTS=   302
    ACC BIN= 0.060     # ACC POINTS=   276
    ACC BIN= 0.065     # ACC POINTS=   281
    ACC BIN= 0.070     # ACC POINTS=   247
    ACC BIN= 0.075     # ACC POINTS=   194
    ACC BIN= 0.080     # ACC POINTS=   165
    ACC BIN= 0.085     # ACC POINTS=    47
    ACC BIN= 0.090     # ACC POINTS=    69
    ACC BIN= 0.095     # ACC POINTS=    38
    ACC BIN= 0.100     # ACC POINTS=    26
    ACC BIN= 0.105     # ACC POINTS=    25
    ACC BIN= 0.110     # ACC POINTS=    34
    ACC BIN= 0.115     # ACC POINTS=    42
    ACC BIN= 0.120     # ACC POINTS=    61
    ACC BIN= 0.125     # ACC POINTS=    40
    ACC BIN= 0.130     # ACC POINTS=     0
    ACC BIN= 0.135     # ACC POINTS=     0
    ACC BIN= 0.140     # ACC POINTS=     0
    ACC BIN= 0.145     # ACC POINTS=     0
    ACC BIN= 0.150     # ACC POINTS=     0
```

Figure 4.4.06 H1PRO4.PRO Profile #11 Parameters

```
INPUT PARAMETERS

    TRUN=  81.920
    NSINES= 12
    FFREQ= 0.012210
    FLAT= 0
    DEL= 247.000
    FILTER=  0
    FPOLE=   0.200
    FPOS=  1.60
    FACC= 0.200
    TLOOP= 0.010

PROFILE DESCRIPTION

    MAX ACCEL= 0.129
    VELMAX=  0.6206
    % USEAGE OF TRACK=100.00
    STARTING POSITION=-0.207
    SCALE= 0.0968

FREQ.  (HZ)   AMP1  (M/S)   AMP2  (G)    PHASE (DEG)
     0.0610          0.10         0.004           0.
     0.0854          0.10         0.005         247.
     0.1099          0.10         0.007         135.
     0.1343          0.10         0.008          22.
     0.1587          0.10         0.010         269.
     0.2075          0.10         0.013         156.
     0.2319          0.10         0.014          43.
     0.2808          0.10         0.017         290.
     0.3540          0.10         0.022         178.
     0.3784          0.10         0.023          65.
     0.4517          0.10         0.028         312.
     0.5005          0.10         0.031         199.

HISTOGRAM DATA

    ACC BIN= 0.005     # ACC POINTS=   715
    ACC BIN= 0.010     # ACC POINTS=   854
    ACC BIN= 0.015     # ACC POINTS=   888
    ACC BIN= 0.020     # ACC POINTS=   810
    ACC BIN= 0.025     # ACC POINTS=   854
    ACC BIN= 0.030     # ACC POINTS=   577
    ACC BIN= 0.035     # ACC POINTS=   597
    ACC BIN= 0.040     # ACC POINTS=   320
    ACC BIN= 0.045     # ACC POINTS=   311
    ACC BIN= 0.050     # ACC POINTS=   268
    ACC BIN= 0.055     # ACC POINTS=   298
    ACC BIN= 0.060     # ACC POINTS=   221
    ACC BIN= 0.065     # ACC POINTS=   213
    ACC BIN= 0.070     # ACC POINTS=   245
    ACC BIN= 0.075     # ACC POINTS=   276
    ACC BIN= 0.080     # ACC POINTS=   178
    ACC BIN= 0.085     # ACC POINTS=   104
    ACC BIN= 0.090     # ACC POINTS=   113
    ACC BIN= 0.095     # ACC POINTS=    85
    ACC BIN= 0.100     # ACC POINTS=    63
    ACC BIN= 0.105     # ACC POINTS=    22
    ACC BIN= 0.110     # ACC POINTS=    29
    ACC BIN= 0.115     # ACC POINTS=    35
    ACC BIN= 0.120     # ACC POINTS=    56
    ACC BIN= 0.125     # ACC POINTS=    20
    ACC BIN= 0.130     # ACC POINTS=    40
    ACC BIN= 0.135     # ACC POINTS=     0
    ACC BIN= 0.140     # ACC POINTS=     0
    ACC BIN= 0.145     # ACC POINTS=     0
    ACC BIN= 0.150     # ACC POINTS=     0
```

Figure 4.4.07 H1PR04.PRO Profile #12 Parameters

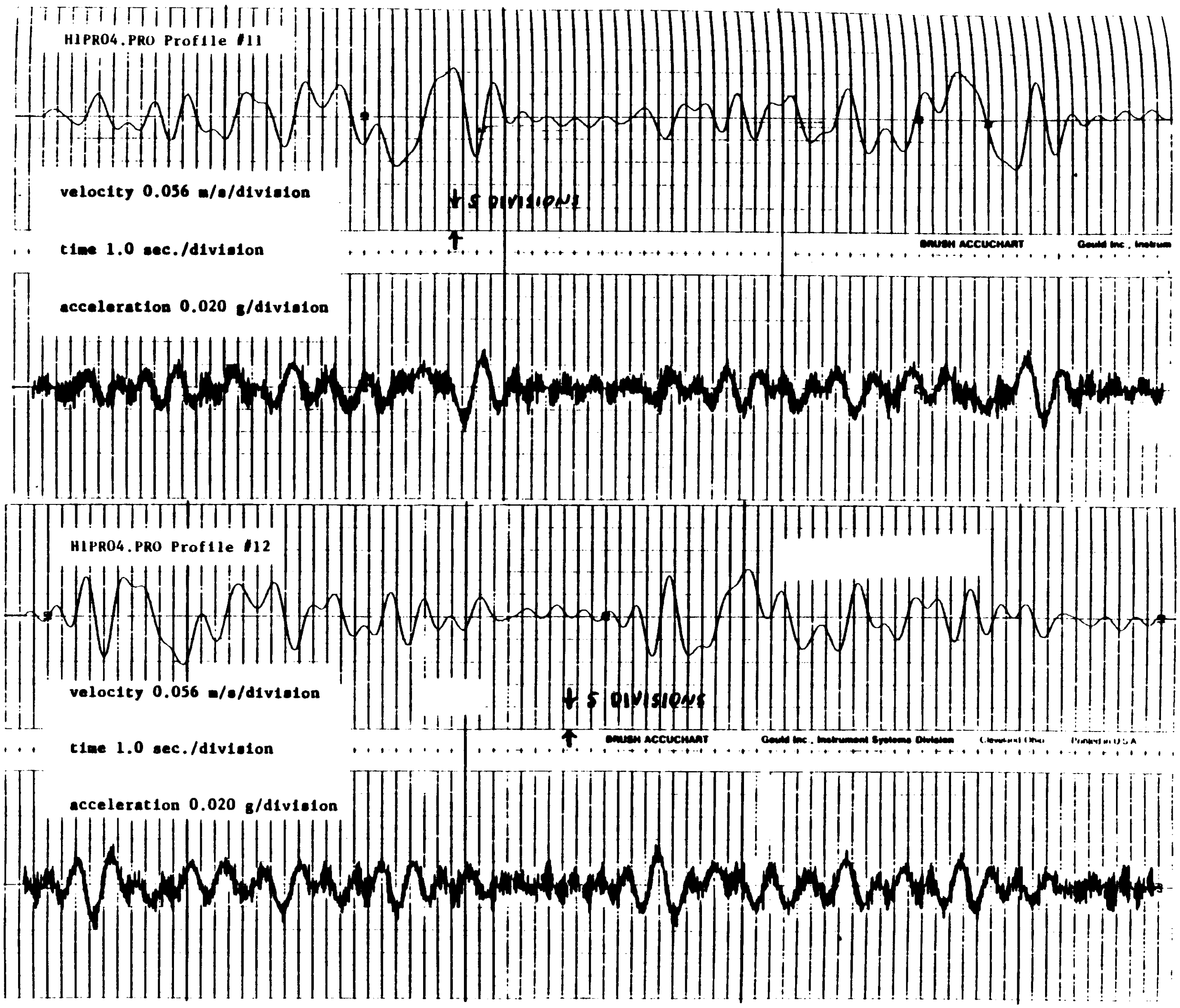


Figure 4.4.08 H1PRO4.PRO Profile #11 and #12 Time Histories

velocity and associated high gain (JSCALE=1.63) may also have contributed to the low run completion rate. Lowering the amplitude would mean an even greater percentage of accleration command points below threshold and less velocity and acceleration reversals which would only worsen the HO performance. In conclusion, flat amplitude profiles can not be used for the final test procedure.

4.4.2 Profiles #3 and #6

Profiles #3 and #6 were set up using constant velocity and first order filter scaling. Due to the results of profile #1 the acceleration and velocity amplitudes were increased at the higher frequencies and lowered at the lower frequencies. Profile #3's amplitudes are higher to try to stay away from the threshold. The maximum velocity and associated joystick gain are high as a result. Profile #6's amplitudes were determined by a maximum velocity limitation of about 0.66 m/s. (From some testing which will not be elaborated upon here it was decided that JSCALE=2.0 should be the practical lower limit of the joystick gain. This allows a maximum velocity of 0.66 m/s with P=95%, which was used instead of P=90% to achieve a slightly higher velocity with the same joystick sensitivity. This is a compromise between the desire for a higher maximum velocity, to stay away from threshold amplitudes, and the desire for precise HO control without a high remnant.) The histograms show a decrease in the number of points below 0.005 g. The time histories show more zero crossings as expected.

Run completion rates with these profiles were low also. This signifies that the emphasis on the lower frequencies was still too great for subjects to be able to control the profile effectively. One run of each profile was completed, though, and plots for profile #6 are shown in Fig.4.4.2.01,.02. The Bode plot shows very little scatter and profile #3 showed low scatter also. The joystick frequency spectrum shows a low remnant except at the high frequencies. At these frequencies the velocity disturbance amplitude is so low that it is difficult to separate the joystick remnant from the joystick disturbance frequency amplitudes. The plots tend to show the flat gain and low phase at low frequencies that is characteristic of the HO. These results support the theory that higher input amplitudes give more consistent data, which is desired for the final test profile.

4.4.3 Profile #12

Profile #12 was set up as a limiting case test. It is just an increase of the previously successful DHPR02.PRO profile #12 to a maximum velocity of 0.62 and JSCALE=2.13 using a P=95% scaling criterion. It represents the greatest amplitudes possible at the high frequencies. (The flat acceleration case may be considered to have the greatest amplitudes possible at the low frequencies so it is also a limiting case.) Profile #11 has some first order filtering and is close to profile #12 in maximum velocity but has less zero crossings. It is included here to illustrate a single point. The time histories of profile #12 show the maximum number of zero crossings possible. The histogram data shows a low number of points below 0.005 g as expected.

The run completion rates for profile #12 were intermediate compared to previous runs. No runs of profile #11 were completed. The time histories show that the maximum velocity activity of profile #12 occurs at the begining and after the midpoint of the run. Those for profile #11 occur

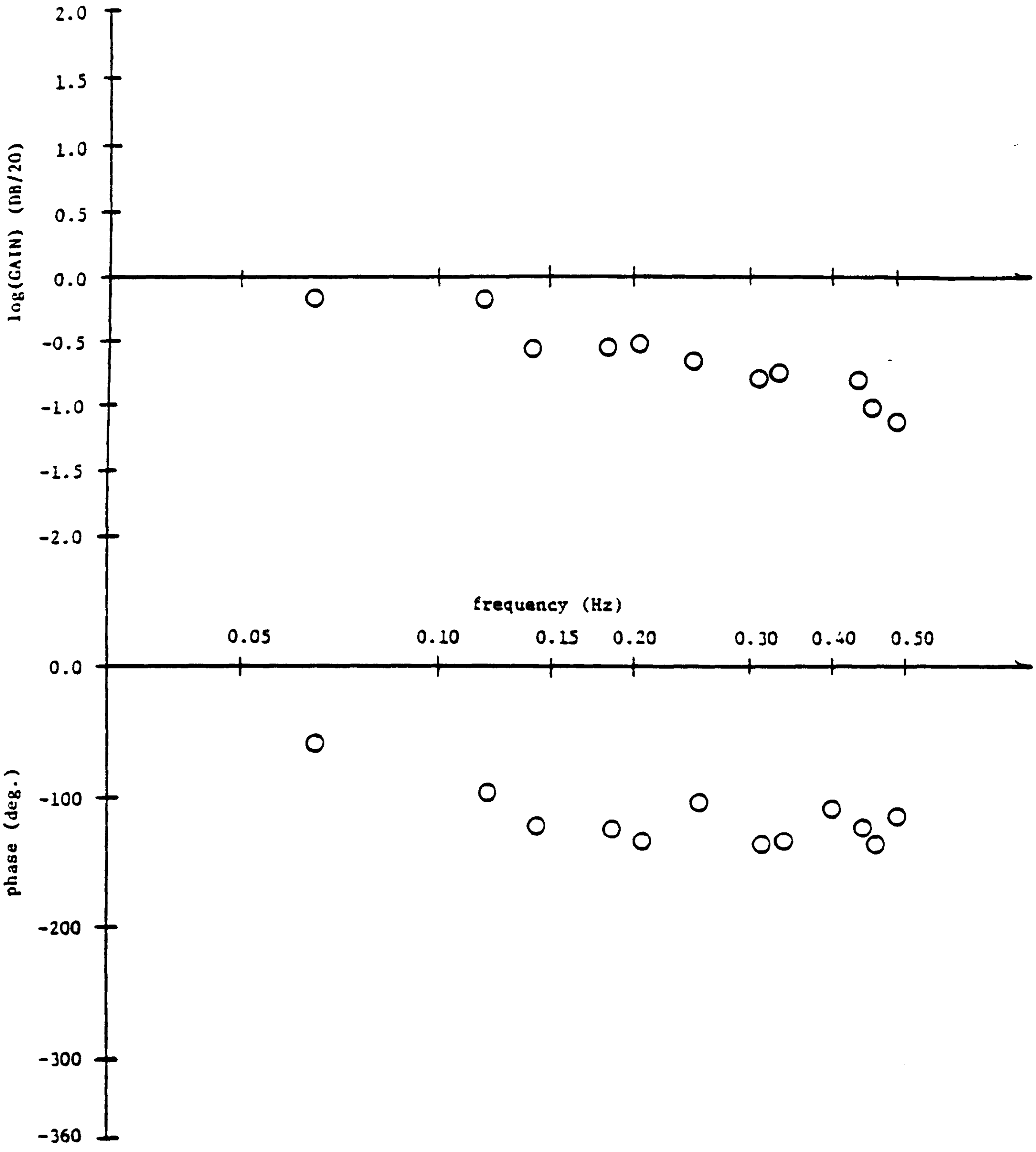
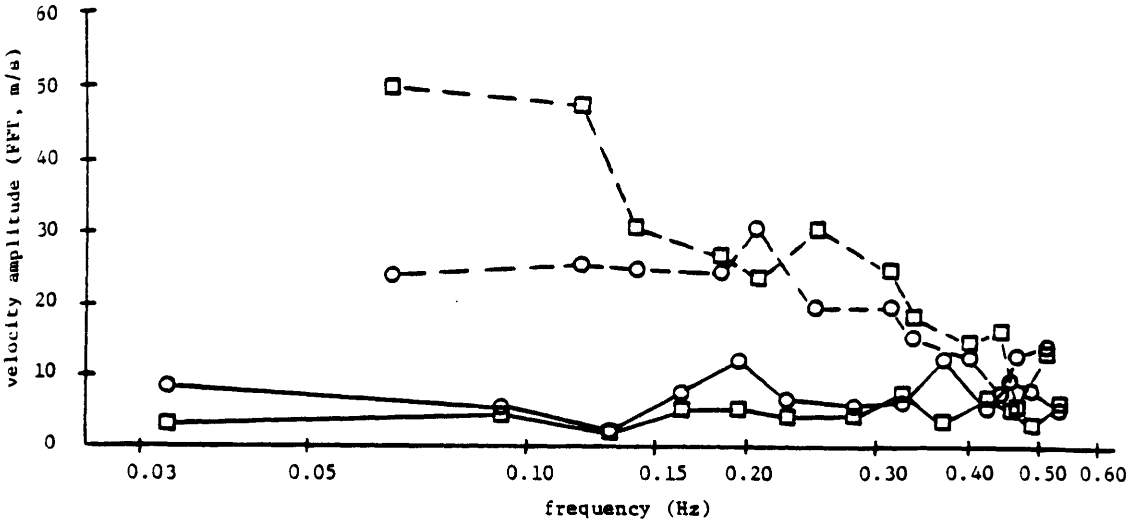


Figure 4.4.2.01 Bode Plot. Subject DH,
H1PR04.PRO Profile #6



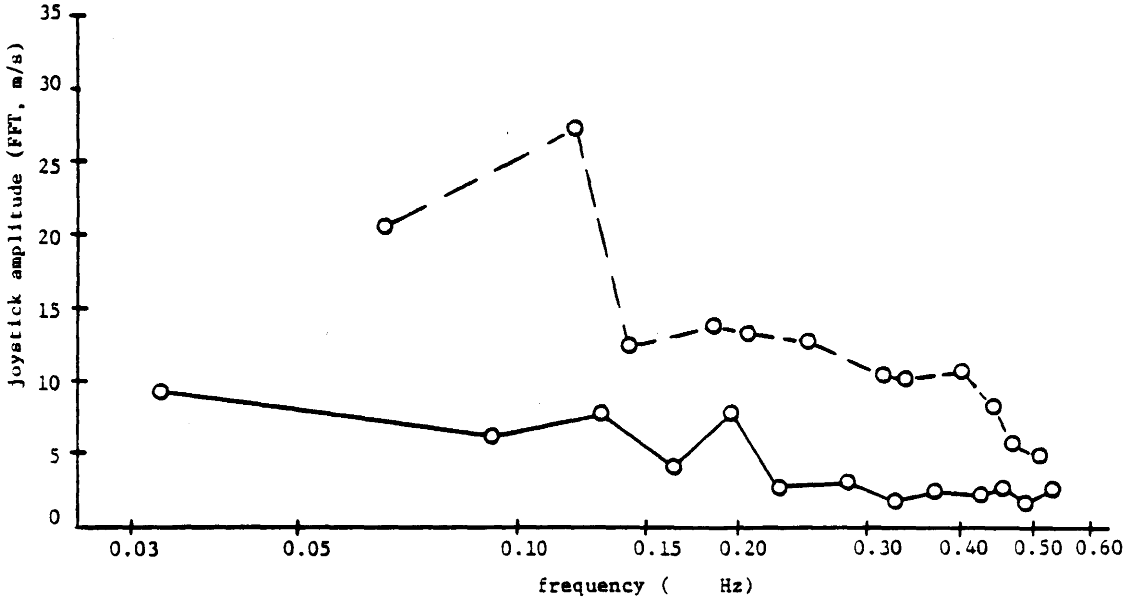


Figure 4.4.2.02 Frequency Spectrum. Subject DH
H1PRO4.PRO Profile #6

before the midpoint and near the end of the run. This is the major difference between the two profiles, and it is felt to contribute to the differences in the run completion rate. It was felt that having the maximum velocity activity near the beginning of the run gave the subject a chance to react to the highest amplitudes of the disturbance while still near the center of the track. This means that the subject was not allowed to drift near the track ends during a low activity period before the first maximum velocity activity. This may also have served to acquaint the subject with the maximum velocity at the begining of the run and thereby improve his awareness of what to expect. This point is debatable but the idea was useful in other ways as will be shown.

Typical plots are shown in Fig. 4.4.3.01,02. The Bode plot shows much scatter. The joystick frequency spectrum shows a low remnant, in general, but the velocity spectrum shows a high remnant and large amplitude oscillations at the disturbance frequencies. This is caused by the difficulty of the subject to respond to the high frequency motion. It is felt that the HO can not adequately control the profile that has predominant amplitudes at the higher frequencies. This is due to the drop-off in gain associated with the otolith system at high frequencies as shown in the Young and Meiry model. In conclusion, flat velocity profiles do not meet the test requirements.

4.4.4 Summary

The main points illustrated by these profiles are:

1) Flat amplitude profiles have input amplitudes that are too high at the low frequencies. This causes a lack of acceleration cues to the HO.

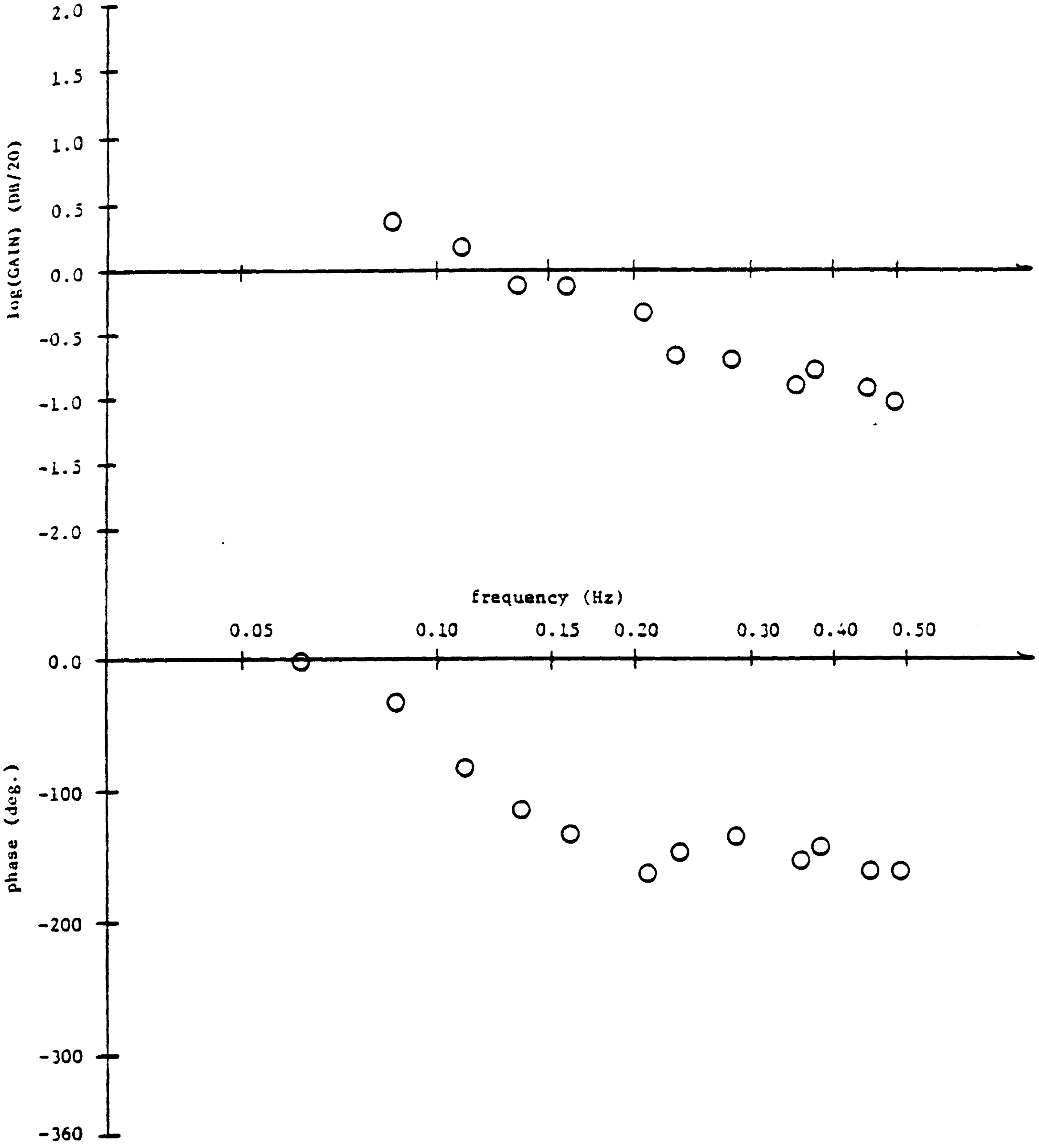
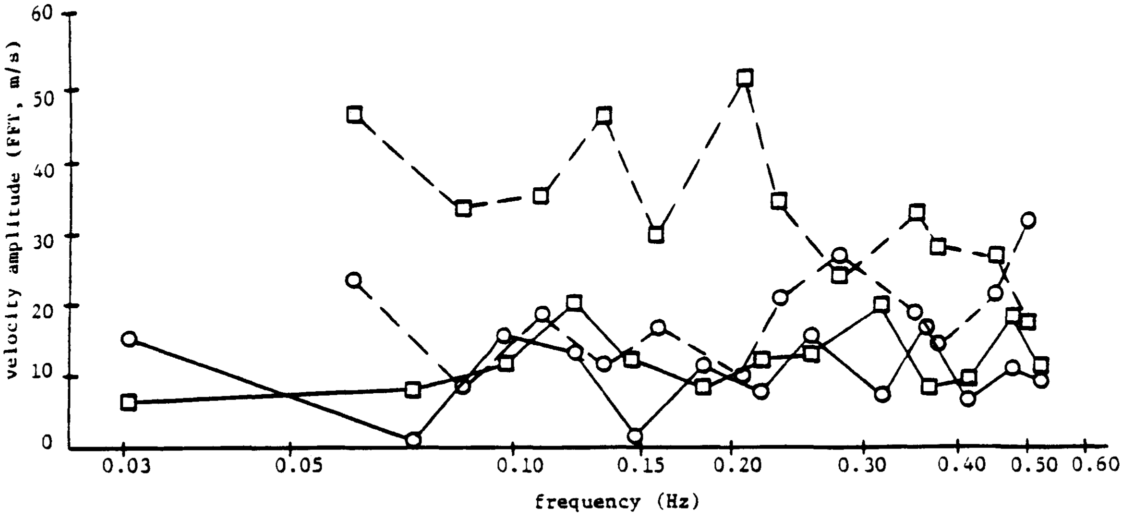


Figure 4.4.3.01 Bode Plot. Subject DH,
H1PR04.PRO Profile #12



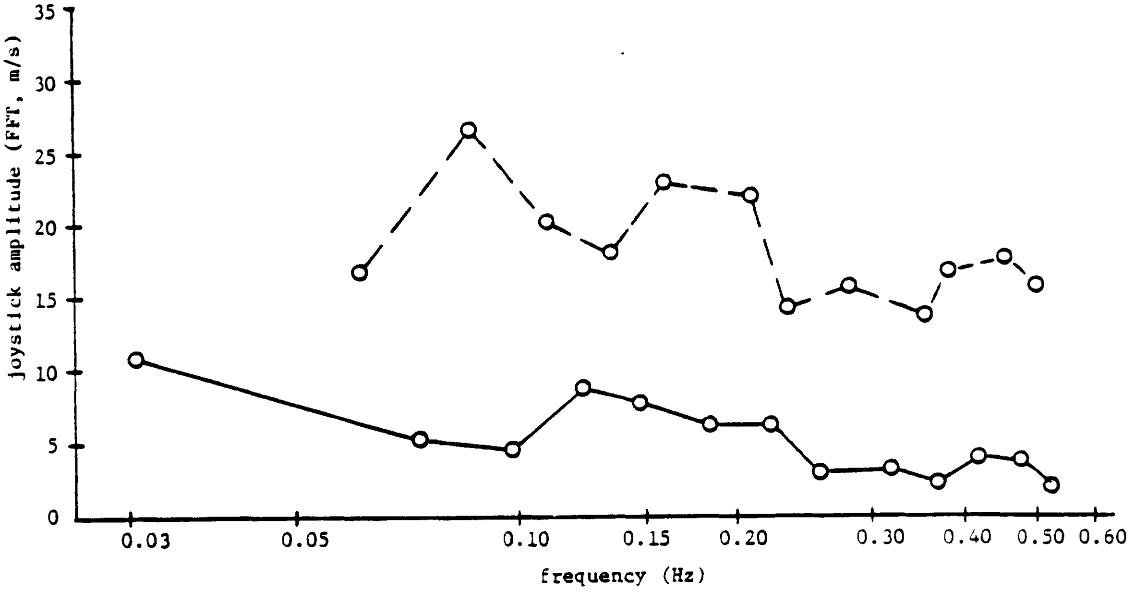


Figure 4.4.3.02 Frequency Spectrum. Subject DH
H1PR04.PRO Profile #12

2) Flat velocity profiles have input amplitudes that are too high at the high frequency end of the spectrum. This causes poor HO performance due to the poor otolith response at higher frequencies.

3) The intermediate scaled case shown gave a low run completion rate, but data with little scatter. This is the type of compromise profile, in terms of input amplitudes at high and low frequencies, that is desired for the final profile.

4.5 Further Population Testing

At this point it was decided that population studies should begin to examine the responses seen in more detail. Profiles #3 and #6 had given the best data so far and with their acceleration amplitudes well above threshold they were the best choice to use in further testing. Profile #6 was favored since its maximum velocity points occurred at similar times to those of profile #12. The max velocity of profile #6 was 0.66 m/s with JSCALE=1.97. This maximum velocity was reduced slightly to 0.65 m/s with JSCALE=2.03 to comply with the JSCALE=2.0 limitation stated in the section 4.4.2. The resulting profile is shown in Fig. 4.5.01,.02. It was felt that in this further testing the suggested veloctiy limitations should be fully complied with to provide more coherency with the previous testing.

Using previous experience, a more procedural method of conducting tests was used. Subjects were seated in the cart and the velocity nulling task was explained. They were told to use any cues and any control strategy desired, but once they felt comfortable with their technique not to change it. A pair of opaque goggles were then put on the subject and kept on

```
INPUT PARAMETERS

    TRUN=  92.160
    NSINES= 12
    FFREQ= 0.010850
    FLAT= 0
    DEL= 247.000
    FILTER=  1
    FPOLE=    0.100
    FPOS=  1.75
    FACC= 0.200
    TLOOP= 0.010

PROFILE DESCRIPTION

    MAX ACCEL= 0.131
    VELMAX=  0.4512
    % USEAGE OF TRACK=100.00
    STARTING POSITION -0.548
    SCALE= 0.2419

FREQ. (HZ)   AMP1  (M/S)   AMP2  (G)    PHASE (DEG)
     0.0651           0.19          0.008          1.
     0.1194           0.15          0.012        248.
     0.1411           0.11          0.010        135.
     0.1845           0.10          0.012         23.
     0.2062           0.09          0.011        270.
     0.2496           0.10          0.015        157.
     0.3147           0.07          0.015         45.
     0.3364           0.06          0.014        292.
     0.4015           0.06          0.017        179.
     0.4449           0.05          0.013         67.
     0.4666           0.04          0.012        314.
     0.5100           0.05          0.015        201.

HISTOGRAM DATA

    ACC BIN= 0.005      # ACC POINTS=  1425
    ACC BIN= 0.010      # ACC POINTS=  1455
    ACC BIN= 0.015      # ACC POINTS=  1259
    ACC BIN= 0.020      # ACC POINTS=  1120
    ACC BIN= 0.025      # ACC POINTS=   864
    ACC BIN= 0.030      # ACC POINTS=   542
    ACC BIN= 0.035      # ACC POINTS=   523
    ACC BIN= 0.040      # ACC POINTS=   424
    ACC BIN= 0.045      # ACC POINTS=   285
    ACC BIN= 0.050      # ACC POINTS=   250
    ACC BIN= 0.055      # ACC POINTS=   223
    ACC BIN= 0.060      # ACC POINTS=   126
    ACC BIN= 0.065      # ACC POINTS=   172
    ACC BIN= 0.070      # ACC POINTS=   145
    ACC BIN= 0.075      # ACC POINTS=   136
    ACC BIN= 0.080      # ACC POINTS=    39
    ACC BIN= 0.085      # ACC POINTS=    57
    ACC BIN= 0.090      # ACC POINTS=    33
    ACC BIN= 0.095      # ACC POINTS=    12
    ACC BIN= 0.155      # ACC POINTS=     0
    ACC BIN= 0.160      # ACC POINTS=     0
    ACC BIN= 0.165      # ACC POINTS=     0
    ACC BIN= 0.170      # ACC POINTS=     0
    ACC BIN= 0.175      # ACC POINTS=     0
    ACC BIN= 0.180      # ACC POINTS=     0
    ACC BIN= 0.185      # ACC POINTS=     0
    ACC BIN= 0.190      # ACC POINTS=     0
    ACC BIN= 0.195      # ACC POINTS=     0
    ACC BIN= 0.200      # ACC POINTS=     0
    ACC BIN= 0.205      # ACC POINTS=     0
```

Figure 4.5.01 H1PRO4.PRO Profile #17 Parameters

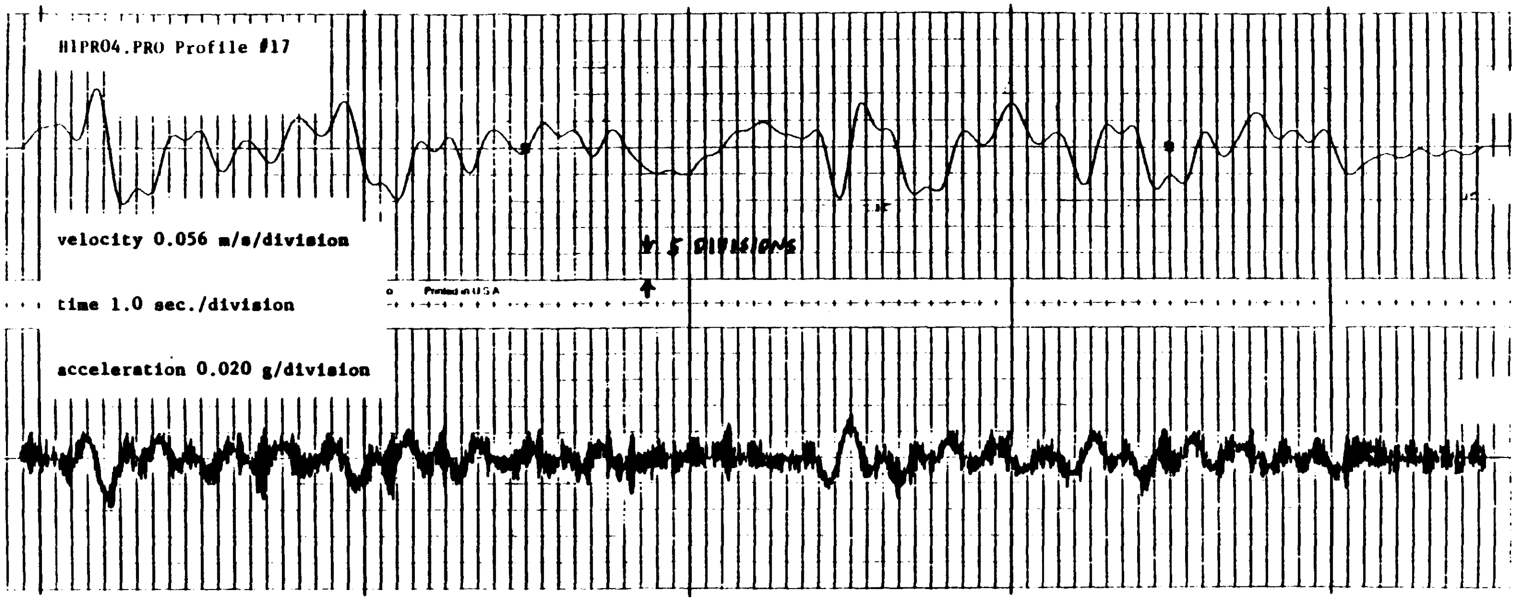


Figure 4.5.02 H1PRO4.PRO Profile #17 Time History

during all runs. The enclosed head restraint was used for this and all further testing. They were then given the null profile run (no disturbance input) and asked to practice with the joystick until they felt comfortable with the control sensitivity. A practice profile was then run with no subject input. This practice profile was then run with subject control until the subject started completing runs or reached his maximum level of performance. The data profile was then run with no control. The data profile was then run with control until 3 runs were completed. Data was stored for data profile runs only. The joystick voltage range was checked after every one or two runs to check for drift. All completed runs were used in the data reduction. Velocity and joystick frequency spectra, and velocity RMS ratio and joystick RMS were obtained for each run. Bode data was obtained from the average of the completed runs.

Most of the reasoning used in this refined procedure is self-explanatory but some points should be made. Subjects were told to use any possible cues so they would not try to avoid cues and so lose concentration on their otolith cues. Subjects were allowed to ride through the profiles without any control so they could be familiarized with the amplitudes and frequency range of the disturbance and the associated motion cues. Often during a run there was confusion as to what was the disturbance and what was the HO control so this helped alleviate this problem. Only three data runs were taken to lessen the amount of data analysis required and to keep the test time limited to roughly one hour. All runs were done with the subject blindfolded so the subject was only concentrating on the cues used in the data runs and not on extraneous cues from other senses.

Four subjects were tested. The rate of completion was not as high as desired but this was expected. It was felt that a profile that gave good results was the top priority and run completion was secondary. The results were mixed, however. Fig. 4.5.03-06 show typical plots. For two subjects three or more runs were completed and the Bode plots were similar to previous plots. The one sigma deviations for one of these subjects, subject MM, were similar to previous data, but the author's deviations were remarkably low. The author was intimately familiar with the profile, knowing when the high and low velocity disturbances occurred, and this greatly helped his control. Also, the author had the most experience of any of the subjects tested. For the other two subjects the run completion rate was low and the data scatter was high.

The velocity RMS ratios are not consistent for these runs but the joystick RMS errors are. (Table 4.5.01) This suggests some difficulty in maintaining precise control and is probably due to still too few acceleration cues and the associated difficulty in controlling the low frequency velocities. This would allow the subject to slowly wander over the full track length, as was noted during some runs, while still yielding effective overall velocity nulling but a higher velocity RMS ratio.

Upon closer examination of the control strategy observed during the tests of these subjects two distinct types of control were seen. The two subjects with the most scattered data were using the control injection technique. Subject MS was one of these subjects and his data is shown in Fig. 4.5.03,04. With this technique the subject attempts to determine what the disturbance is by inputing some high frequency control of significant amplitude and noting the response. The control position is then adjusted by noting if the motion is increased or decreased. As is seen from the

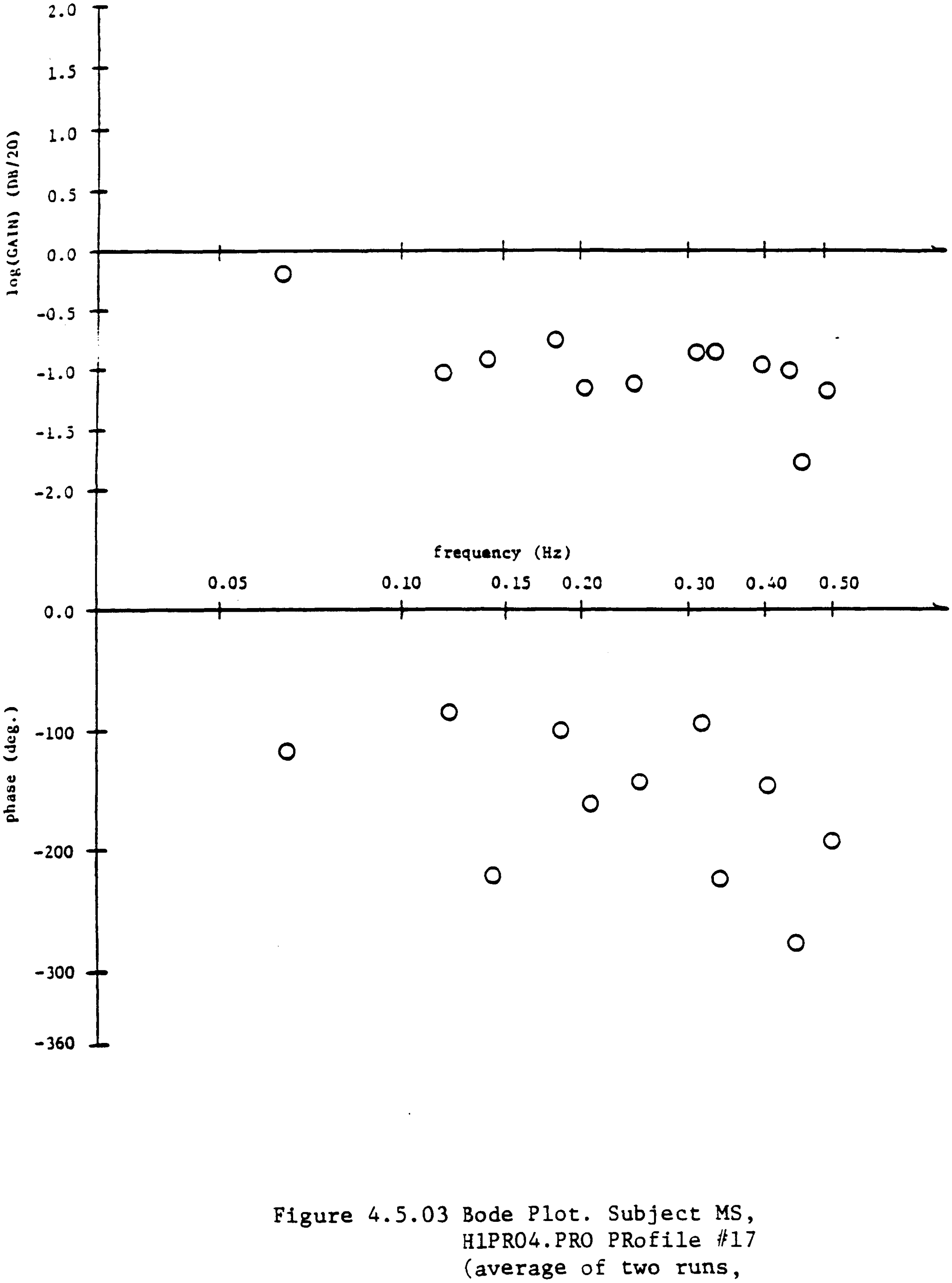
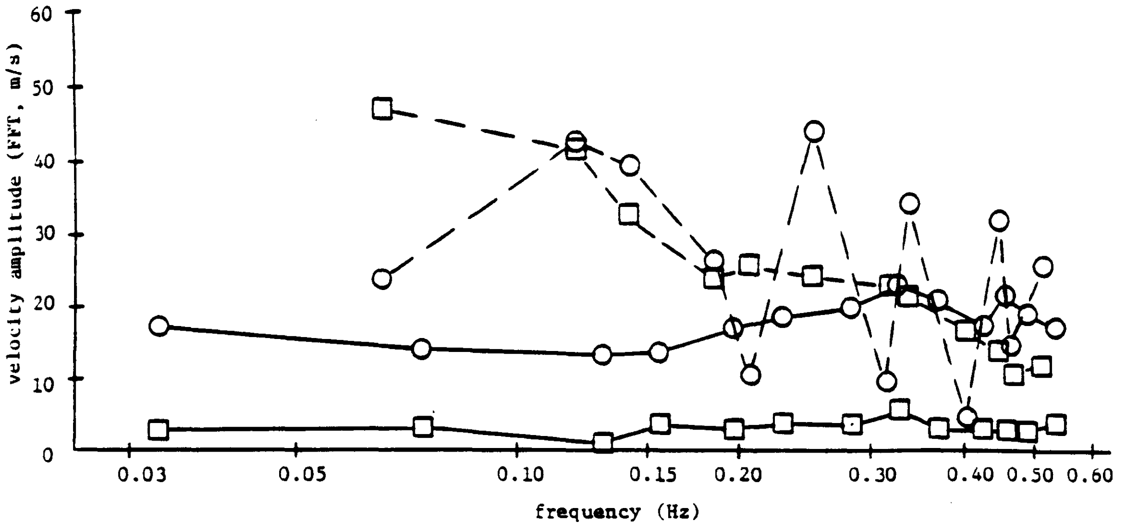


Figure 4.5.03 Bode Plot. Subject MS,
H1PR04.PRO PRofile #17
(average of two runs,
deviations not shown)



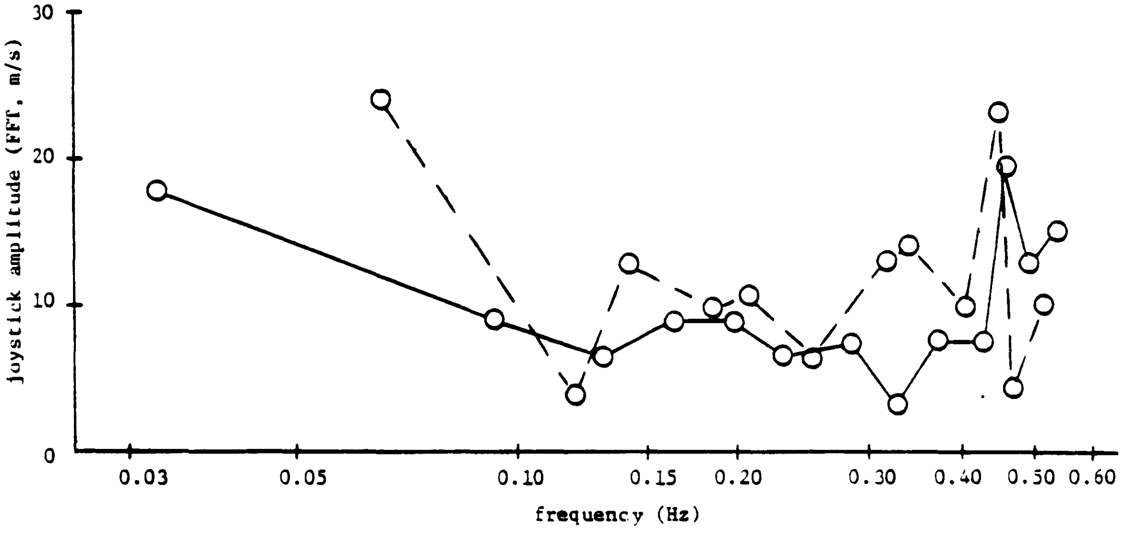


Figure 4.5.04 Frequency Spectrum. Subject MS,
H1PR04.PRO Profile #17

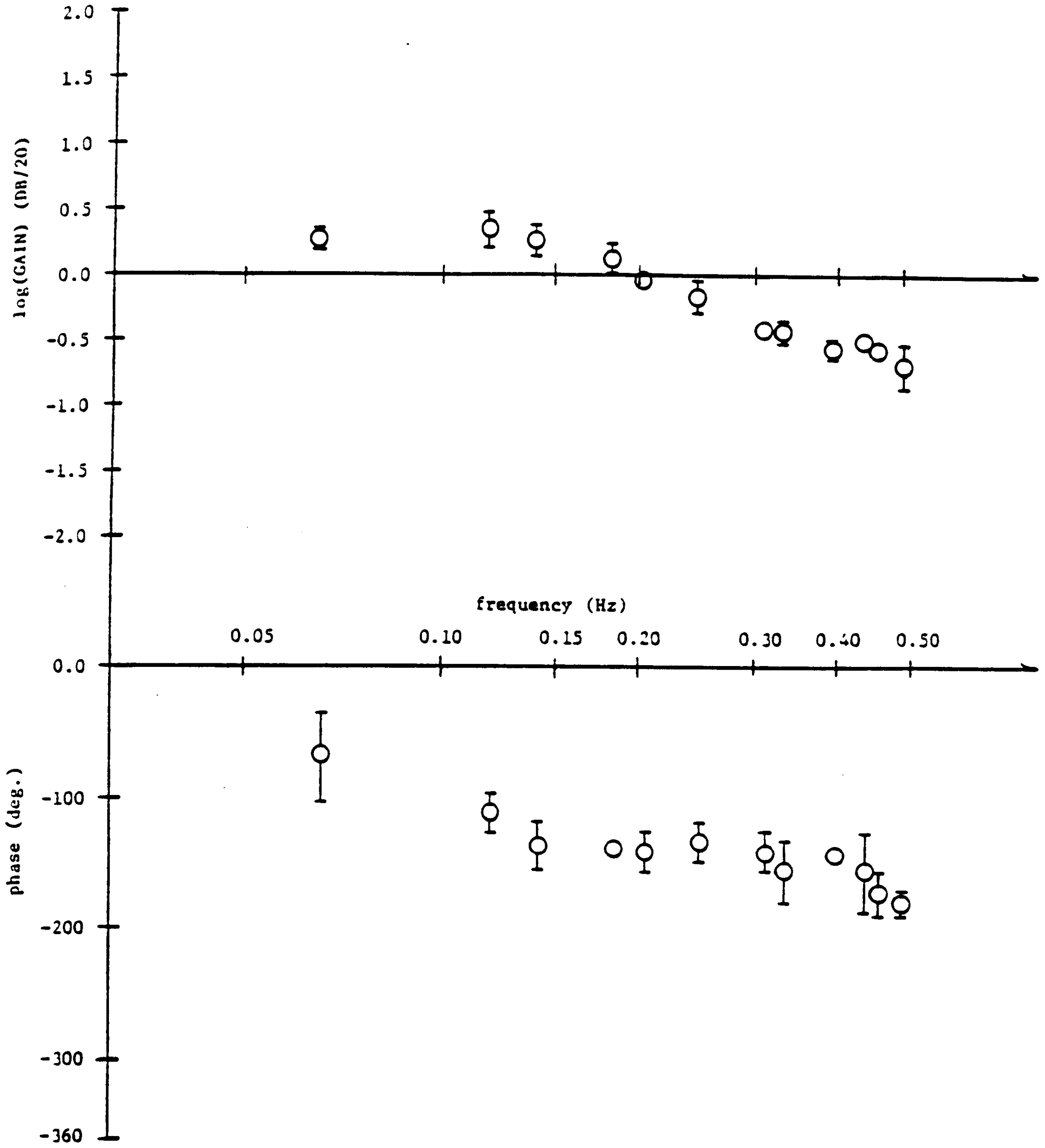
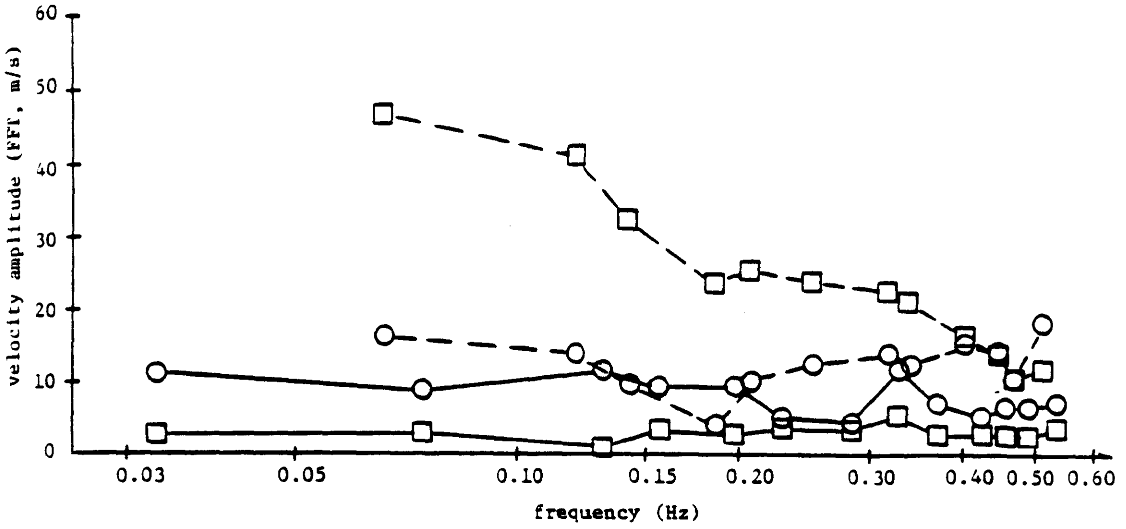


Figure 4.5.05 Bode Plot. Subject DH,
H1PR04.PRO PRofile #17



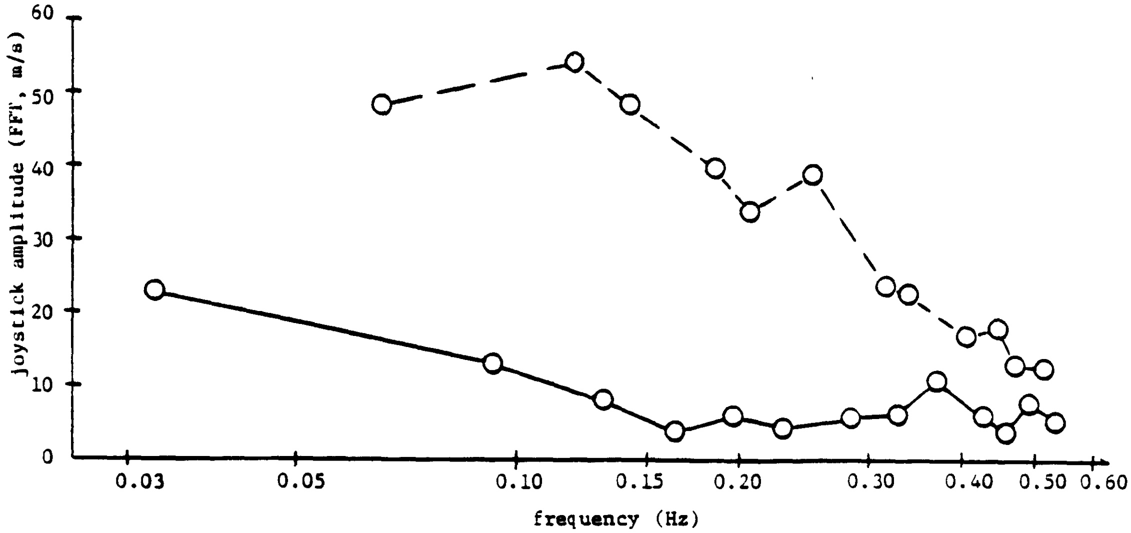


Figure 4.5.06 Frequency Spectrum. Subject DH,
H1PR04.PRO Profile #17

SUBJECT	DATA FILE	RMS VELOCITY RATIO	RMS JOYSTICK
AA	03	3.63	0.346
MS	04	1.19	0.173
	11	3.06	0.241
MM	02	0.790	0.221
	03	1.22	0.223
	05	2.01	0.242
DH	05	1.01	0.191
	08	0.642	0.180
	12	1.76	0.207

TABLE 4.5.01 RMS Data. H1PRO4.PRO Profile #17

plots this type of control results in high remnants of velocity and joystick and also does not have much effect on the disturbance velocity.

Subjects DH and MM used a more passive, reactionary control. This technique is to wait for the disturbance before responding with the control. Some minimal control injection may also be used but it is not a significant amount of the control. The primary cue is then the acceleration sensed during the acceleration reversals. As is seen in the data for subject DH the results are much more consistent. It is also noticed that although these Bode plots show the same general trends, there are differences in the break frequencies of the gain plots. This was a satisfying and desirable result as it showed that the transfer functions could detect differences in subject performance.

4.5.1 Summary

The conclusions of this testing are as follows:

1) For data with little scatter and overall better velocity nulling the HO should try to REACT to the disturbance and not attempt to search out the disturbance.

2) This profile still has input amplitudes that are too high at the lower frequencies.

3) The data for the reacting subjects was similar in quality to that for other HO experiments. Individual differences could also be seen which is an indication of the effectiveness of the profile and the closed-loop test.

4) Practice and knowledge of the profile can greatly improve the subjects performance and the quality of the data.

5) The test procedure and data analysis procedure are basically sound.

There were still some major problems with this profile. One was the low run completion rate. It was felt that the amplitudes at the low frequencies were still too high, resulting in too few acceleration cues. Another problem was the low velocity amplitude at the high frequencies. As is seen from the disturbance velocity frequency spectrum the velocity of the disturbance and the remnant will often mesh at the high frequencies. It is difficult to distinguish between the two and this makes the remnant and control effectiveness question more difficult. Also, in order to get higher amplitudes at the lower frequencies while maintaining the track length and maximum velocity constraints it was necessary to limit the number of low frequency disturbance frequencies. This resulted in only one very low frequency point at 0.065 Hz with the next at 0.11 Hz. It was felt that a profile with more evenly distributed frequencies on the log(rad/sec) scale was desirable. Another profile was needed.

CHAPTER 5

THE FINAL EXPERIMENT

5.1) The Experimental Method

All of the lessons of the previous testing were used to determine the final profile. Consistent data had been obtained from a very low amplitude flat velocity profile, DHPR02.PRO profile #12. However, the input amplitudes of this profile were too low to fulfill the test procedure requirements. Flat acceleration profiles yielded low run completion rates and were not favorable due to the portions of the profile that had minimal acceleration disturbances and few zero-crossings.

Profiles with acceleration amplitudes in the 0.008-0.017 g range gave very consistent Bode plots. However, these profiles were still emphasizing the amplitudes at low frequencies too much. A flat velocity profile with increased amplitudes to 0.004-0.031 g gave a high number of zero crossings and a high run completion rate. The Bode plots from this profile showed some inconsistency and it was felt that the results would suffer due to the low amplitudes at the low frequencies and corresponding emphasis on the high frequencies. This is particularly important since better velocity nulling generally occurrs at the low frequencies. This also points out the need for more low frequency points than had been used in the previous test. As is so often the case in engineering work a compromise was needed.

In generating a final profile the desire was to lower the input amplitudes at the low frequencies and raise them at the high frequencies. An average range between H1PR04.PRO profiles #17 and #12 was felt to yield the best values of input acceleration amplitudes. This range was 0.06-0.24 g. It was also felt that the 81.92 second run time should be used as it had given the desired track length of about 2 m and a maximum velocity of about 0.65 m/s while allowing more low frequency points.

It was impossible to obtain these input amplitude requirements while maintaining the track length and maximum velocity limits. The input amplitudes had to be lowered to resolve this situation as higher input amplitudes had given poorer results in the past. The final profiles are shown in Fig. 5.1.01-.03. As is seen the range of acceleration amplitudes is 0.005-0.021 g. The lowest amplitude is still not below threshold so it was felt to be acceptable. The maximum velocity has also been lowered to 0.63 m/s giving JSCALE=2.13, to allow slightly less joystick sensitivity than that for the profile of section 4.5. The overall emphasis of the input amplitudes have been shifted to the higher frequencies as desired. A frequency determined by an even number multiplying the base frequency was included to prevent the profile from being made up of two identical halves. Two profiles were found to meet these conditions, one with DEL=253 and the other with DEL=103 degrees. In order to chose one profile for obtaining data the time histories were checked. (Fig. 5.1.03) As is seen profile #2 has its maximum velocity activity at the beginning and after the midpoint of the run. Profile #1 is about 180 degrees out of phase with this activity but is almost a mirror image of profile #2. Using the theory of section 4.5, on the occurrence of the maximum velocity activity, profile #2 was chosen to be the data profile with profile #1 being the practice profile. A further advantage of profile #2, and similar profiles, is that at the end of the run when all the sinusoids are converging to zero amplitude, the disturbance is low. This means that the HO's control input will be low so there should not be a bias in the joystick data that could influence the FFT data reduction. This should result in cleaner data than with profile #1, and is a more valid reason for chosing profile #2 to be the data profile.

5.2) The Formal Test Procedure

The same basic test procedure used for population tests with the last profile was used for these population tests. However, a major modification was made in the instruction given to the subject. The basic test procedure has been described in section 4.5, but its main features will be repeated here.

The enclosed head restraint and joystick controller are used for all testing. The instruction given to the subjects is to maintain zero velocity, or keep their motion stopped, by REACTING to the disturbance. To do this subjects must sense their motion and respond with a joystick input. The clearest sense of motion seems to occur during acceleration changes and this should be the primary motion cue to the subject. For the cleanest data subjects should REACT to this acceleration. That is, they should clearly sense their acceleration before responding with a control input. This input should then not be changed until the subjects sense their acceleration changing again. If no acceleration is sensed the joystick should be moved to the zero input position. Above all, subjects should not try to search out the disturbance by inputing high frequency control. This is a tendency noted with many subjects and should be avoided as it leads to poor data. This explanation should be told to the subjects and their control technique

