VERIFICATION OF SIMULATOR PERFORMANCE BY FREQUENCY RESPONSE MEASUREMENT

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INTRODUCTION

The usual method for verifying the implementation of airframe dynamics in a flight trainer is transient response tests. These tests have the advantage of requiring both less test time and less data reduction effort than the alternate technique of measuring the frequency response of the system. However, this saving in time and effort is made at the cost of less information about the performance of the simulator.

The addition of visual systems to flight trainers creates the need for more critical testing of the simulated aircraft dynamics. One reason for more stringent testing is that the visual system magnifies differences between the simulator and the actual aircraft performance. Shortcomings in the simulator that were not noticed in instrument flying become obvious with the addition of the visual system. Another reason for trenchant examination of the simulator with a visual system is the different mode in which a pilot flies such a device. In instrument flying, the pilot tends to make small, careful corrections. With a visual system, he makes large, more abrupt changes in the control settings, leading to higher-amplitude and higher-frequency inputs to the simulator program. This may result in discrepancies in the simulation which do not occur for the instrument flight mode.

When a contract was let to add a visual system to the TA-4J Aircraft Operational Flight Trainer $(OFT)^2$, Device 2F90, frequency response testing of both the simulated aircraft dynamics and the visual system operation were made part of the test requirements. This paper presents the result of those tests.

STATEMENT OF THE PROBLEM

Simulator response tests are performed by establishing an appropriate level flight condition, then exciting the axis to be tested. The usual input for transient response testing is a pulse of fixed magnitude and relatively short duration. For example, the pitch axis test performed on the simulator used a 2° elevator deflection of one second duration. This excites oscillations at two different frequencies, as shown in Figure 1. These test results can be used to determine the periods and damping for the two oscillations.

There are two problems which limit the information which can be obtained in this manner. The first is the form of the transfer function. Observe that the short period oscillation is almost damped out before one cycle is complete. This makes accurate measurement of the higher-frequency oscillation difficult.