```
INPUT PARAMETERS

    TRUN=  81.920
    NSINES= 12
    FFREQ= 0.012210
    FLAT= 0
    DEL= 103.000
    FILTER=  1
    FPOLE=   0.150
    FPOS=  2.15
    FACC= 0.200
    TLOOP= 0.010

PROFILE DESCRIPTION

    MAX ACCEL= 0.117
    VELMAX=  0.6285
    % USEAGE OF TRACK=100.00
    STARTING POSITION= 0.158
    SCALE= 0.2551

FREQ.  (HZ)    AMP1  (M/S)    AMP2  (G)     PHASE (DEG)
     0.0610           0.13           0.005            2.
     0.0854           0.13           0.007          106.
     0.1099           0.12           0.008          210.
     0.1343           0.11           0.010          314.
     0.1587           0.12           0.012           57.
     0.2075           0.11           0.015          162.
     0.2319           0.10           0.014          266.
     0.2808           0.11           0.020           11.
     0.3540           0.09           0.021          116.
     0.3906           0.07           0.019          220.
     0.4517           0.07           0.021          325.
     0.5005           0.06           0.020           70.

HISTOGRAM DATA

    ACC BIN= 0.005      # ACC POINTS=   815
    ACC BIN= 0.010      # ACC POINTS=  1034
    ACC BIN= 0.015      # ACC POINTS=  1095
    ACC BIN= 0.020      # ACC POINTS=   848
    ACC BIN= 0.025      # ACC POINTS=   698
    ACC BIN= 0.030      # ACC POINTS=   555
    ACC BIN= 0.035      # ACC POINTS=   509
    ACC BIN= 0.040      # ACC POINTS=   463
    ACC BIN= 0.045      # ACC POINTS=   344
    ACC BIN= 0.050      # ACC POINTS=   344
    ACC BIN= 0.055      # ACC POINTS=   307
    ACC BIN= 0.060      # ACC POINTS=   193
    ACC BIN= 0.065      # ACC POINTS=   217
    ACC BIN= 0.070      # ACC POINTS=   173
    ACC BIN= 0.075      # ACC POINTS=   177
    ACC BIN= 0.080      # ACC POINTS=   114
    ACC BIN= 0.085      # ACC POINTS=   107
    ACC BIN= 0.090      # ACC POINTS=    31
    ACC BIN= 0.095      # ACC POINTS=    25
    ACC BIN= 0.100      # ACC POINTS=    28
    ACC BIN= 0.105      # ACC POINTS=    46
    ACC BIN= 0.110      # ACC POINTS=    37
    ACC BIN= 0.115      # ACC POINTS=    14
    ACC BIN= 0.120      # ACC POINTS=    18
    ACC BIN= 0.125      # ACC POINTS=     0
    ACC BIN= 0.130      # ACC POINTS=     0
    ACC BIN= 0.135      # ACC POINTS=     0
    ACC BIN= 0.140      # ACC POINTS=     0
    ACC BIN= 0.145      # ACC POINTS=     0
    ACC BIN= 0.150      # ACC POINTS=     0
```

Figure 5.1.01 H1PR05.PRO Profile #2 Parameters

```
INPUT PARAMETERS

    TRUN= 81.920
    NSINES= 12
    FFREQ= 0.012210
    FLAT= 0
    DEL= 253.000
    FILTER= 1
    FPOLE=  0.160
    FPOS= 2.05
    FACC= 0.200
    TLOOP= 0.010

PROFILE DESCRIPTION

    MAX ACCEL= 0.113
    VELMAX=  0.6290
    % USEAGE OF TRACK= 100.00
    STARTING POSITION=-0.236
    SCALE= 0.2502

FREQ.  (HZ)    AMP1  (M/S)    AMP2  (G)     PHASE (DEG)
     0.0610            0.12           0.005            0.
     0.0854            0.13           0.007          253.
     0.1099            0.12           0.008          147.
     0.1343            0.11           0.009           40.
     0.1587            0.12           0.012          293.
     0.2075            0.11           0.015          186.
     0.2319            0.10           0.014           79.
     0.2808            0.11           0.019          332.
     0.3540            0.09           0.021          226.
     0.3906            0.07           0.019          119.
     0.4517            0.07           0.021           12.
     0.5005            0.06           0.020          265.

HISTOGRAM DATA

    ACC BIN= 0.005     # ACC POINTS=   862
    ACC BIN= 0.010     # ACC POINTS=  1059
    ACC BIN= 0.015     # ACC POINTS=  1048
    ACC BIN= 0.020     # ACC POINTS=   908
    ACC BIN= 0.025     # ACC POINTS=   664
    ACC BIN= 0.030     # ACC POINTS=   551
    ACC BIN= 0.035     # ACC POINTS=   559
    ACC BIN= 0.040     # ACC POINTS=   426
    ACC BIN= 0.045     # ACC POINTS=   355
    ACC BIN= 0.050     # ACC POINTS=   342
    ACC BIN= 0.055     # ACC POINTS=   313
    ACC BIN= 0.060     # ACC POINTS=   210
    ACC BIN= 0.065     # ACC POINTS=   207
    ACC BIN= 0.070     # ACC POINTS=   175
    ACC BIN= 0.075     # ACC POINTS=   180
    ACC BIN= 0.080     # ACC POINTS=   126
    ACC BIN= 0.085     # ACC POINTS=    83
    ACC BIN= 0.090     # ACC POINTS=    41
    ACC BIN= 0.095     # ACC POINTS=    26
    ACC BIN= 0.100     # ACC POINTS=    30
    ACC BIN= 0.105     # ACC POINTS=    49
    ACC BIN= 0.110     # ACC POINTS=    37
    ACC BIN= 0.115     # ACC POINTS=    21
    ACC BIN= 0.120     # ACC POINTS=     0
    ACC BIN= 0.125     # ACC POINTS=     0
    ACC BIN= 0.130     # ACC POINTS=     0
    ACC BIN= 0.135     # ACC POINTS=     0
    ACC BIN= 0.140     # ACC POINTS=     0
    ACC BIN= 0.145     # ACC POINTS=     0
    ACC BIN= 0.150     # ACC POINTS=     0
```

Figure 5.1.02 H1PRO5.PRO Profile #1 Parameters

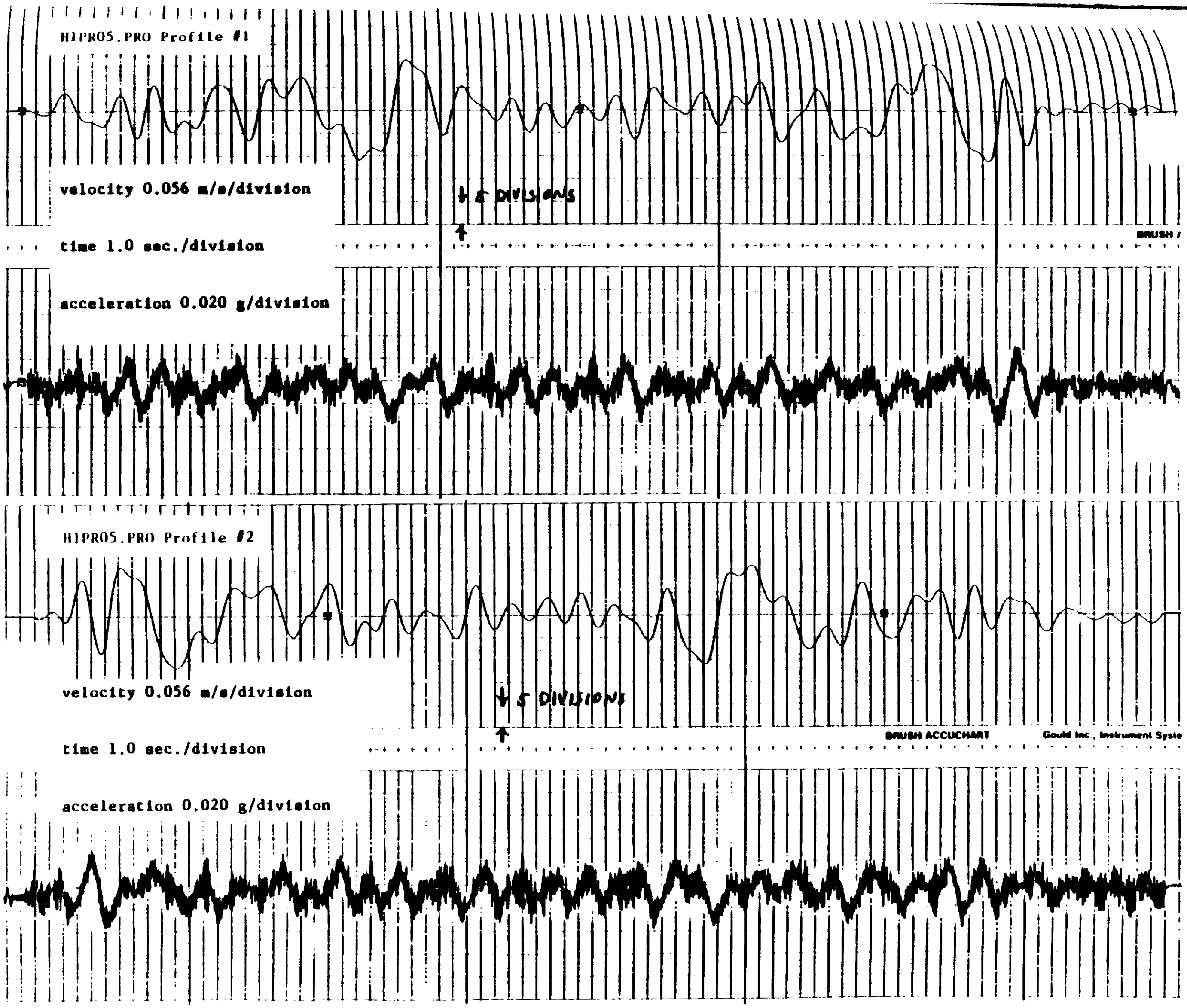


Figure 5.1.03 H1PRO5.PRO Profile #1 and #2 Time Histories

closely monitored. The explanation to REACT to the disturbance should be repeated if necessary.

Once this instruction is given subjects are given a ride through the practice profile with the joystick disabled. This is done to familiarize them with the motion disturbance. The joystick is then enabled and the practice profile run until subjects reach their maximum performance level or start completing runs. Subjects are then given a ride through the data profile without control. The data profile is then run with subject control until 4 or 5 runs are completed. This completes the test session. Data is stored for data runs only, but all runs should be logged on the run data sheets.

The data analysis is started by determining frequency spectrum plots for all completed runs. The velocity RMS ratio and the joystick RMS should also be calculated to provide additional information to that contained in the plots. The three best runs are then chosen from these plots and RMS data and used to determine the Bode plots. To chose the best runs the following criteria should be used as a guide. The joystick remnant should be low, below or about 10 units. The joystick remnant should be 25-30% or less of the joystick amplitudes at the disturbance frequencies. The velocity remnant with control should be roughly that of the no subject velocity remnant. The velocity disturbance frequency amplitudes with control should be less than the amplitude with no subject. This will vary depending upon the capability of the subject to perform the velocity nulling task so no definite value can be stated. All curves should be smooth with no erratic oscillations. The RMS data should be consistent for the three chosen runs , but this is of secondary importance. If the frequency plots and RMS data do not conform to the above criteria, the data should not be used in further analysis.

A formal test procedure checklist is shown in Appendix D. This lists all the important steps required for acceptable results. It covers the entire spectrum from setting up the Sled system to plotting data. This checklist should be used in all future testing.

It should be emphasized that a very important part of the procedure is the instruction to the subject. It should be made clear to the subject to try to REACT to the disturbance. This should be discussed with subject/test conductor dialogue during the practice runs. Practice is also important and data runs should not be made until all involved are sure that no improvement in subject performance can occur. These are the two critical subjective elements of the test procedure that must be monitored closely.

It is expected that some subjects will give desirable results with little variance, while others will not. It is felt that most of the astronaut participants, due to their skill at operating complex man-machine systems, will yield desirable results. However, subjects who have difficulty in performing the task should not be used in the final analysis.

CHAPTER 6

RESULTS AND DISCUSSION

6.1) Results

Five subjects were tested with the procedure described in Chapter 5. However, in all but the first test an unwanted vibration hampered the subjects performance. This vibration occurred at the low velocity portion of velocity zero-crossings. It was of such a magnitude and frequency that it tended to mask the change in acceleration. As this change in acceleration is the major cue to the subject, it was difficult for the subjects to determine the proper control input. Either much practice was needed for the subject to sense the acceleration changes more readily, or the low velocity acceleration was ignored since it could not be sensed clearly. Although this vibration hampered the testing, it is felt that the major goals of this work have been accomplished.

The plotted results of the tests are shown in Appendix E, which also contains an explanation of the plot formats. Two typical plots are shown in Fig. 6.1.01,.02. RMS data is shown in Table 6.1.01. As is seen the data shows little scatter for most subjects. Also, the one sigma deviations are as low or lower than those of other human subject experiments. The general trends seen in previous testing are also shown. There is a flatness or peak of gain and phase at low frequencies, and a drop-off at high frequencies. Individual plots show differences which is desired. Table 6.1.01 shows the RMS data for all subjects. The velocity ratios tend to show the relative level of velocity nulling performance. For most of the subjects tested the velocity and joystick remnants were low, and the data smooth. Under these conditions, the velocity RMS ration can indicate general performance levels. It is noted that there is some inconsistency among individual subjects, however. The joystick RMS shows the level of joystick activity, as always.

Fig. 6.1.03 shows a Bode plot of the average values of the four subjects with acceptable data. (Subject LR did not have valid data as will be explained in the next section.) The consistency between the subjects is encouraging. An acceptable range of values can encompass all of the valid runs. Fig. 6.1.04 shows the average values of all the significant tests for subject DH. The consistency of this data is also encouraging.

6.2) Discussion of Individual Subject Results

The results of subject MS are shown in Fig. E6.1.01,.08-.11. This was the first subject tested with the final procedure. As noted in Chapter 4 subject MS had done poorly in the previous testing because he used the control injection technique. With this testing, and the instruction to REACT to the disturbance his results have greatly improved. The frequency spectrum plots show a clear seperation between the joystick disturbance frequency amplitudes and the remnant, with the remnant at 30-40% of the disturbance. The velocity nulling has been somewhat effective, being 50-90% of the velocity disturbance. Runs 07, 08, and 09 yielded the best joystick disturbance frequency amplitude/remnant separation and the best velocity nulling. Run 02 was not included due to the high velocity remnant. The RMS data is also consistent for these three runs and improving. These three runs were used to generate the Bode plot. The plot shows acceptable deviations and scatter in log(GAIN), 0.0-0.25 log units,

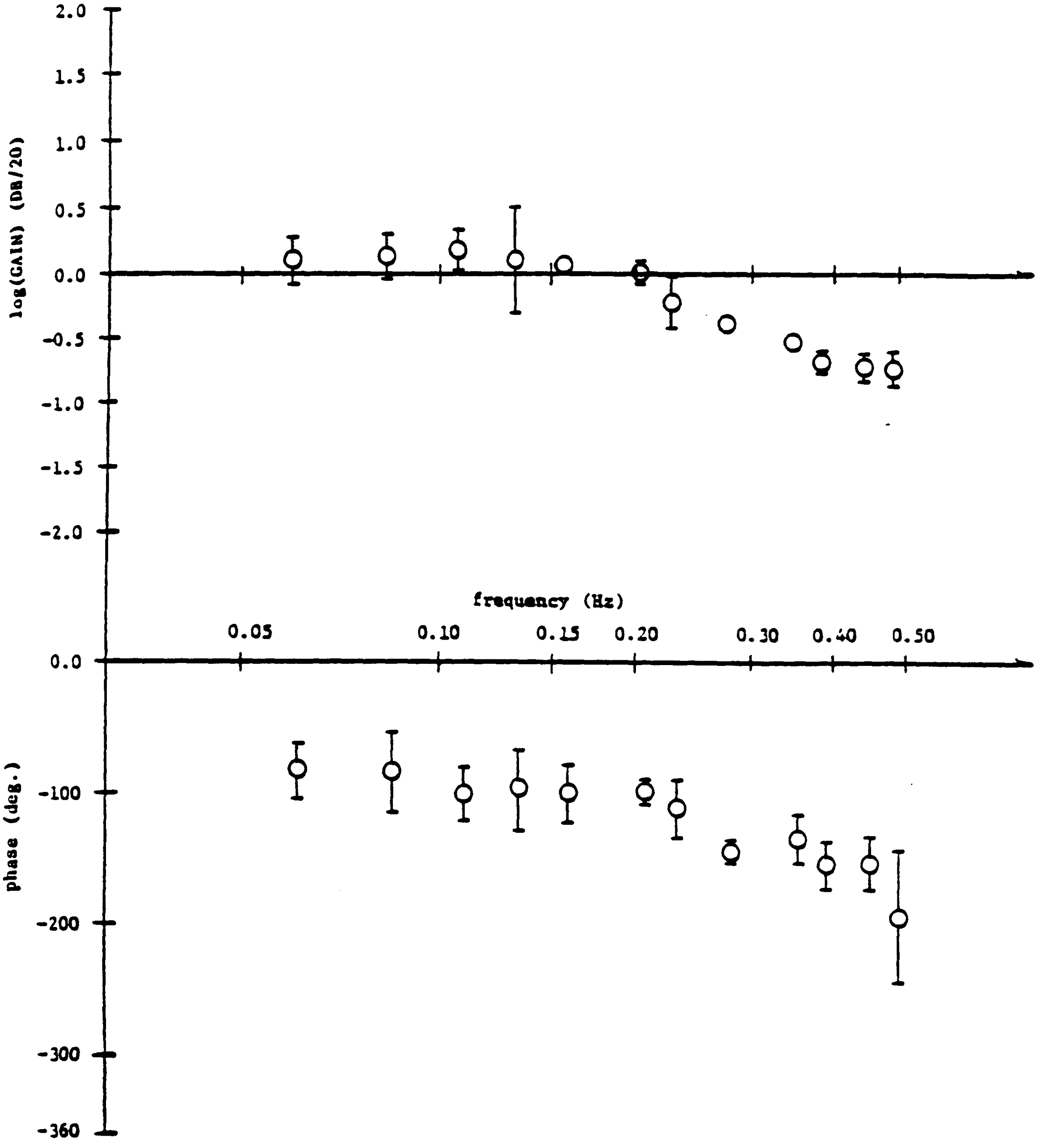
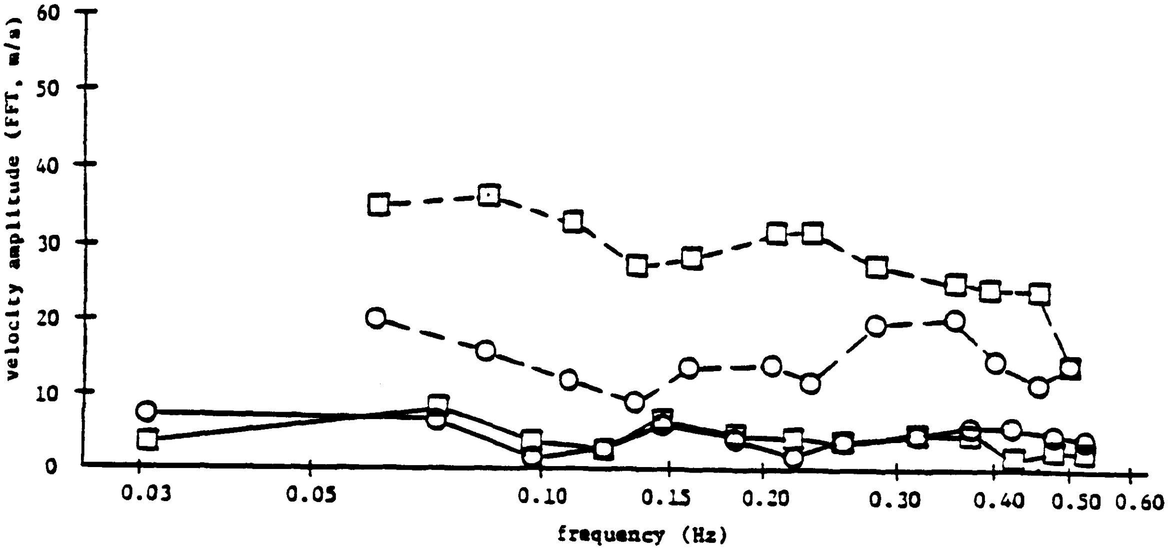


Figure 6.1.01 Bode Plot. Subject DH, Final Profile
Average of Runs 15,21,22



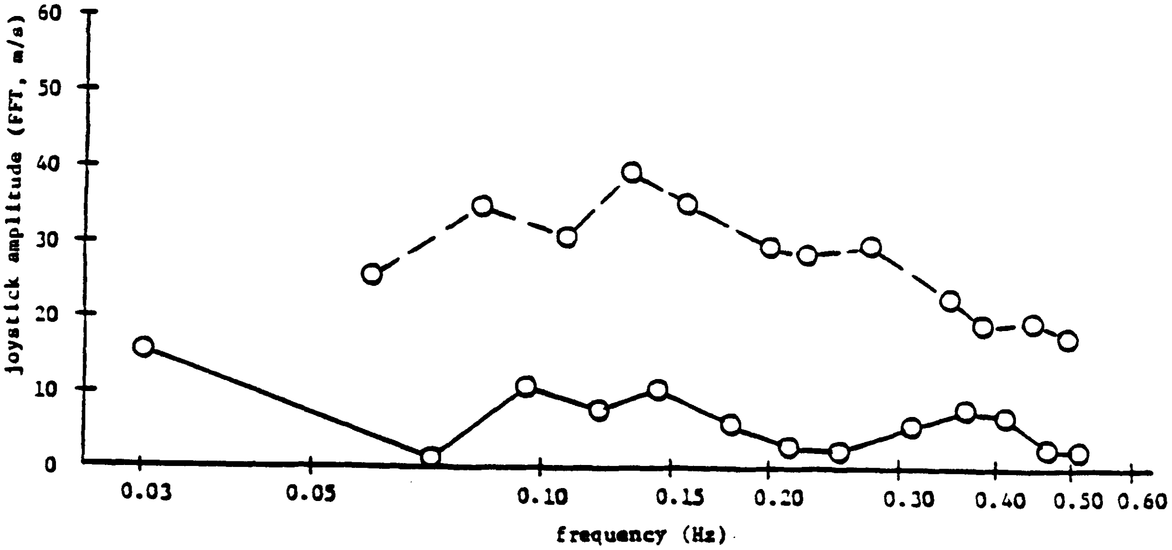


Figure 6.1.02 Frequency Spectrum. Subject DH, Run 15, Final Profile

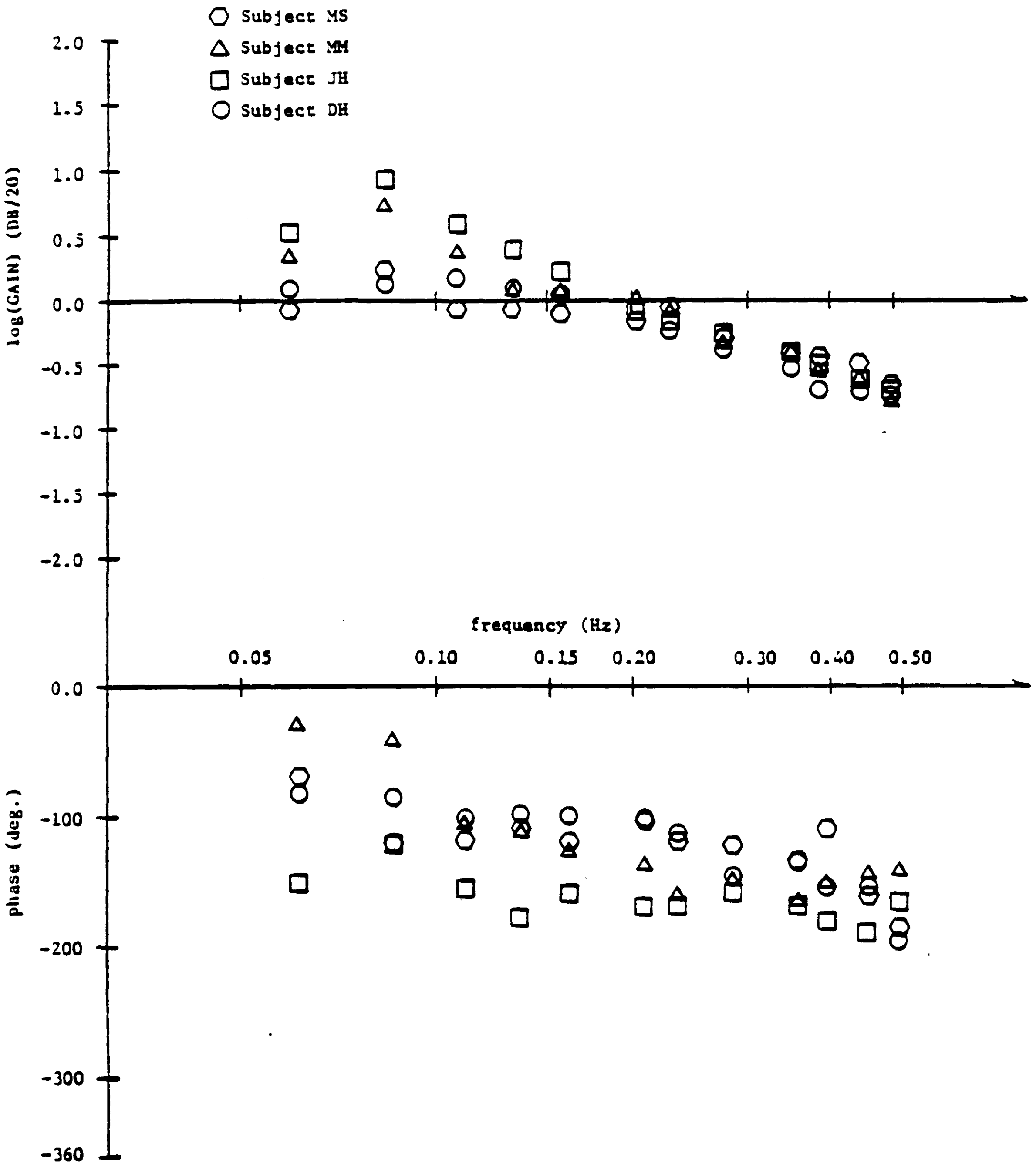


Figure 6.1.03 Summary Bode Plot, All Subjects, Final Profile

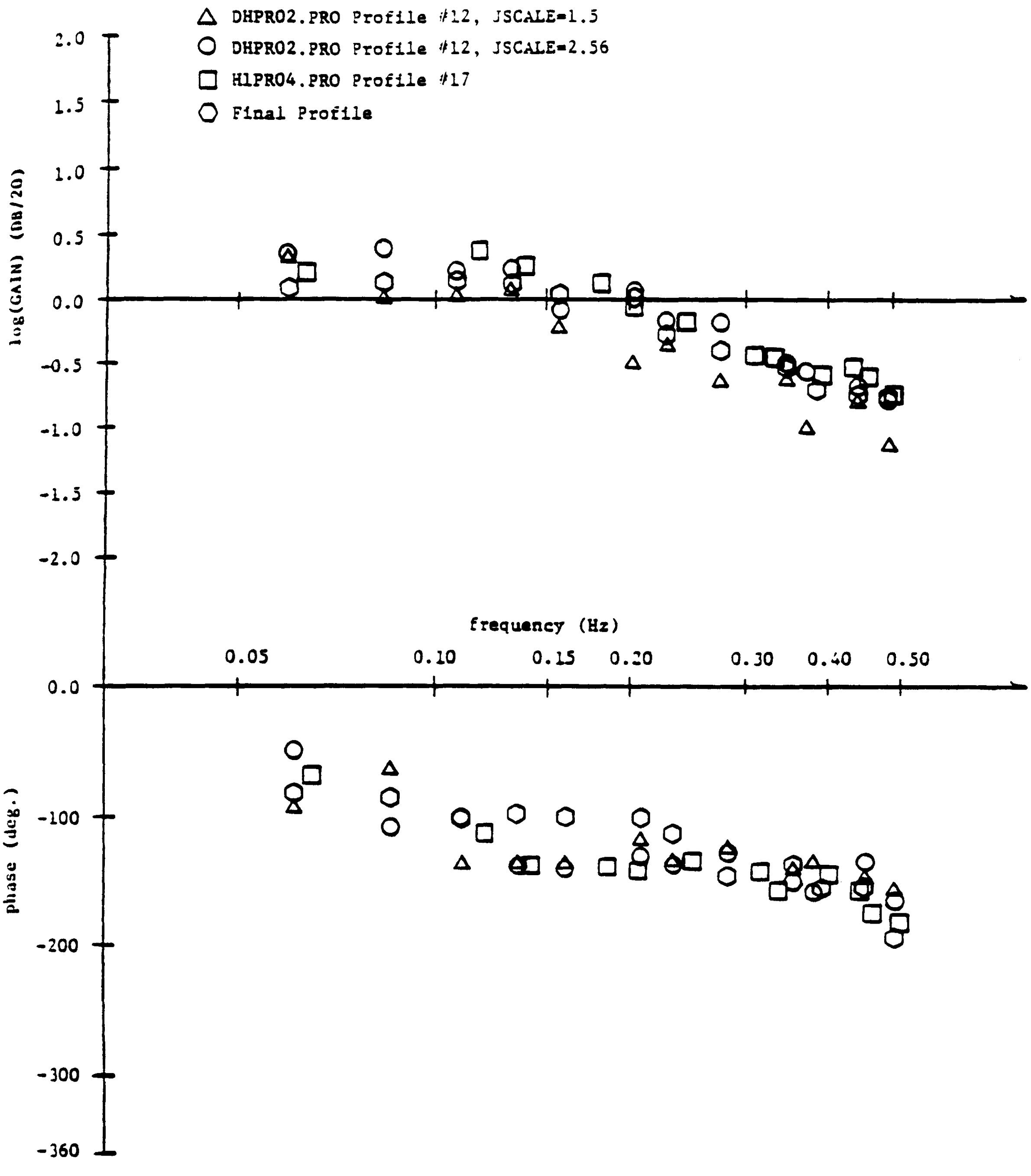


Figure 6.1.04 Summary Bode Plot, Subject DH

SUBJECT	DATA FILE	RMS VELOCITY RATIO	RMS JOYSTICK
MS	02	2.33*	0.206
	07	1.56	0.210
	08	1.29	0.216
	09	1.11	0.189
LR	02	3.51	0.284
	03	2.47	0.304
	06	1.24	0.284
JH	03	0.885*	0.242
	06	0.627	0.253
	08	0.979	0.245
	09	0.720	0.251
DH	12	1.39*	0.190
	15	0.870	0.170
	21	0.699	0.175
	22	0.735	0.195
	23	0.777*	0.160
MM	03	0.697	0.215
	09	0.702	0.206
	12	0.812	0.213
	15	0.716*	0.212
	18	0.759*	0.205

* Not used for Bode plots.

TABLE 6.1.01 RMS Data. H1PRO5.PRO Profile #2.

and phase, 0.0-50.0 deg. There is also an approximately zero gain at low frequencies, and a break at about 0.2 Hz. These are the characteristics of this subject which will be quantified further in section 6.3.

Sbject MM was tested twice with this procedure. The run completion rate was 100% during the first testing. Unfortunately the data was not stored. The vibration was also not prevalant during this test. This gives strong support to the fulfillment of the test requirements, however.

Subject MM had always given acceptable results in past testing and had never used the control injection technique. The overall high quality of his data is readily seen. (FIg. E6.1.02,.12-.16) Runs 03,09, and 12 were used to generate the Bode plot. As is seen, there is a higher gain at low frequencies than for subject MS. This is also shown in the frequency spectrum plots which show velocity nulling at 50% of the disturbance values. The nulling is not effective at the high frequencies, being 70-100% of the disturbance values. This is shown as a drop-off in gain at the higher frequencies. The phase data also follows the same trends as the gain data. The data scatter and deviations are quite acceptable, at roughly 0.3 log(GAIN) and 50 deg. phase. The RMS data shows roughly the same level of joystick activity, but much lower velocity activity than subject MS. This is as suggested by the plots.

Subject JH had a large amount of experience as a sled subject in the experiments of Ref. 8. The data shows a joystick disturbance frequency amplitude/remnant seperation that is the highest seen at low frequencies. (Fig. E6.1.03,.17-.20) The velocity remnant is low, approximating the no-subject remnant, and the nulling is the best seen at low frequencies, being pushed down into the remnant at about 25% of the disturbance. This is reflected in the Bode plot which shows the highest gain seen at low frequencies. The nulling is poor at high frequencies, 80-100%, which seems to be a general characteristic of the HO. The phase data is also the lowest seen at low frequencies. The joystick RMS shows the next to the highest values, reflecting the high joystick disturbance frequency amplitudes. The RMS velocity ratios are some of the lowest seen, as expected.

Subject DH had the most experience with the type of testing of this work. The data shows average joystick disturbance frequency amplitude/remnant seperation, 25-30% of the disturbance, but there is some fluctuation in the disturbance frequency amplitude values. (Fig. E6.1.04,.21-.25) The joystick remnant is the lowest observed being at or below 10 units. The velocity nulling is effective through the mid-frequency range, being about 60-100% of the disturbance. This results in the flatness in gain and phase through this same frequency range seen in the Bode plot. The RMS data shows the lowest joystick values, which is due to the low remnant. The velocity ratios are also some of the lowest seen. The experience of the subject was felt to have resulted in the lowest remnants observed. The experience, then, has caused the subject to be able to sense and respond only to the disturbance, while clearly showing his specific level of performance. This is an encouraging result and shows that practice leads to better data and not to the best velocity nulling performance.

The DH summary Bode plot shows some encouraging results. (Fig. 6.1.04,E6.1.07) All the individual tests show acceptable agreement except for DHPR02.PRO profile #12, JSCALE=1.5 and the phase of H1PR05.PRO profile #2. It is noted that all tests used a P=90 or 95% JSCALE criterion except for the profile #12 JSCALE=1.5 test. Since the joystick voltage is stored before it is scaled the JSCALE directly effects the magnitude of the log(GAIN). The JSCALE=1.5 data was obtained from the same profile as the DHPR02.PRO profile #12, JSCALE=2.56 data. If a correction of log(2.56/1.5)=0.23 is applied to the JSCALE=1.5 data it would then agree with all the other data. The JSCALE=1.5 data does have the most scatter, however, which was caused by the joystick gain being too sensitive. The H1PR05.PRO profile #2 data shows a difference in low frequency phase, and the lowest log(GAIN) of all tests. It is suspected that this was mainly caused by the cart vibration problems as noted in Chapter 5. The overall agreement of the different tests is still acceptable, though, which supports the validity of the closed-loop test.

Subject LR was the only female and non-graduate student tested. She also had the least experience with the Sled, as this was her second test session. Only three runs were completed during her testing. The plots show high remnant activity of joystick and velocity. (Fig. E6.1.05,.26-.28) The control is only effective at the low frequencies. The Bode plots show the general trends, but there is much scatter, particularly at the high frequencies, and some larger than desirable deviations, 80 deg. in phase. The RMS data shows the highest joystick and velocity activity, which is suggested by the high remnant. As will be shown in section 6.4, the joystick disturbance frequency amplitude/remnant separation is not sufficient to yield valid results. Thusly, the Bode data is not included in the plot of Fig. 6.1.03,E6.1.06. The data is shown as an illustration only. The data does show steady improvement, though, so in future test sessions better data may be obtained.

6.3) The Transfer Function Model

A transfer function model is desired so that the characteristics seen in the HO responses can be quantified. A BMDP non-linear regression analysis program was used to determine the model. (Ref. 16) It was originally desired to fit a model with two real poles, as in the Young and Meiry model. However, the BMDP program contains numerical problems which does not allow this restriction. Rather, a 2nd order system equation must be used as this allows the poles to become complex. Various structures were tried in attempts to define a structure that would be sufficiently general to include all the variations seen in the HO responses, while being as simple as possible. The final structure used was as follows:

$$\frac{K(j\omega + a)}{(j\omega + b)(j\omega^2 + 2\zeta\omega_n j\omega + \omega_n^2)}$$

The following limits were placed on the parameters:

parameter	min	max
K	0.0	100.0
a	0.0	25.0
b	0.0	25.0
ζ	0.0	10.0
ω_n	0.0	100.0

The HO response data was converted to GAIN (amplitude ratio) and frequency (rad/sec) units before inputing them to the regression analysis. Only the GAIN data was used in the fit. No phase data was used in the analysis.

Fig. 6.3.01-.04,E6.3.01-.04 show the models and their curves ploted against the Bode plots. As is seen the gain fits are very precise but the

corresponding phase fits are poor. For all but subject DH a shift of about 50 deg. would be needed for the phase curve to conform to the data. Also, more phase adjustment is needed at the low frequencies than at the high frequencies. No other simple phase adjustment, without a corresponding gain adjustment, would yield a better fit. The data therefore does not conform to a minimum phase system with this model.

On all the models the zero has been placed at the limit value of 0.0, resulting in a differentiator. This is the lead term as suggested in the Young and Meiry model by the zero at 0.0076 rad/sec. That the zero is 0.0 reflects the accuracy of the regression analysis and also the problems of trying to define the system over a narrow range of frequencies.

The pole shows some variation and is the main factor in determining the individual structure for each subject. In two cases the pole has been placed at the limit of 25 rad/sec. This suggests that for these cases the pole is not needed. This is seen in the high frequency slopes which are approximately -1.0 (log(GAIN)/log(freq., rad/sec)). The large pole has also caused the K, gain, values of these cases to be larger than necessary. In the range of the disturbance frequencies, 0.383-3.145 rad/sec, the magnitude of this pole remains at approximately 25.0. The K values should therefore be lowered by a factor of 25.0. The corrected values are shown in brackets.

For subject DH the pole has been placed at 0.0 resulting in an integrator. This implies that for this case neither the pole nor zero are needed. This is due to the flatness in gain at the low frequencies and the slope of approximately -2.0 (log(GAIN)/log(freq., rad/sec)) at the high

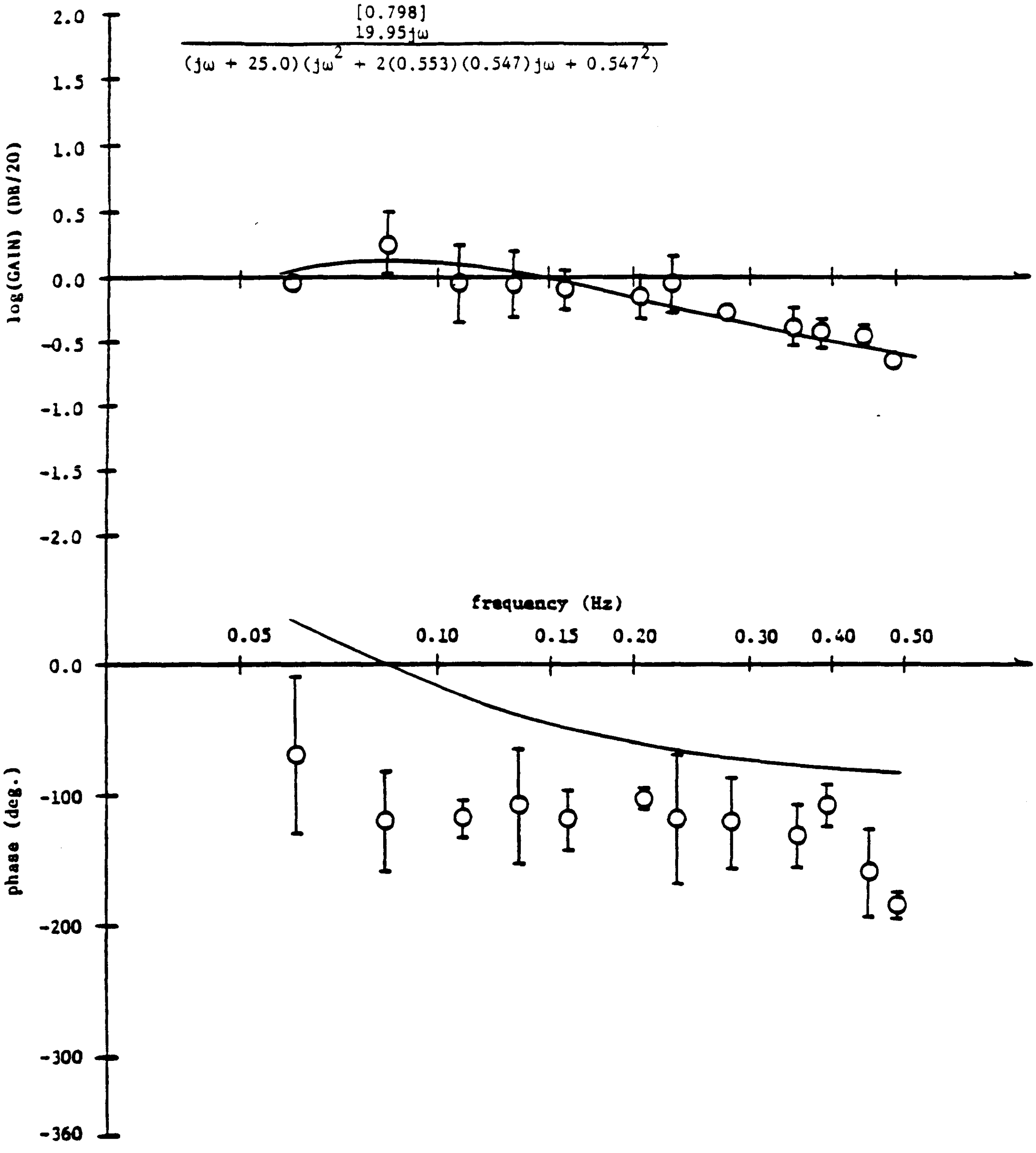


Figure 6.3.01 Model and Curve Fit. Subject MS

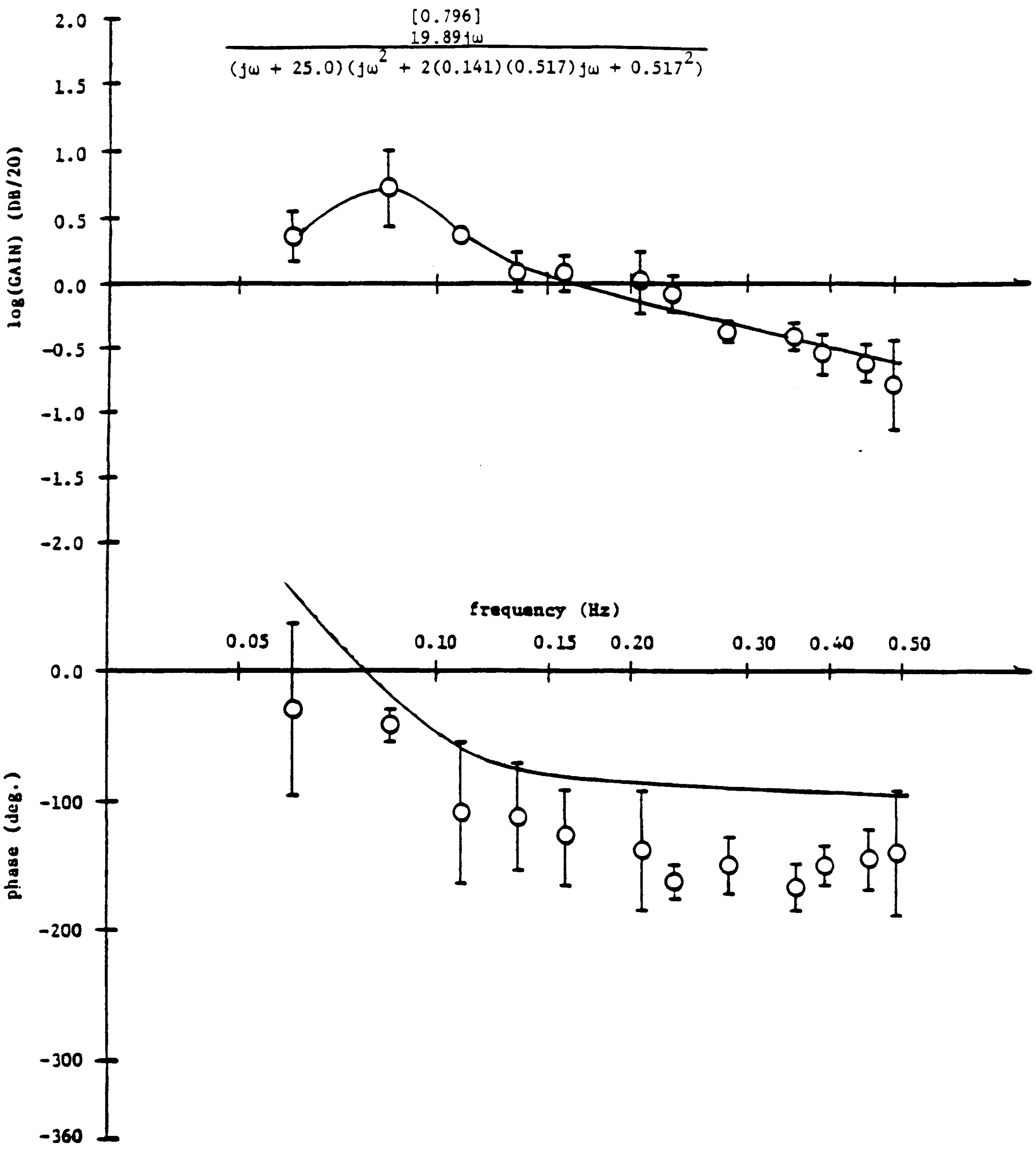


Figure 6.3.02 Model and Curve Fit. Subject MM

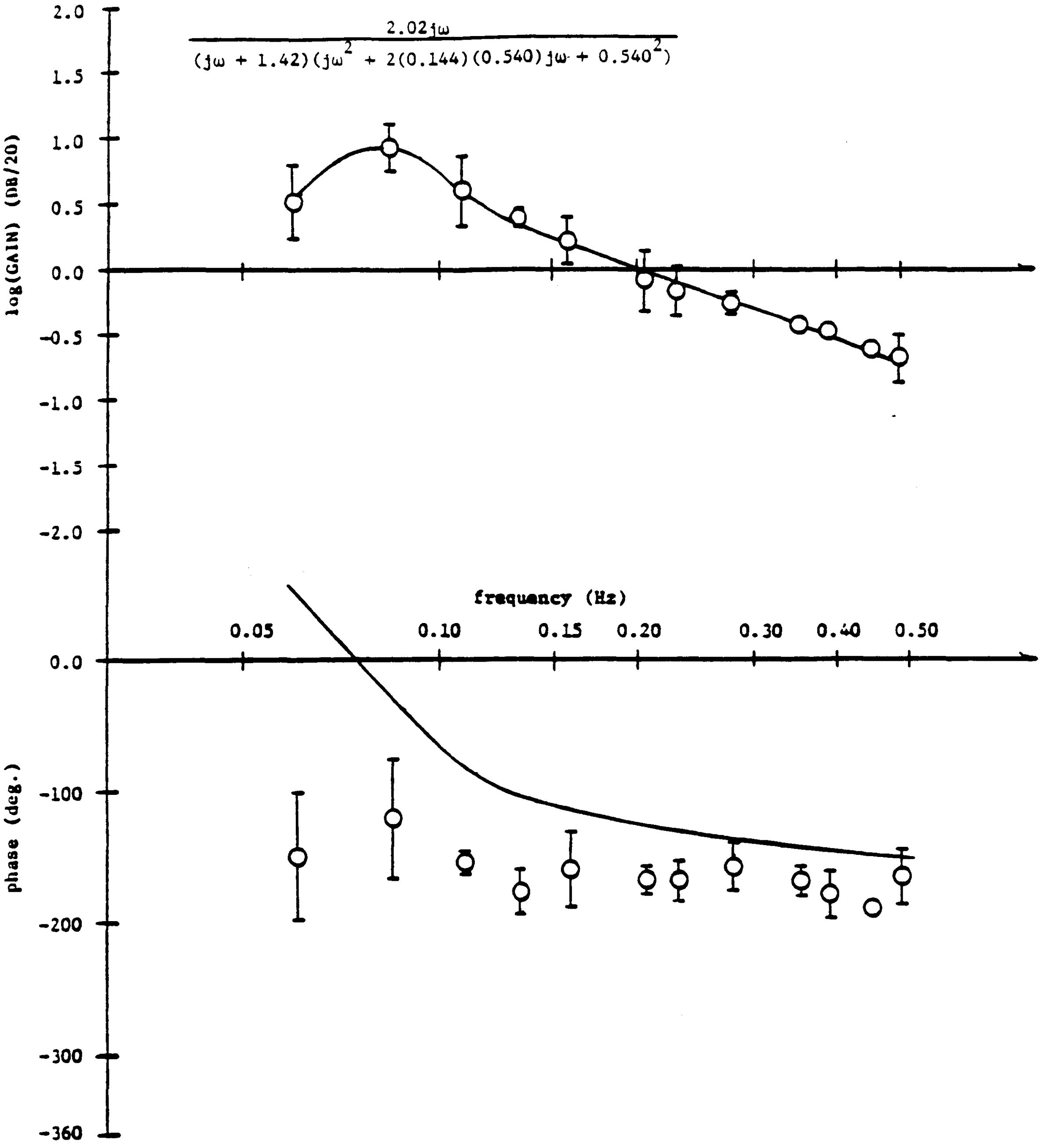


Figure 6.3.03 Model and Curve Fit. Subject JH

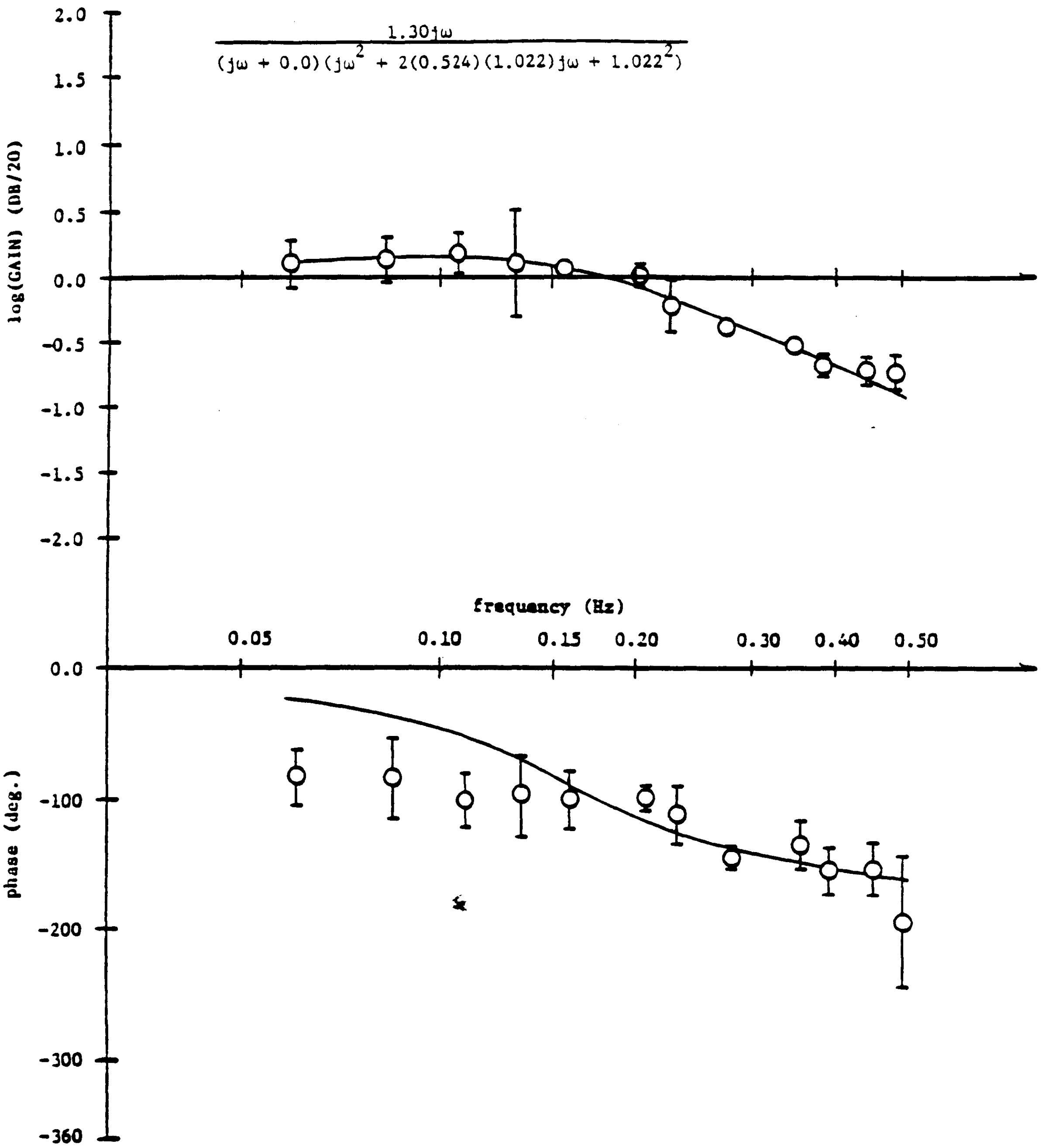


Figure 6.3.04 Model and Curve Fit. Subject DH

frequencies. The resulting model would then be a 2^{nd} order system. In the case for subject JH, the pole has been precisely placed at 1.42 rad/sec. This accurately shows that the high frequency slope is between -1.0 and -2.0 (log(GAIN)/log(freq., rad/sec)).

The values of most importance, in terms of reflecting the task performance, are K, ζ, and ω_n. The ω_n precisely defines the break frequency of the response. For cases where the low frequency log(GAIN) shows no peak, ζ=0.5 or less, the ω_n is the break frequency below which the velocity nulling has been most effective. (subject DH) The model for subject MS emphasizes the low peak too much and does not follow this trend, as it seems it should from looking at the plot. This may show the limitations of the regression analysis. For cases where ζ is much lower than 0.5, there is a reasonance peak. For these cases the plots show that the velocity nulling has been very effective, roughly 25-30% of the disturbance in the region of ω_n. (subjects MM,JH)

There does not seem to be a corelation between all K values and the task performance. Subject MM had much better velocity nulling than subject MS. Their K values are the same but their ζ values and low frequency responses are different. However, for cases with similar ζ values, yielding similar low frequency responses, K corresponds to the level of velocity nulling performance. In this way K can be used to determine varying performance levels. (Compare subjects DH and MS, and subjects MM and JH.) In summary, the zero defines the low frequency response. The K, ζ , and ω_n define the task performance in the frequency range of the disturbance. And the pole shows modifications needed for the high frequency response at the higher frequencies of the disturbance.

6.4) Remnant Analysis

No remnant correction has been applied to the data in this work. However, a criteria can be used to determine if the joystick remnant is too large to yield valid results. The full developement of this criteria is found in Ref. 7. Only the final result will be shown here.

The system under consideration is shown in Fig. 6.4.01 with the joystick remnant shown. The required parameters are also labeled. The analysis of Ref. 7 results in a function based on the power spectrum of these parameters. This function is:

$$|\alpha| = \left\{[\phi_{\lambda\lambda}/\phi_{AA} - \hat{\phi}_{\lambda\lambda}/\phi_{AA}]/[1 - |G_c|^2(\hat{\phi}_{\lambda\lambda}/\phi_{AA})]\right\}^{1/2}$$

where; $\phi_{\lambda\lambda}$ is the power of the joystick output, including the remnant: $\hat{\phi}_{\lambda\lambda}$ is the power of the joystick remnant at the disturbance frequencies, found by linear interpolation: ϕ_{AA} is the power of the disturbance acceleration: $|G_c|^2$ is the power of the cart dynamics taken from the plot of Chapter 3.

The limiting behavior of this $|\alpha|$ function is based on the remnant power:

$$|\alpha| \Rightarrow (\phi_{\lambda\lambda}/\phi_{AA})^{1/2} \quad G_{HO} \quad \text{as} \quad \hat{\phi}_{\lambda\lambda} \Rightarrow 0.0$$

$$|\alpha| \Rightarrow 1.0/G_c = \text{inverse plant dynamics} \quad \text{as} \quad \hat{\phi}_{\lambda\lambda} = \infty$$

This says that for the transfer function of the HO as defined in this work to be valid, the joystick remnant must be low. How low is not suggested, so a typical test run was used to find specific values for the above

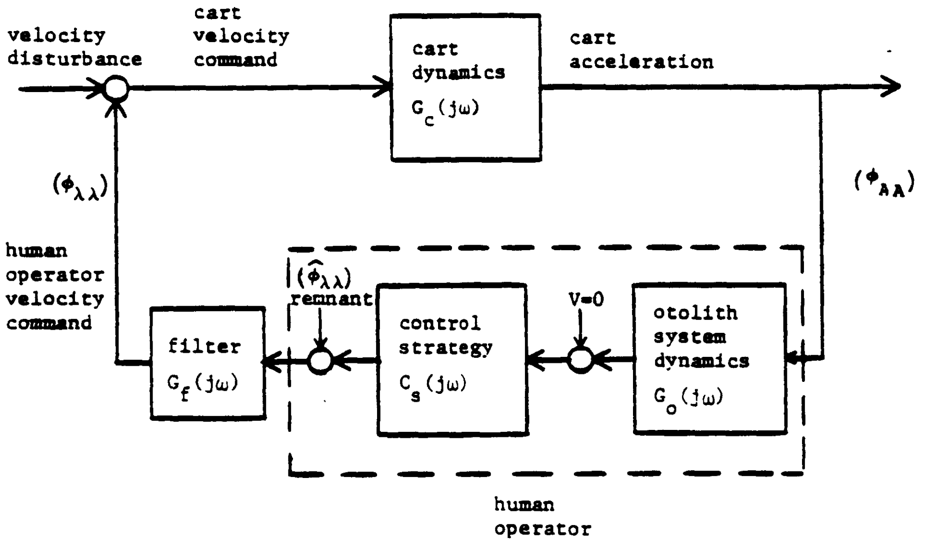


Figure 6.4.01 The Closed-Loop System with Remnant Analysis Parameters Labeled

equations. The data from subject DH, H1PR05.PRO profile #2, run 22 was used as it showed a middle range of joystick disturbance frequency amplitude/remnant separation. The data is shown in Table 6.4.01.

The table shows the transfer function GAIN as well as $|\alpha|$ and the other parameters needed in the calculation. As is seen, for all but two points there is no major difference between $|\alpha|$ and the GAIN. The two points noted are seen to have a joystick remnant value of about 80% of the joystick amplitudes at the disturbance frequencies. For all other points the joystick remnant is 25-30% of the joystick disturbance frequency amplitudes. The resulting $|\alpha|$ and GAIN values have a maximum difference of 12%. A 12% error in the GAIN data of this type of experiment is considered quite acceptable. Therefore the joystick remnant of 25-30% of the disturbance frequency amplitudes can be considered as a guideline to determining the quality of the data. All of the results obtained in this work have joystick disturbance frequency amplitude/remnant ratios in this range, except those of subject LR, which confirms the validity of the data.

In the work of Ref. 10 any point with a high joystick remnant was discarded. In this work, the velocity and joystick frequency spectra were checked and if the remnants were low for most frequencies the entire run was used. This may have introduced some unwanted error at a few frequencies. The overall quality of the data appears to be acceptable, however. Possibly, the above remnant analysis shoud be done for all runs and bad points discarded in the future.

As described previously, if the joystick remnant is high the HO transfer function should approximate the inverse plant dynamics. However, if the HO

FREQ. (Hz)	JOYSTICK REMNANT	JOYSTICK AMPLITUDE	ACC. AMPLITUDE	$\|G\|$	$\|\alpha\|$	GAIN	%
0.061	13.69	37.49	24.86	0.575	1.48	1.51	1.89
0.085	7.15	25.65	25.77	0.390	0.961	0.995	3.54
0.110	5.14	43.84	21.15	0.637	2.08	2.07	-0.53
0.134	9.81	18.52	32.50	1.07	0.511	0.570	11.55
0.159	12.14	38.50	33.26	1.13	1.21	1.16	4.14
0.207	11.99	40.59	32.38	1.28	1.36	1.25	-7.93
0.232	11.95	25.79	31.11	1.78	1.01	0.829	17.59*
0.281	8.43	30.59	64.89	1.96	0.469	0.471	0.43
0.354	12.13	29.54	86.10	2.36	0.332	0.343	3.31
0.391	12.96	19.15	104.47	3.19	0.147	0.183	24.49*
0.452	6.73	24.83	114.89	3.30	0.212	0.216	1.89
0.500	6.61	15.82	116.64	3.29	0.126	0.136	7.94

* Out of tolerance points.

TABLE 6.4.01 Remnant Analysis. Subject DH, H1PRO5.PRO
Profile #2, Run 22.

transfer function approximates the inverse plant dynamics it can mean effective velocity nulling. The closed-loop transfer function of the system, neglecting the filter, is:

$$G_{cl} = \frac{-G_{HO}G_{cl}}{1.0-G_cG_{HO}} \qquad \frac{\text{Acceleration}}{\text{Disturbance}}$$

If the HO matches the inverse plant dynamics exactly, except for the opposite sign, the result is:

$$G_{cl} = 1/2 \quad \Rightarrow \quad \text{Acceleration} = 1/2 \text{ Disturbance}$$

The HO has therefore effectively nulled 50% of the disturbance acceleration or aproximately 50% of the disturbance velocity. Since the HO is very adaptable, it is not unlikely that his control strategy would cause him to approximate the inverse cart dynamics. However, if the remnant is high and the velocity nulling is not effective, the remnant analysis also shows that the HO transfer function should approach the inverse cart dynamics. In short, with this type of testing it is difficult to separate the HO transfer function from the inverse plant dynamics. It is clear, however, that when the joystick remnant is low, the data is accurate. The remnant analysis, then, is the most important criteria for determining the data quality.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1) Conclusions

The requirements of the test procedure have been fulfilled by the procedure developed in this work. It is felt that the test procedure is the best that can be obtained using the simplest disturbance profiles and data reduction techniques possible. The procedure yields high run completion rates for most subjects. It is expected to yield near 100% completion rates for most of the participating astronauts as suggested in Chapter 5. The procedure also clearly shows different levels of velocity nulling task performance with different subjects. Therefore, there is a high probability that the procedure will be able to reveal any differences in otolith sensitivity that may occur between the pre- and post-flight testing.

The procedure also yields very accurate results. The one sigma deviation and data scatter of the valid results are at or below those of other human subject testing. This is shown for individual results as well as the results of all subjects compared together. Consistency of response with varying profiles is also shown. This proves that the closed-loop test used in this work is an accurate test method. This response consistency is the most encouraging result discovered in this work.

The major effort of this work has been to optimize the test procedure so that this consistency could be obtained as readily as possible. A major factor in the success of the procedure has been restricting the disturbance profile to a maximum velocity of approximately 0.63 m/s and a track length to roughly 2.0 m. This allows some margin for error and varying levels of performance while still yielding a high run completion rate. Another major factor has been scaling the joystick gain to the maximum velocity using the p=95% criterion. (Chapter 3) This gives a quantitative value for the lowest practical sensitivity of the joystick control for any profile. Perhaps the most important factor has been the scaling of the velocity amplitudes at the disturbance frequencies. With this scaling, the disturbance profile has been tailored to the capabilities of the human operator. This has significantly helped the run completion rate and the quality of the results. These are the most important factors discovered in the development of the profile itself. It is felt that a successful profile is not unique, but that the factors described above are. Therefore, there are many possibilities for further work with similar profiles.

A final major factor in the success of the results has been the instruction to the subject to REACT to the disturbance. With subjects following this instruction the results have been improved. This improvement not only shows in the data, but in the subjects performance during the test sessions. This was a major discovery for obtaining consistent data.

No washout filtering was used in the procedure development as it was desired to keep the procedure as simple as possible. A desirable washout would add a below threshold velocity to the cart if it was moving toward the track center and subtract this same velocity if it was moving away from the track center. This would tend to help keep the cart at the center of the track. It would be especially useful during periods of small oscillations when the cart is near the track limits. This type of motion was often seen during the testing and usually led to a short run. It is felt that a washout would not allow more than a 15% increase in the maximum velocity or a disturbance frequency below 0.03 Hz. Larger changes in these requirements would require larger washout amplitudes. This would tend to destroy the quasi-linearity of the sum of sines disturbance and the describing function analysis. A non-linear analysis would then be needed which would be much more difficult to use and interpret.

The procedure reveals differences in subject response which is desirable. These differences are difficult to quantify with the model used, however. Due to numerical problems a simpler transfer function with non-complex poles could not be obtained, as noted in Chapter 6. Although the structure used yielded models with excellent agreement to the log(GAIN) data, it was difficult to compare the parameter values of the models with the associated task performance. The model parameters do not show a simple direct comparison to task performance in all cases, which would be desirable.

The models also do not show good agreement with the phase data. This is primarily due to the emphasis on the low frequency peak, seen in the Bode plot log(GAIN) data, which adds more phase lead. Since such peaks were not clearly shown until the final testing, it is suspected that they are caused by the influence of the excessive cart vibration on the subjects performance. Also, for the small disturbance frequency range used in this testing it is difficult to find a model which will show good log(GAIN) and phase agreement by using only the GAIN data. Since the log(GAIN) showed less variance, however, it is the best data to use for modeling purposes. Either the peaks are not valid and therefore should not be emphasized, or the HO is not a minimum phase system. Further population testing, without the cart vibration, should resolve this discrepancy.

That the phase data shows more variance is not suprising. It has been stated that the otolith organs act as accelerometers and would not sense a constant velocity motion. This often occurred in testing. Subjects usually could sense their motion, through the cart noise and vibration, but were often unsure of their direction. During the acceleration reversals the magnitude and direction could be clearly sensed, but between these reversals there was confusion. Subjects often used small control inputs to determine their motion during these parts of the profile. Such inputs would have little influence on the GAIN data, due to their low amplitudes, but would have much influence on the phase data, due to their sign reversals. It is probably this effect which results in more phase variance.

7.2) Recommendations for Further Work

The most important recommendation is the need for further population testing. A larger subject sample is needed to confirm that the trends seen in this work are valid. This will also help determine the effects of the cart vibration.

Another model structure should be investigated. A more consistent structure for all subject responses would be desirable. A more simple and direct performance indication from the model parameters is also desired. A better phase fit may also be obtained by a different model structure. Possibly both the GAIN and the phase data could be used in the modeling to achieve this.

A washout filter should also be investigated. The main result desired would be to increase the run completion rate. If this occurred perhaps the effects of a higher maximum velocity and/or a lower disturbance frequency range could be investigated. This would help to more fully define the low frequency response.

Since the cart dynamics have not been clearly seperated form the HO response in this work, it is felt that this should be investigated. It would be interesting to see what effects varying cart dynamics had on the HO response. It would be desirable to use a system with cart dynamics clearly different than the HO response discovered in this work. This would hopefully reveal more clearly the capabilitiy and adaptability of the HO in this particular task.

APPENDIX A

SLED SYSTEM PICTURES

The following pictures show the various head restraint and joystick configurations used in the testing.

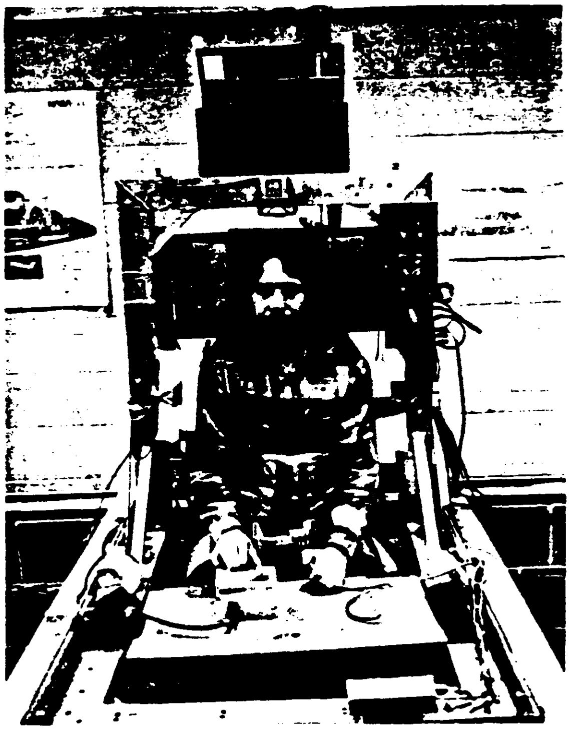


Figure A.1 Seated Subject with Open-Faced Head Restraint Used in Initial Tests

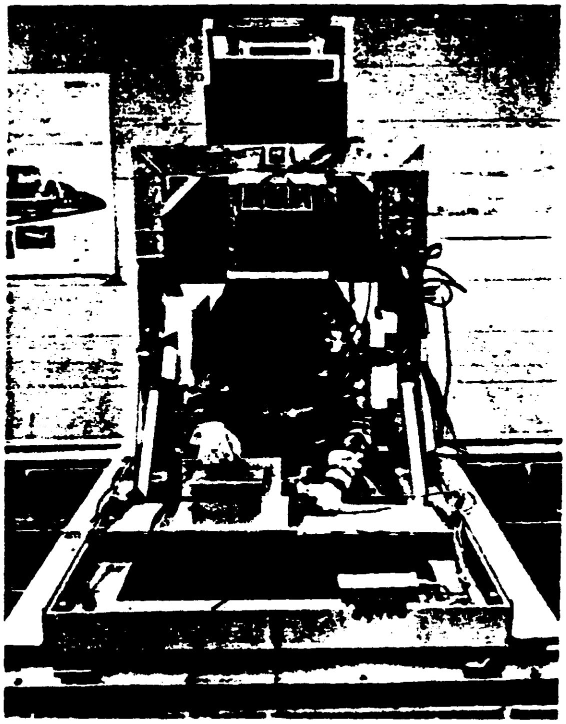


Figure A.2 Seated Subject with Enclosed Head Restraint

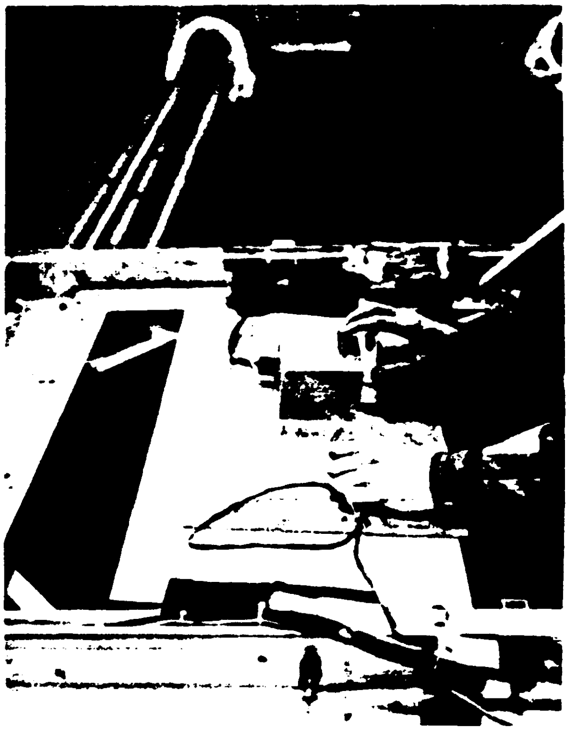


Figure A.3 Seated Subject with Wheel Joystick Used in Initial Tests

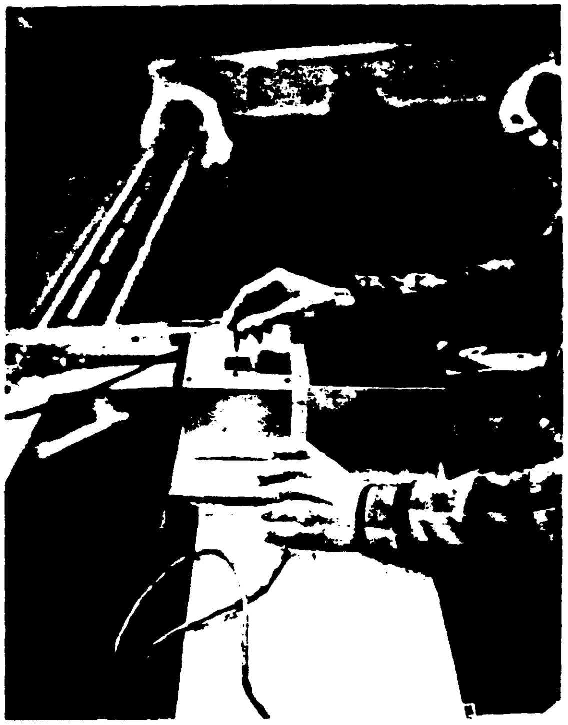


Figure A.4 Seated Subject with Joystick Controller

APPENDIX B

PROFILE GENERATION PROGRAMS

The two versions of the profile generation program used in this work are listed. The hierarchy is as follows:

Program	Subroutines	Data Files	Page
QSOS.FUN	SUMSIN.FUN,POWER.FUN	PRIMES.DAT	131-139
DSOS.FOR	SUMSIN.FOR, FPOWER.FOR	PRIMES.DAT, DSOS.DAT AMPAG.DAT	140-145

Program QSOS.FUN is a CART program subroutine accessed by the SO command. It is used with the PDP 11/34 minicomputer. Program DSOS.DAT is used on the VAX computer and is a simplified copy of QSOS.FUN. (DSOS.DAT is also a subroutine, as a simple command program (not listed) is used to run it.)

Both programs are the same except for their input and output formats. Program QSOS.FUN is user friendly. Only the prime numbers are input from a separate data file. The program prompts the user for all other inputs. The inputs and outputs are displayed in a self-explanatory format. A sample input and output is shown.

Program DSOS.FOR uses inputs from separate files. PRIMES.DAT contains the prime numbers as in the QSOS.FUN program. DSOS.DAT contains all other parameter inputs. The program prompts the user to determine if single or multiple DEL frequencies are to be used. The multiple DEL frequencies must be set in the program itself. It also prompts the user to determine if arbitrary amplitudes will be used as contained in file AMPAG.DAT, and to determine if histogram data is required. The input aand output parameters are displayed by their variable names as described in Chapter 3. The profile amplitudes and frequencies are then displayed as in QSOS.FUN. Input and output is also shown for the same example run used for the QSOS.FUN program example.