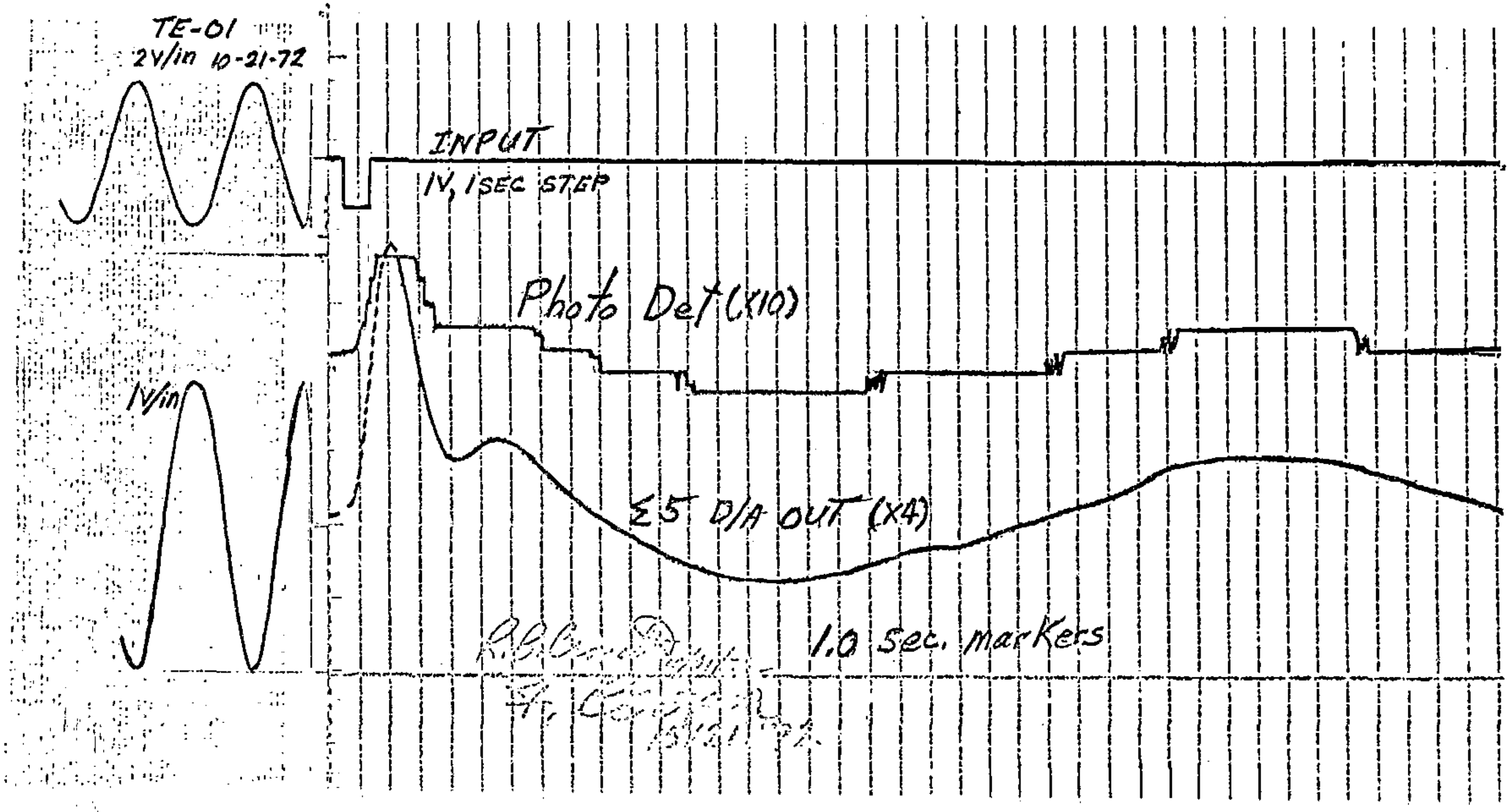


Figure 1. Transient Response Test Example

A more serious restriction is that the transient-test results allow derivation of the frequency response for only a limited range of frequencies on either side of the fundamental frequency of the pulse.[1] The transient response test is even less useful if the system has significant non-linearities.

SIMULATOR DESCRIPTION

The TA-4J OFT consists of four separate, identical, and independently operated cockpits and their associated instructor stations, input/output controllers, and conversion units. The trainer is controlled by two Xerox Sigma 5 computers. One computer is dedicated to flight simulation for all four cockpits. The second computer executes the programs for aircraft systems simulation, communications and navigation, problem demonstrations, performance monitoring, and instructor console control. A common core memory is used to store common variables and data and to buffer I/O operations to the trainer/instructor stations. Figure 2 is a configuration diagram of Device 2F90 with the visual attachment hardware. The added visual equipment which was installed are identified by the circled numbers.[3]

VISUAL SYSTEM

The visual attachment required the addition of a Direct Input/Output Interface, XDS Model 7930. The attachment also resulted in the addition of approximately 1600 words[4] to the operational 2F90 simulation program. The visual system is composed of three main subsystems and some instructor console equipment. The subsystems are: (1) Computer Subsystem, (2) Image Generation Subsystem, and (3) Display Subsystem.

The Computer Subsystem includes an SEL 840, its disc file, card reader, paper tape punch and reader, a remote teletypewriter, a high-speed special processor, and a Nova 800 mini-computer.

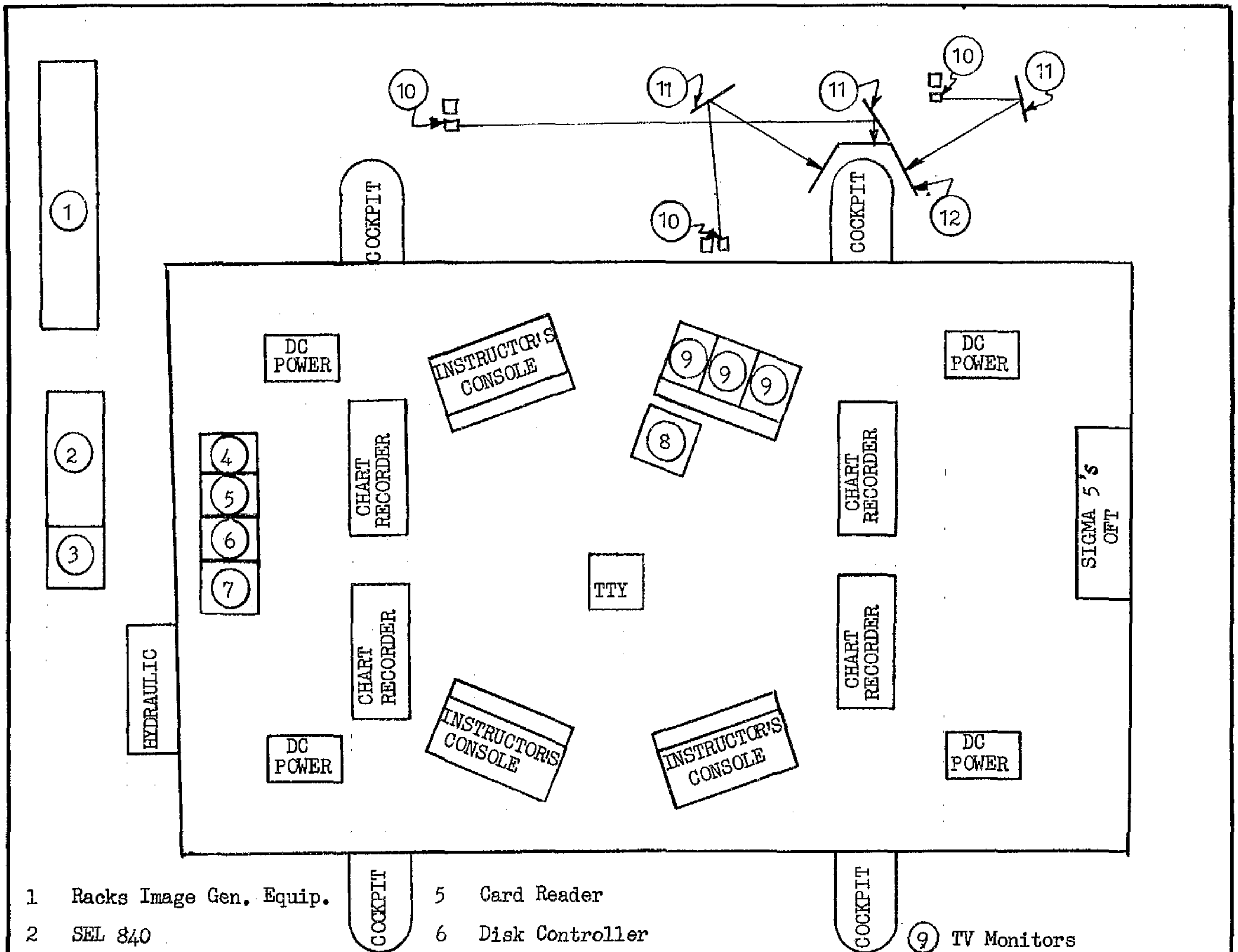
The Image Generation Subsystem consists of nine racks of logic. It receives information from the Computer Subsystem and performs the computations necessary to define the raster line element locations of the true perspective image for presentation by the Display Subsystem.

The Display Subsystem consists of three General Electric PJ-500 color television light valve projectors, three rear projection display screens, and three mirrors to fold the light beams onto the display screens.

The Instructor Console Equipment includes three color television monitors, which display the scene being presented to the trainee, and a "joystick" used to control the movement of the eyepoint within the visual environment for off-line data base creation and maintenance operations.