```
CART SYSTEM V03
      INTEGER FUNCTION QSOS (TRUN,STPOS,TLOOP,RSINES,TO)
C
C  Sets parameters for sum of sinusoids profile.
C  Author: A.P. Arrott
C  Adapted from RANDOM.SUB (Arrott,4-May-79)
C  Required subprograms:
C     FUNCTION POWER  (which shares COMMON BLOCK/FILCOM/)
C     FUNCTION SUMSIN
C     FUNCTION ACCEPT
C     FUNCTION IACCEP
C
C  ============
C  DECLARATIONS
C  ============
C
      INTEGER PCODE,PRIME(50),FLAMPA
      LOGICAL ANSWER,YES
      REAL LVEL
      REAL W(50),WT(50),BOXW(51),COSAMP(50),COSPHI(50)
C
      INTEGER ZNSINE,ZTO,FLAT
      INTEGER FILTER
      REAL TL(5)
      REAL KCMD
      REAL AMP(50),WDELT(50),PHI(50),AMPAG(50)
C
      COMMON/GLOBAL/ TRACK,GMAX,DECMAX,TL
      COMMON/UNITS/  KCMD
      COMMON/SOS/    AMP,WDELT,PHI,ZTRUN,ZSTPOS,ZTLOOP,ZNSINE,ZTO,
     +                  DELPHI,POSLIM,ACCLIM,FLAT
      COMMON/FILCOM/ FILTER,POLE
C
      DATA PI/3.14159/,YES/'Y'/,INFLAG/0/
      DATA PRIME/3,5,7,11,13,17,19,23,29,31,37,41,43,47,53,61,73,83,
     +    101,113,137,149,163,181,199,233,263,293,317,353,383,421,457,
     +    499,547,587,619,661,691,739,787,823,863,911,947,997,1051,
     +    1091,1163,1193/
C
      QSOS=4
      FLAMPA=0
C
C   Convert phase angles from phase at t=TO-TLOOP to phase at t=0.
      DO 112 I=1,ZNSINE
112   PHI(I)=PHI(I)+(ZTO/ZTLOOP-1)*WDELT(I)
C   Convert amplitudes from m/s to cart command units.
      DO 114 I=1,ZNSINE
114   AMP(I)=AMP(I)/KCMD
C
C   Previous parameters
      TRUN=ZTRUN
      STPOS=ZSTPOS
      TLOOP=ZTLOOP
      NSINES=ZNSINE
      TO=ZTO
C
C  ==========================
C  OBTAIN PRIME NUMBER SERIES
C  ==========================
C
      CALL TTYOUT('$Use prime number table ? $')
      READ(5,116) ANSWER
116   FORMAT(A1)
      IF(ANSWER.NE.YES) GOTO 120
      CALL ASSIGN(4,'PRIMES.DAT')
      READ(4,117) NPRIME
117   FORMAT(I5)
      DO 118 I=1,NPRIME
      READ(4,117) IPRIME
118   PRIME(I)=IPRIME
      DO 119 I=NPRIME+1,50
119   PRIME(I)=0
      CALL CLOSE(4)
      WRITE(7,1195) PRIME
1195  FORMAT(2X,5I5)
C
```

```
C   ==========================
C   DISPLAY TABLE OF PARAMETERS
C   ==========================
C
 120   WRITE(7,121) TRUN,NSINES,1./TRUN,FLAT,360.*DELPHI/(2.*PI),
     +    FILTER,POLE/(2.*PI),POSLIM*2.,ACCLIM/9.812,TLOOP,FLAMPA
 121   FORMAT ('0==================================================='/
     +          '  SUM OF SINES PROFILE'//
     +          '     1. DURATION OF PROFILE:    ',F7.2,' SEC'/
     +          '  PARAMETERS OF SINUSOIDS:'/
     +          '     2. NUMBER OF SINUSOIDS:    ',I6,/
     +          '     3. FUNDAMENTAL FREQUENCY: ',F9.4,' HZ'/
     +          '     4. EQUAL AMPLITUDE DOMAIN:',I6,' (-1,P;0,V;+1,A)'/
     +          '     5. SUCCESSIVE PHASE ANGLE:',F7.0,'    DEG'/
     +          '  PARAMETERS OF SHAPING FUNCTION:'/
     +          '     6. ORDER OF FILTER:        ',I6,/
     +          '     7. POLE:                   ',F9.2,' HZ'/
     +          '  PHYSICAL CONSTRAINTS:'/
     +          '     8. LENGTH OF TRACK:         ',F9.2,' M'/
     +          '     9. ALLOWED ACCELERATION:  ',F9.2,' G'/
     +          '    10. TIME INCREMENT:        ',F10.3,' SEC'/
     +          '  ARBITRARY ACCELERATION AMPLITUDE:'/
     +          '    11. ARBITRARY AMP FLAG:     ',I6,' (0,NO;1,YES)'/)
       IF (INFLAG.EQ.0) GO TO 650
       WRITE(7,122)
 122   FORMAT ('0 RESULTING IN THE SUM OF SINUSOIDS:'/
     +          '        FREQ        AMP       ACCEL AMP    PHASE'/
     +          '        [HZ]       [M/S]         [G]       [DEG]')
C
C   =======================
C   GENERATE FREQUENCY TABLE
C   =======================
C
 200   CONTINUE
C
C   FIRST METHOD:  USE PRIME NUMBERS STORED IN FILE, 'PRIMES.TAB'
C
C      CALCULATE HARMONIC FREQUENCIES
       FUNDA=2.*PI/TRUN      ! FUNDAMENTAL FREQUENCY
       DO 220 J=1,NSINES
        W(J)=PRIME(J)*FUNDA     ! HARMONIC FREQUENCIES
        WDELT(J)=W(J)*TLOOP     ! INCREMENT OF SINE ARGUMENT FOR W(J)
 220    CONTINUE
       GO TO 230
C
C   SECOND METHOD:  DETERMINE EQUAL SPACING OF LN(PRIMES)
C                   (ALLOWS INDEPENDENT SETTING OF HIGH,LOW,
C                    AND NO. OF FREQUENCIES IN SIGNAL)
C
C              ** TO BE DEVELOPED **
C
C   ======================
C   GENERATE AMPLITUDE TABLE
C   ======================
C
C USE ARBITRARY ACCELERATION AMPLITUDES FROM FILE 'AMPAG.DAT'
 230   IF(FLAMPA.EQ.0)GO TO 240
       CALL ASSIGN(10,'AMPAG.DAT')
       READ(10,*)(AMPAG(I),I=1,NSINES)
       DO 232 I=1,NSINES
 232   AMP(I)=AMPAG(I)*9.81/W(I)
       GO TO 260
C
C
 240   CONTINUE
       IF(FLAT) 241,242,243
C
 241   DO 2415 J=1,NSINES      ! EQUAL AMPLITUDES OF POSITION
 2415   AMP(J)=W(J)
       GO TO 244
C
 242   DO 2425 J=1,NSINES      ! EQUAL AMPLITUDES OF VELOCITY
 2425   AMP(J)=1.
       GO TO 244
C
 243   DO 2435 J=1,NSINES      ! EQUAL AMPLITUDES OF ACCELERATION
 2435   AMP(J)=1./W(J)
C
 244   CONTINUE
C
```

```
          IF(FILTER.EQ.0) GO TO 260
          IF(NSINES.EQ.1) GO TO 260
C
C   S H A P I N G    F U N C T I O N
C         (adapted from LNKRUN by G.L.Zacharias)
C
C   CALCULATE FICTITIOUS END FREQUENCIES
          WO=W(1)*W(1)/W(2)
          W(NSINES+1)=W(NSINES)*W(NSINES)/W(NSINES-1)
C
C   CALCULATE BOX FREQUENCIES
          DO 245 J=NSINES+1,2,-1
245        BOXW(J)=SQRT(W(J-1)*W(J))
          BOXW(1)=SQRT(WO*W(1))
C
C   CALCULATE AMPLITUDES
          GAIN=2./(POWER(BOXW(NSINES+1))-POWER(BOXW(1)))
          DO 248 J=1,NSINES
248        AMP(J)=AMP(J)*SQRT(GAIN*(POWER(BOXW(J+1))-POWER(BOXW(J))))
C
C  ===================
C  GENERATE PHASE ARRAY
C  ===================
C
260     CONTINUE
C
C  FIRST METHOD: CONSTANT PHASE DIFFERENCE
          PHI(1)=0.
          DO 264 J=2,NSINES
           PHI(J)=PHI(J-1)+DELPHI
           PHI(J)=AMOD(PHI(J),2.*PI)    ! REMAINDER FUNCTION
264        CONTINUE                     !  (ADJUSTS PHASES > 2*PI)
          GO TO 400
C
C  SECOND METHOD: SET PHASES INDIVIDUALLY
C
C          ** TO BE DEVELOPED **
C
C  ========================
C  FIND FIRST ZERO CROSSING    (THEREBY ESTABLISHING THE
C  ========================      BEGINNING OF THE SIGNAL)
C
400     CONTINUE
C
C   GENERATE VELOCITY SIGNAL
C     INITIALIZE
          TO=0.
          DO 420 J=1,NSINES
420        WT(J)=-WDELT(J)
          LVEL=SUMSIN(NSINES,AMP,WT,WDELT,PHI)  ! VALUE AT T=0
C                (ALGORITHM IGNORES POSSIBILITY THAT T=0 IS
C                                   A ZERO CROSSING)
C     ITERATE
430       TO=TO+TLOOP
          VEL=SUMSIN(NSINES,AMP,WT,WDELT,PHI)
C
C   COMPARE VALUE WITH VALUE OF PREVIOUS ITERATION
          IF (VEL.GE.O.AND.LVEL.LE.O.) GO TO 440
          IF (VEL.LE.O.AND.LVEL.GE.O.) GO TO 440
          LVEL=VEL   ! ZERO CROSSING NOT FOUND: UPDATE 'LVEL',
          IF (TO.GT.TRUN) GO TO 434       ! CHECK FOR END OF SIGNAL,
          GO TO 430                       ! AND ITERATE AGAIN.
C
C   ERROR: NO ZERO CROSSING FOUND IN SIGNAL
434       WRITE(7,435)
435       FORMAT (' ===>Error[QSOS] Unable to find zero crossing of',
         +    ' signal.')
          GOTO 120
C
C   ZERO CROSSING DETECTED
440       CONTINUE
C
```

```
C  ============================
C  DETERMINE SIGNAL SCALE FACTOR
C  ============================
C
C   GENERATE POSITION PROFILE
C     INITIALIZE
      DO 520 J=1,NSINES
       WT(J)=TO*W(J)-WDELT(J)     ! START SIGNAL AT TO
       COSAMP(J)=AMP(J)/W(J)      ! INTEGRATION COEFFICIENT
       COSPHI(J)=PHI(J)-.5*PI     ! INTEGRATION PHASE (1/4 CYCLE LAG)
520    CONTINUE
      NSTEPS=TRUN/TLOOP
      POSMAX=0.
      POSMIN=0.
C     ITERATE
      DO 540 IT=1,NSTEPS
       POS=SUMSIN(NSINES,COSAMP,WT,WDELT,COSPHI)
C
C   FIND MAX/MIN
       IF(POS.GT.POSMAX) POSMAX=POS
       IF(POS.LT.POSMIN) POSMIN=POS
540    CONTINUE
C
C   SCALE SIGNAL TO LENGTH OF TRACK
      PSF=POSLIM*2./(POSMAX-POSMIN)  ! POSITION SCALE FACTOR
C
C   GENERATE ACCELERATION PROFILE
C     INITIALIZE
      DO 570 J=1,NSINES
       WT(J)=TO*W(J)-WDELT(J)
       COSAMP(J)=PSF*AMP(J)*W(J)  ! DERIVATIVE COEFFICIENT
       COSPHI(J)=PHI(J)+.5*PI     ! DERIVATIVE PHASE (1/4 CYCLE LEAD)
570    CONTINUE
      ACCMAX=0.
      ACCMIN=0.
C     ITERATE
      DO 580 IT=1,NSTEPS
       ACC=SUMSIN(NSINES,COSAMP,WT,WDELT,COSPHI)
C
C   FIND MAX/MIN ACCELERATION
       IF (ACC.GT.ACCMAX) ACCMAX=ACC
       IF (ACC.LT.ACCMIN) ACCMIN=ACC
580    CONTINUE
C
C   DETERMINE ACCELERATION SCALE FACTOR
      IF (ABS(ACCMIN).GT.ACCMAX) ACCMAX=-ACCMIN
      ASF=ACCLIM/ACCMAX
      IF (ACCMAX.LE.ACCLIM) ASF=1.
C
C   CALCULATE SIGNAL SCALE FACTOR AND SCALE AMPLITUDES
      USAGE=ASF*100.         ! PERCENT USAGE OF TRACK
      SCALE=PSF*ASF          ! SIGNAL SCALE FACTOR
      DO 590 J=1,NSINES
590    AMP(J)=SCALE*AMP(J)
      ACCMAX=ASF*ACCMAX  ! MAXIMUM ACCELERATION IN SIGNAL
C
C   CALCULATE STARTING POSITION
      DO 594 J=1,NSINES
       WT(J)=TO*W(J)-WDELT(J)
       COSAMP(J)=AMP(J)/W(J)
       COSPHI(J)=PHI(J)-.5*PI  !CHANGED + TO - DWH 25/AUG/82
594    CONTINUE
      STPOS=SUMSIN(NSINES,COSAMP,WT,WDELT,COSPHI)
     +             -(POSMAX+POSMIN)*.5*SCALE
C
C  ============================
C  DISPLAY SIGNAL CHARACTERISTICS
C  ============================
C
600   CONTINUE
C
C   DISPLAY FREQUENCIES, AMPLITUDES, AND PHASES OF SINUSOIDS
      DO 620 J=1,NSINES
       WRITE(7,611) W(J)/(2.*PI), AMP(J), AMP(J)*W(J)/9.81,
     +              W(J)*TO+360.*PHI(J)/(2.*PI)
611    FORMAT(F11.3,F11.2,F11.3,F11.0)
620    CONTINUE
C
```

```
C     DISPLAY OTHER SIGNAL CHARACTERISTICS
      WRITE(7,631) ACCMAX/9.81         ! CONVERT TO UNITS OF GRAV.ACC.
631   FORMAT('OMAXIMUM ACCELERATION IN SIGNAL:',F7.3,' G')
      WRITE(7,635) USAGE               ! PERCENT USAGE OF TRACK
635   FORMAT(' PERCENT USAGE OF TRACK:',F7.2,'%')
C     WRITE(7,637) STPOS,TO*100/TRUN
C637  FORMAT(' INITIAL POSITION:',F5.2,' FT
C     +             [SIGNAL SHIFT:',F6.2,'%]')
C
      WRITE(7,638) STPOS
638   FORMAT(' STARTING POSITION:',F7.2)
C     WRITE(7,6383) SCALE,SCALE*POSMAX,SCALE*POSMIN
C6383 FORMAT(' SCALE:',F5.2,'PMAX:',F6.2,'PMIN:',F6.2)
C     WRITE(7,6385) SCALE*(POSMIN+POSMAX)*.5,SCALE*(POSMAX-POSMIN)*.5
C6385 FORMAT(' AVG:',F7.2,'TRACK USED:',F7.2)
      WRITE(7,639)
639   FORMAT(' ====================================================')
C
C   ============================
C   INTERACTIVE PARAMETER CHANGES
C   ============================
C
640   WRITE(7,641)
641   FORMAT('$OK? ')
      READ(5,643) ANSWER
643   FORMAT(A1)
      IF (ANSWER.EQ.YES) GO TO 750
C
C    CHANGE PARAMETERS
650   INFLAG=1
      WRITE(7,651)
651   FORMAT('$ PARAMETER #')
      READ(5,653,ERR=650) PCODE
653   FORMAT(I9)
      IF (PCODE.EQ.0) GO TO 120    ! REDISPLAY SIGNAL PARAMETERS
660   IF (PCODE.LT.1.OR.PCODE.GT.15) GO TO 650
      GO TO (701,702,703,704,705,706,707,708,709,710,711,712,
     +          713,714,715) PCODE
C
C    DURATION OF RUN
701   WRITE(7,7011) TRUN
7011  FORMAT('$DURATION OF RUN:',F5.0,' SEC.        ENTER NEW VALUE: ')
      READ(5,7013,ERR=701) TEMP
7013  FORMAT(F15.6)
      IF (ACCEPT(TEMP,1.,10000.)) 660,650,7016
7016  TRUN=TEMP
      W(1)=2.*PI/TRUN
      W(NSINES)=PRIME(NSINES)*W(1)
      GO TO 650
C
C    NUMBER OF SINES
702   WRITE(7,7021) NSINES
7021  FORMAT('$NUMBER OF SINUSOIDS:',I5,'         ENTER NEW VALUE: ')
      READ(5,7023,ERR=702) ITEMP
7023  FORMAT(I9)
      IF (IACCEP(ITEMP,1,50)) 660,650,7026
7026  NSINES=ITEMP
      W(NSINES)=PRIME(NSINES)*W(1)
      GO TO 650
C
C    FUNDAMENTAL FREQUENCY
703   WRITE(7,7031) W(1)/(2.*PI)
7031  FORMAT('$FUNDAMENTAL FREQUENCY:',F7.4,' HZ. ENTER NEW VALUE: ')
      READ(5,7013,ERR=703) TEMP
      IF (ACCEPT(TEMP,.0001,1.)) 660,650,7036
7036  W(1)=TEMP*2.*PI
      TRUN=1./TEMP
      W(NSINES)=PRIME(NSINES)*W(1)
      GO TO 650
C
C    EQUAL AMPLITUDE DOMAIN
704   WRITE(7,7041) FLAT
7041  FORMAT('$POS=-1,VEL=0,ACC=+1, NOW=',I2,'    ENTER NEW VALUE: ')
      READ(5,7023,ERR=704) ITEMP
      IF (IACCEP(ITEMP,-1,1)) 660,7046,7046
7046  FLAT=ITEMP
      GO TO 650
C
```

```
C   SUCCESSIVE PHASE ANGLES
705   WRITE(7,7051) DELPHI*360./(2.*PI)
7051  FORMAT('$SUCCESSIVE PHASE ANGLE:',F5.0,' DEG. ENTER NEW VALUE: ')
      READ(5,7013,ERR=705) TEMP
      IF (ACCEPT(TEMP,0.,36000.)) 660,650,7056
7056  DELPHI=TEMP*2.*PI/360.
      GO TO 650
C
C   ORDER OF FILTER
706   WRITE(7,7061) FILTER
7061  FORMAT('$ORDER OF FILTER:',I5,'           ENTER NEW VALUE: ')
      READ(5,7023,ERR=706) ITEMP
      IF (IACCEP(ITEMP,1,3)) 660,7066,7066
7066  FILTER=ITEMP
      GO TO 650
C
C   POLE OF FILTER
707   WRITE(7,7071) POLE/(2.*PI)
7071  FORMAT('$POLE OF FILTER:',F5.2,'             ENTER NEW VALUE: ')
      READ(5,7013,ERR=707) TEMP
      IF (ACCEPT(TEMP,.001,10.)) 660,650,7076
7076  POLE=TEMP*2.*PI
      GO TO 650
C
C   LENGTH OF TRACK
708   WRITE(7,7081) POSLIM*2.
7081  FORMAT('$LENGTH OF TRACK:',F5.2,' M.         ENTER NEW VALUE: ')
      READ(5,7013,ERR=708) TEMP
      IF (ACCEPT(TEMP,1.,15.)) 660,650,7086
7086  POSLIM=TEMP*.5
      GO TO 650
C
C   MAXIMUM ALLOWED ACCELERATION
709   WRITE(7,7091) ACCLIM/9.812
7091  FORMAT('$ALLOWED ACCELERATION:',F5.3,',       ENTER NEW VALUE: ')
      READ(5,7013,ERR=709) TEMP
      IF (ACCEPT(TEMP,.001,1.)) 660,650,7096
7096  ACCLIM=TEMP*9.812
      GO TO 650
C
C   TIME INCREMENT
710   WRITE(7,7101) TLOOP
7101  FORMAT('$TIME INCREMENT: ',F5.3,' SEC        ENTER NEW VALUE: ')
      READ(5,7013,ERR=705) TEMP
      IF (ACCEPT(TEMP,.001,.500)) 660,650,7106
7106  TLOOP=TEMP
      GO TO 650
C
C ARBITRARY ACCELERATION AMPLITUDE FLAG
711   WRITE(7,7111) FLAMPA
7111  FORMAT('$ARBITRARY ACCEL AMP FLAG:',I5,'     ENTER NEW VALUE: ')
      READ(5,7023,ERR=711) ITEMP
      IF (IACCEP(ITEMP,0,1))660,7116,7116
7116  FLAMPA=ITEMP
      GO TO 650
712   CONTINUE
713   CONTINUE
714   CONTINUE
715   CONTINUE
      GO TO 650
C
750   RSINES=NSINES                 ! Float no. of sines.
C   Convert from phase angles at t=0 to phase angles at t=T0-TLOOP
      DO 755 I=1,NSINES
755   PHI(I)=PHI(I)+(T0/TLOOP-1)*WDELT(I)
C   Convert amplitudes from m/s to cart command units.
      DO 760 I=1,NSINES
760   AMP(I)=KCMD*AMP(I)
C
      WRITE(7,762)KCMD
762   FORMAT(5X,'KCMD=',F10.4)
C
C   Save parameter values.
      ZTRUN=TRUN
      ZSTPOS=STPOS
      ZTLOOP=TLOOP
      ZNSINE=NSINES
      ZT0=T0
C
      RETURN
      END
```

```
CART SYSTEM V03
      FUNCTION SUMSIN (N,A,WT,WDELT,PHI)
C
C  AUTHOR: ARROTT
C  CREATION DATE: 18-JAN-79
C
C  PURPOSE: ITERATES SUM OF SINES SIGNAL
C
C     N:      NUMBER OF SINES IN SUM.
C     A:      ARRAY OF SINE AMPLITUDES.
C     WT:     ARRAY OF PRODUCTS OF SINE FREQUENCIES AND CURRENT TIME.
C                                       (IN RADIANS)
C     WDELT: ARRAY OF PRODUCTS OF SINE FREQUENCIES AND ITERATION
C                INTERVAL.
C     PHI:    ARRAY OF PHASE ANGLES
C
C
      DIMENSION A(50),WT(50),WDELT(50),PHI(50)
      SUMSIN=0.
      DO 1 J=1,N
       WT(J)=WT(J)+WDELT(J)
       SUMSIN=SUMSIN+A(J)*SIN(WT(J)+PHI(J))
1      CONTINUE
      END
SUMSIN
```

```
      FUNCTION POWER (W)
C
C  Used in calculation of amplitudes of discrete frequencies
C  in the shaping function algorithm in subprogram QSOS.FUN
C
C  Author: G.L.Zacharias (originally FUNCTION PWR in LNKRUN program).
C  Adapted by Arrott for use by module RANDOM.SUB in the SLED program.
C  Adaptation date: 18-Jan-79
C  No changes necessary for use by module QSOS.FUN in CART program.
C
      INTEGER FILTER
      COMMON/FILCOM/FILTER,POLE
C
      TEMP=(ATAN(W/POLE))/POLE
      GO TO (1,2,3) FILTER
C
C  FIRST ORDER FILTER
1     POWER=TEMP
      RETURN
C
C  SECOND ORDER FILTER
2     PP=POLE*POLE
      POWER=(W/(PP+W*W)+TEMP)/(2.*PP)
      RETURN
C
C  THIRD ORDER FILTER
3     PP=POLE*POLE
      PI=PP+W*W
      POWER=-(W*W*W/(PI*PI)-(5.*W/PI+3*TEMP)*.5)/(4.*PP*PP)
      RETURN
C
      END
POWER
```

```
PRIMES.DAT

12
5
7
9
11
13
17
19
23
29
32
37
41
```

```
AMPAG.DAT

0.08,0.09,0.09,0.10,0.10,0.13,0.13,0.12,0.13,0.11,0.11,0.13
```

```
 RUN H1CAR7

CART CONTROLLER      V04.7 (9-NOV-81)      06-JAN-83       16:26:06
CART>SO
Use prime number table ? YES
     5    7    9   11   13
    17   19   23   29   32
    37   41    0    0    0
     0    0    0    0    0
     0    0    0    0    0
     0    0    0    0    0
     0    0    0    0    0
     0    0    0    0    0
     0    0    0    0    0
     0    0    0    0    0

==================================================
 SUM OF SINES PROFILE

    1. DURATION OF PROFILE:     184.32 SEC
 PARAMETERS OF SINUSOIDS:
    2. NUMBER OF SINUSOIDS:        25
    3. FUNDAMENTAL FREQUENCY:    0.0054 HZ
    4. EQUAL AMPLITUDE DOMAIN:     0 (-1,P;0,V;+1,A)
    5. SUCCESSIVE PHASE ANGLE:   247.   DEG
 PARAMETERS OF SHAPING FUNCTION:
    6. ORDER OF FILTER:             2
    7. POLE:                        0.31 HZ
 PHYSICAL CONSTRAINTS:
    8. LENGTH OF TRACK:              4.00 M
    9. ALLOWED ACCELERATION:        0.41 G
   10. TIME INCREMENT:            0.015 SEC
 ARBITRARY ACCELERATION AMPLITUDE:
   11. ARBITRARY AMP FLAG:          0 (0,NO;1,YES)

 PARAMETER #1
DURATION OF RUN: 184. SEC.         ENTER NEW VALUE: 81.92
 PARAMETER #2
NUMBER OF SINUSOIDS:   25          ENTER NEW VALUE: 12
 PARAMETER #3
FUNDAMENTAL FREQUENCY: 0.0122 HZ. ENTER NEW VALUE: 0.0122
 PARAMETER #5
SUCCESSIVE PHASE ANGLE: 247. DEG. ENTER NEW VALUE: 253.
 PARAMETER #6
ORDER OF FILTER:    2              ENTER NEW VALUE: 1
 PARAMETER #7
POLE OF FILTER: 0.31               ENTER NEW VALUE: 0.16
 PARAMETER #8
LENGTH OF TRACK: 4.00 M.           ENTER NEW VALUE: 2.05
 PARAMETER #9
ALLOWED ACCELERATION:0.408,        ENTER NEW VALUE: 0.20
 PARAMETER #10
TIME INCREMENT: 0.015 SEC          ENTER NEW VALUE: .010
 PARAMETER #
```

```
=================================================
SUM OF SINES PROFILE

   1. DURATION OF PROFILE:      81.92 SEC
PARAMETERS OF SINUSOIDS:
   2. NUMBER OF SINUSOIDS:        12
   3. FUNDAMENTAL FREQUENCY:     0.0122 HZ
   4. EQUAL AMPLITUDE DOMAIN:      0 (-1,P;0,V;+1,A)
   5. SUCCESSIVE PHASE ANGLE:    253.    DEG
PARAMETERS OF SHAPING FUNCTION:
   6. ORDER OF FILTER:             1
   7. POLE:                        0.10 HZ
PHYSICAL CONSTRAINTS:
   8. LENGTH OF TRACK:              2.05 M
   9. ALLOWED ACCELERATION:        0.20 G
  10. TIME INCREMENT:             0.010 SEC
ARBITRARY ACCELERATION AMPLITUDE:
  11. ARBITRARY AMP FLAG:          0 (0,NO;1,YES)


RESULTING IN THE SUM OF SINUSOIDS:
      FREQ         AMP        ACCEL AMP      PHASE
      [HZ]        [M/S]          [G]         [DEG]
     0.061         0.12        0.005           0.
     0.085         0.13        0.007         253.
     0.110         0.12        0.008         147.
     0.134         0.11        0.009          40.
     0.159         0.12        0.012         293.
     0.208         0.11        0.015         186.
     0.232         0.10        0.014          79.
     0.281         0.11        0.019         332.
     0.354         0.09        0.021         226.
     0.391         0.07        0.019         119.
     0.452         0.07        0.021          12.
     0.500         0.06        0.020         265.

MAXIMUM ACCELERATION IN SIGNAL:  0.113 G
PERCENT USAGE OF TRACK: 100.00%
STARTING POSITION:  -0.24
==================================================
OK? YES
```

```
      SUBROUTINE DSOS
C
C
C Profile generation for VAX. By Dale W. Hiltner Sept-82
C Copied from CART program subroutine DSOS.FUN
C
C
      REAL LVEL,TL(5),KCMD,AMP(50),WDELT(50),PHI(50)
      REAL W(50),WT(50),BOXW(51),COSAMP(50),COSPHI(50)
      REAL AMPA(50)
      INTEGER PCODE,PRIME(50),ZNSINE,ZTO,FLAT,FILTER
      INTEGER A1,A2,IBC,NBIN,NABIN(41)
      COMMON AMP,WDELT,PHI,TLOOP,NSINES,NSTEPS,TRUN
      COMMON/FILCOM/FILTER,POLE
      DATA PI/3.14159/
C SET PRIME NUMBERS
      CALL ASSIGN(4,'PRIMES.DAT')
      READ(4,500)NPRIME
  500 FORMAT(I5)
      DO 10 I1=1,NPRIME
      READ(4,500)IPRIME
   10 PRIME(I1)=IPRIME
      DO 20 I2=NPRIME+1,50
   20 PRIME(I2)=0.0
C SET OTHER INPUT PARAMETERS
      CALL ASSIGN(6,'DSOS.DAT',0)
      READ(6,*)TRUN,NSINES,FFREQ,FLAT,DEL,FILTER,FPOLE,FPOS,FACC,TLOOP
C
C INPUT ACCELERATION AMPLITUDES ARBITRARILY AND OTHER CHECKS
      WRITE(5,212)
  212 FORMAT(5X,'SET ACCEL AMPS PER AMPAG.DAT? (1=Y/0=N)')
      READ(5,213)A1
  213 FORMAT(I4)
      WRITE(5,214)
  214 FORMAT(5X,'MULTIPLE DEL FREQUENCIES? (1=YES/0=NO)')
      READ(5,215)A2
  215 FORMAT(I4)
      WRITE(5,110)
  110 FORMAT(5X,'CALCULATE HISTOGRAM DATA? (YES=1/NO=0)')
      READ(5,112)IBC
  112 FORMAT(I4)
C
      IF(A2.EQ.0)GO TO 501
C
C SET DEL FREQUENCIES FOR MULTIPLE RUNS
C
      DO 900 III=1,12
      DEL=(III-1)*30.0+13.0
 501  WRITE(7,499)
 499  FORMAT(1X,'INPUT PARAMETERS',/)
      WRITE(7,502)TRUN,NSINES,FFREQ,FLAT,DEL,FILTER,FPOLE,FPOS,FACC,TLOOP
 502  FORMAT(5X,'TRUN=',F8.3,/,5X,'NSINES=',I3,/,5X,'FFREQ=',F9.6,/,
     +        5X,'FLAT=',I2,/,5X,'DEL=',F8.3,/,5X,'FILTER=',I3,/,
     +        5X,'FPOLE=',F8.3,/,5X,'FPOS=',F6.2,/,5X,'FACC=',F6.3,/,
     +        5X,'TLOOP=',F6.3)
C
      DELPHI=DEL*2.0*PI/360.0
      POLE=FPOLE*2.0*PI
      POSLIM=FPOS*0.5
      ACCLIM=FACC*9.812
C FIND HARMONIC FREQUENCIES
      FUNDA=2.0*PI/TRUN
      DO 30 I3=1,NSINES
      W(I3)=PRIME(I3)*FUNDA
      WDELT(I3)=W(I3)*TLOOP
   30 CONTINUE
C
C SET ACCELERATION AMPLITUDES ARBITRARILY
      IF(A1.EQ.0)GO TO 240
      CALL ASSIGN(10,'AMPAG.DAT',0)
      READ(10,*)(AMPA(I),I=1,NSINES)
      CALL CLOSE(10)
      DO 220 I=1,NSINES
  220 AMP(I)=AMPA(I)*9.81/W(I)
      GO TO 260
C
C GENERATE AMPLITUDE TABLE
  240 IF(FLAT)241,242,243
  241 DO 2415 I1=1,NSINES
 2415 AMP(I1)=W(I1)
      GO TO 244
```

```
  242   DO 2425 I2=1,NSINES
 2425   AMP(I2)=1.0
        GO TO 244
  243   DO 2435 I3=1,NSINES
 2435   AMP(I3)=1.0/W(I3)
C
  244   IF(FILTER.EQ.0)GO TO 260
        IF(NSINES.EQ.1)GO TO 260
C
C SHAPING FUNCTION
C
C CALCULATE FICTICTIOUS END FREQUENCIES
C
        WO=W(1)*W(1)/W(2)
        W(NSINES+1)=W(NSINES)*W(NSINES)/W(NSINES-1)
C
C CALCULATE BOX FREQUENCIES
        DO 245 J=NSINES+1,2,-1
  245   BOXW(J)=SQRT(W(J-1)*W(J))
        BOXW(1)=SQRT(WO*W(1))
C
C CALCULATE AMPLITUDES
        GAIN=2.0/(FPOWER(BOXW(NSINES+1))-FPOWER(BOXW(1)))
        DO 248 J=1,NSINES
  248   AMP(J)=AMP(J)*SQRT(GAIN*(FPOWER(BOXW(J+1))-FPOWER(BOXW(J))))
C
C
  260   CONTINUE
C CONSTANT PHASE DIFFERENCE
        PHI(1)=0
        DO 264 J=2,NSINES
        PHI(J)=PHI(J-1)+DELPHI
        PHI(J)=AMOD(PHI(J),2.0*PI)
  264   CONTINUE
C GENERATE VELOCITY SIGNAL
        TO=0.0
        DO 420 J=1,NSINES
  420   WT(J)=-WDELT(J)
        LVEL=SUMSIN(NSINES,AMP,WT,WDELT,PHI)
  430   TO=TO+TLOOP
        VEL=SUMSIN(NSINES,AMP,WT,WDELT,PHI)
        IF(VEL.GE.0.AND.LVEL.LE.0)GO TO 440
        IF(VEL.LE.0.AND.LVEL.GE.0)GO TO 440
        LVEL=VEL
        IF(TO.GT.TRUN)GO TO 434
        GO TO 430
  434   WRITE(7,435)
  435   FORMAT('NO ZERO CROSSING FOUND. TERMINATE  PROGRAM.')
        GO TO 99999
C FIND MAX, MIN VELOCITY
  440   NSTEPS=TRUN/TLOOP
        VELMAX=0.0
        VELMIN=0.0
        DO 445 I4=1,NSINES
  445   WT(J)=TO*W(J)-WDELT(J)
        DO 450 I5=1,NSTEPS
        VEL=SUMSIN(NSINES,AMP,WT,WDELT,PHI)
        IF(VEL.GT.VELMAX)VELMAX=VEL
        IF(VEL.LT.VELMIN)VELMIN=VEL
  450   CONTINUE
        IF(ABS(VELMIN).GT.VELMAX)VELMAX=-VELMIN
C
C GENERATE POSITION PROFILE
        DO 520 J=1,NSINES
        WT(J)=TO*W(J)-WDELT(J)
        COSAMP(J)=AMP(J)/W(J)
        COSPHI(J)=PHI(J)-0.5*PI
  520   CONTINUE
C FIND MAX AND MIN POSITION
        NSTEPS=TRUN/TLOOP
        POSMAX=0.0
        POSMIN=0.0
        DO 540 IT=1,NSTEPS
        POS=SUMSIN(NSINES,COSAMP,WT,WDELT,COSPHI)
        IF(POS.GT.POSMAX)POSMAX=POS
        IF(POS.LT.POSMIN)POSMIN=POS
  540   CONTINUE
C SCALE SIGNAL TO LENGTH OF TRACK
        PSF=POSLIM*2.0/(POSMAX-POSMIN)
```

```
C GENERATE ACCELERATION PROFILE
        DO 570 J=1,NSINES
        WT(J)=TO*W(J)-WDELT(J)
        COSAMP(J)=PSF*AMP(J)*W(J)
        COSPHI(J)=PHI(J)+0.5*PI
  570   CONTINUE
C FIND MAX AND MIN ACCELERATION
        ACCMAX=0.0
        ACCMIN=0.0
        DO 580 IT=1,NSTEPS
        ACC=SUMSIN(NSINES,COSAMP,WT,WDELT,COSPHI)
        IF(ACC.GT.ACCMAX)ACCMAX=ACC
        IF(ACC.LT.ACCMIN)ACCMIN=ACC
  580   CONTINUE
C DETERMINE ACCELERATION SCALE FACTOR
        IF(ABS(ACCMIN).GT.ACCMAX)ACCMAX=-ACCMIN
        ASF=ACCLIM/ACCMAX
        IF(ACCMAX.LE.ACCLIM)ASF=1.0
C CALCULATE SIGNAL SCALE FACTOR AND SCALE AMPLITUDES
        USAGE=ASF*100.0
        SCALE=PSF*ASF
        DO 590 J=1,NSINES
  590   AMP(J)=SCALE*AMP(J)
        ACCMAX=ASF*ACCMAX
C CALCULATE STARTING POSITION
        DO 594 J=1,NSINES
        WT(J)=TO*W(J)-WDELT(J)
        COSAMP(J)=AMP(J)/W(J)
        COSPHI(J)=PHI(J)-0.5*PI
  594   CONTINUE
        STPOS=SUMSIN(NSINES,COSAMP,WT,WDELT,COSPHI)
     +         -(POSMAX+POSMIN)*0.5*SCALE
C HISTOGRAM DATA CALCULATION
        IF(IBC.EQ.0)GO TO 831
        DO 120 J=1,NSINES
        WT(J)=TO*W(J)-WDELT(J)
        COSAMP(J)=AMP(J)*W(J)
        COSPHI(J)=PHI(J)+0.5*PI
  120   CONTINUE
        ACC=0.0
        DO 124 I=1,41
  124   NABIN(I)=0
        DO 122 I=1,NSTEPS
        ACC=SUMSIN(NSINES,COSAMP,WT,WDELT,COSPHI)
        VACC=ABS(ACC/9.81)/0.005
        NBIN=VACC+1
        NABIN(NBIN)=NABIN(NBIN)+1
  122   CONTINUE
C
C DISPLAY OUTPUT
        WRITE(7,829)
  829   FORMAT(1X,/,'PROFILE DESCRIPTION',/)
  831   WRITE(7,830)ACCMAX/9.81,VELMAX*SCALE,USAGE,STPOS,SCALE
  830   FORMAT(5X,'MAX ACCEL=',F6.3,/,5X,'VELMAX=',F8.4,/,
     +         5X,'% USEAGE OF TRACK=',F6.2,/,
     +         5X,'STARTING POSITION=',F6.3,/,
     +         5X,'SCALE=',F7.4,/)
        WRITE(7,800)
  800   FORMAT(1X,'FREQ.  (HZ)',3X,'AMP1  (M/S)',3X,'AMP2  (G)  ',
     +         2X,'PHASE (DEG)')
        DO 620 J=1,NSINES
        WRITE(7,810)W(J)/(2.0*PI),AMP(J),AMP(J)*W(J)/9.81,
     +                 W(J)*TO+360.0*PHI(J)/(2.0*PI)
  810   FORMAT(1X,F11.4,3X,F11.2,3X,F11.3,3X,F11.0)
  620   CONTINUE
C
C OUTPUT HISTOGRAM VALUES
        IF(IBC.EQ.0)GO TO 899
        WRITE(7,117)
  117   FORMAT(/,1X,'HISTOGRAM DATA',/)
        DO 116 I=1,41
        VBIN=I*0.005
        WRITE(7,118)VBIN,NABIN(I)
  118   FORMAT(5X,'ACC BIN=',F6.3,5X,'# ACC POINTS=',I6)
  116   CONTINUE
  899   IF(A2.EQ.0)GO TO 99999
C
  900   CONTINUE
C
99999   RETURN
        END
```

```
      FUNCTION SUMSIN(N,A,WT,WDELT,PHI)
C
C Calculates sum of sinusoids. From SUMSIN.FUN in
C CART program. Stored by Dale W. Hiltner/ SEPT-82
C
      REAL A(50),WT(50),WDELT(50),PHI(50)
      SUMSIN=0.0
      DO 10 I1=1,N
      WT(I1)=WT(I1)+WDELT(I1)
      SUMSIN=SUMSIN+A(I1)*SIN(WT(I1)+PHI(I1))
   10 CONTINUE
      END
```

```
      FUNCTION FPOWER(W)
C
C Calculates filter amplitudes for magnitude
C scaling in dbs. From POWER.FUN in CART
C program. Stored by Dale W. Hiltner/ OCT-82
      INTEGER FILTER
      COMMON/FILCOM/FILTER,POLE
C
      TEMP=(ATAN(W/POLE))/POLE
      GO TO (1,2,3)FILTER
C
C FIRST ORDER FILTER
    1 FPOWER=TEMP
      GO TO 9999
C
C SECOND ORDER FILTER
    2 PP=POLE*POLE
      FPOWER=(W/(PP+W*W)+TEMP)/(2.0*PP)
      GO TO 9999
C
C THIRD ORDER FILTER
    3 PP=POLE*POLE
      PI=PP+W*W
      FPOWER=-(W*W*W/(PI*PI)-(5.0*W/PI+3*TEMP)*0.5)/(4.0*PP*PP)
      GO TO 9999
C
 9999 END
```

```
PRIMES.DAT

12
5
7
9
11
13
17
19
23
29
32
37
41


DSOS.DAT

81.92,12,0.01221,0,253.0,1,0.16,2.05,0.20,0.010


AMPAG.DAT

0.08,0.09,0.09,0.10,0.10,0.13,0.13,0.12,0.13,0.11,0.11,0.13
```

```
   SET ACCEL AMPS PER AMPAG.DAT? (1=Y/0=N)
  0
   MULTIPLE DEL FREQUENCIES? (1=YES/0=NO)
  0
   CALCULATE HISTOGRAM DATA? (YES=1/NO=0)
  1

INPUT PARAMETERS

    TRUN=  81.920
    NSINES= 12
    FFREQ= 0.012210
    FLAT= 0
    DEL= 253.000
    FILTER=  1
    FPOLE=    0.160
    FPOS=   2.05
    FACC= 0.200
    TLOOP= 0.010

PROFILE DESCRIPTION

    MAX ACCEL= 0.113
    VELMAX=   0.6290
    % USEAGE OF TRACK=100.00
    STARTING POSITION=-0.236
    SCALE= 0.2502

FREQ.  (HZ)    AMP1   (M/S)    AMP2   (G)     PHASE (DEG)
     0.0610             0.12          0.005            0.
     0.0854             0.13          0.007          253.
     0.1099             0.12          0.008          147.
     0.1343             0.11          0.009           40.
     0.1587             0.12          0.012          293.
     0.2075             0.11          0.015          186.
     0.2319             0.10          0.014           79.
     0.2808             0.11          0.019          332.
     0.3540             0.09          0.021          226.
     0.3906             0.07          0.019          119.
     0.4517             0.07          0.021           12.
     0.5005             0.06          0.020          265.

HISTOGRAM DATA

    ACC BIN= 0.005      # ACC POINTS=    862
    ACC BIN= 0.010      # ACC POINTS=   1059
    ACC BIN= 0.015      # ACC POINTS=   1048
    ACC BIN= 0.020      # ACC POINTS=    808
    ACC BIN= 0.025      # ACC POINTS=    684
    ACC BIN= 0.030      # ACC POINTS=    551
    ACC BIN= 0.035      # ACC POINTS=    559
    ACC BIN= 0.040      # ACC POINTS=    426
```

```
ACC BIN= 0.045      $ ACC POINTS=   355
ACC BIN= 0.050      $ ACC POINTS=   342
ACC BIN= 0.055      $ ACC POINTS=   313
ACC BIN= 0.060      $ ACC POINTS=   210
ACC BIN= 0.065      $ ACC POINTS=   207
ACC BIN= 0.070      $ ACC POINTS=   175
ACC BIN= 0.075      $ ACC POINTS=   180
ACC BIN= 0.080      $ ACC POINTS=   126
ACC BIN= 0.085      $ ACC POINTS=    83
ACC BIN= 0.090      $ ACC POINTS=    41
ACC BIN= 0.095      $ ACC POINTS=    26
ACC BIN= 0.100      $ ACC POINTS=    30
ACC BIN= 0.105      $ ACC POINTS=    49
ACC BIN= 0.110      $ ACC POINTS=    37
ACC BIN= 0.115      $ ACC POINTS=    21
ACC BIN= 0.120      $ ACC POINTS=     0
ACC BIN= 0.125      $ ACC POINTS-     0
ACC BIN= 0.130      $ ACC POINTS=     0
ACC BIN= 0.135      $ ACC POINTS=     0
ACC BIN= 0.140      $ ACC POINTS=     0
ACC BIN= 0.145      $ ACC POINTS=     0
ACC BIN= 0.150      $ ACC POINTS=     0
ACC BIN= 0.155      $ ACC POINTS=     0
ACC BIN= 0.160      $ ACC POINTS=     0
ACC BIN= 0.165      $ ACC POINTS=     0
ACC BIN= 0.170      $ ACC POINTS=     0
ACC BIN= 0.175      $ ACC POINTS=     0
ACC BIN= 0.180      $ ACC POINTS=     0
ACC BIN= 0.185      $ ACC POINTS      0
ACC BIN= 0.190      $ ACC POINTS=     0
ACC BIN= 0.195      $ ACC POINTS=     0
ACC BIN= 0.200      $ ACC POINTS=     0
ACC BIN= 0.205      $ ACC POINTS=     0
```

APPENDIX C

DATA REDUCTION PROGRAMS

The programs used in the data reduction are listed. Their hierarchy is as follows:

Program	Subroutines	Data File	Page
H1PIKY.DHF	H1CNDY.DHF		148-151
H1CY.DHF	H1FFTC.DHF, H1TRFY.DHF H1TY.DHF, H1NFC.DHF		152-159
H1PIKP.DHF	H1CNDP.DHF, H1SUM.DHF	H1RATK.DAT	160-166

Program H1PIKY.DHF is the first program used in the data reduction process. It accesses and concatenates the 8192 points of channels 1,2,3,4, and 6 stored in the run data file into 1024 points. It then prints out the statistics of each channel and outputs the 1024 points of channels 2,3,4, and 6 into separate files. (The statistics are output in count units so the calibrations of Chapter 3 must be used to convert them to engineering units. The position data is not used beyond finding its statistics.) Program H1CY.DHF then accesses these files, performs the FFT, and outputs the desired response results. A sample run is shown.

Program H1PIKP.DHF is used to generate statistcs for groups of data files. Up to 30 data files with the same first three letters in their filenames, and therefore from the same test session, can be processed in one run. All points contained in full blocks are used in the calculations. (If the last block in the data file is not full, the data in this block is not used.) Individual statistics are output as with H1PIKY.DHF, but in engineering units. The file H1RATK.DAT stores the position, velocity, acceleration, and command RMS values from the no subject runs, or any other baseline values desired. These values sre then used to produce the RMS ratios which are ouput in summary form. A sample input and output is shown.

```
      PROGRAM H1FINY
C
C  Author: Jen-Kuang Huang/Dale W. Hiltner
C  Creation Date: 22-APR-82/SEPT-82
C
C  Pick up sled data(5 channels, 256 word record, 385 blocks)
C  Currently assumes input data file is 10240 ticks long, with data
C    points per time tick
C  Program writes out a data point for every tick, for one specified
C    channel of data  ==> can run H1CY to reduce data.
C
      DIMENSION INBUF(256),IOBUF(256)
      REAL JSCALE,TRUN
      INTEGER OUT1(10240)
      INTEGER PRFILE(30)
      LOGICAL*1 ZFILE(10),FILEP(3),FILEN(120),FILEE(4)
      COMMON/CM1/IBR,II9
      COMMON/CM2/JSCALE,TRUN
      DATA FILEE/'.','C','V','4'/
C
      WRITE(7,100)
  100 FORMAT(' Pick up input/output sled data. Channels 1,2,3,4,6.',/,
     +  '     Currently accepts maximum of 10240 samples per channel ')
C
C
      WRITE(7,121)
  121 FORMAT(/,2X,'ENTER JSCALE FACTOR,RUN TIME TRUN')
      READ(5,123)JSCALE,TRUN
  123 FORMAT(F6.2,F9.4)
C
 101  WRITE(7,102)
  102 FORMAT(/,2X,'ENTER INPUT FILE 6 LETTER CODE (XXXXXX.CV4)')
      READ(5,120)((FILEP(I),I=1,3),(FILEN(I),I=1,3))
  120 FORMAT(3A1,3A1)
C     WRITE(7,122)
C  122    FORMAT(/,2X,'ENTER #FILES TO BE REDUCED')
C     READ(5,124)NFILE
C  124    FORMAT(I2)
C     WRITE(7,126)
C  126    FORMAT(/,2X,'ENTER PR FILE #, DATA FILE NUMBER.
C     +          ONE SET PER LINE')
C     DO 127 I7=1,NFILE
C     READ(5,128)PRFILE(I7),(FILEN(I),I=(I7-1)*3+1,(I7-1)*3+3)
C  128    FORMAT(I3,3A1)
C  127    CONTINUE
      NFILE=1
      INC=0
C
      DO 710 I7=1,NFILE
      INF=I7
      DO 720 I2=1,3
  720 ZFILE(I2)=FILEP(I2)
      DO 740 I4=1,3
      IN=3+I4
      INC=INC+1
  740 ZFILE(IN)=FILEN(INC)
      DO 760 I6=1,4
      IE=6+I6
  760 ZFILE(IE)=FILEE(I6)
C
C
      CALL ASSIGN(1,ZFILE,10)
      DEFINE FILE 1 (0,256,U,NREC)
C
      WRITE(7,770)(ZFILE(I),I=1,10)
  770 FORMAT('0',2X,'CURRENT FILE',3X,10A1)
      DO 600 I9=1,6
C
C     DEFINE FILE 1 (0,256,U,NREC)
C
      IF(I9.EQ.5)GO TO 600
      II9=I9
C
```

```
      DO 130 K=1,10240
  130 OUT1(K)=2048                    ! Initialization
      NREC=2
      DO 150 J=1,384
      READ(1'NREC,END=200) INBUF
      ISAVE=32*(J-1)
      DO 140 I=1,32
      I1=8*(I-1)+I9
      OUT1(ISAVE+I)=INBUF(I1)
  140 CONTINUE
  150 CONTINUE
C
C  200    IBR=INT((J-2)/8.)+1
  200 IBR=INT((J-1)/8.0)
      IF(II9.GT.1)GO TO 220
      WRITE(7,210) J-1,IBR
  210 FORMAT(2X,I4,' Records(256 words/record) => ',I2,' Records')
C
C CALL H1CNDY TO CONCATENATE DATA
C
  220 CALL H1CNDY(OUT1)
C
  600 CONTINUE
C
      CALL CLOSE(1)
C
  710 CONTINUE
C
      END
H1PIKY
```

```
      SUBROUTINE H1CNDY(OUT1)
C
C  Author: Jen-Kuang Huang/Dale W. Hiltner
C  Creation Date: 8-JUN-82/ SEPT-82
C
C  Concatenates sled data(1 channel, 256 word record, up to 48 blocks)
C  Method: Window filter (Window: two standard deviation)
C  Currently assumes input data file has max 12288 ticks long, with
C   data points per time tick
C  Program writes out 1024 data points, for two
C    channels of data  ==> can run H1CY to output final results.
C
      INTEGER OUT(1024)
      INTEGER OUT1(10240)
      REAL JSCALE,TRUN
      COMMON/CM1/IBR,II9
      COMMON/CM2/JSCALE,TRUN
C
      IF(II9.GT.1)GO TO 120
      WRITE(7,100)
  100 FORMAT(' Sled data concatenation. Channels 1,2,3,4,6.',/,
     +  '     Currently accepts maximum of 10240(256*40) samples ')
C
  120 INTVLE=INT(256*IBR/1024+0.)
      IF(II9.GT.1)GO TO 130
      WRITE(7,116) INTVLE
  116 FORMAT(2X,'Pick up one point from every ',I2,' points.')
      WRITE(7,125)
  125 FORMAT(' ')
C
  130     NREC=1
      IR=0
      SUM=0.
      RMSE=0.
C
C PERFORM WINDOW FILTERING
C
      DO 190 L=1,1024
      TSUM1=0.
      TSUM2=0.
      TRMSE=0.
      IA=0
      IC=INTVLE*(L-1)
      DO 170 M=1,INTVLE
      P1=OUT1(IC+M)-2048
      TSUM1=TSUM1+OUT1(IC+M)-2048
      TRMSE=TRMSE+P1*P1
  170 CONTINUE
      TAVG=TSUM1/INTVLE
      TRMS=SQRT(TRMSE/INTVLE)
      TSTD=SQRT(TRMS**2-TAVG**2)
      ULIM=TAVG+TSTD*2
      LLIM=TAVG-TSTD*2
      DO 180 N=1,INTVLE
      P1=OUT1(IC+N)-2048
      IF(P1.GT.ULIM) GOTO 180
      IF(P1.LT.LLIM) GOTO 180
      TSUM2=TSUM2+OUT1(IC+N)-2048
      IA=IA+1
  180 CONTINUE
      OUT(L)=INT(2048+TSUM2/IA)
C     OUT(L)=2048+TSUM2/IA
      IR=IR+INTVLE-IA
  190 CONTINUE
C
C FIND STATISTICS FOR 1024 POINTS
C
      DO 305 I=1,1024
      P1=OUT(I)-2048
      SUM=SUM+OUT(I)-2048
      RMSE=RMSE+P1*P1
  305 CONTINUE
      AVG=SUM/1024
      RMS=SQRT(RMSE/1024)
      STD=SQRT(RMS**2-AVG**2)
      RPC=IR*100./INTVLE/1024.
C
      GO TO(510,520,530,540,550,560)II9
```

```
C
C OUTPUT 1024 POINTS TO RESPECTIVE FILES
C
  510     WRITE(7,515)
      GO TO 307
  520     WRITE(7,525)
C
      CALL ASSIGN(2,'H1TMPV.DAT')
      DEFINE FILE 2 (1,2048,U,IREC2)
      WRITE(2'1)OUT
      CALL CLOSE(2)
C
      GO TO 307
  530     CALL ASSIGN(2,'H1TMPA.DAT')
      DEFINE FILE 2 (1,2048,U,IREC2)
      WRITE(2'1)OUT
      CALL CLOSE(2)
C
      WRITE(7,535)
      GO TO 307
  540     WRITE(7,545)
C
      CALL ASSIGN(2,'H1TMPC.DAT')
      DEFINE FILE 2 (1,2048,U,IREC2)
      WRITE(2'1)OUT
      CALL CLOSE(2)
C
      GO TO 307
  550 WRITE(7,555)
      GO TO 9999
  560     CALL ASSIGN(2,'H1TMPJ.DAT')
      DEFINE FILE 2 (1,2048,U,IREC2)
      WRITE(2'1)OUT
      CALL CLOSE(2)
      WRITE(7,565)
C
  307 WRITE(7,309) RPC,RMS,AVG,STD
  309 FORMAT(10X,F10.2,5X,3(F8.4,2X))
C
C OUTPUT STATISTICS
C
      WRITE(7,570)
  570 FORMAT(' ')
C
  515 FORMAT(' POSITION',6X,'REJECT(%)',3X,'RMS',7X,'AVG',7X,'STD')
  525 FORMAT(' VELOCITY',6X,'REJECT(%)',3X,'RMS',7X,'AVG',7X,'STD')
  535 FORMAT(' ACCEL   ',6X,'REJECT(%)',3X,'RMS',7X,'AVG',7X,'STD')
  545 FORMAT(' COMMAND ',6X,'REJECT(%)',3X,'RMS',7X,'AVG',7X,'STD')
  555 FORMAT(' !! ERROR !! II9=5. EXIT CONDTD')
  565 FORMAT(' JOYSTICK',6X,'REJECT(%)',3X,'RMS',7X,'AVG',7X,'STD')
C
 9999 RETURN
  400 END
H1CNDY
```

```
      PROGRAM H1CY
C
C
C Written by Dale W. Hiltner. Sept-82
C Computes FFT from files created by H1PKIY and
C outputs response results.
C
C
      INTEGER I1R(1024)
      REAL A1R,JSCALE,TRUN
      REAL AMP1(60),PHASE1(60),AI1R(1024)
      COMPLEX A1C(1024)
      COMMON/CM2/JSCALE,TRUN
C
C
C
      WRITE(7,02)
   02 FORMAT(5X,'INPUT JSCALE,RUN TIME TRUN')
      READ(7,04)JSCALE,TRUN
   04 FORMAT(F9.4,F9.4)
C
      CALL CLOSE(5)
      CALL CLOSE(6)
      CALL CLOSE(7)
      CALL CLOSE(8)
C
      II=1
  900 GO TO (10,20,30,40,50)II
C
C RRAD IN 1024 DATA POINTS AND SCALE PER CALIBRATION BEFORE GOING
C TO FFT. THEN STORE FIRST 60 AMPLITUDE AND PHASE VALUES
C IN ANOTHER FILE.
C
   10 DEFINE FILE 1 (1,2048,U,IREC1)
      CALL ASSIGN (1,'H1TMPA.DAT')
      READ(1'1)I1R
      DO 12 I=1,1024
   12 AI1R(I)=I1R(I)*0.01
      GO TO 100
  210 CALL CLOSE(1)
      CALL ASSIGN(5,'H1OUTA.DAT')
      WRITE(5,*)(AMP1(I),I=1,60)
      WRITE(5,*)(PHASE1(I),I=1,60)
      CALL CLOSE(5)
      II=2
      GO TO 900
C
   20 DEFINE FILE 2 (1,2048,U,IREC2)
      CALL ASSIGN(2,'H1TMPJ.DAT')
      READ(2'1)I1R
      DO 22 I=1,1024
   22 AI1R(I)=I1R(I)*0.003998/JSCALE
      GO TO 100
  220 CALL CLOSE(2)
      CALL ASSIGN(6,'H1OUTJ.DAT')
      WRITE(6,*)(AMP1(I),I=1,60)
      WRITE(6,*)(PHASE1(I),I=1,60)
      CALL CLOSE(6)
      II=3
      GO TO 900
C
   30 DEFINE FILE 3 (1,2048,U,IREC3)
      CALL ASSIGN(3,'H1TMPV.DAT')
      READ(3'1)I1R
      DO 32 I=1,1024
   32 AI1R(I)=I1R(I)*0.002722
      GO TO 100
  230 CALL CLOSE(3)
      CALL ASSIGN(7,'H1OUTV.DAT')
      WRITE(7,*)(AMP1(I),I=1,60)
      WRITE(7,*)(PHASE1(I),I=1,60)
      CALL CLOSE(7)
      II=4
      GO TO 900
C
   40 DEFINE FILE 4 (1,2048,U,IREC4)
      CALL ASSIGN(4,'H1TMPC.DAT')
      READ(4'1)I1R
      DO 42 I=1,1024
   42 AI1R(I)=I1R(I)*0.003998
      GO TO 100
```

```
  240   CALL CLOSE(4)
      CALL ASSIGN(8,'H1OUTC.DAT')
      WRITE(8,*)(AMP1(I),I=1,60)
      WRITE(8,*)(PHASE1(I),I=1,60)
      CALL CLOSE(8)
      II=5
      GO TO 900
C
  100 DO 110 I1=1,1024
      A1R=AI1R(I1)
      A1C(I1)=CMPLX(A1R,0.0)
  110 CONTINUE
C
C CALL FFT SUBROUTINE
C
      CALL H1FTCY(A1C,10,1024)
C
C CALCULATE AMPLITUDE AND PHASE FROM FFT OUTPUTS
C
      DO 120 I2=1,60
      AMP1(I2)=SQRT(REAL(A1C(I2+1))**2+AIMAG(A1C(I2+1))**2)
      PHASE1(I2)=ATAN2(REAL(A1C(I2+1)),AIMAG(A1C(I2+1)))*57.29577949
  120 CONTINUE
C
      GO TO (210,220,230,240)II
C
C CALL H1TRFY TO CALCULATE AND OUTPUT RESPONSE RESULTS
C
   50 CALL H1TRFY
C
C
C
C
      STOP
 9999 END
H1CY
```

```
      SUBROUTINE H1FTCY(A,M,N)
C
C
C Fortran FFT subroutine. Stored by Dale W. Hiltner 16-sept-82
C
C
      COMPLEX A(N),U,W,T
      INTEGER N,M
C
C
      N=2**M
      NV2=N/2
      NM1=N-1
      J=1
      DO 7 I=1,NM1
      IF(I.GE.J)GO TO 5
      T=A(J)
      A(J)=A(I)
      A(I)=T
    5 K=NV2
    6 IF(K.GE.J)GO TO 7
      J=J-K
      K=K/2
      GO TO 6
    7 J=J+K
      PI=3.141593  !653589793
      DO 20 L=1,M
      LE=2**L
      LE1=LE/2
      U=(1.0,0.0)
      W=CMPLX(COS(PI/LE1),SIN(PI/LE1))
      DO 20 J=1,LE1
      DO 10 I=J,N,LE
      IP=I+LE1
      T=A(IP)*U
      A(IP)=A(I)-T
   10 A(I)=A(I)+T
   20 U=U*W
      RETURN
      END
H1FTCY
```

```
        SUBROUTINE H1TRFY
C
C     Author: Jen-Kuang Huang/Dale W. Hiltner
C     Date:    14-Mar-82/AUG-82
C
C       Accesses phase and amplitude output from H1CY and
C       outputs transfer function and frequency spectrum data.
C
C
        REAL PHASE(60),FREQ(60),FREQR(60),LFREQR(60)
      REAL GAINDB(60),LGAIN(60)
      REAL AMPA(60),AMPJ(60),AMPV(60),AMPC(60)
      REAL PHASEA(60),PHASEJ(60),PHASEV(60),PHASEC(60)
      REAL JSCALE,TRUN,NFC(25)
      COMMON/CM2/JSCALE,TRUN
C
C ACCESS DATA FILES
C
      CALL ASSIGN(5,'H1OUTA.DAT')
      READ(5,*)(AMPA(I),I=1,60)
      READ(5,*)(PHASEA(I),I=1,60)
      CALL CLOSE(5)
C
      CALL ASSIGN(6,'H1OUTJ.DAT')
      READ(6,*)(AMPJ(I),I=1,60)
      READ(6,*)(PHASEJ(I),I=1,60)
      CALL CLOSE(6)
C
      CALL ASSIGN(7,'H1OUTV.DAT')
      READ(7,*)(AMPV(I),I=1,60)
      READ(7,*)(PHASEV(I),I=1,60)
      CALL CLOSE(7)
C
      CALL ASSIGN(8,'H1OUTC.DAT')
      READ(8,*)(AMPC(I),I=1,60)
      READ(8,*)(PHASEC(I),I=1,60)
      CALL CLOSE(8)
C
C
      DO 5 I=1,60
C
C COMPUTE TRANSFER FUNCTION DATA
C
      IF(AMPJ(I).EQ.0.0)GO TO 11
      IF(AMPA(I).EQ.0.0)GO TO 11
C
      GAINDB(I)=20.*ALOG10(AMPJ(I)/AMPA(I))
      GO TO 12
   11 GAINDB(I)=0.0
   12 LGAIN(I)=GAINDB(I)/20.0
      PHASE(I)=PHASEJ(I)-PHASEA(I)+180.0
      IF(PHASE(I).LT.-360.0)PHASE(I)=PHASE(I)+360.0
      IF(PHASE(I).GT.0.0)PHASE(I)=PHASE(I)-360.0
      FREQ(I)=I/TRUN
      FREQR(I)=I/TRUN*6.2832
      LFREQR(I)=ALOG10(FREQR(I))
    5 CONTINUE
C
C OUTPUT TRANSFER FUNCTION DATA
C
      WRITE(7,220)
  220 FORMAT(//,5X,'N',2X,'NF',4X,'FREQH',4X'FREQR',4X,'LOG F',8X,
     +        'GAINDB',7X,'LGAIN',8X,'PHASE',/)
      WRITE(7,230)(I,I,FREQ(I),FREQR(I),LFREQR(I),
     +               GAINDB(I),LGAIN(I),PHASE(I),I=1,45)
  230 FORMAT(2X,2I4,2X,F7.3,2X,F7.3,2X,F7.3,3F12.3)
C
```

```
C
C CALL H1TY FOR DATA REORDRING
C
       CALL H1TY(AMPA,AMPA)
       CALL H1TY(AMPJ,AMPJ)
       CALL H1TY(AMPV,AMPV)
       CALL H1TY(AMPC,AMPC)
       CALL H1TY(PHASEA,PHASEA)
       CALL H1TY(PHASEJ,PHASEJ)
       CALL H1TY(PHASEV,PHASEV)
       CALL H1TY(PHASEC,PHASEC)
C
       CALL H1NFC(NFC,NFC)
C
C
C OUTPUT FREQUENCY SPECTRUM DATA
C
       WRITE(7,260)
   260 FORMAT(//,5X,'I',3X,'NF',7X,'INAMPACC',8X,'INPHS',5X,
     +          'OUTAMPJOY',7X,'OUTPHS',4X,'VELAMP',10X,'VELPHS',4X,
     +          'COMAMP',10X,'COMPHS',/)
       WRITE(7,270)(I,NFC(I),AMPA(I),PHASEA(I),
     +                   AMPJ(I),PHASEJ(I),
     +                   AMPV(I),PHASEV(I),
     +                   AMPC(I),PHASEC(I),I=1,25)
   270 FORMAT(4X,I2,2X,F5.1,1X,3X,E12.5,2X,F9.4,3X,E12.5,2X,F9.4,
     +         3X,E12.5,2X,F9.4,3X,E12.5,2X,F9.4)
C
C
C
       RETURN
       END
H1TRFY
```

```
      SUBROUTINE H1TY(AIN,AOUT)
C
C
C Output reordering. Remnant average calculations
C
C
      REAL AIN(60),AOUT(60)
C
C
      AOUT(1)=(AIN(1)+AIN(2)+AIN(3)+AIN(4))/4.0
      DO 20 I=2,10
   20 AOUT(I)=AIN(I+3)
C
      AOUT(11)=(AIN(14)+AIN(15)+AIN(16))/3.0
      DO 40 I=12,14
   40 AOUT(I)=AIN(I+5)
C
      AOUT(15)=(AIN(20)+AIN(21)+AIN(22))/3.0
      AOUT(16)=AIN(23)
      AOUT(17)=(AIN(24)+AIN(25)+AIN(26)+AIN(27)+AIN(28))/5.0
      AOUT(18)=AIN(29)
      AOUT(19)=(AIN(30)+AIN(31))/2.0
      AOUT(20)=AIN(32)
      AOUT(21)=(AIN(33)+AIN(34)+AIN(35)+AIN(36))/4.0
      AOUT(22)=AIN(37)
      AOUT(23)=(AIN(38)+AIN(39)+AIN(40))/3.0
      AOUT(24)=AIN(41)
      AOUT(25)=(AIN(42)+AIN(43)+AIN(44))/3.0
      RETURN
      END
H1TY
```

```
      SUBROUTINE H1NFC(A1,A)
C
C
C Set up N values for frequency spectrum output.
C
C
      REAL A(25),A1(25)
      A(1)=2.5
      DO 10 I=2,10
   10 A(I)=I+3.0
      A(11)=15.0
      A(12)=17.0
      A(13)=18.0
      A(14)=19.0
      A(15)=21.0
      A(16)=23.0
      A(17)=26.0
      A(18)=29.0
      A(19)=30.5
      A(20)=32.0
      A(21)=34.5
      A(22)=37.0
      A(23)=39.0
      A(24)=41.0
      A(25)=43.0
      RETURN
      END
H1NFC
```

```
.RUN H1PIKY
Pick up input/output sled data. Channels 1,2,3,4,6.
   Currently accepts maximum of 10240 samples per channel

 ENTER JSCALE FACTOR,RUN TIME TRUN
2.1,81.92

 ENTER INPUT FILE 6 LETTER CODE (XXXXXX.CV4)
H1I506

  CURRENT FILE   H1I506.CV4
  256 Records(256 words/record) => 32 Records
Sled data concatenation. Channels 1,2,3,4,6.
   Currently accepts maximum of 10240(256*40) samples
 Pick up one point from every  8 points.

POSITION       REJECT(%)   RMS       AVG       STD
                5.54     366.2113  -73.0781  358.8458

VELOCITY       REJECT(%)   RMS       AVG       STD
                6.51      98.9566  -23.1777   96.2039

ACCEL          REJECT(%)   RMS       AVG       STD
                6.97      58.4783   -4.1484   58.3310

COMMAND        REJECT(%)   RMS       AVG       STD
                0.78      49.0192    4.6982   48.7935

JOYSTICK       REJECT(%)   RMS       AVG       STD
                3.76      85.1156   13.8730   83.9774

STOP --

.RUN H1CY
    INPUT JSCALE,RUN TIME TRUN
2.1,81.92

     N  NF     FREQH      FREQR     LOG F        GAINDB       LGAIN        PHASE

     1   1     0.012      0.077    -1.115        11.859       0.593       -2.409
     2   2     0.024      0.153    -0.814        13.306       0.665     -185.733
     3   3     0.037      0.230    -0.638        10.653       0.533     -309.691
     4   4     0.049      0.307    -0.513         9.321       0.466     -112.378
     5   5     0.061      0.383    -0.416         4.831       0.242      -20.619
     6   6     0.073      0.460    -0.337        -9.560      -0.478     -123.847
     7   7     0.085      0.537    -0.270         9.920       0.496      -11.427
     8   8     0.098      0.614    -0.212         0.476       0.024     -275.422
     9   9     0.110      0.690    -0.161         0.173       0.009     -104.327
    10  10     0.122      0.767    -0.115         1.763       0.088     -207.855
    11  11     0.134      0.844    -0.074        -1.527      -0.076      -91.992
    12  12     0.146      0.920    -0.036       -11.614      -0.581     -196.790
    13  13     0.159      0.997    -0.001        -3.277      -0.164     -111.106
    14  14     0.171      1.074     0.031        -0.039      -0.002       39.861
    15  15     0.183      1.150     0.061         5.334       0.267     -155.023
    16  16     0.195      1.227     0.089        -6.209      -0.310     -255.527
    17  17     0.208      1.304     0.115        -5.477      -0.274     -110.918
    18  18     0.220      1.381     0.140         6.256       0.313     -194.005
    19  19     0.232      1.457     0.164        -7.620      -0.381     -149.175
    20  20     0.244      1.534     0.186        -0.286      -0.014     -256.559
    21  21     0.256      1.611     0.207        -1.779      -0.089     -202.910
    22  22     0.269      1.687     0.227       -13.788      -0.689     -261.260
    23  23     0.281      1.764     0.247        -8.311      -0.416     -123.637
    24  24     0.293      1.841     0.265       -11.249      -0.562     -270.350
    25  25     0.305      1.917     0.283       -21.572      -1.079     -241.995
    26  26     0.317      1.994     0.300        -6.288      -0.314     -254.745
    27  27     0.330      2.071     0.316       -12.571      -0.629     -237.121
    28  28     0.342      2.148     0.332       -10.857      -0.543     -235.816
    29  29     0.354      2.224     0.347       -17.166      -0.858     -122.504
    30  30     0.366      2.301     0.362        -3.425      -0.171      110.388
    31  31     0.378      2.378     0.376        -7.832      -0.392     -271.848
    32  32     0.391      2.454     0.390       -11.362      -0.568     -158.459
    33  33     0.403      2.531     0.403        -8.445      -0.422       80.213
    34  34     0.415      2.608     0.416        -5.589      -0.279      111.461
    35  35     0.427      2.684     0.429        -7.037      -0.352     -309.420
    36  36     0.439      2.761     0.441        -3.497      -0.175     -238.041
    37  37     0.452      2.838     0.453       -17.499      -0.875     -169.986
    38  38     0.464      2.915     0.465        -9.906      -0.495     -225.813
    39  39     0.476      2.991     0.476       -10.603      -0.530     -259.397
    40  40     0.488      3.068     0.487        -6.041      -0.302     -245.417
```

```
 41   41     0.500     3.145     0.498     -15.469       -0.773     -167.939
 42   42     0.513     3.221     0.508      -7.248       -0.362       96.345
 43   43     0.525     3.298     0.518     -11.626       -0.581     -106.323
 44   44     0.537     3.375     0.528     -12.078       -0.604     -243.301
 45   45     0.549     3.451     0.538     -13.509       -0.675     -212.177



   I     NF         INAMPACC         INPHS     OUTAMPJOY        OUTPHS     VELAMP            VELPHS

   1     2.5      0.66695E+01      60.2222    0.25057E+02      -2.3307    0.16548E+02     -11.7246
   2     5.0      0.24067E+02      79.6106    0.41973E+02    -121.0087    0.16966E+02     148.8168
   3     6.0      0.91114E+01    -132.0222    0.30311E+01     -75.8689    0.76074E+01     128.5295
   4     7.0      0.10824E+02     -49.6864    0.33915E+02     118.8866    0.21012E+02      74.9835
   5     8.0      0.93956E+01     -81.6831    0.99246E+01    -177.1055    0.43357E+01      71.1522
   6     9.0      0.22955E+02     -79.9227    0.23416E+02      -4.2493    0.24299E+02      -3.3412
   7    10.0      0.73120E+01      92.6190    0.89580E+01      64.7642    0.11401E+02    -127.4970
   8    11.0      0.25363E+02     159.1630    0.21273E+02    -112.8292    0.22157E+02     -94.0382
   9    12.0      0.59945E+01     108.0695    0.15742E+01      91.2791    0.45189E+01       8.6655
  10    13.0      0.40620E+02      73.7615    0.27855E+02     142.6557    0.13312E+02     166.0447
  11    15.0      0.83275E+01     -78.1470    0.64369E+01     -21.7099    0.87842E+01       3.4708
  12    17.0      0.48100E+02     -11.5155    0.25604E+02      57.5666    0.22678E+02      81.9786
  13    18.0      0.28506E+01     -89.1315    0.58582E+01    -102.1369    0.71245E+01     -66.0477
  14    19.0      0.59440E+02    -104.3898    0.24722E+02     -73.5648    0.12970E+02     -12.4083
  15    21.0      0.81336E+01      87.9839    0.42859E+01      27.7408    0.44437E+01     -21.2059
  16    23.0      0.73136E+02     154.6477    0.28091E+02    -148.9891    0.23776E+02    -114.4484
  17    26.0      0.11571E+02      59.7801    0.33207E+01      -8.2254    0.64729E+01      -3.0979
  18    29.0      0.91271E+02      61.6987    0.12648E+02     119.1949    0.32483E+02     151.7377
  19    30.5      0.96311E+01       9.3120    0.46275E+01     108.5822    0.49632E+01     -14.3616
  20    32.0      0.79010E+02     -15.8167    0.21360E+02       5.7247    0.22982E+02      88.7080
  21    34.5      0.13236E+02     -39.2202    0.64904E+01      51.8331    0.60775E+01     -60.4718
  22    37.0      0.12468E+03    -115.5391    0.16629E+02    -105.5256    0.24003E+02     -23.7358
  23    39.0      0.17577E+02      20.0071    0.63231E+01     -43.5354    0.52098E+01      23.4820
  24    41.0      0.10299E+03     153.1838    0.17352E+02     165.2443    0.15809E+02    -115.9404
  25    43.0      0.12054E+02       3.8769    0.40758E+01      99.4505    0.58476E+01     -25.7926
STOP --

              COMAMP          COMPHS

              0.22681E+02      -4.2415
              0.40994E+02     -19.7886
              0.38364E+01     -85.9229
              0.35627E+02     -98.2199
              0.86879E+01    -179.0743
              0.38705E+02    -178.6416
              0.82803E+01      64.8018
              0.36411E+02      84.6310
              0.19444E+01     126.5418
              0.39206E+02     -10.1903
              0.58240E+01     -28.3612
              0.34272E+02    -107.2774
              0.42274E+01    -106.7055
              0.36801E+02     170.1163
              0.43229E+01      18.0284
              0.36560E+02      71.6213
              0.30703E+01      47.1517
              0.37374E+02     -25.5031
              0.44440E+01      97.1317
              0.31863E+02    -100.3662
              0.54566E+01      40.1723
              0.37331E+02     161.9321
              0.56506E+01     -59.5094
              0.31416E+02      71.4905
              0.33353E+01      57.9965
```

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              PROGRAM H1PIKP
      C
      C  Author: Jen-Kuang Huang/Dale W. Hiltner
      C  Creation Date: 22-APR-82/ Sept-82
      C
      C  Pick up sled data(5 channels, 256 word record, 385 blocks)
      C  Currently assumes input data file is 10240 ticks long.
      C  Program finds RMS ratios, AVG, STD for all points in full
      C  blocks. Can access groups of files with one program run.
      C  Uses H1SUM.DHF to output data by channel number.
      C  This program is a variant of H1PIKY.DHF
      C
              DIMENSION INBUF(256),IOBUF(256)
              REAL DURT(30),JSCALE
              REAL POSR(30),POSS(30),POSA(30),POSRAT(30)
              REAL VELR(30),VELS(30),VELA(30),VELRAT(30)
              REAL ACCR(30),ACCS(30),ACCA(30),ACCRAT(30)
              REAL COMR(30),COMS(30),COMA(30),COMRAT(30)
              REAL JOYR(30),JOYS(30),JOYA(30)
              INTEGER OUT1(10240),PRFILE(30)
              LOGICAL*1 ZFILE(10),FILEP(3),FILEN(120),FILEE(4)
              COMMON/CM1/OUT1,IBR,II9,JSCALE,PRFILE
              COMMON/SUMP/POSR,POSS,POSA,POSRAT
              COMMON/SUMV/VELR,VELS,VELA,VELRAT
              COMMON/SUMA/ACCR,ACCS,ACCA,ACCRAT
              COMMON/SUMC/COMR,COMS,COMA,COMRAT
              COMMON/SUMJ/JOYR,JOYS,JOYA
              COMMON/WFILE/FILEP,FILEN,FILEE
              COMMON/CFILE/NFILE,INF,DURT
              DATA FILEE/'.','C','V','4'/
      C
              WRITE(7,100)
          100 FORMAT(' Pick up input/output sled data. Channels 1,2,3,4,6.',/,
            +  '     Currently accepts maximum of 10240 samples per channel ')
      C
      C
              WRITE(7,121)
          121 FORMAT(/,2X,'ENTER JSCALE FACTOR')
              READ(5,123)JSCALE
          123 FORMAT(F6.2)
      C
      C ENTER MULTIPLE FILES
      C
         101  WRITE(7,102)
          102 FORMAT(/,2X,'ENTER INPUT FILE 3 LETTER CODE')
              READ(5,120)(FILEP(I),I=1,3)
          120 FORMAT(3A1)
              WRITE(7,122)
          122 FORMAT(/,2X,'ENTER #FILES TO BE REDUCED')
              READ(5,124)NFILE
          124 FORMAT(I2)
              WRITE(7,126)
          126 FORMAT(/,2X,'ENTER PR FILE #, DATA FILE NUMBER.
            +  ONE SET PER LINE')
              DO 127 I7=1,NFILE
              READ(5,128)PRFILE(I7),(FILEN(I),I=(I7-1)*3+1,(I7-1)*3+3)
          128 FORMAT(I3,3A1)
          127 CONTINUE
              INC=0
      C
              DO 710 I7=1,NFILE
              INF=I7
              DO 720 I2=1,3
          720 ZFILE(I2)=FILEP(I2)
              DO 740 I4=1,3
              IN=3+I4
              INC=INC+1
          740 ZFILE(IN)=FILEN(INC)
              DO 760 I6=1,4
              IE=6+I6
          760 ZFILE(IE)=FILEE(I6)
      C
      C
              CALL ASSIGN(1,ZFILE,10)
              DEFINE FILE 1 (0,256,U,NREC)
      C
              WRITE(7,770)(ZFILE(I),I=1,10)
          770 FORMAT('0',2X,'CURRENT FILE',3X,10A1)
              DO 600 I9=1,6
      C
```

```
      IF(I9.EQ.5)GO TO 600
      II9=I9
C
      DO 130 K=1,10240
  130 OUT1(K)=2048                       ! Initialization
      NREC=2
      DO 150 J=1,384
      READ(1'NREC,END=200) INBUF
      ISAVE=32*(J-1)
      DO 140 I=1,32
      I1=8*(I-1)+I9
      OUT1(ISAVE+I)=INBUF(I1)
  140 CONTINUE
  150 CONTINUE
C
C  200    IBR=INT((J-2)/8.)+1
  200 IBR=INT((J-1)/8.0)
      IF(II9.GT.1)GO TO 220
      WRITE(7,210) J-1,IBR
  210 FORMAT(2X,I4,' Records(256 words/record) => ',I2,' Records')
C
C CALL H1CNDP TO CALCULATE STATISTICS
C
  220 CALL H1CNDP
C
  600 CONTINUE
C
      CALL CLOSE(1)
      DURT(INF)=IBR*256*0.01
C
  710 CONTINUE
C
C CALL H1SUM TO OUTPUT STATISTICS BY CHANNEL NUMBER
C
      CALL H1SUM
C
      END
H1PIKP
```

```
      SUBROUTINE H1CNDP
C
C  Author: Jen-Kuang Huang/ Dale W. Hiltner
C  Creation Date: 8-JUN-82/ SEPT-82
C
C  Program finds RMS ratios, AVG, STD of 256*ibr points.
C  The no-subject RMS values are stored in file H1RATK.DAT
C  This is the maximum number of points contained in all
C  full blocks of the file. This program is a variant of
C  H1CNDY.DHF
C
C
      DIMENSION INBUF(256)
      REAL POSR(30),POSS(30),POSA(30),POSRAT(30)
      REAL VELR(30),VELS(30),VELA(30),VELRAT(30)
      REAL ACCR(30),ACCS(30),ACCA(30),ACCRAT(30)
      REAL COMR(30),COMS(30),COMA(30),COMRAT(30)
      REAL JOYR(30),JOYS(30),JOYA(30),DURT(30),JSCALE,RATK(17,4)
      LOGICAL*1 FILEP(3),FILEN(120),FILEE(4)
      INTEGER OUT1(10240),PRFILE(30)
      COMMON/SUMP/POSR,POSS,POSA,POSRAT
      COMMON/SUMV/VELR,VELS,VELA,VELRAT
      COMMON/SUMA/ACCR,ACCS,ACCA,ACCRAT
      COMMON/SUMC/COMR,COMS,COMA,COMRAT
      COMMON/SUMJ/JOYR,JOYS,JOYA
      COMMON/CFILE/NFILE,INF,DURT
      COMMON/CM1/ OUT1,IBR,II9,JSCALE,PRFILE
C
C FILE H1RATK.DHF CONTAINS ALL THE NO-SUBJECT RMS VALUES
C
      CALL ASSIGN(10,'H1RATK.DAT','NC')
      DO 10 I=1,17
      DO 20 J=1,4
   20 RATK(I,J)=0.0
   10 CONTINUE
C
      READ(10,*)((RATK(I,J),J=1,4),I=1,7)
      READ(10,*)((RATK(I,J),J=1,4),I=10,17)
C
      IF(II9.GT.1)GO TO 120
      WRITE(7,100)
  100 FORMAT(' Sled data reduction. Channels 1,2,3,4,6.',/,
     +  '     Currently accepts maximum of 10240(256*40) samples ')
C
      NPNTS=IBR*256
      DURT(INF)=NPNTS*0.01
      IPR=PRFILE(INF)
C
      WRITE(7,116)NPNTS
  116 FORMAT(2X,'Analysis of 'I5,' points.')
      WRITE(7,125)
  125 FORMAT(' ')
C
  120     SUM=0.
      RMSE=0.
C
C CALCULATE STATISTICS USING 2*VARIUANCE WINDOW FILTER
C
      DO 305 I=1,NPNTS
      P1=OUT1(I)-2048
      SUM=SUM+OUT1(I)-2048
      RMSE=RMSE+P1*P1
  305 CONTINUE
      AVG=SUM/NPNTS
      RMS=SQRT(RMSE/NPNTS)
      STD=SQRT(RMS**2-AVG**2)
C
C SCALE AND STORE VALUES IN FILES TO BE OUTPUT PER CHANNEL
C NUMBER BY H1SUM.DHF
C
      GO TO(510,520,530,540,550,560)II9
  510 RMS=RMS*0.002
      STD=STD*0.002
      AVG=AVG*0.002
      WRITE(7,515)
      POSR(INF)=RMS
      POSS(INF)=STD
      POSA(INF)=AVG
C
```

```
      POSRAT(INF)=POSR(INF)/RATK(IPR,1)
      GO TO 307
  520 RMS=RMS*0.002722
      STD=STD*0.002722
      AVG=AVG*0.002722
      WRITE(7,525)
      VELR(INF)=RMS
      VELS(INF)=STD
      VELA(INF)=AVG
      VELRAT(INF)=VELR(INF)/RATK(IPR,2)
      GO TO 307
  530 RMS=RMS*0.01
      STD=STD*0.01
      AVG=AVG*0.01
      WRITE(7,535)
      ACCR(INF)=RMS
      ACCS(INF)=STD
      ACCA(INF)=AVG
      ACCRAT(INF)=ACCR(INF)/RATK(IPR,3)
      GO TO 307
  540 RMS=RMS*0.003998
      STD=STD*0.003998
      AVG=AVG*0.003998
      WRITE(7,545)
      COMR(INF)=RMS
      COMS(INF)=STD
      COMA(INF)=AVG
      COMRAT(INF)=COMR(INF)/RATK(IPR,4)
      GO TO 307
  550 WRITE(7,555)
      GO TO 9999
  560 RMS=RMS*0.003998/JSCALE
      STD=STD*0.003998/JSCALE
      AVG=AVG*0.003998/JSCALE
      WRITE(7,565)
      JOYR(INF)=RMS
      JOYS(INF)=STD
      JOYA(INF)=AVG
      GO TO 307
C
C OUTPUT STATISTICS FOR EACH INDIVIDUAL RUN
C
  307 WRITE(7,309)RMS,AVG,STD
  309 FORMAT(15X,F8.4,2X,F8.4,2X,F8.4)
C
      WRITE(7,570)
  570 FORMAT(' ')
C
  515 FORMAT(' POSITION',9X,'RMS',7X,'AVG',7X,'STD')
  525 FORMAT(' VELOCITY',9X,'RMS',7X,'AVG',7X,'STD')
  535 FORMAT(' ACCEL    ',9X,'RMS',7X,'AVG',7X,'STD')
  545 FORMAT(' COMMAND ',9X,'RMS',7X,'AVG',7X,'STD')
  555 FORMAT(' !! ERROR !! II9=5. EXIT H1CNDP')
  565 FORMAT(' JOYSTICK',9X,'RMS',7X,'AVG',7X,'STD')
C
      CALL CLOSE(10)
 9999 RETURN
  400 END
H1CNDP
```

```
      SUBROUTINE H1SUM
C
C
C Written by Dale W. Hiltner / Sept-82
C Uses files generated by H1CNDP.DHF and
C outputs RMS ratio, AVG, STD values by
C channel content. This provides a quick
C summary of a test session.
C
C
      REAL POSR(30),POSS(30),POSA(30),POSRAT(30)
      REAL VELR(30),VELS(30),VELA(30),VELRAT(30)
      REAL ACCR(30),ACCS(30),ACCA(30),ACCRAT(30)
      REAL COMR(30),COMS(30),COMA(30),COMRAT(30)
      REAL JOYR(30),JOYS(30),JOYA(30),DURT(30)
      LOGICAL*1 FILEP(3),FILEN(120),FILEE(4)
      COMMON/SUMP/POSR,POSS,POSA,POSRAT
      COMMON/SUMV/VELR,VELS,VELA,VELRAT
      COMMON/SUMA/ACCR,ACCS,ACCA,ACCRAT
      COMMON/SUMC/COMR,COMS,COMA,COMRAT
      COMMON/SUMJ/JOYR,JOYS,JOYA
      COMMON/WFILE/FILEP,FILEN,FILEE
      COMMON/CFILE/NFILE,INF,DURT
C
C SUMMARY OF DATA FROM H1PIKP
C
      WRITE(7,600)
  600 FORMAT('0','H1PIKP DATA ANALYSIS SUMMARY')
C
      WRITE(7,610)(FILEP(I),I=1,3),(FILEE(I),I=1,4)
  610 FORMAT('0',5X,'DATA FILE',2X,3A1,'XXX',4A1)
C
C OUTPUT ALL DATA BY CHANNEL CONTENT
C
      DO 710 I1=1,5
C
      IF(I1.EQ.5)GO TO 500
      WRITE(7,720)
  720 FORMAT('0',4X,'CHANNEL',3X,'FILE #',7X,'RMS',7X,'RMSRAT',4X,
     +           'STD',7X,'AVG',6X'DURATION')
C
      GO TO (100,200,300,400,500)I1
C
  100 DO 120 I2=1,NFILE
  120 WRITE(7,130)(FILEN(I),I=(I2-1)*3+1,(I2-1)*3+3),
     +                  POSR(I2),POSRAT(I2),POSS(I2),POSA(I2),DURT(I2)
  130 FORMAT(5X,'POSITION',2X,3A1,7X,5(F8.4,2X))
      GO TO 710
C
  200 DO 220 I2=1,NFILE
  220 WRITE(7,230)(FILEN(I),I=(I2-1)*3+1,(I2-1)*3+3),
     +                VELR(I2),VELRAT(I2),VELS(I2),VELA(I2),DURT(I2)
  230 FORMAT(5X,'VELOCITY',2X,3A1,7X,5(F8.4,2X))
      GO TO 710
C
  300 DO 320 I2=1,NFILE
  320 WRITE(7,330)(FILEN(I),I=(I2-1)*3+1,(I2-1)*3+3),
     +                ACCR(I2),ACCRAT(I2),ACCS(I2),ACCA(I2),DURT(I2)
  330 FORMAT(5X,'ACCEL    ',2X,3A1,7X,5(F8.4,2X))
      GO TO 710
C
  400 DO 420 I2=1,NFILE
  420 WRITE(7,430)(FILEN(I),I=(I2-1)*3+1,(I2-1)*3+3),
     +                COMR(I2),COMRAT(I2),COMS(I2),COMA(I2),DURT(I2)
  430 FORMAT(5X,'COMMAND ',2X,3A1,7X,5(F8.4,2X))
      GO TO 710
C
  500 WRITE(7,510)
  510 FORMAT('0',4X,'CHANNEL',3X,'FILE #',7X,'RMS',7X,'STD',7X,
     +           'AVG',6X,'DURATION')
      DO 520 I2=1,NFILE
  520 WRITE(7,530)(FILEN(I),I=(I2-1)*3+1,(I2-1)*3+3),
     +                JOYR(I2),JOYS(I2),JOYA(I2),DURT(I2)
  530 FORMAT(5X,'JOYSTICK',2X,3A1,7X,4(F8.4,2X))
C
  710 CONTINUE
C
      RETURN
C
C
      END
H1SUM
```

```
 H1RATK.DAT

0.5373,0.5436,1.2651,0.5944
0.8623,0.4777,0.9994,0.3959
1.0367,0.5045,1.1612,0.4583
0.5432,0.4749,1.0417,0.3381
0.7032,0.4888,1.0931,0.2770
0.4359,0.4646,1.0182,0.2993
0.7495,0.5704,1.1825,0.3077
1.0,1.0,1.0,1.0
0.7937,0.5897,1.2313,0.1538
0.7426,0.5662,1.2086,0.1870
0.6731,0.5557,1.1438,0.1869
0.5999,0.5690,1.1520,0.1700
1.0452,0.6367,0.6537,0.1790
0.3347,0.6107,0.7184,0.1949
0.6214,0.6289,0.6776,0.1632/




 RUN H1PIKP
Pick up input/output sled data. Channels 1,2,3,4,6.
   Currently accepts maximum of 10240 samples per channel

 ENTER JSCALE FACTOR
3.3

 ENTER INPUT FILE 3 LETTER CODE
H1H

 ENTER #FILES TO BE REDUCED
3

 ENTER PR FILE #, DATA FILE NUMBER.           ONE SET PER LINE
11,404
12,407
13,409

  CURRENT FILE   H1H404.CV4
   64 Records(256 words/record) =>  8 Records
Sled data reduction. Channels 1,2,3,4,6.
   Currently accepts maximum of 10240(256*40) samples
 Analysis of  2048 points.

POSITION           RMS       AVG       STD
                  1.0248    0.7592    0.6883

VELOCITY           RMS       AVG       STD
                  0.4600   -0.1152    0.4453

ACCEL              RMS       AVG       STD
                  0.9594   -0.0310    0.9589

COMMAND            RMS       AVG       STD
                  0.2142    0.1147    0.1809

JOYSTICK           RMS       AVG       STD
                  0.1397    0.0845    0.1112


  CURRENT FILE   H1H407.CV4
  256 Records(256 words/record) => 32 Records
Sled data reduction. Channels 1,2,3,4,6.
   Currently accepts maximum of 10240(256*40) samples
 Analysis of  8192 points.

POSITION           RMS       AVG       STD
                  1.0107    0.1444    1.0003

VELOCITY           RMS       AVG       STD
                  0.3862   -0.0353    0.3846

ACCEL              RMS       AVG       STD
                  1.0753   -0.0524    1.0740

COMMAND            RMS       AVG       STD
                  0.2026   -0.0156    0.2020

JOYSTICK           RMS       AVG       STD
                  0.1356   -0.0090    0.1353
```

```
   CURRENT FILE    H1H409.CV4
   224 Records(256 words/record) =  28 Records
 Sled data reduction. Channels 1,2,3,4,6.
    Currently accepts maximum of 10240(256*40) samples
  Analysis of  7168 points.

POSITION           RMS        AVG        STD
                  0.7708    -0.6053     0.4773

VELOCITY           RMS        AVG        STD
                  0.3891    -0.0532     0.3855

ACCEL              RMS        AVG        STD
                  0.9971    -0.0661     0.9949

COMMAND            RMS        AVG        STD
                  0.1915     0.0196     0.1905

JOYSTICK           RMS        AVG        STD
                  0.1303     0.0168     0.1292


H1PIKP DATA ANALYSIS SUMMARY

     DATA FILE  H1HXXX.CV4

    CHANNEL    FILE #        RMS        RMSRAT     STD        AVG       DURATION
    POSITION   404          1.0248     1.2911     0.6883     0.7592    20.4800
    POSITION   407          1.0107     1.3610     1.0003     0.1444    81.9200
    POSITION   409          0.7708     1.1452     0.4773    -0.6053    71.6800

    CHANNEL    FILE #        RMS        RMSRAT     STD        AVG       DURATION
    VELOCITY   404          0.4600     0.7800     0.4453    -0.1152    20.4800
    VELOCITY   407          0.3862     0.6822     0.3846    -0.0353    81.9200
    VELOCITY   409          0.3891     0.7002     0.3855    -0.0532    71.6800

    CHANNEL    FILE #        RMS        RMSRAT     STD        AVG       DURATION
    ACCEL      404          0.9594     0.7792     0.9589    -0.0310    20.4800
    ACCEL      407          1.0753     0.8897     1.0740    -0.0524    81.9200
    ACCEL      409          0.9971     0.8717     0.9949    -0.0661    71.6800

    CHANNEL    FILE #        RMS        RMSRAT     STD        AVG       DURATION
    COMMAND    404          0.2142     1.3926     0.1809     0.1147    20.4800
    COMMAND    407          0.2026     1.0833     0.2020    -0.0156    81.9200
    COMMAND    409          0.1915     1.0245     0.1905     0.0196    71.6800

    CHANNEL    FILE #        RMS        STD        AVG       DURATION
    JOYSTICK   404          0.1397     0.1112     0.0845    20.4800
    JOYSTICK   407          0.1356     0.1353    -0.0090    81.9200
    JOYSTICK   409          0.1303     0.1292     0.0168    71.6800
STOP --
```

Appendix D

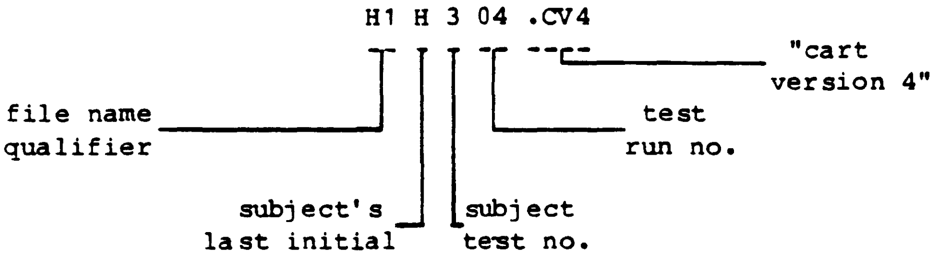
Test Procedure Checklist

The formal Test Procedure Checklist is listed on pages 169-170. The Sled General Checklist, which covers the Sled start-up and shutdown procedures, is listed on pages 171-173. The Test Procedure Checklist is a step-by-step instruction list that should be used to conduct the tests properly. It lists all the steps used to obtain the final results of this work. The subject testing procedure, and the data reduction procedure, are both described in the checklist. It is recommended that this checklist be adhered to in all further testing.

The log sheet form used during the testing of this work is shown on page 174. This form was found to be invaluable during the analysis of the data. In addition to providing a log of all the tests, it helped reveal the various response trends of the subjects. It is recommended that this log form be used to take vigorous notes during all testing. All runs, practice and data, should be noted on the log sheets. COMMENTS should include any difficulties, irregularities, or pertinent observations of the test conductor or subject regarding the subjects performance and the test proceedings.

D.1 Data Filename Convention

The data filenames are defined by the test conductor according to the following convention: A filename consists of a series of three characters plus three numbers. The three characters begin with H1, and the third character is the first letter of the subject's last name (key subject initial). The three numbers begin with the test session number (a 1 for the first session, 2 for the second, etc...), followed by two which indicate the run numbers. The run numbers are automatically set in sequential order during the test session. An illustration follows.



Test Procedure Checklist

1. Start-Up Procedure: Follow Sled General Checklist through section seven for all standard procedures. Add the following changes.

    1.1 Check AA1 cable (joystick command).
    1.2 RUN H1CAR7 and set program parameters DA, PR, and JO. (Data filename, protocol file, and JSCALE)
    1.3 Explain the task to the subject.
    1.4 Seat subject in chair and adjust head restraint height, shoulder pads seatbelt and goggles.
    1.5 Attach joystick with voltmeter wired in and set to +2.0v. Check that joystick calibration is within +/- .17v.
    1.6 Put masking noise level at maximum (as long as subject is comfortable.)