TEST DESCRIPTION

This paper primarily concerns the 2F90/Visual System frequency response tests. These tests were performed to determine the response characteristics of the 2F90/Visual System to various sinusoidal signals. Figure 3 is the test hardware configuration. Software changes and additions were required for scaling and to input and output appropriate signals and parameters.[5]



1 Racks Image Gen. Equip.
2 SEL 840
3 Special Proc.&NOVA 800
4 Paper Tape Reader/Printer
5 Card Reader
6 Disk Controller
7 Disk Unit
8 TTY
9 TV Monitors
10 Light Valve
11 Mirror
12 Display Screen

FIGURE 2. DEVICE 2F90 CONFIGURATION DIAGRAM

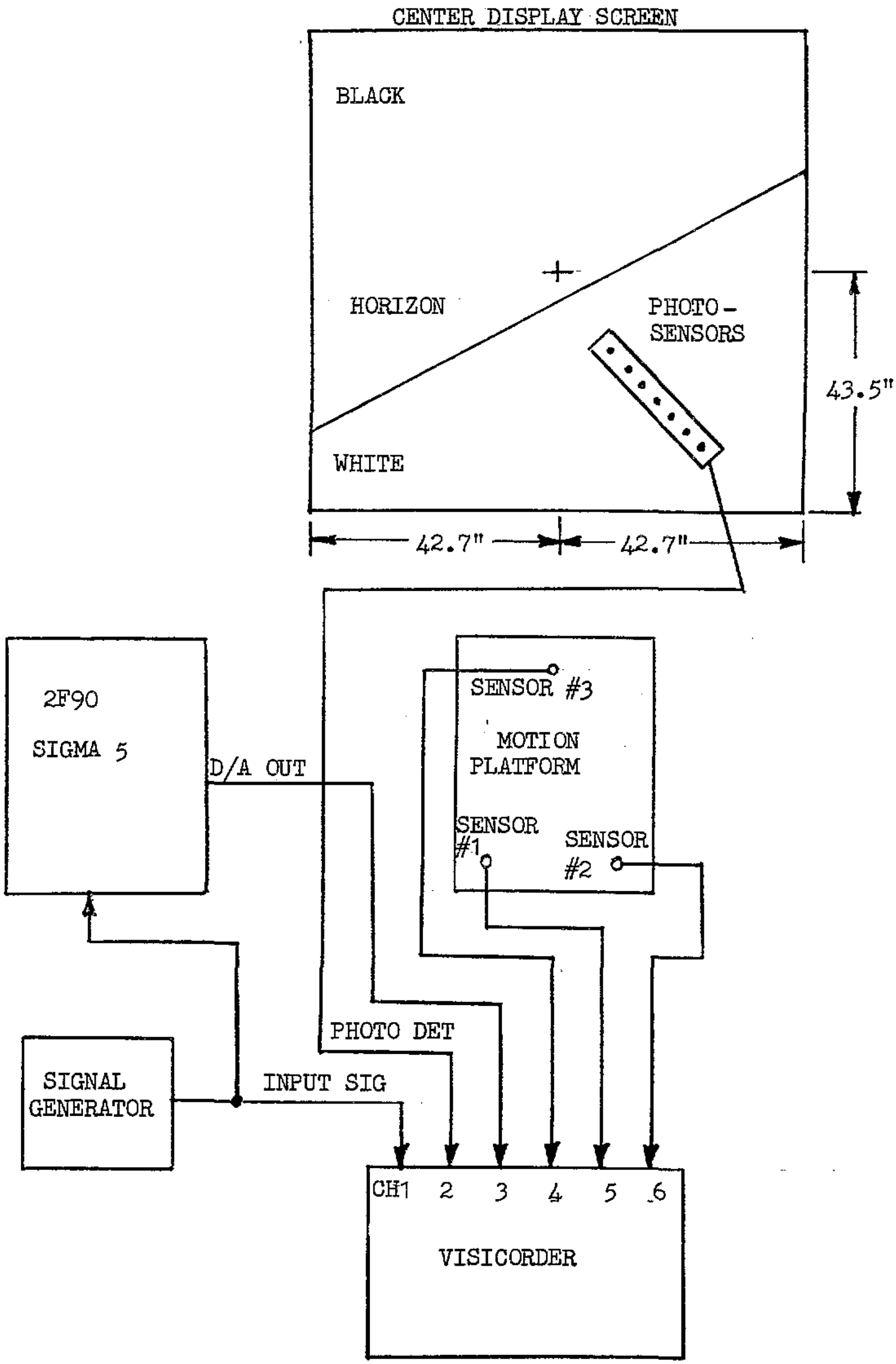


FIGURE 3. FREQUENCY/TRANSIENT RESPONSE TEST CONFIGURATION

Seven equally spaced photosensors mounted on a strip of clear plastic were used to sense the output of the visual system at the surface of the display screen. Potentiometers were mounted on each of three hydraulic cylinders driving the cockpit motion platform to sense the positions of the actuating cylinders. A spare 2F90 D/A output channel was used to output the program solution of the aircraft angular position resulting from the respective perturbed control inputs.

The test philosophy was to manually fly the simulator to a nominal altitude of 10,000 feet, airspeed of 300 knots, and a gross weight of 14,000 lbs. with the aircraft in a clean configuration. Upon reaching these nominal conditions the test software, when initiated, would freeze the aircraft control stick input values and then algebraically add a sinusoid from a signal generator to one of the three control inputs. For example, for perturbing the pitch axis, roll and yaw control inputs were frozen and the sinusoid was added to the pitch input normally provided from the control stick.

Sinusoidal inputs of low, medium, and high amplitudes and at 1/4, 1/2, 3/4, 1, 2, and 4 cps were inserted separately into each of the roll, pitch and yaw axes. For each input amplitude and frequency, the following signals were recorded on an analog strip chart:

1. The sinusoid test input signal.

2. The output from the set of photosensors.

3. The output from the simulator for the axis being tested.

4. The position of the hydraulic jack for pitch motion.

5. The position of the left hydraulic jack for roll motion.

6. The position of the right hydraulic jack for roll motion.