2. Standard Run Pocedure: Use to conduct each run.

    2.1 Enable sled, push START.
    2.2 SEND protocol file number command.
    2.3 Notify subject when program has STARTED.
    2.4 Notify subject when sled is MOVING to home position.
    2.5 When digital display on the sled control panel reads 333, start stopwatch and turn on masking noise.
    2.6 Fill in Data Sheet with RANGE, STOP, DURATION and any other observations.
    2.7 Check that the subject is comfortable, record any comments.
    2.8 If there will be more than a few moments between runs, press STOP.
    2.9 If sled has triggered limit switch, press STOP, disable sled, and push sled off of limit switch while holding down START, and press STOP.
    2.10 Check joystick calibration.

3. Test Procedure

    3.1 Explain RIDE ONLY to the subject.
    3.2 Disable joystick and data storage.
    3.3 Run practice profile.
    3.4 Explain PRACTICE RUN to the subject.
    3.5 Check joystick calibration, enable joystick control.
    3.6 Run practice profile as per standard run procedures.
    Continue sequence (calibration check, profile run) until subject does not improve performance or starts completing runs.
    3.7 Explain DATA RUN to subject and inform subject of RIDE ONLY.
    3.8 Disable joystick.
    3.9 Run data file, RIDE ONLY.
    3.10 Check joystick calibration, enable joystick.
    3.11 Notify subject of DATA RUN.
    3.12 Run data profile.
    Continue sequence (calibration check, data run) until 4-5 completed runs have been stored in the computer.

4. Power Shutdown Procedure: Follow Sled General Checklist.

5. Data Reduction

5.1 Delete generated files as file space allows if NOT COMPLETE.
5.2 LIST saved files.
5.3 RUN H1PIKY for each complete data file.
5.3.1 Inputs: JSCALE, RUN TIME, FILE NAME.
5.4 RUN H1CY immediately after running H1PIKY.
5.4.1 Inputs: JSCALE, RUN TIME.
5.5 Plot results.
5.5.1 Plot velocity Frequency Spectrum on graph with no-subject data already plotted.
5.5.2 Plot joystick frequency spectrum.
5.5.3 Pick three "best" runs to make BODE plot.
5.5.4 Record velocity RMS RATIO, joystick RMS.
5.5.5 Find average, variance of Log(GAIN) and phase.
5.5.6 Plot Bode plot.

Sled General Checklist

PRE-EXPERIMENT

1.00 Power On
1.1 SLED ELECTRONICS CABINET: sled disabled.
1.2 240 VOLT MAIN POWER BOX: main power on.
1.3 CART:Remove covers from rails.
1.4 SLED POWER SWITCH:Press START.

2.00 Mechanical Safety Checks
2.1 CART:Before moving the sled make sure that everything on the sled is secured.
2.2 CART:Check to see that the subject's panic button is in working order.
2.3 SLED POWER SWITCH:Press START.
2.4 CART:Check to see that the limit switches at both ends of the track are working: manually slide the sled over left limit switch, press START (on sled power switch), slide sled over right limit switch, and press START (on sled power switch) again.
2.5 CART:Inspect the umbilical cable attached to the back of the sled to make sure that everything is in working order.

3.00 Wiring
3.1 SLED CONTROL PANEL:Check cables to make sure they are in the proper configurations.
 3.1.1 CABLE-D1 (cart position)
 3.1.2 CABLE-D2 (cart velocity)
 3.1.3 CABLE-D3 (cart acceleration)
 3.1.4 CABLE-D11 (velocity command signal)
 3.1.5 CABLE-C11 ("SEND" signal)
 3.1.6 CABLE-C12 ("ABORT" signal)

4.00 Power Check
4.1 SLED POWER SWITCH:Make sure that the Sled Power Switch "STOP" has been pressed before going to computer room.

5.00 Computer Program
5.1 Make sure that the computer is free by checking that the last user has logged out in the log book.
5.2 Log in the log book.
5.3 PDP 11/34 CONTROL PANEL:Boot the computer: press and hold down "CONTROL" and then press "BOOT".
5.4 KEYBOARD: type DP0 (return).
5.5 KEYBOARD: enter date and time when prompted by computer.
5.6 KEYBOARD: run cart-control program by typing RUN A1CART (return).
5.7 PATCH PANEL CABINET:make sure that the sled patch panel is in the patch panel holder.
5.8 PATCH PANEL CABINET: "Sled General" cables 1,2,7 and 8 are in their respective 1,2,7,8 receptors on the back of the patch panel cabinet.

5.9 CABINET 2: check that the green digital input/output cables in back of the cabinet are hooked to the digital input/output receptors.
5.10 KEYBOARD: set cart program parameters.
5.11 KEYBOARD: load protocol file in cart control program.
5.12 KEYBOARD: issue "REMOTE" command to computer.
5.13 Post signs indicating a "REMOTE OPERATED EXPERIMENT IN PROGRESS".

6.00 Cart Preparation
6.1 SLED CONTROL PANEL: verify blinking minus sign on digital LED display. If not there, return to computer room, check program status and wiring configurations.
6.2 Make sure all personnel are clear of the sled area.
6.3 SLED ELECTRONICS CABINET: enable sled controller.
6.4 SLED CONTROL PANEL: press START.
6.5 SLED CONTROL PANEL: if you are using a NEW protocol file, run each entry with the sled EMPTY. If you are using an OLD file, run ONE example of each type of profile (e.g. sine, step, etc.) with the sled EMPTY.
6.6 SLED POWER SWITCH:push STOP (i.e. put the brake on.)

7.00 Subject Preparation
7.1 Log experiment in SLED log book.
7.2 Explain to the subject the experiment and any risks involved.
7.3 Have subject read and sign "Informed Consent Form".
7.4 SLED ELECTRONICS CABINET: sled disabled.
7.5 SLED POWER SWITCH: press sled power STOP.
7.6 Have subject enter the sled, making sure that he/she does not step on the rails or the chair frame.
7.7 CART: demonstrate panic button and give to the subject.
7.8 SUBJECT/CART: adjust head restraint height, foot rests and shoulder pads.
7.9 CART: complete specialized instrumentation (e.g. biteboards, electrodes, camera focus, etc.).
7.10 SUBJECT/CART: tighten seat belt.
7.11 SUBJECT/CART: tighten chest straps (optional).
7.12 SUBJECT/CART: tighten and adjust forehead and chin straps.
7.13 SUBJECT/CART/SLED CONTROL PANEL: determine masking noise level.
7.14 SUBJECT: check to make sure that the subject is comfortable.
7.15 CART: lower hood.
7.16 CART: attach cowl.
7.17 SLED ELECTRONICS CABINET: turn ventilation fan on.

EXPERIMENT

8.00 Consult respective protocol for individual experiment.

POST-EXPERIMENT

9.00 Subject egress
9.1 SLED CONTROL PANEL: sled power off.
9.2 SLED ELECTRONICS CABINET: sled disabled.
9.3 CART: cowl off.
9.4 CART: raise hood.
9.5 CART/SUBJECT: disconnect specialized instrumentation.

9.6 SUBJECT: remove restraints.
9.7 SUBJECT: subject egress, again with no stepping on rails or chair frame.

10.00 Shutting Down
10.1 CART: lower and secure hood and all items on the cart.
10.2 SLED ELECTRONICS CABINET: disable sled (with sled power START).
10.3 CART: move sled manually to home position.
10.4 CART: place covers on rail.
10.5 SLED CONTROL PANEL: send control to computer terminal ("2000" command).
10.6 240 V MAIN POWER BOX: main power OFF.

ACLOSAP TEST DATA SHEET

DATE:
SUBJECT:
CONDUCTOR:
PROTOCOL FILE:
JSCALE:
DATA FILE:

MISC.:

DATA FILE	PR FILE #	STOP	TIME	RANGE	COMMENTS

APPENDIX E

THE EXPERIMENTAL RESULTS

The plotted results are presented in the next pages. The Bode plots are shown first followed by the frequency spectrum plots. Bessel's corrected one sigma deviations have been calculated and plotted for all points of the Bode plots. If no deviation is shown, the deviation is within the point symbol. An explanation of the meaning of these plots follows.

E.1 Plot Format Discussion

The Bode plot represents the transfer function of the Human Operator (HO). It relates the acceleration input, in m/s^2, to the joystick commanded velocity, in m/s. The GAIN is calculated from the amplitude of the joystick velocity divided by the amplitude of the acceleration. These amplitudes are obtained directly from the FFT output at the disturbance frequencies. The GAIN is plotted in units of log(GAIN), which may also be stated as units of DB/20. DB was not used in the plots as it is felt that the factor of 20 is not meaningful for the type of work involved in this thesis. The frequencies have been plotted on a linear scale of log(freq., rad/sec) but are labled in Hz. The log(GAIN) section of the Bode plot shows the factor, or GAIN, by which the input acceleration has been increased by the HO to obtain the output joystick velocity command.

The phase data of the Bode plot is calculated from the phase angle of the joystick velocity command minus the phase angle of the acceleration. 180 deg. is then added to this value to correct for the negative sign of the joystick signal, since it opposes the acceleration. The resulting phase is

then that for the HO, and not that for the HO transfer function block in the closed-loop block diagram. The phase angles are taken directly from the FFT output. The phase section of the Bode plot shows the lead or lag the HO has applied to the acceleration disturbance in order to obtain the joystick velocity command. The log(GAIN) and phase data together show the capabilities of the HO to respond to the acceleration disturbance in attempting to perform the velocity nulling task.

The frequency spectrum plots show the velocity and joystick amplitudes obtained directly from the FFT. In the velocity plot, the squares show the amplitudes obtained from running the disturbance profile without a subject in the cart, the no subject case. This shows the disturbance input to the subject. The dashed line connects the amplitudes at the disturbance frequencies. The solid line connects the amplitudes of the remnant. The remnant data is found by averaging all the frequency and amplitude data obtained from the FFT between the disturbance frequencies. The end remnant points are found by averaging the three frequencies and amplitudes before and after the first and last disturbance frequencies. (It is noted that the no subject data represents the disturbance profile. The true disturbance profile would have no remnant, as it is generated by a sum of sines signal. Since the no subject data is obtained from the Sled system itself, however, errors are introduced which cause the non-zero remnant. These errors probably occur mainly from noise in the acceleration signal and the averaging needed to reduce the number of data points to 1024. Thusly, the remnant shows the limitations of the test system, and should be considered as a rough reference value for the zero amplitude level.)

The circles show the velocity amplitudes obtained from the FFT from runs with subject control. As in the no subject case the dashed line connects the disturbance frequency amplitudes and the solid line connects the remnant amplitudes. Comparing the two dashed lines shows how effectively the subject performed the velocity nulling task. Ideally the amplitudes obtained with subject control should be much lower than the amplitudes of the no subject case, meaning very effective velocity nulling by the HO. Comparing the two solid lines shows how exclusively the subject responded to the disturbance velocity. Ideally the remnant obtained with subject control should be about the same as the remnant of the no subject case, meaning that the HO was responding only to the disturbance.

The joystick frequency spectrum shows the amplitudes of the joystick velocity command obtained directly from the FFT. Since there is no joystick output for the no subject case only the subject control case can be shown. As for the velocity plot the dashed lines connect the amplitudes at the disturbance frequencies and the solid line connects the remnant amplitudes. The disturbance frequency amplitudes show the level of the joystick velocity output, or the level of control the HO used to perform the velocity nulling task. The remnant amplitudes show how exclusively the HO responded to the disturbance, as similarly indicated by the velocity remnant. Ideally, the joystick amplitudes at the disturbance frequencies should be high, and the remnant amplitudes should be low. This gives a wide joystick disturbance frequency amplitude/remnant separation, which is needed for accurate data. (Chapter 6)

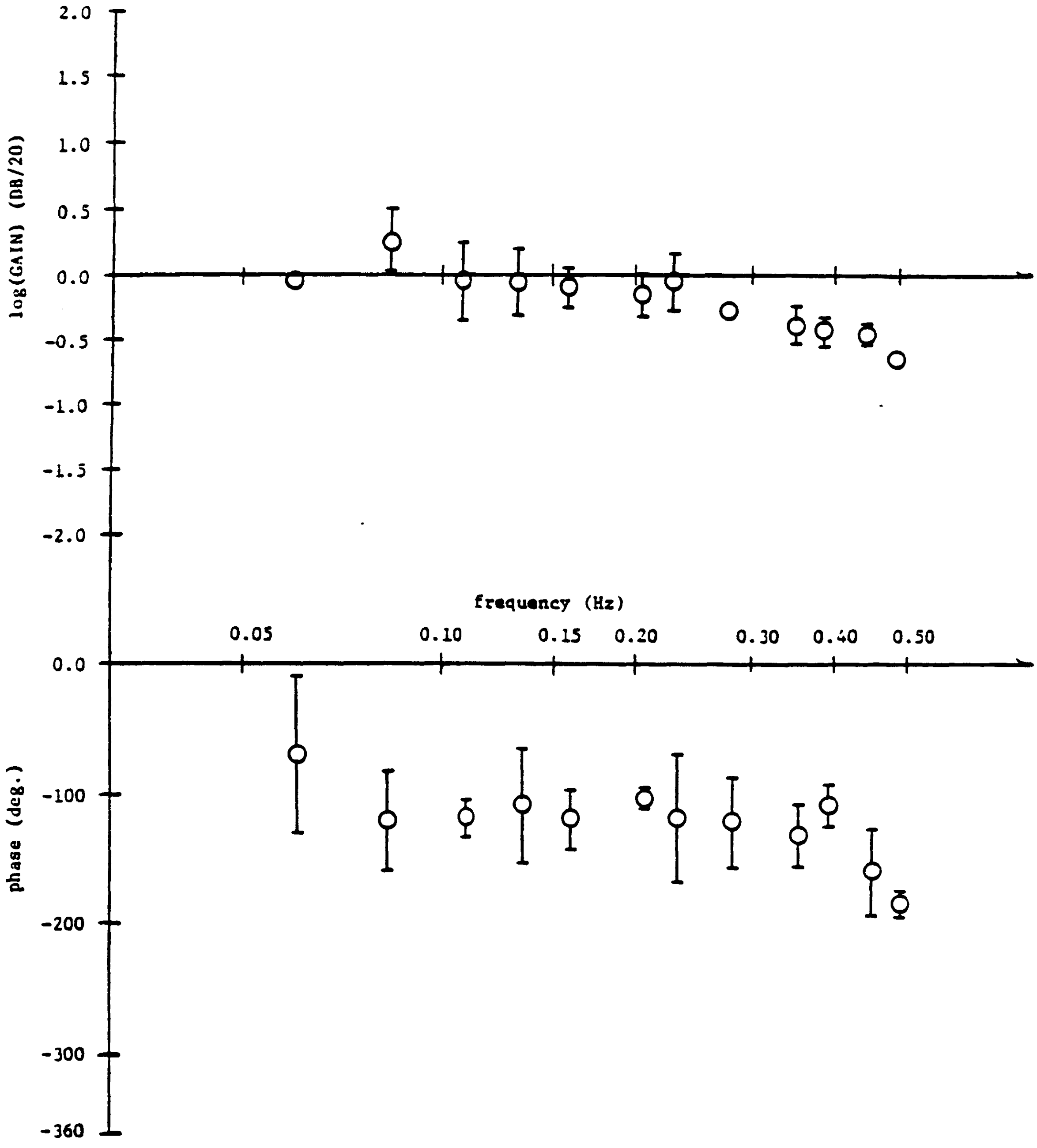


Figure E6.1.01 Bode Plot. Subject MS, Final Profile
Average of Runs 07,08,09

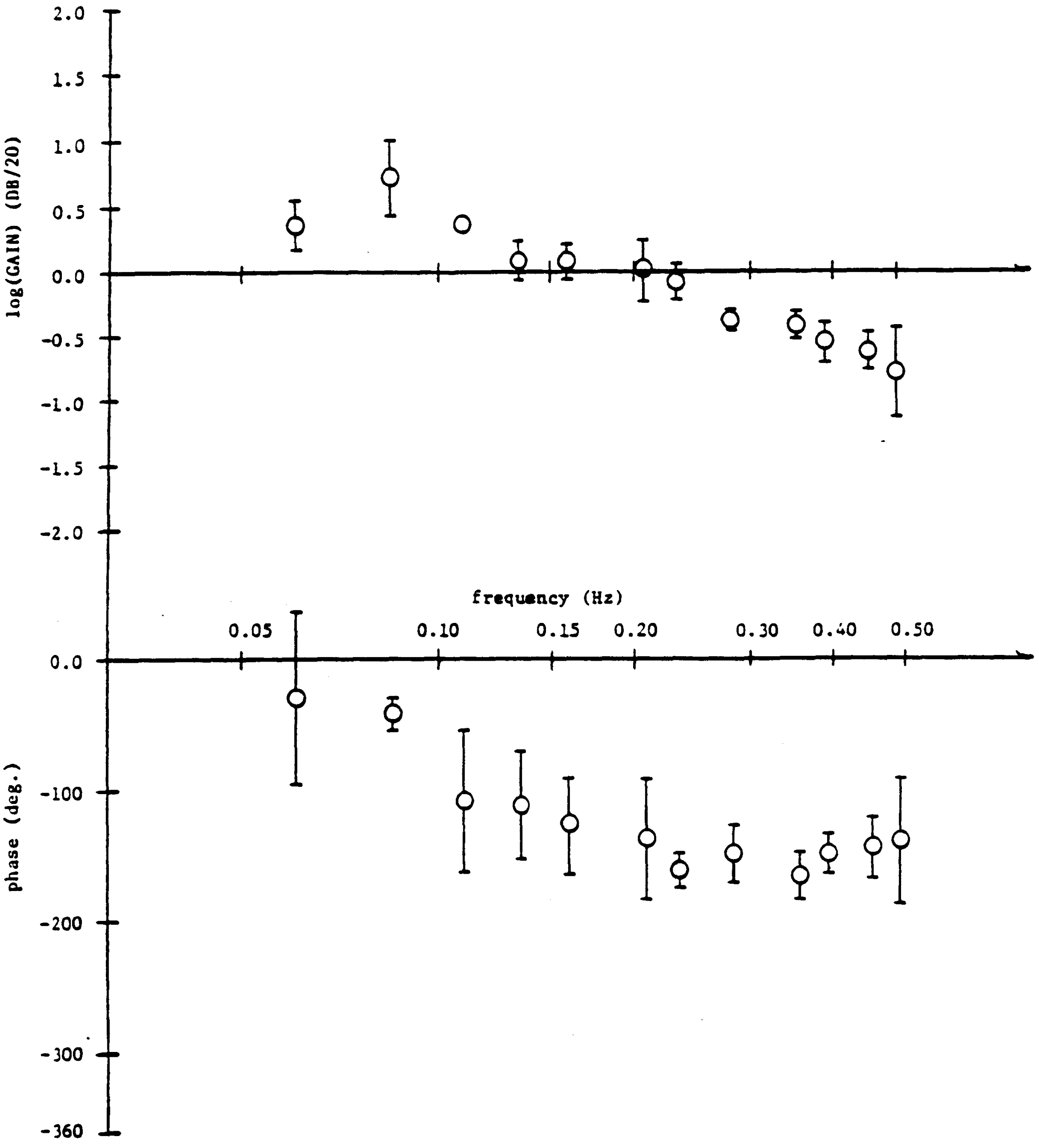


Figure E6.1.02 Bode Plot. Subject MM, Final Profile
Average of Runs 03,09,12

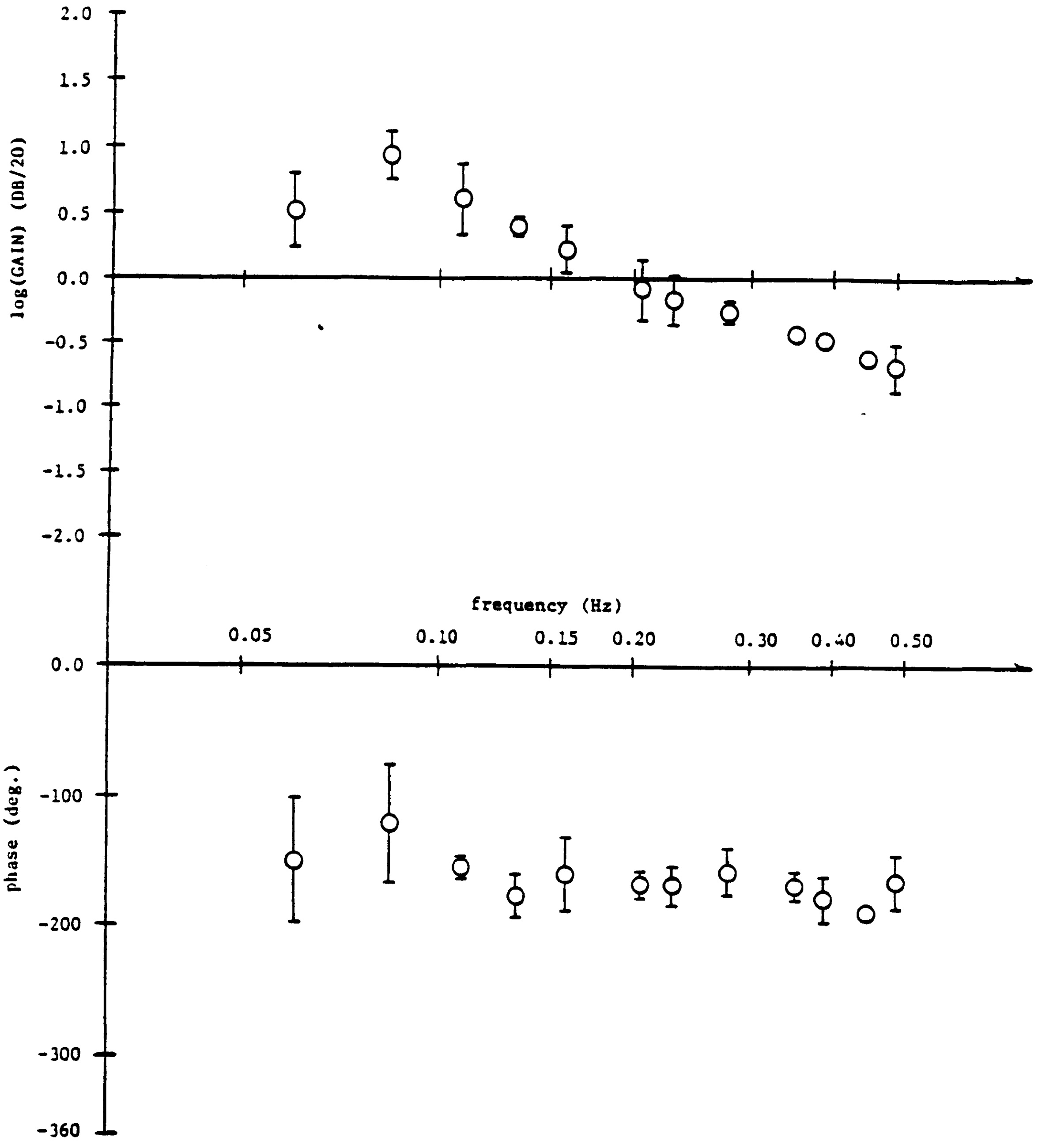


Figure E6.1.03 Bode Plot. Subject JH, Final Profile
Average of Runs 06,08,09

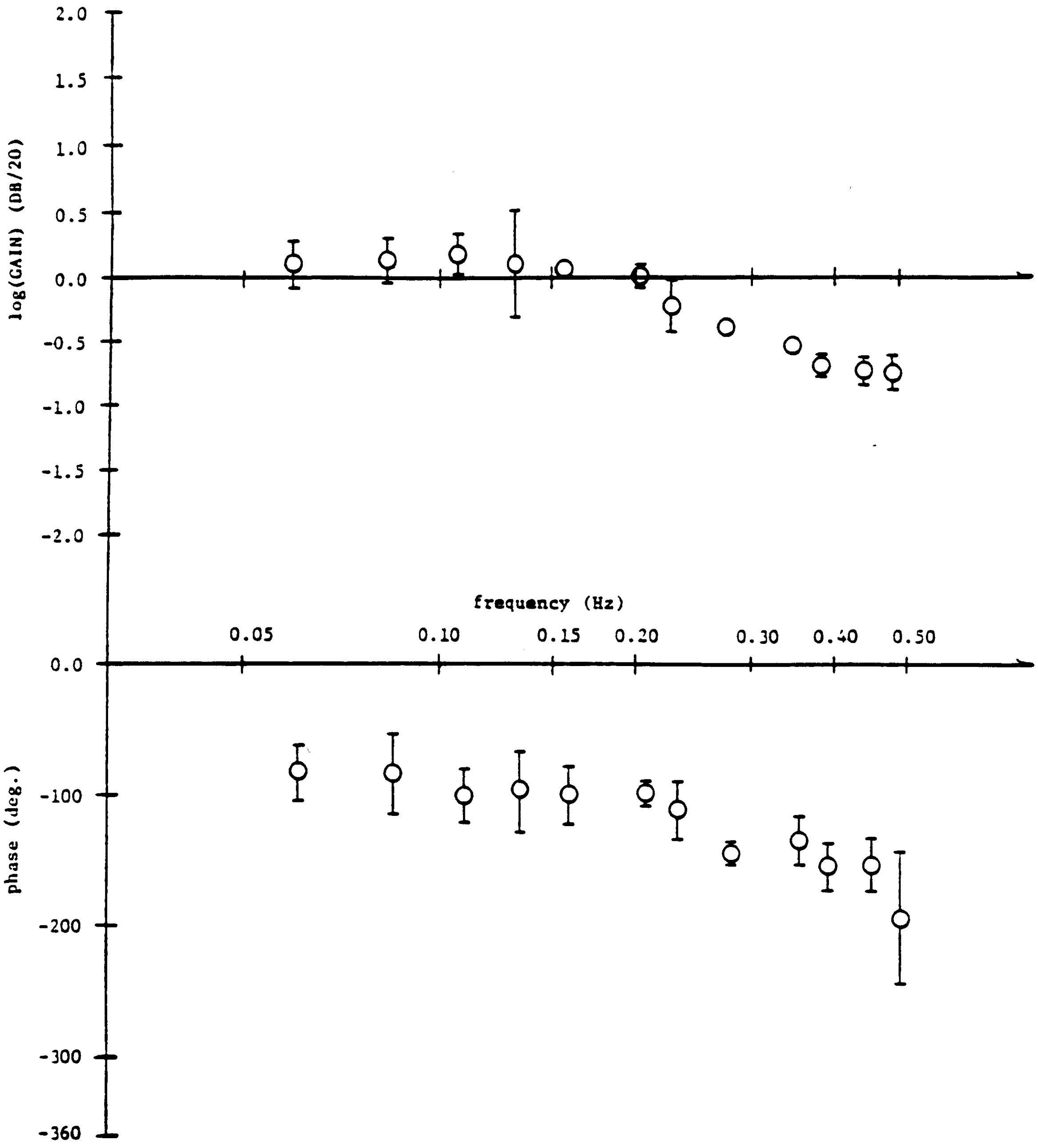


Figure E6.1.04 Bode Plot. Subject DH, Final Profile
Average of Runs 15,21,22

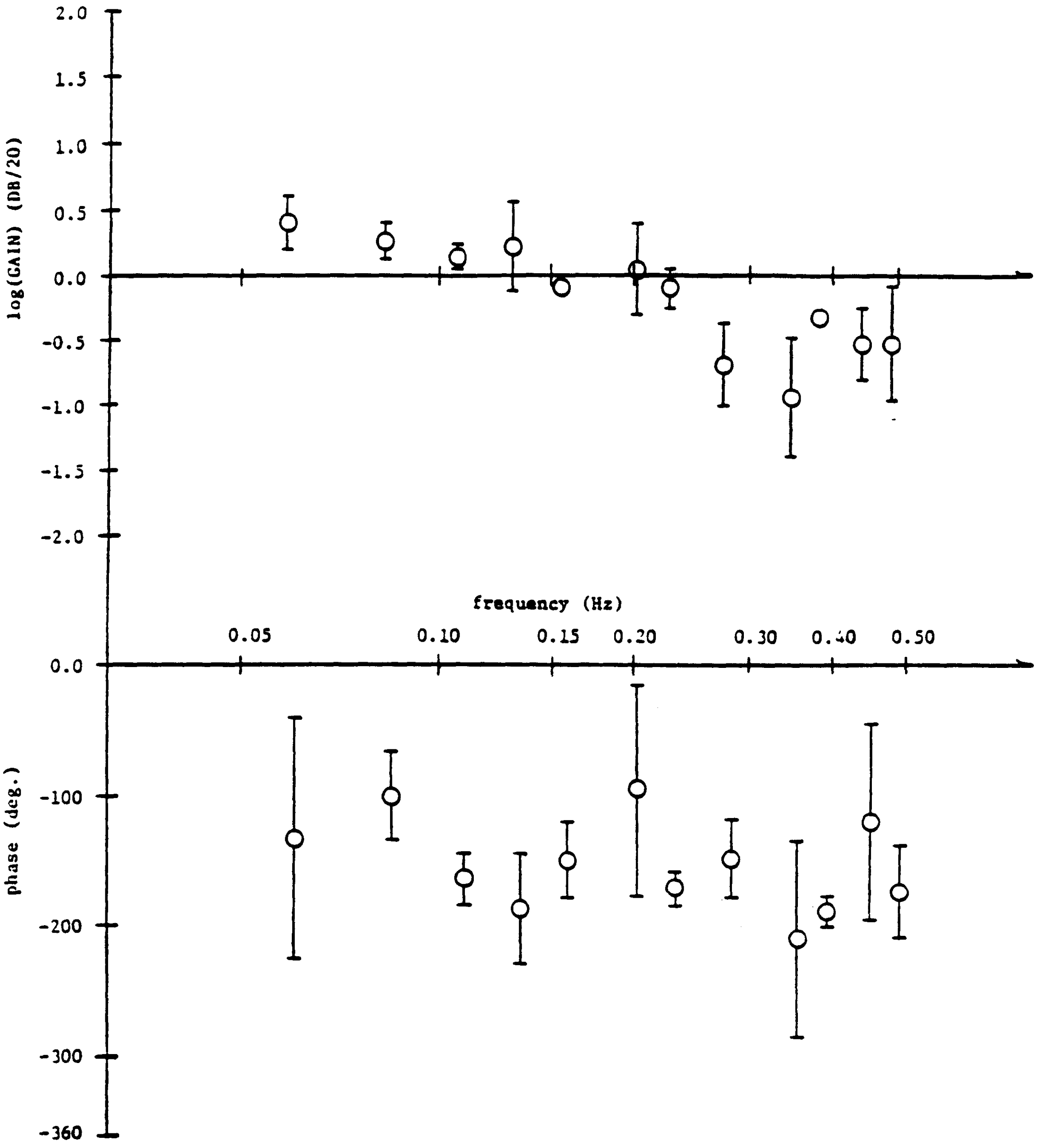


Figure E6.1.05 Bode Plot. Subject LR, Final Profile
Average of Runs 02,03,06

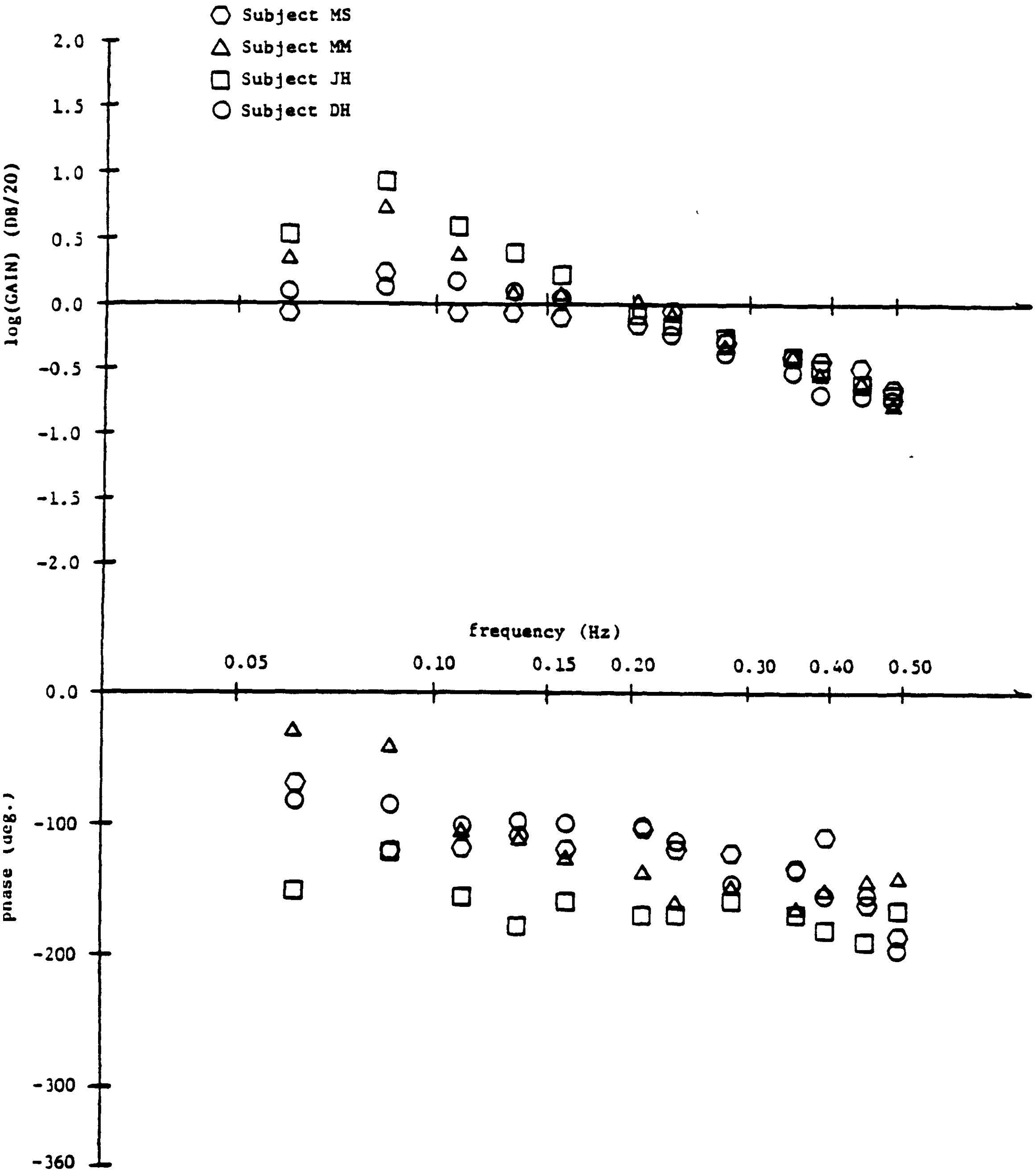


Figure E6.1.06 Summary Bode Plot, All Subjects, Final Profile

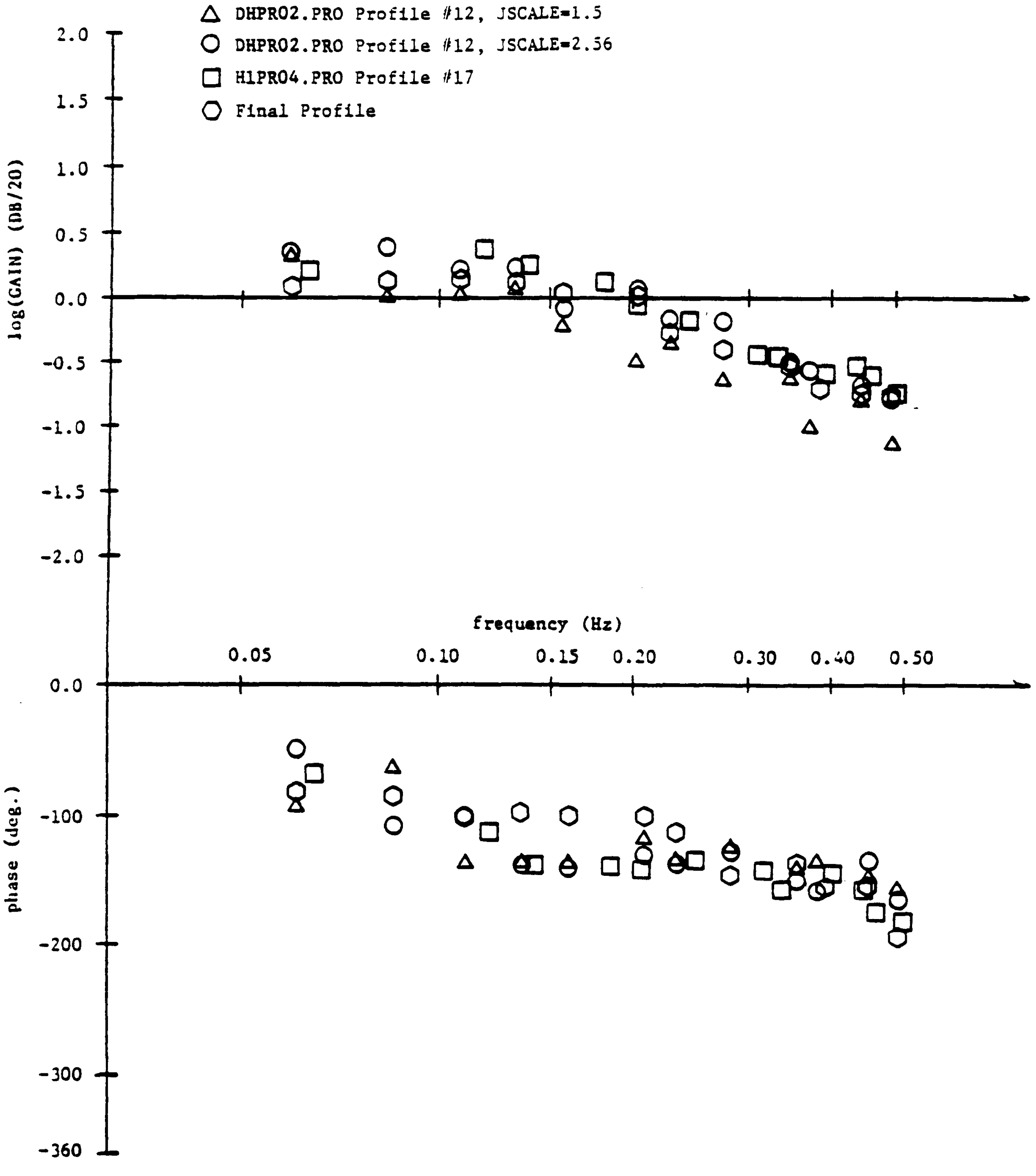
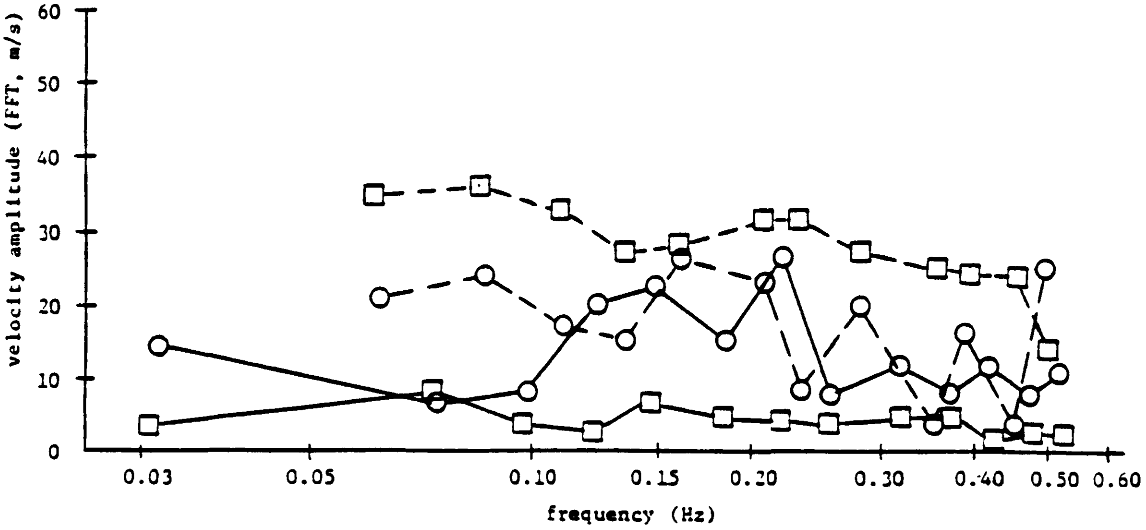


Figure E6.1.07 Summary Bode Plot, Subject DH



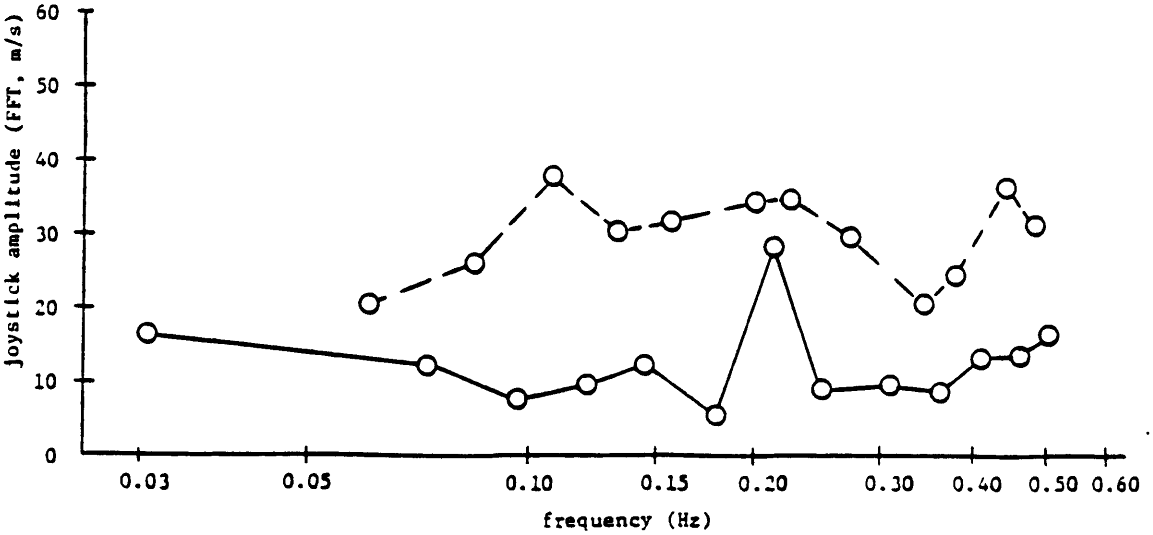
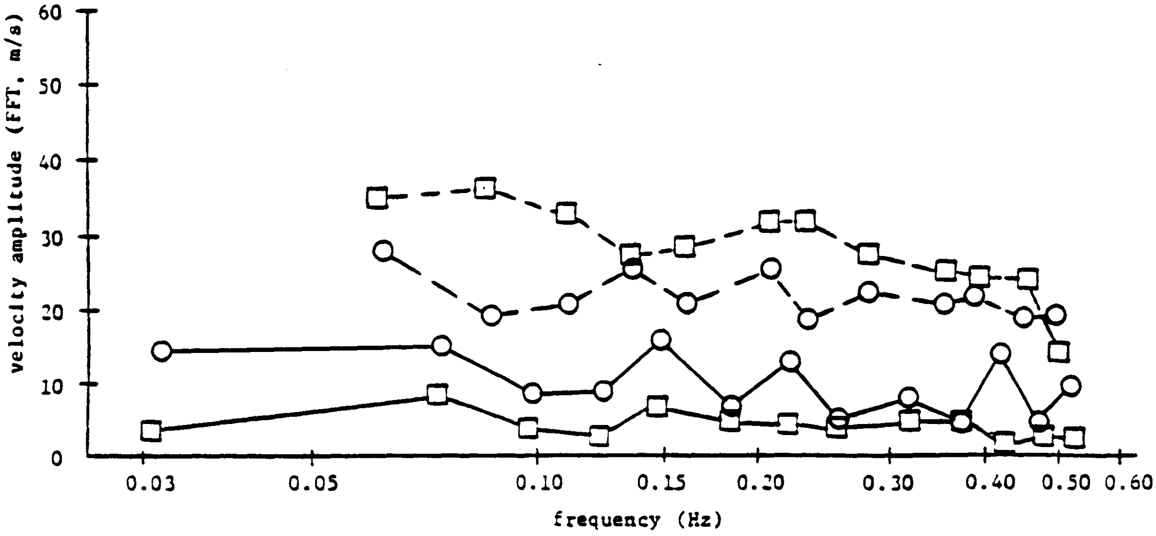


Figure E6.1.08 Frequency Spectrum, Subject MS
Run 02, Final Profile



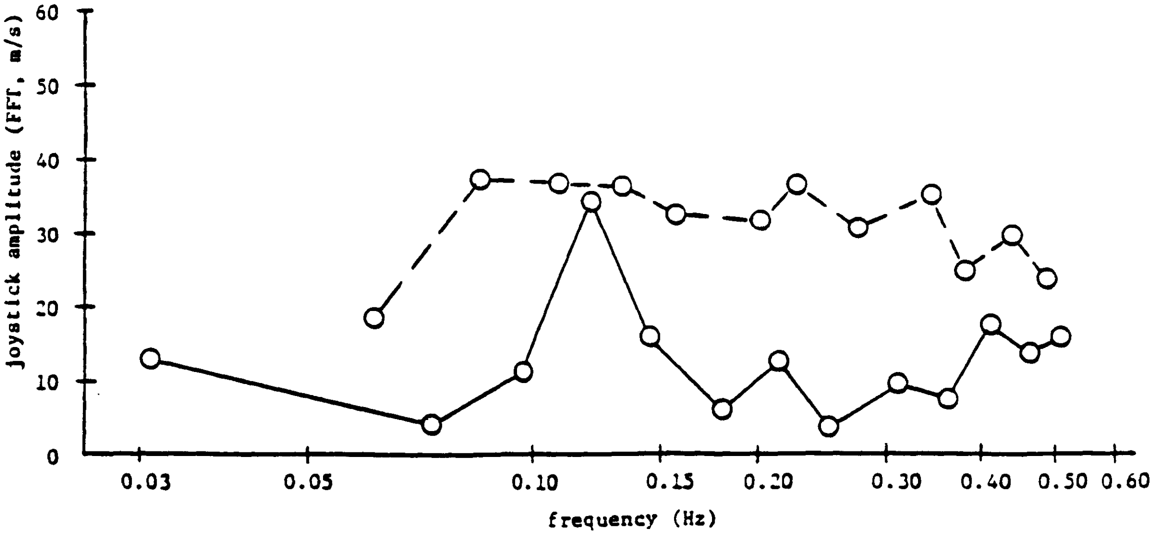
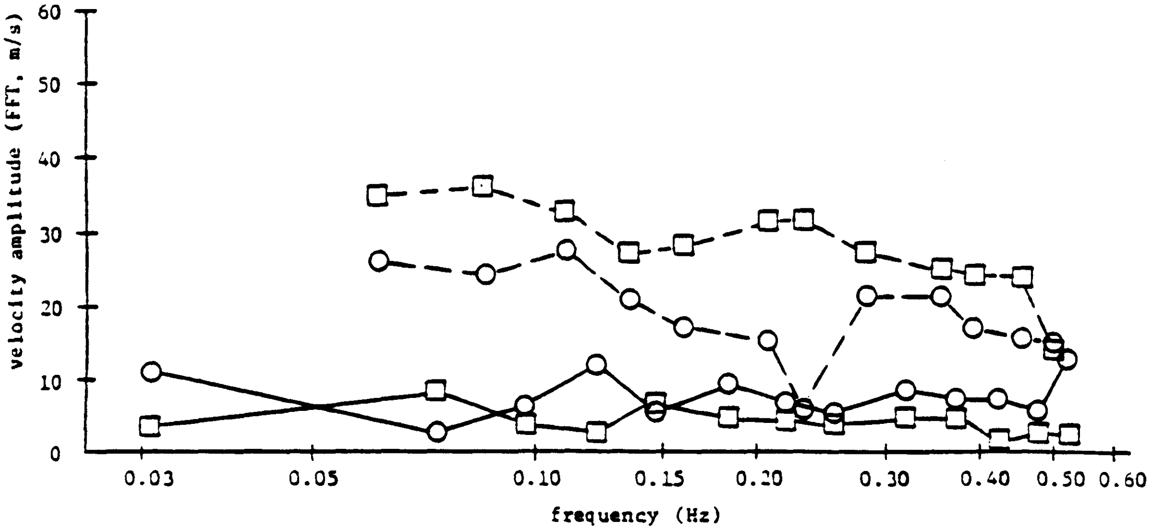


Figure E6.1.09 Frequency Spectrum, Subject MS
Run 07, Final Profile



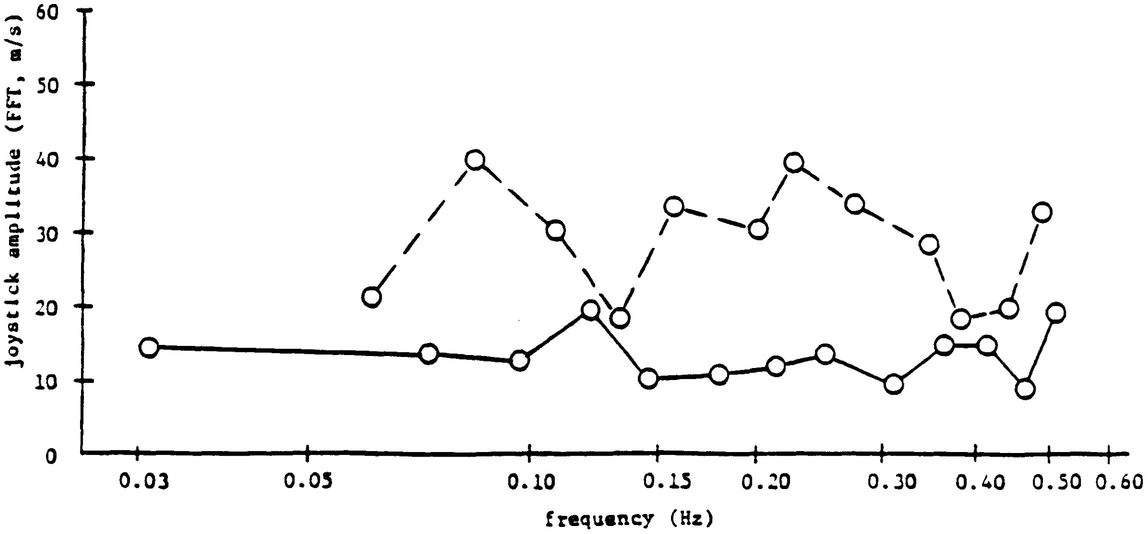
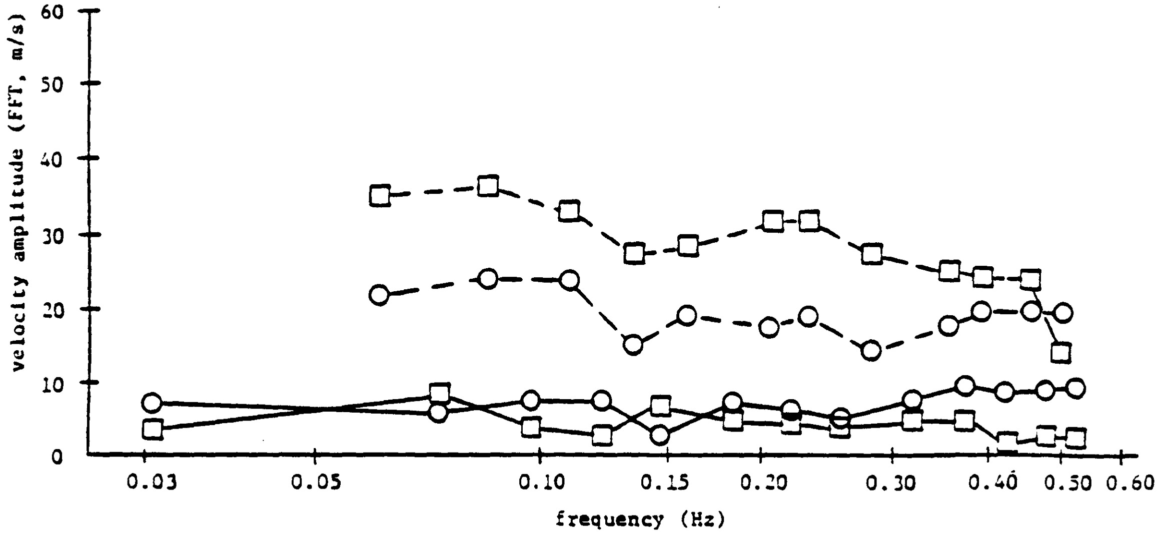


Figure E6.1.10 Frequency Spectrum, Subject MS
Run 08, Final Profile



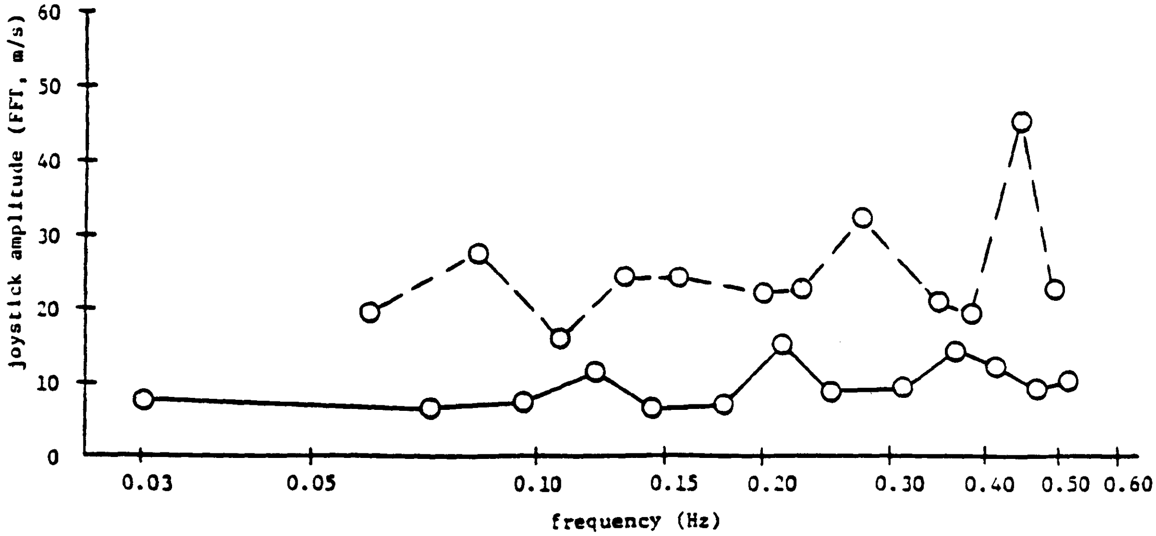
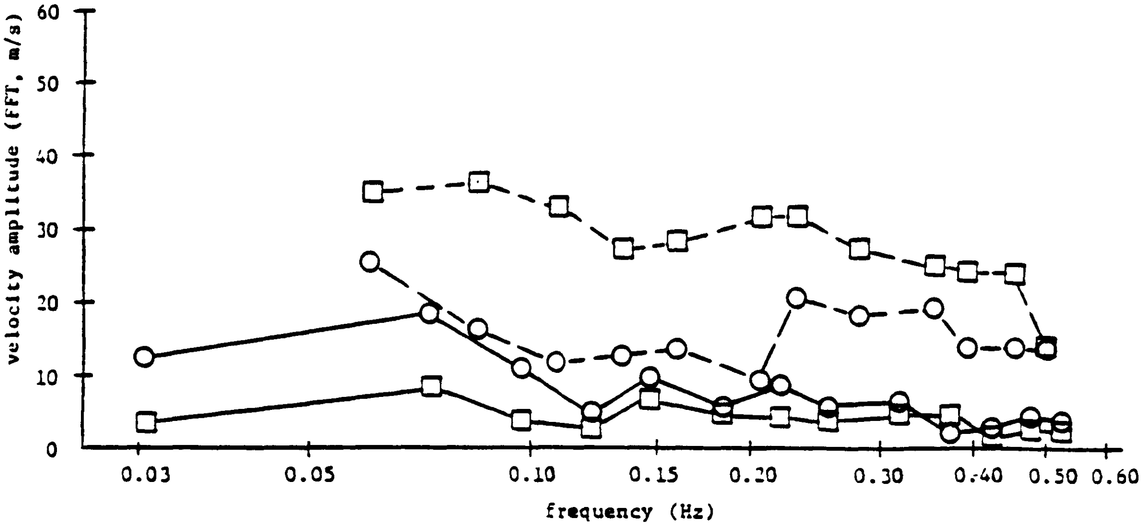


Figure E6.1.11 Frequency Spectrum, Subject MS
Run 09, Final Profile



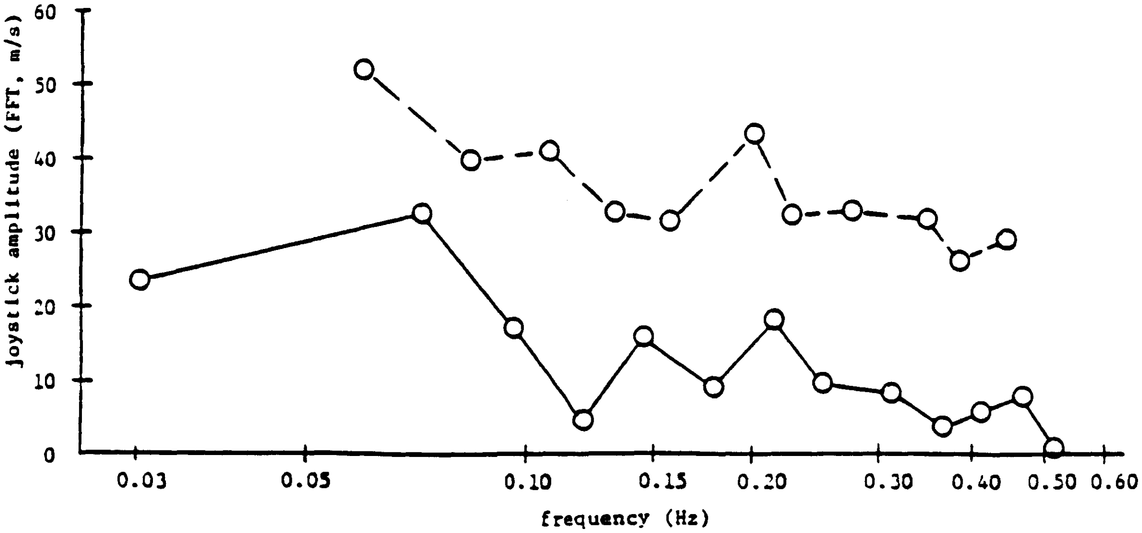
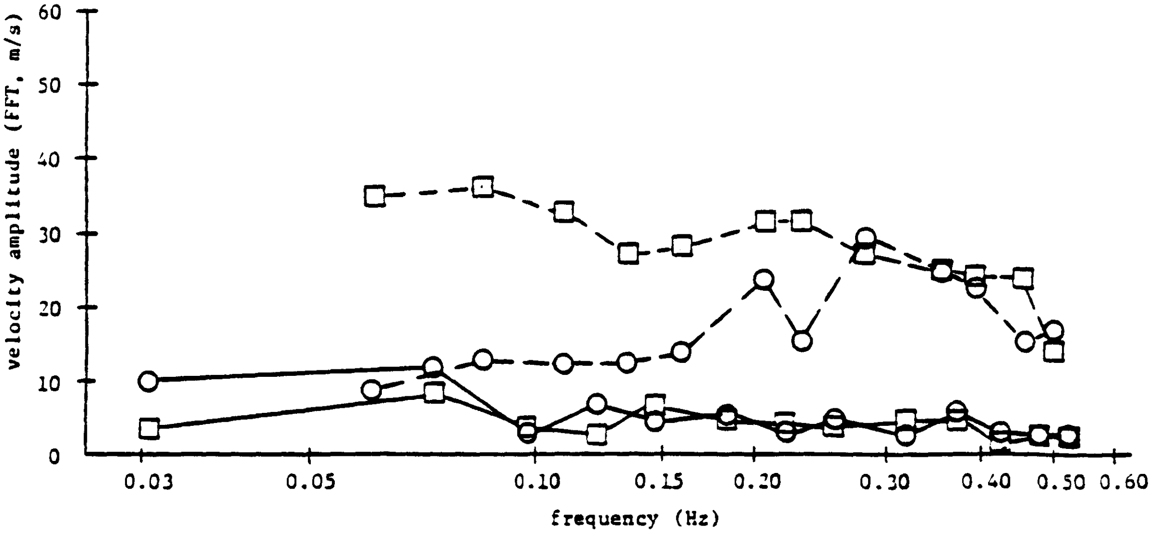


Figure E6.1.12 Frequency Spectrum, Subject MM
Run 03, Final Profile



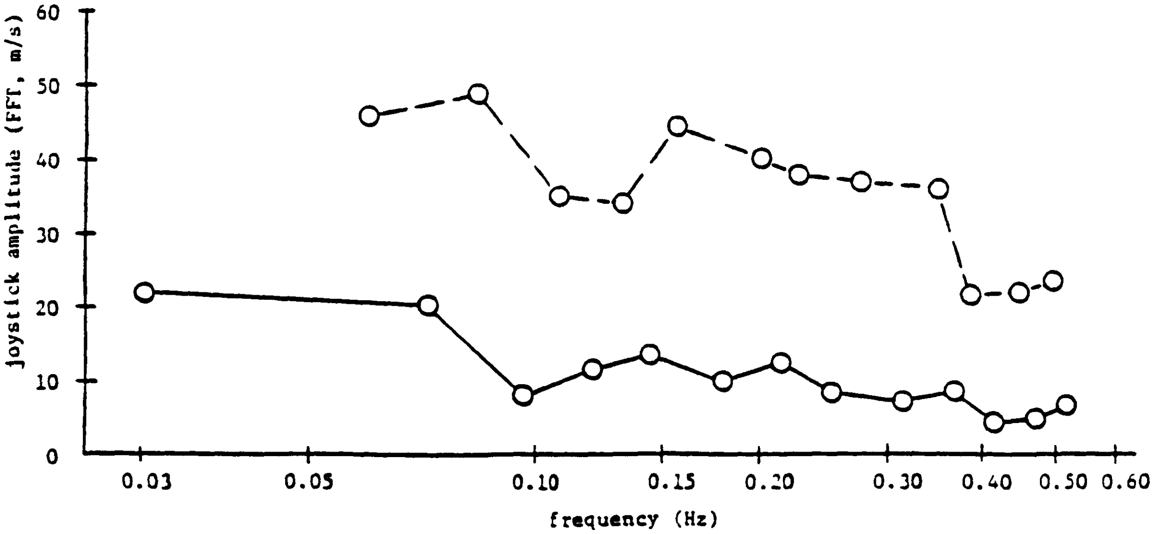
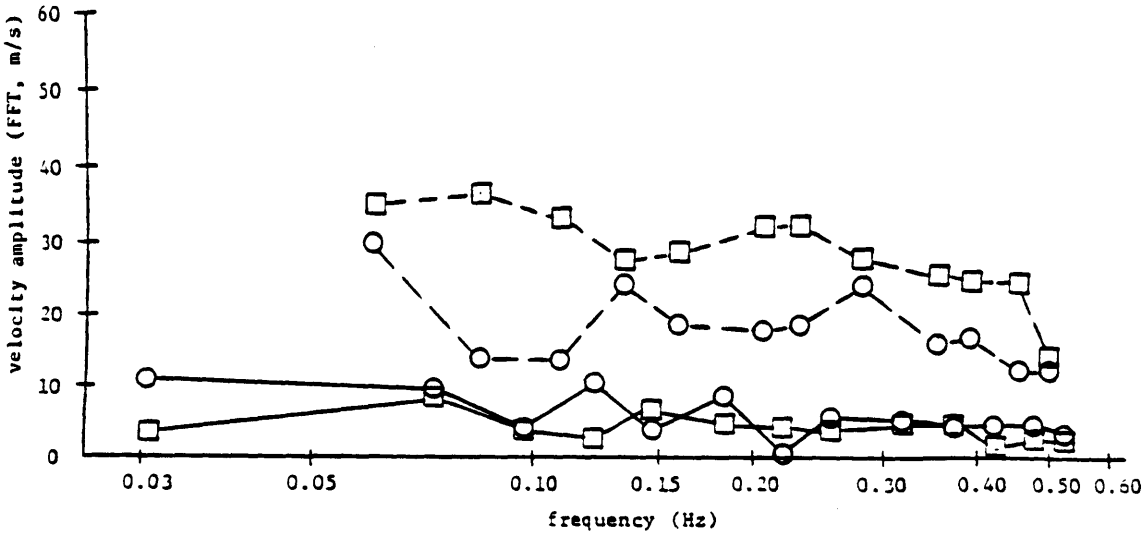


Figure E6.1.13 Frequency Spectrum, Subject MM
Run 09, Final Profile



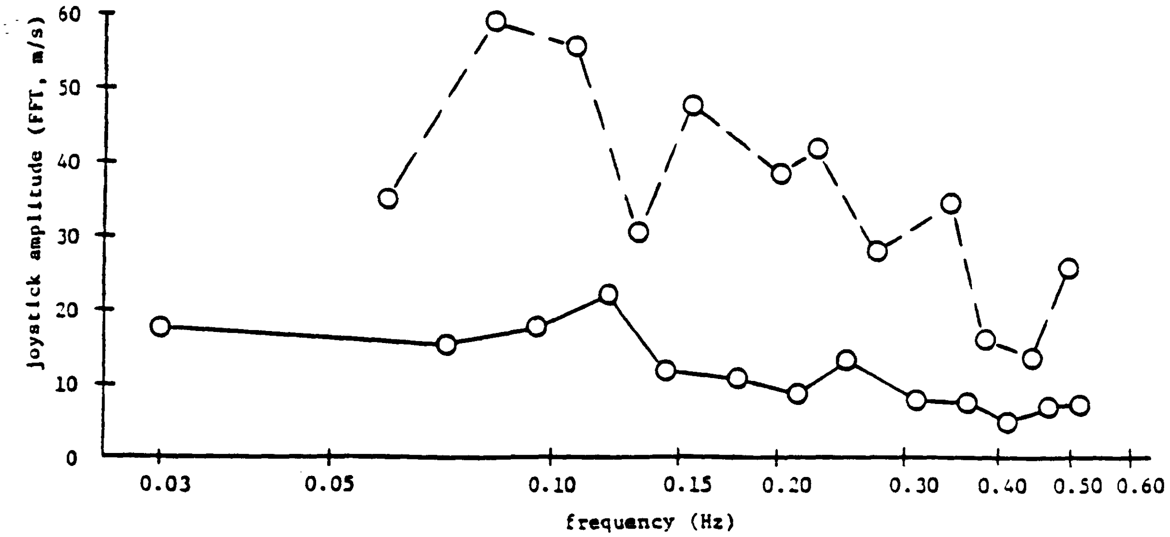
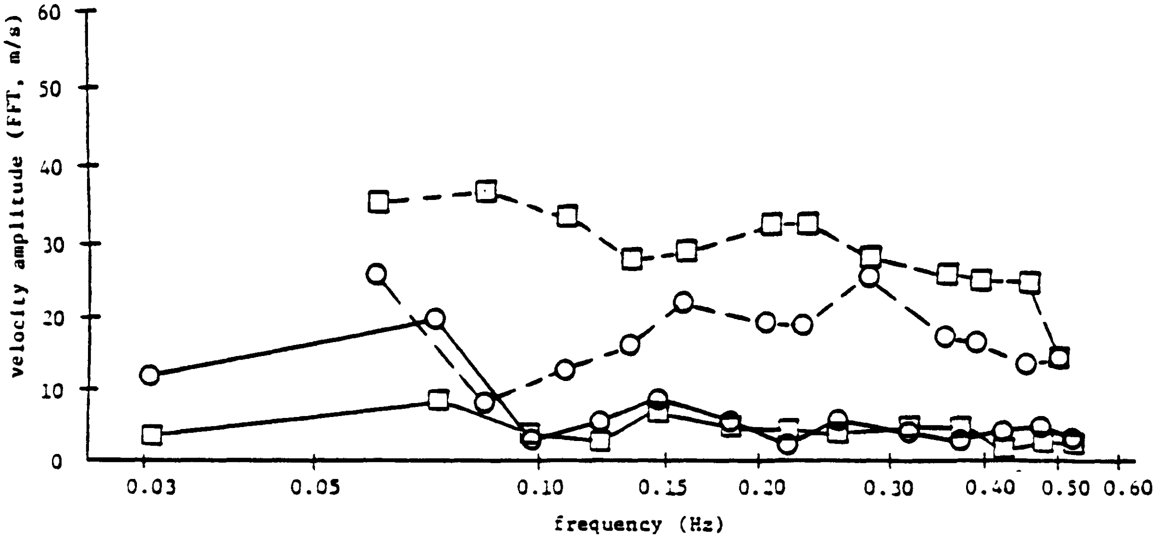


Figure E6.1.14 Frequency Spectrum, Subject MM
Run 12, Final Profile



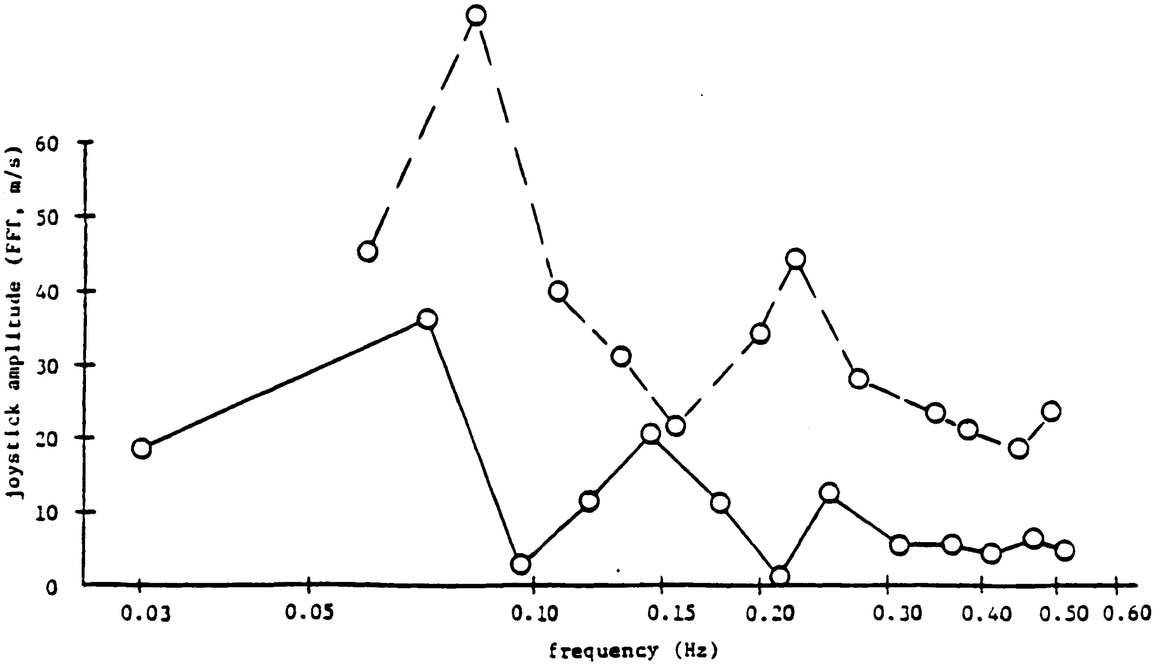
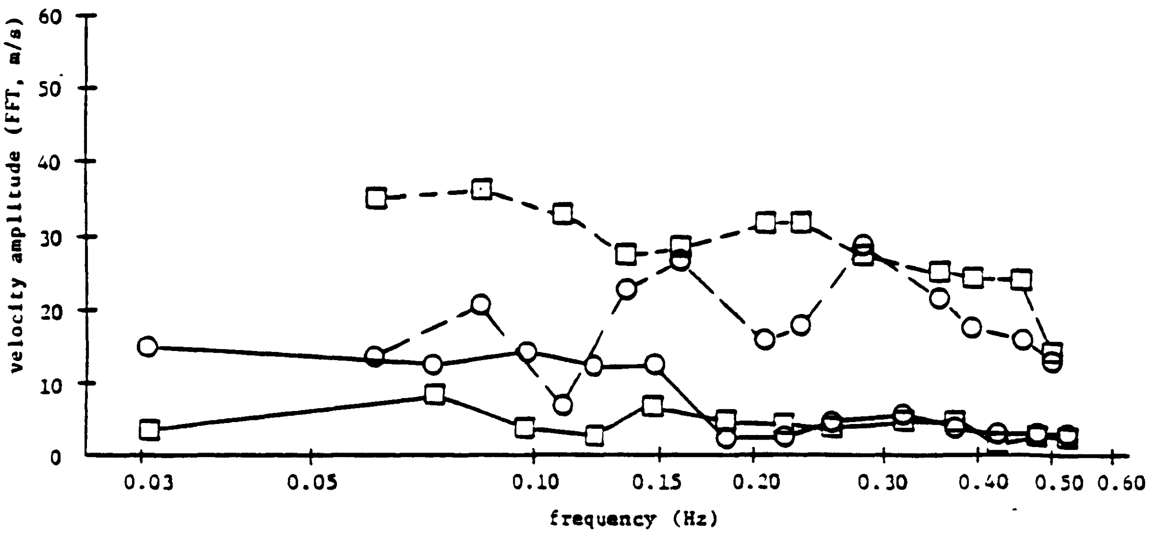


Figure E6.1.15 Frequency Spectrum, Subject MM
Run 15, Final Profile



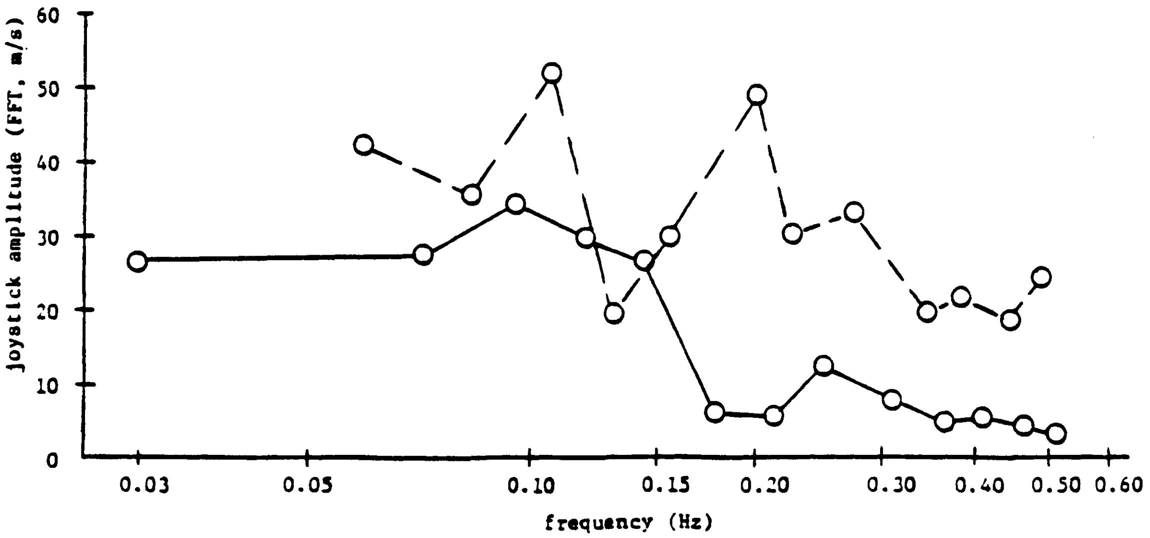
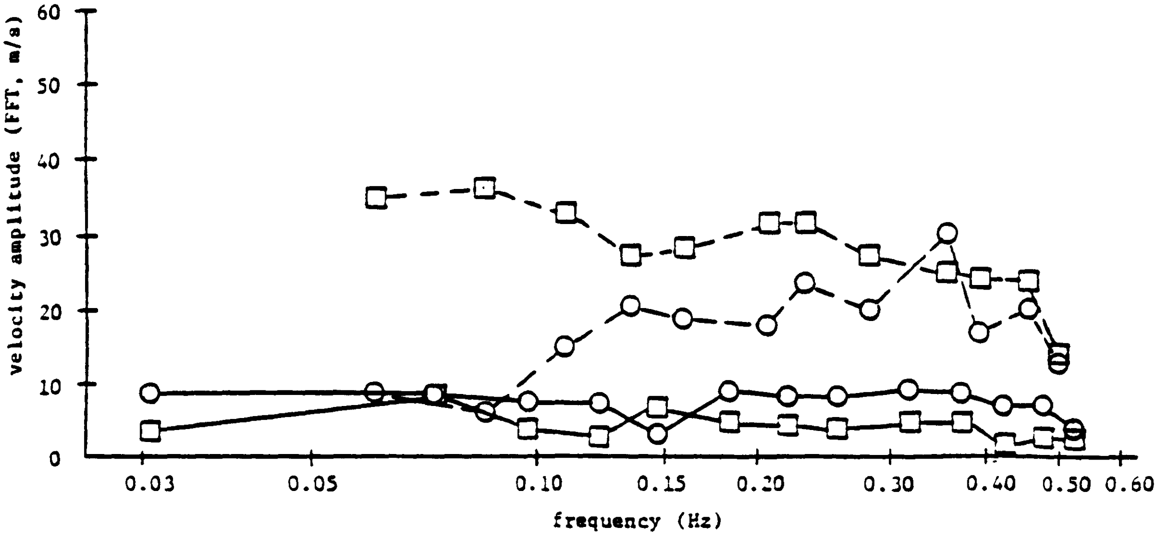


Figure E6.1.16 Frequency Spectrum, Subject MM
Run 18, Final Profile



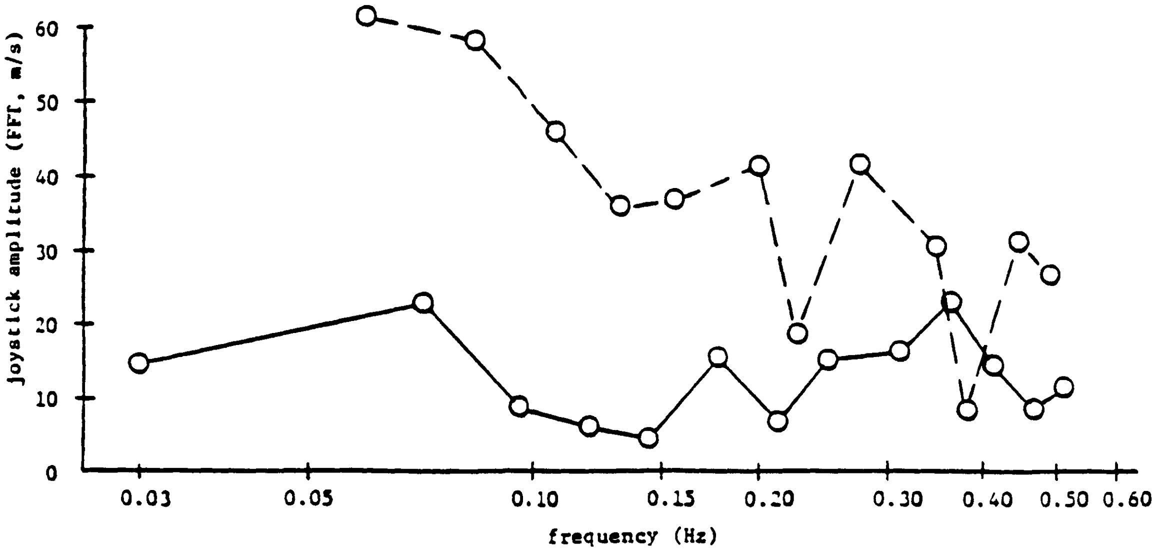
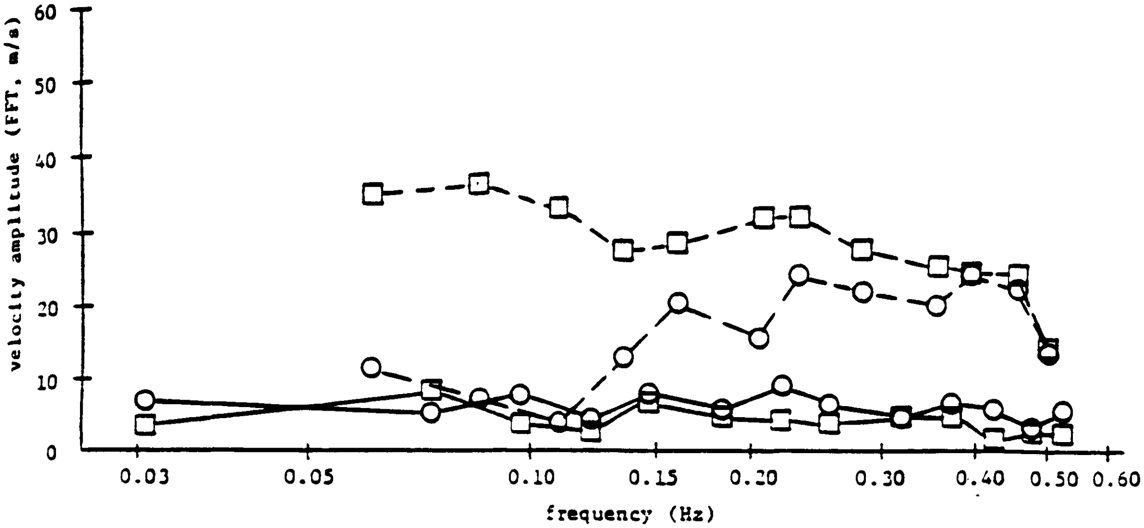


Figure E6.1.17 Frequency Spectrum, Subject JH
Run 03, Final Profile



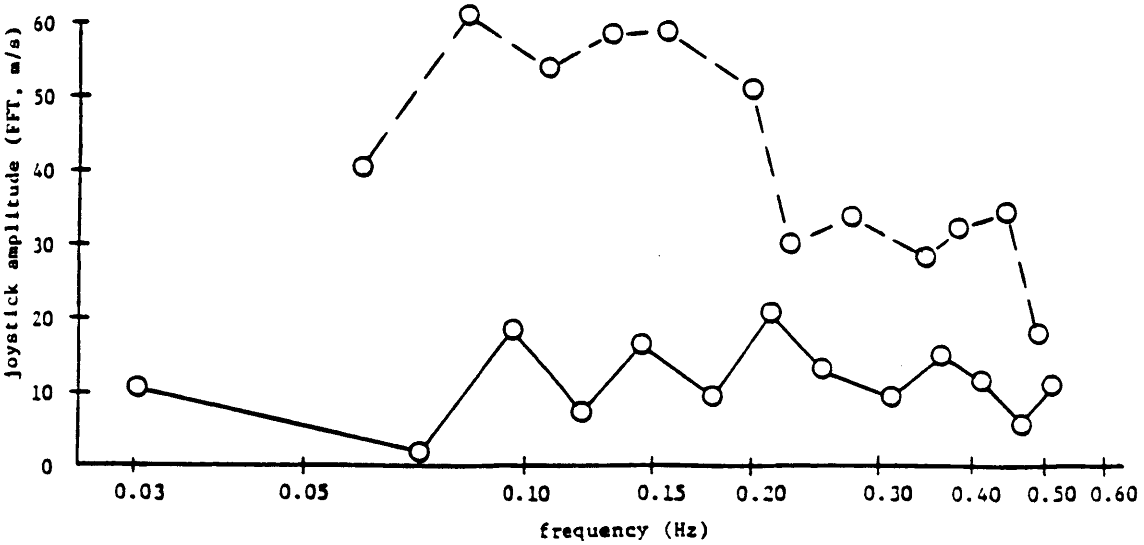
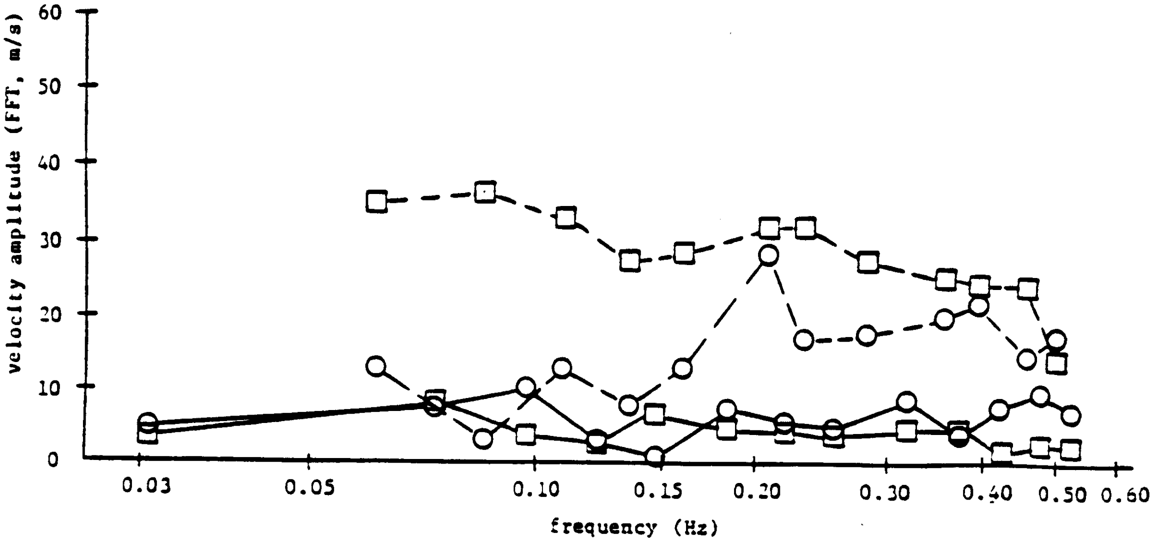


Figure E6.1.18 Frequency Spectrum, Subject JH
Run 06, Final Profile



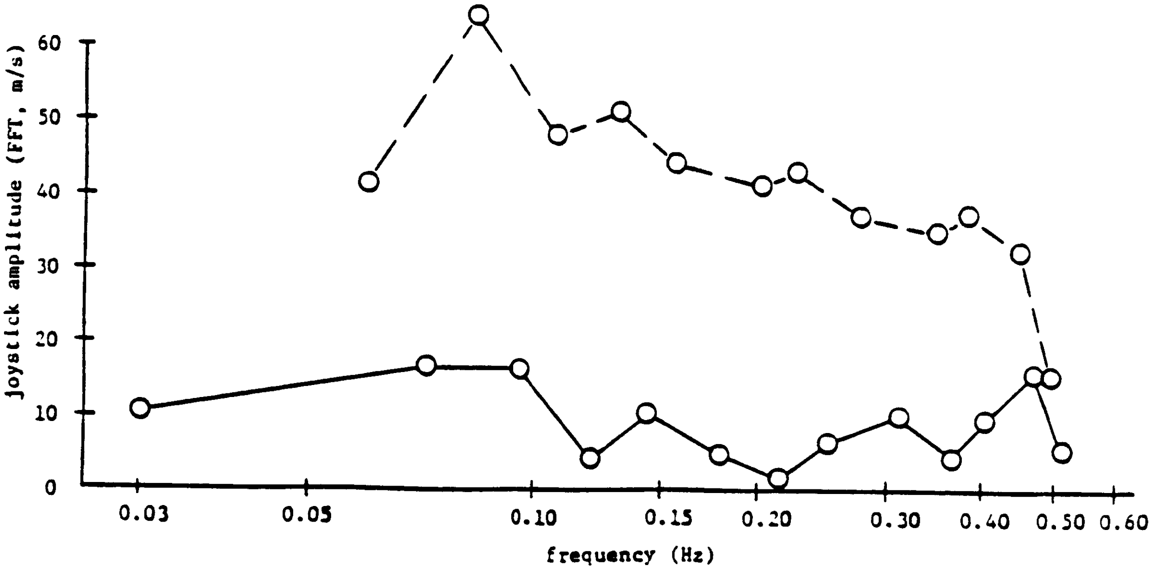
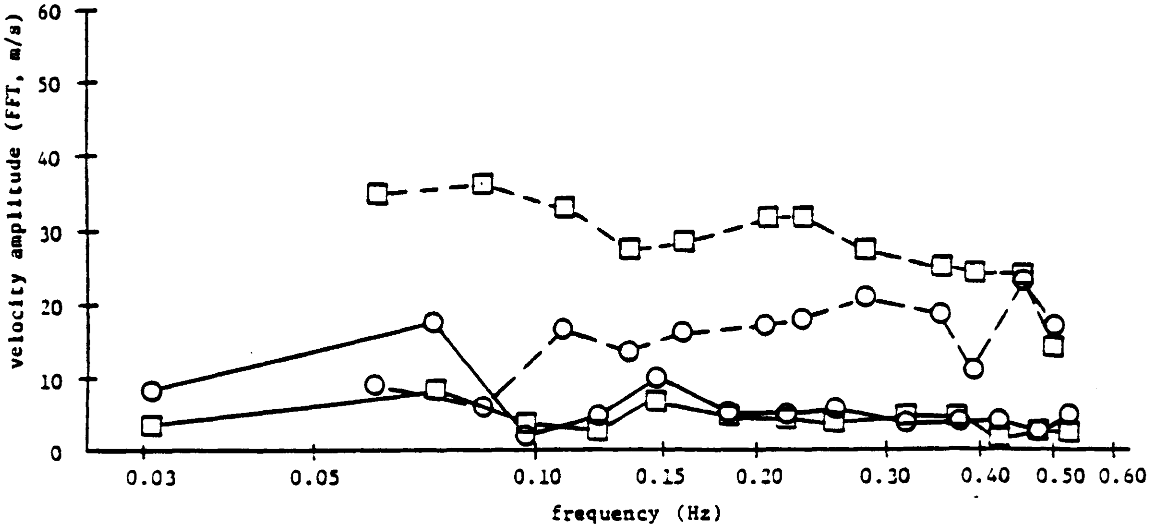


Figure E6.1.19 Frequency Spectrum, Subject JH
Run 08, Final Profile



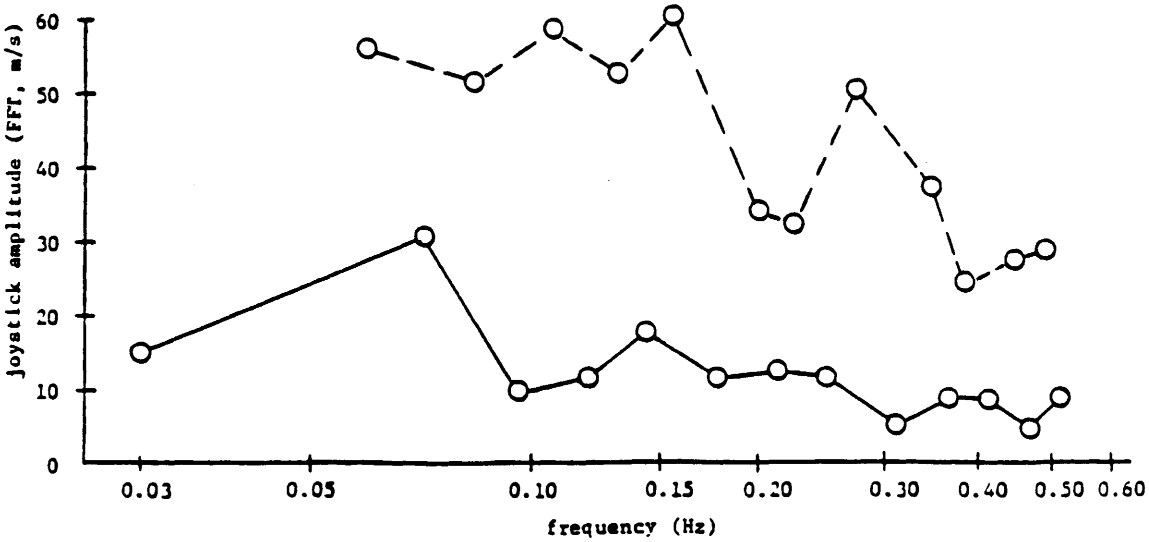
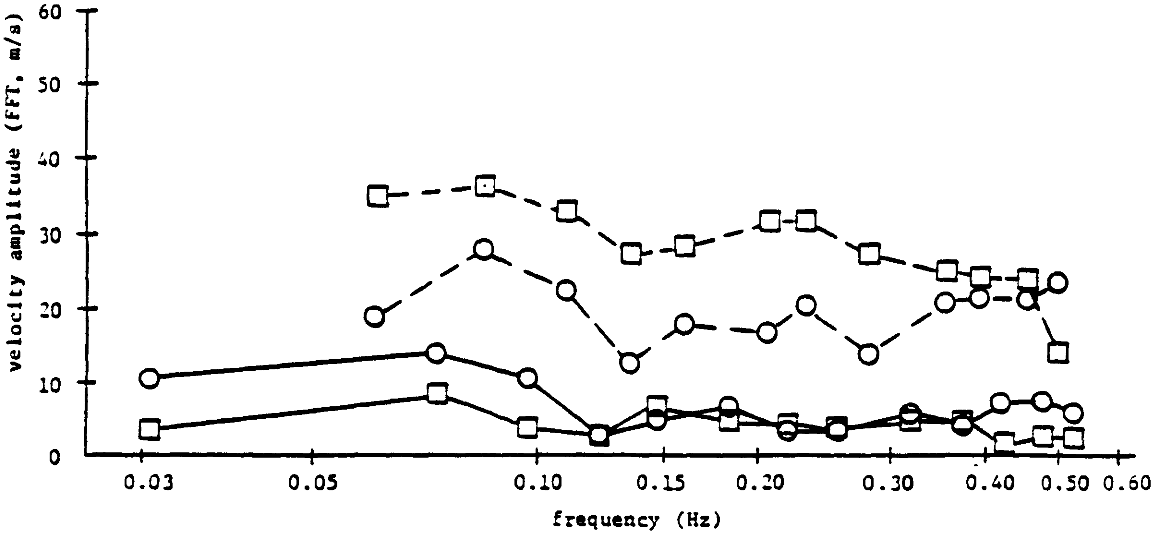


Figure E6.1.20 Frequency Spectrum, Subject JH
Run 09, Final Profile



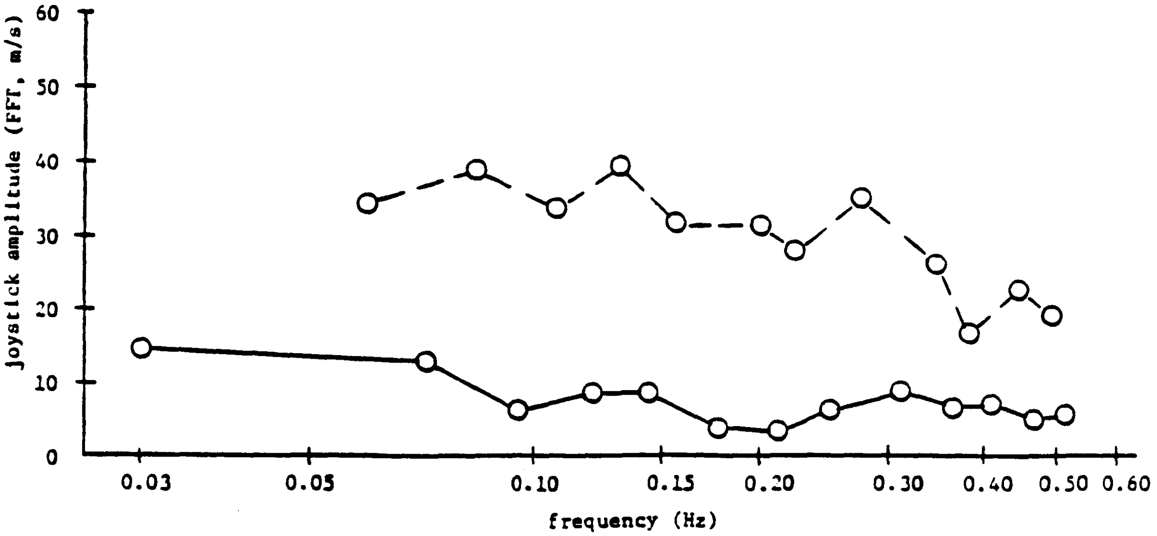
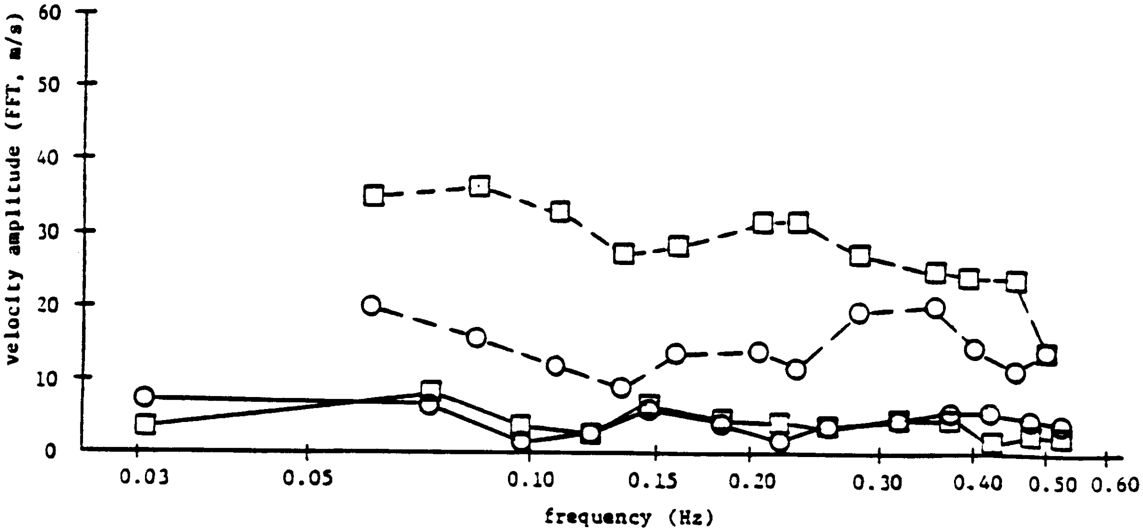


Figure E6.1.21 Frequency Spectrum, Subject DH
Run 12, Final Profile



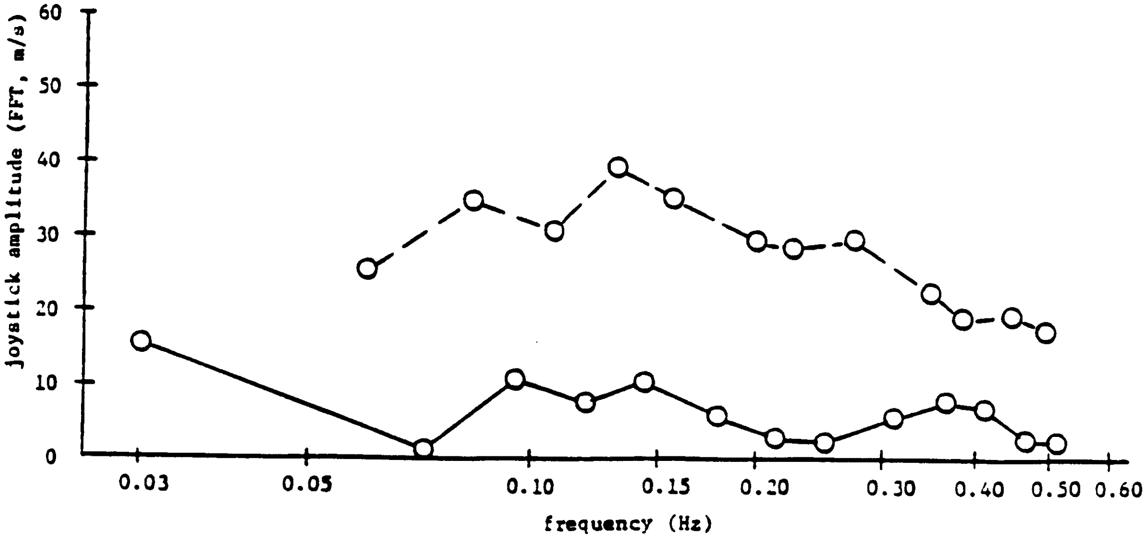
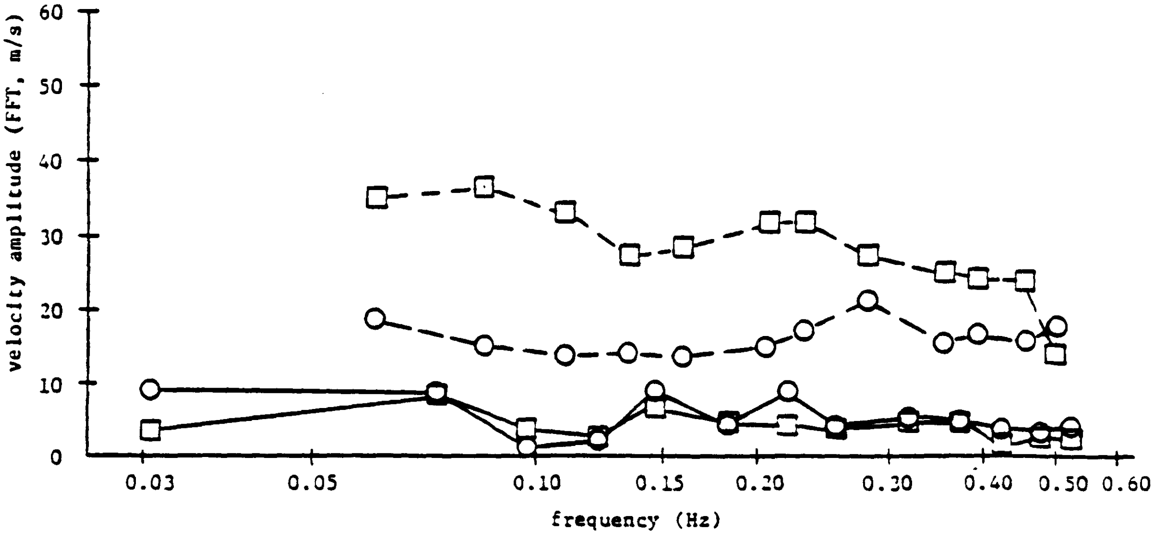


Figure E6.1.22 Frequency Spectrum, Subject DH
Run 15, Final Profile



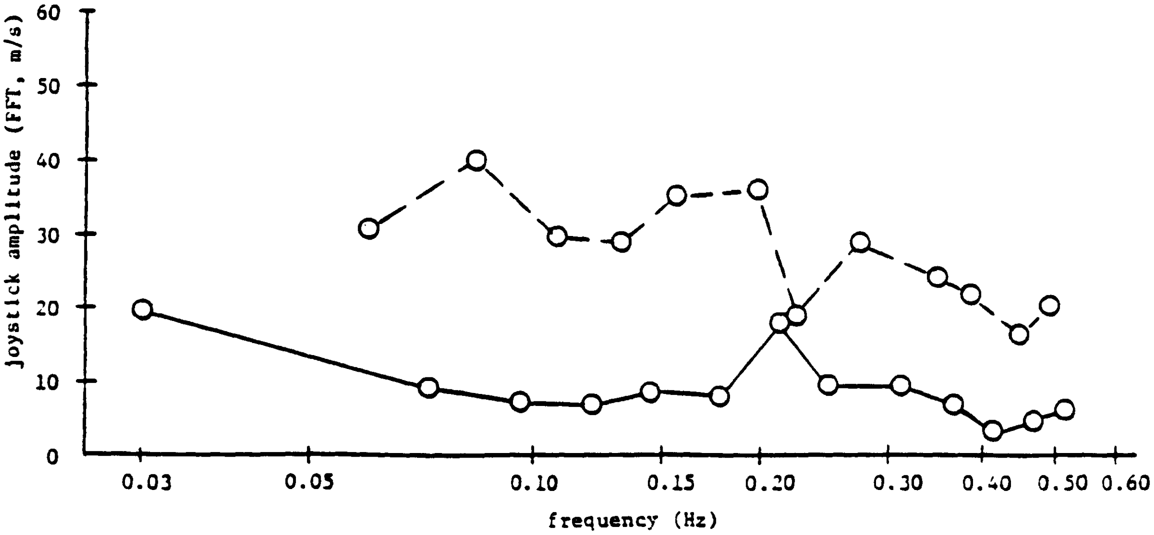
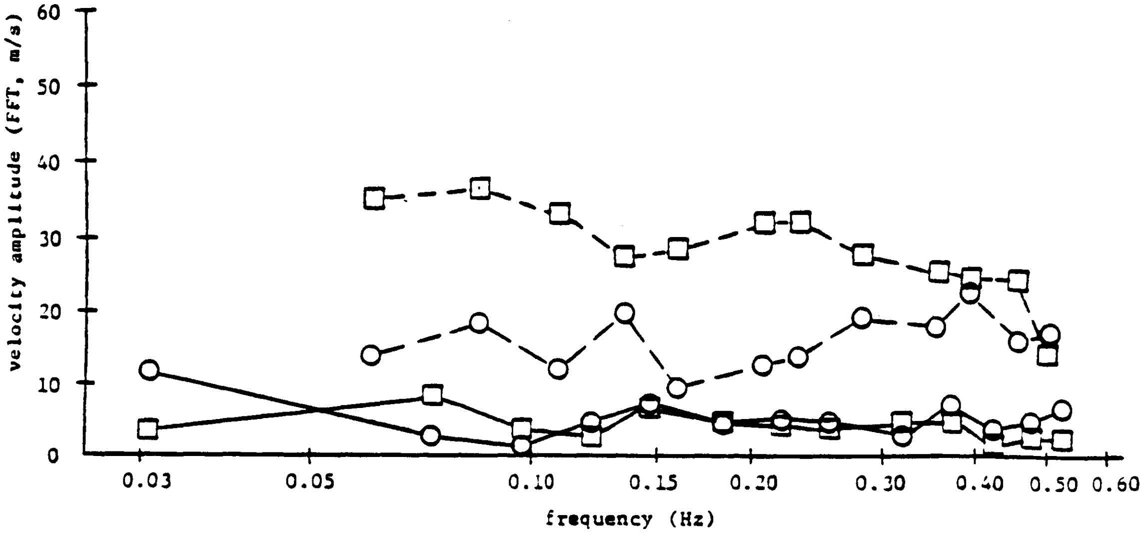


Figure E6.1.23 Frequency Spectrum, Subject DH
Run 21, Final Profile



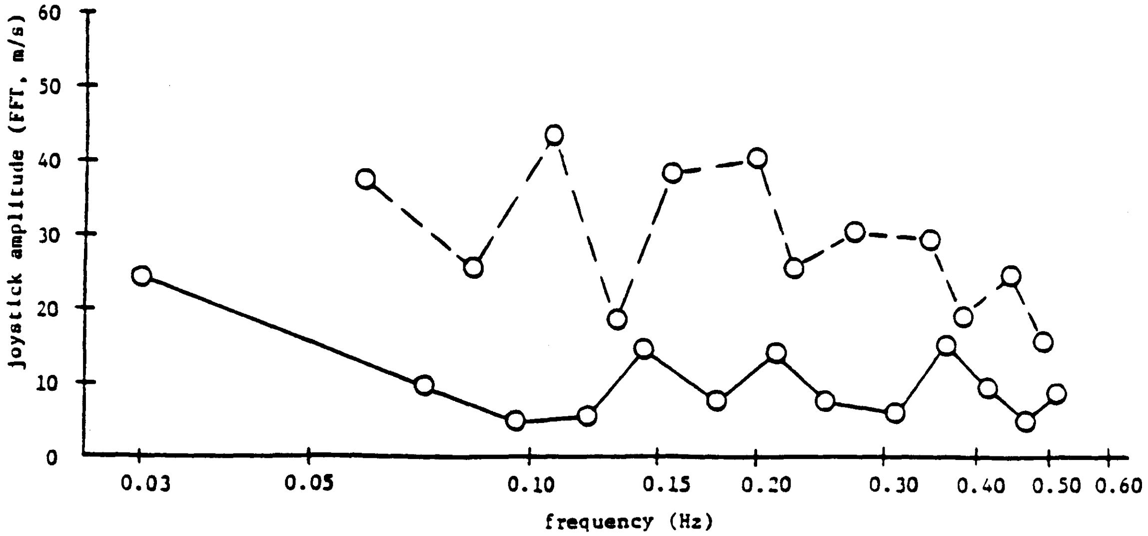
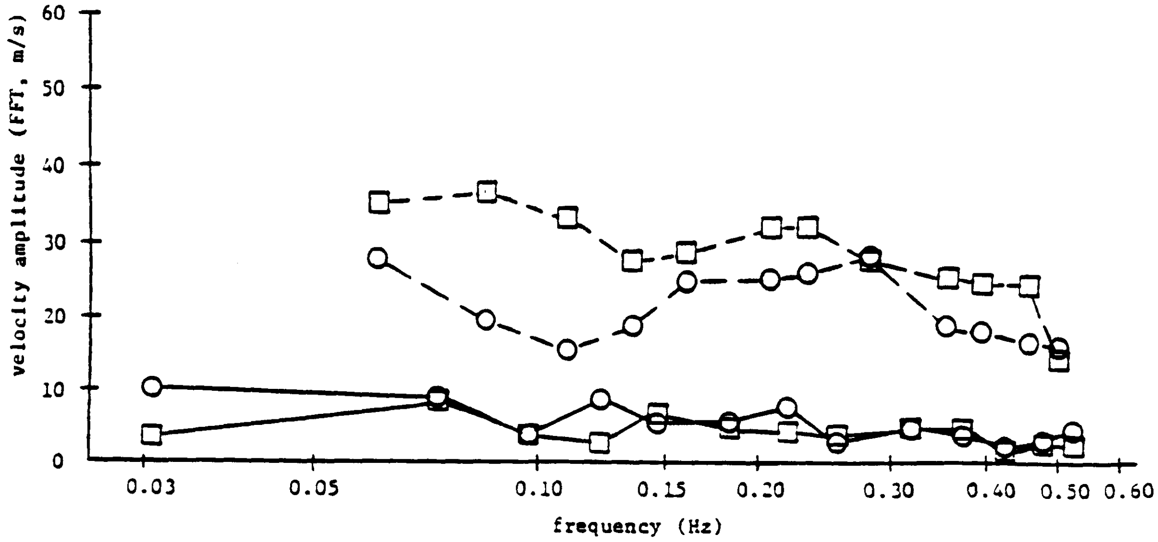


Figure E6.1.24 Frequency Spectrum, Subject DH
Run 22, Final Profile



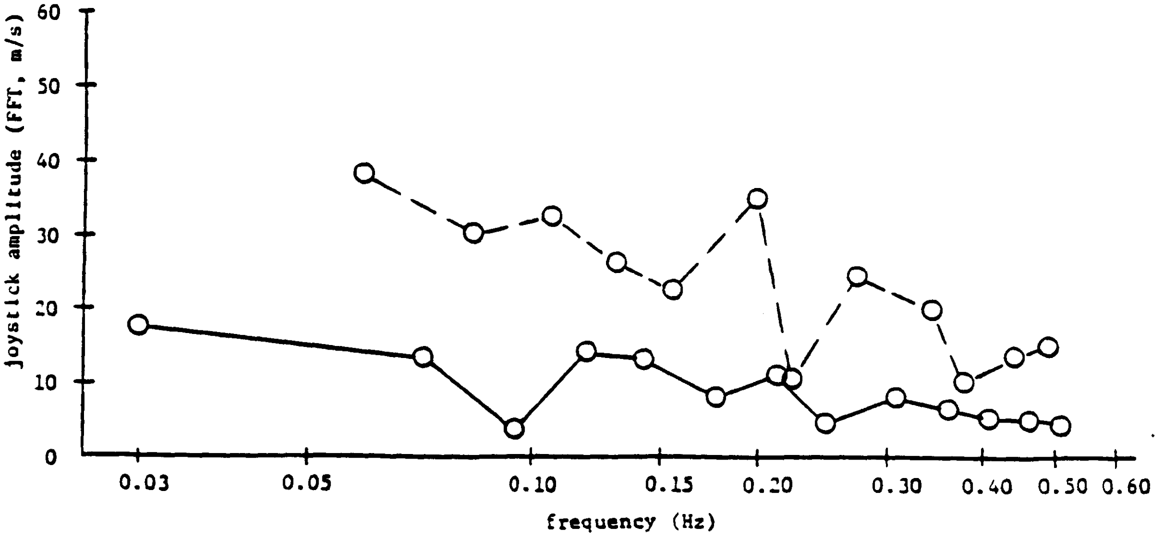


Figure E6.1.25 Frequency Spectrum, Subject DH
Run 23, Final Profile

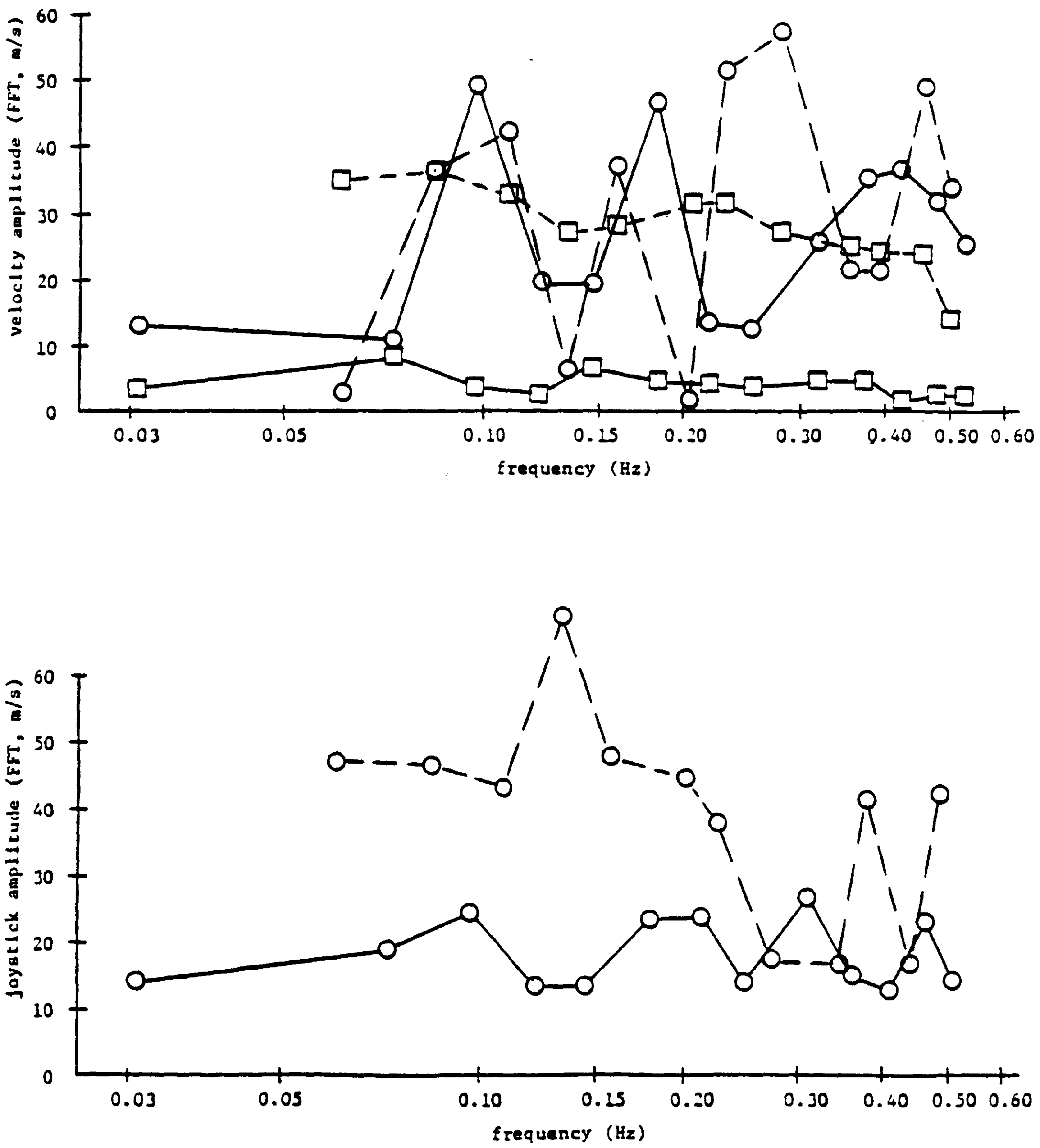
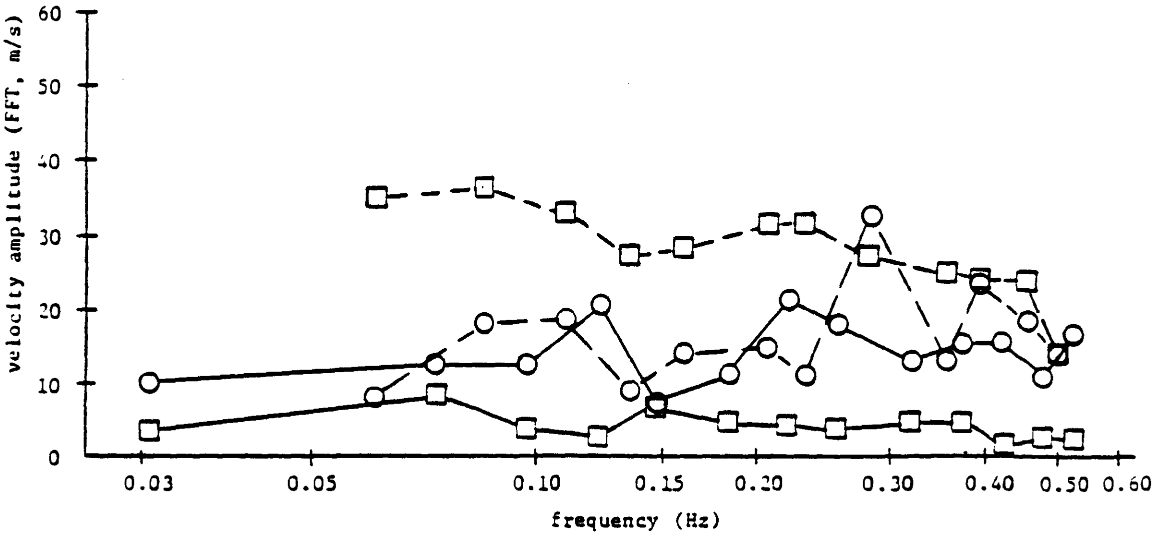


Figure E6.1.26 Frequency Spectrum, Subject LR
Run 02, Final Profile



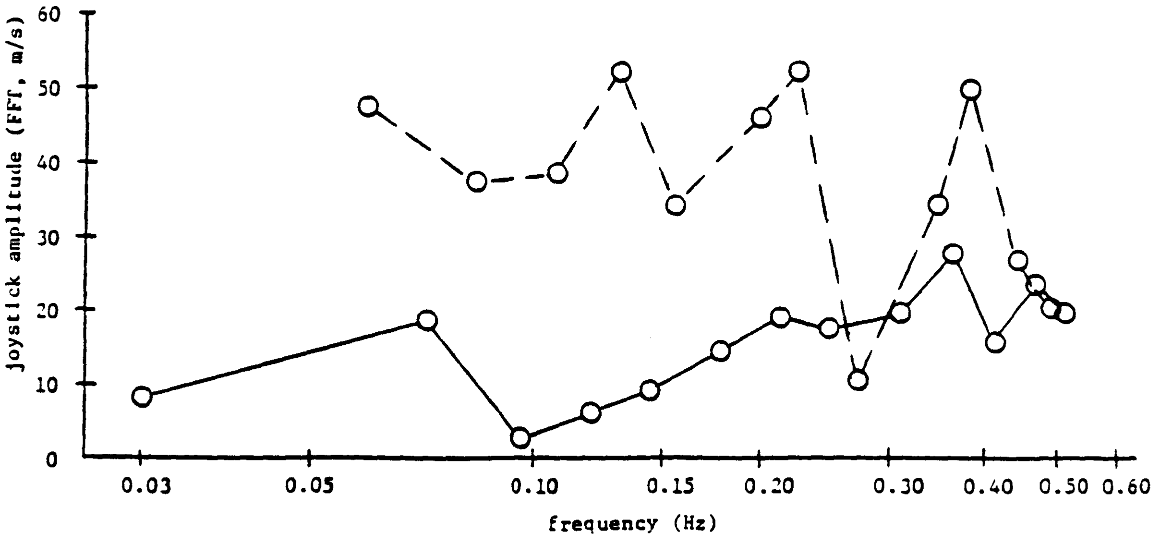
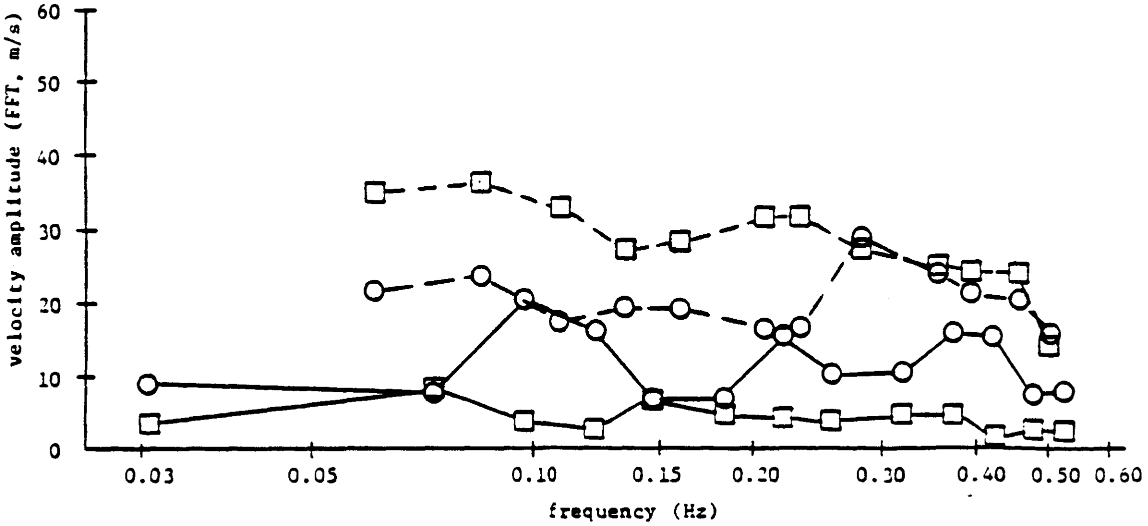


Figure E6.1.27 Frequency Spectrum, Subject LR
Run 03, Final Profile



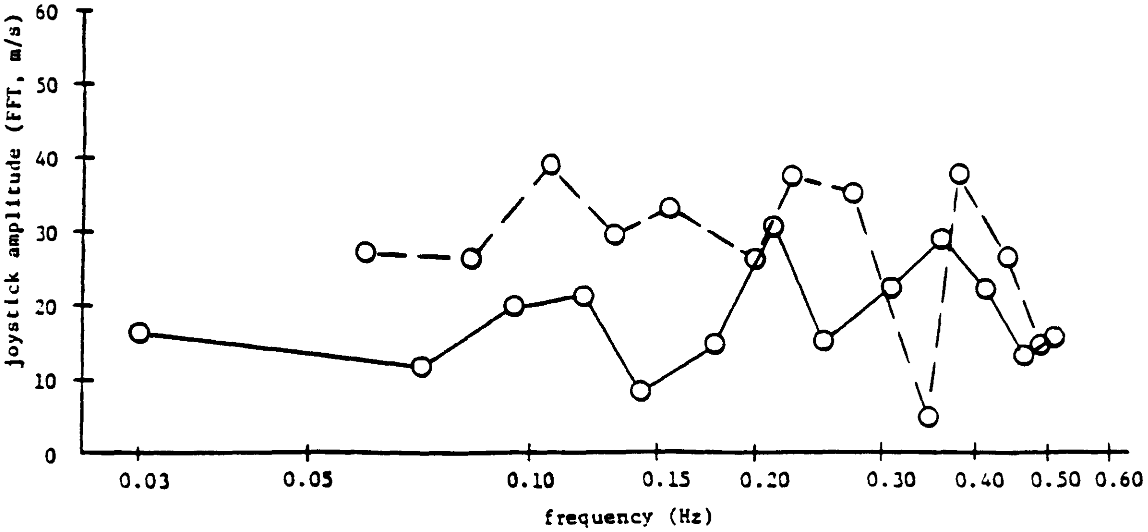


Figure E6.1.28 Frequency Spectrum, Subject LR
Run 06, Final Profile

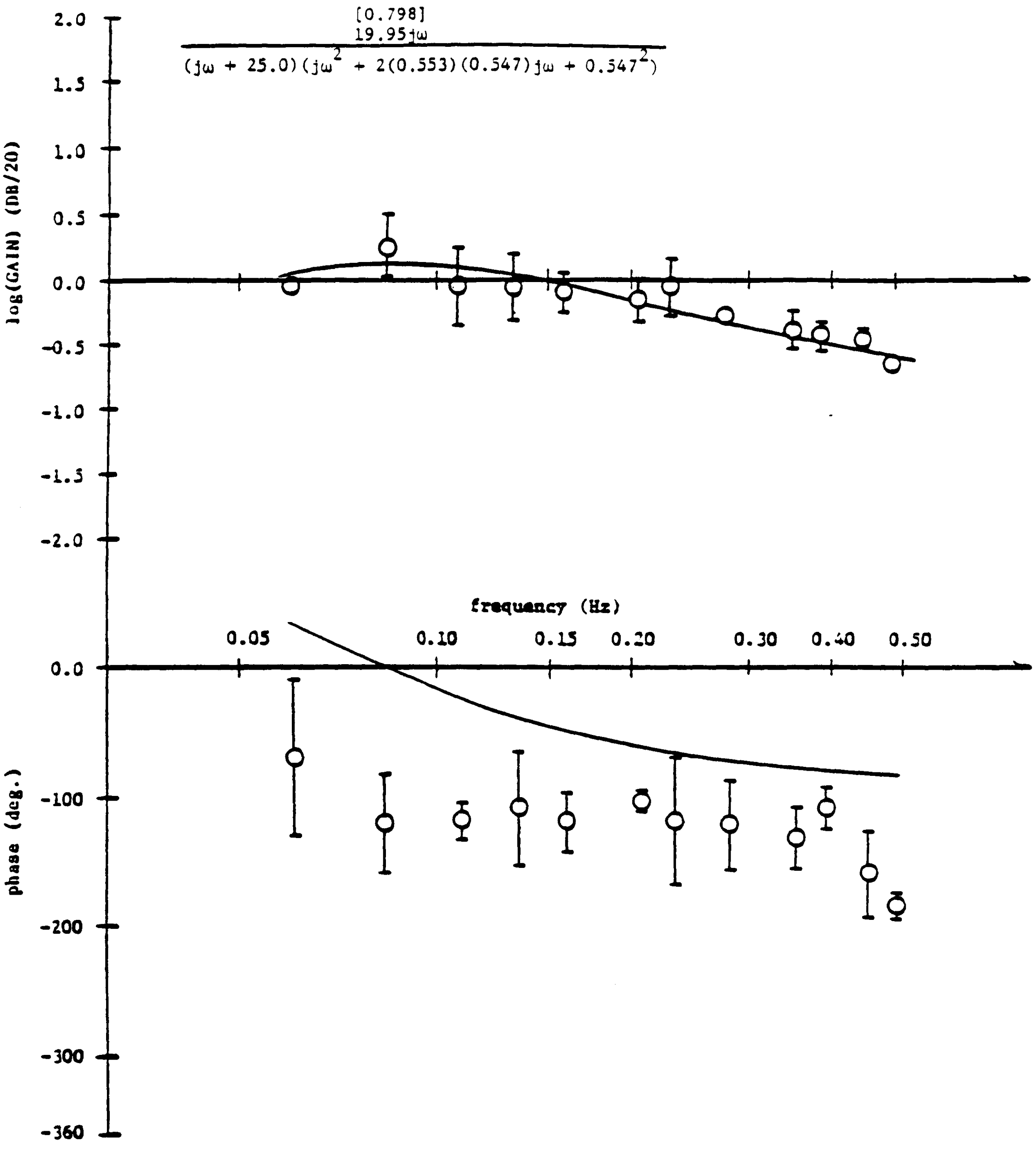


Figure E6.3.01 Model and Curve Fit. Subject MS

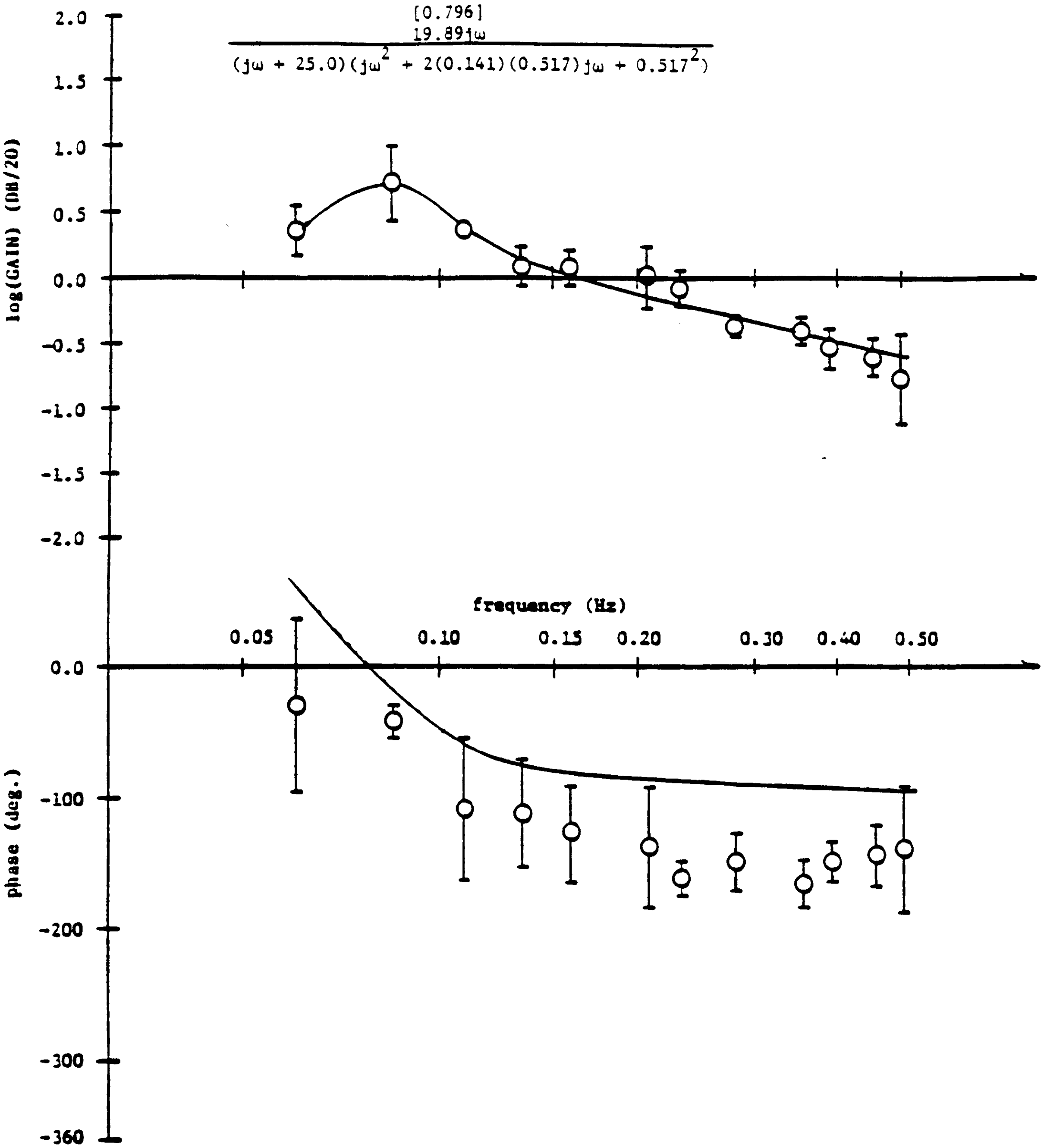


Figure E6.3.02 Model and Curve Fit. Subject MM

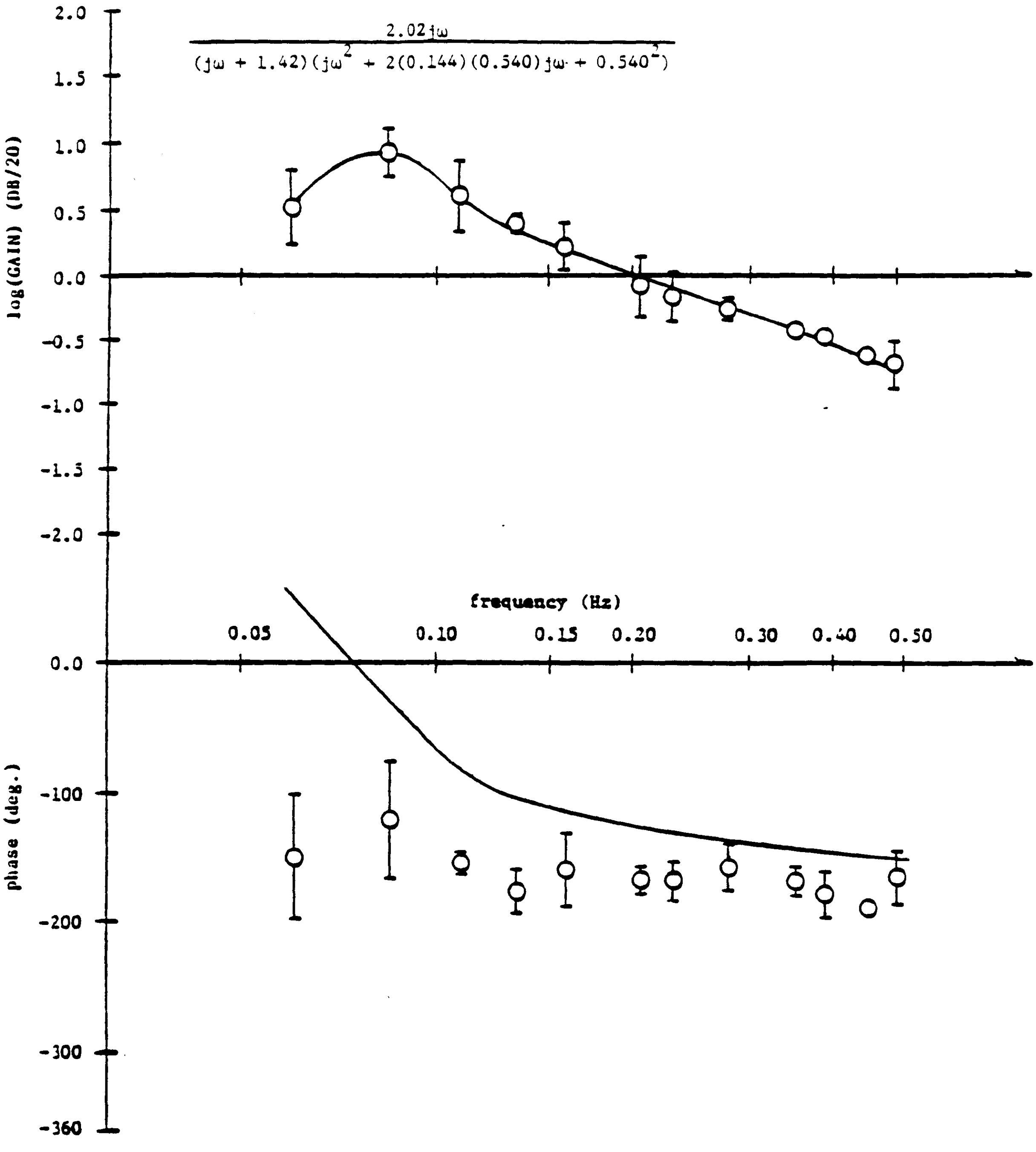


Figure E6.3.03 Model and Curve Fit. Subject JH

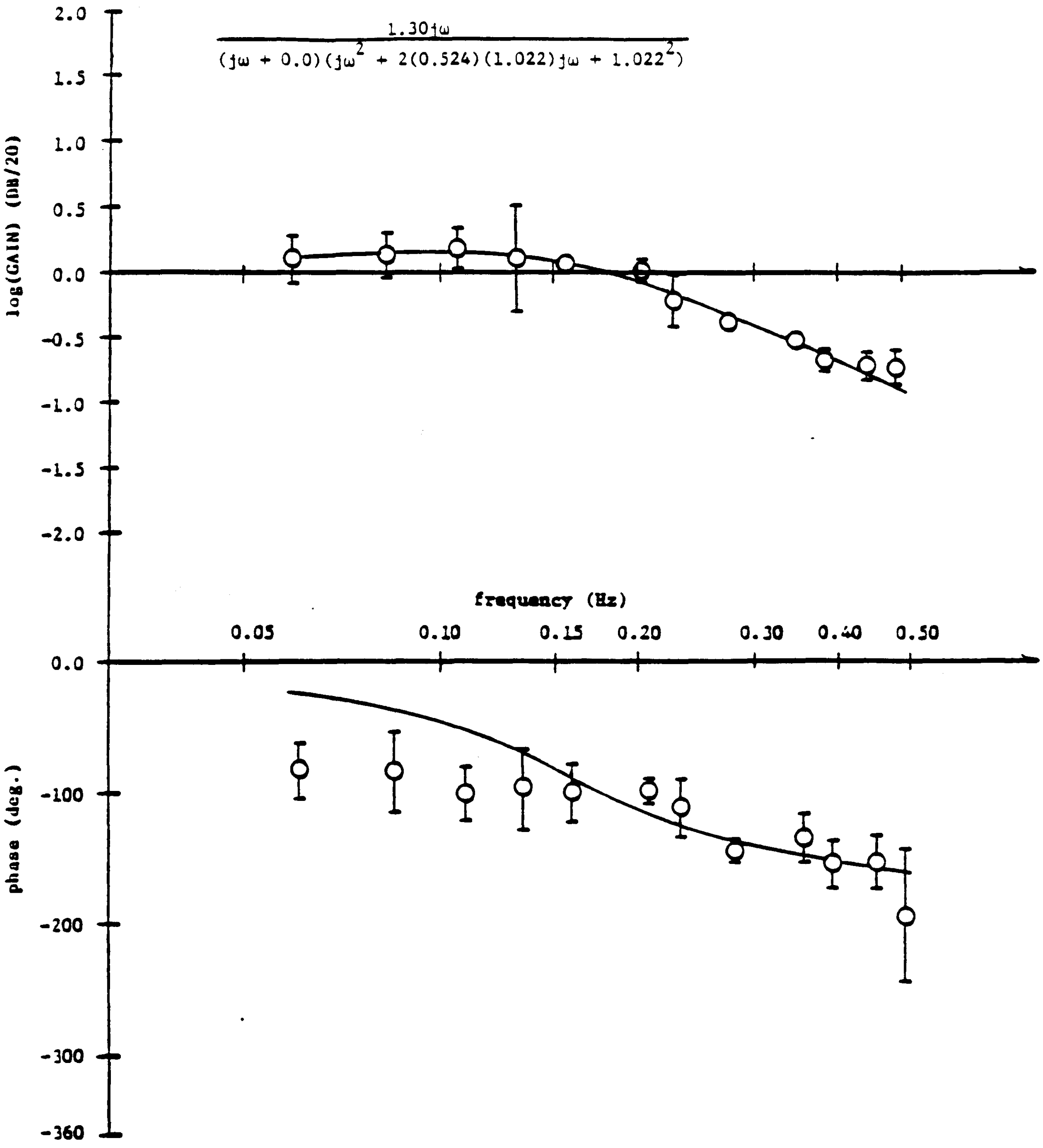


Figure E6.3.04 Model and Curve Fit. Subject DH

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