Figure 4 is a recording of test data for an input of 2 volts (6° elevator deflection) peak-to-peak inserted in the pitch control. The test consists of calibration data followed by test results. Chart speeds of 0.8 and 2.0 inches per second were used.

DATA REDUCTION

The data reduction problem with the frequency response measurement is transformation of the strip-chart data from the tests performed into Bode plots of the describing functions for simulated aircraft dynamics and the visual scene change. This is done in the following steps: (1) prepare the data in a form suitable for input into the digital computer, (2) estimate the best sinusoidal fit to the data, (3) determine the actual amplitude of the signals, and (4) plot the data as a function of the input-signal frequency.

Data Preparation

The information on the strip charts was converted into a form suitable for input to the digital computer by use of a Science Accessories Corporation GRAF-PEN interfaced with a Varian 620/i computer. At least twenty points on each continuous curve were digitized. The photosensor data was digitized at each step available for at least one cycle. Figure 5 shows a set of digitized points superimposed upon the data of Figure 4. Data for each test was stored on punched paper tape to provide a permanent record.

Curve Fitting

The digitized data for each test was processed to give the best sinusoidal fit to the data points. The assumed solution is of the form:

$$y = A + Bx + C\sin\left(\frac{2\pi x}{T} + \theta\right) \quad (1)$$

where A is the average value of the sinusoid in inches

B is a coefficient which allows compensation for any gradual slope in the data.

C is a coefficient for the amplitude of the sinusoid in inches.

θ is the phase shift in the sinusoid with respect to an arbitrary origin.

T is the period of the sinusoid in inches.

x is the distance along the time axis in inches.

y is the distance along the voltage axis in inches.

The input signal for each test was fit to the assumed form by selecting a value for the period T and solving for A, B, C, and θ to give a minimum mean squared error. The value of T was perturbed and the computation repeated to select a value of period to give the least mean squared error. The computation was stopped when the decrease in the mean squared error became less than .00000005 inches.

The response data was fit to the same form except that the value of the period computed from the input signal was used and only A, B, C, and θ were determined from the data. Figure 6 shows the resulting fit for the test data of Figure 4.

Amplitude and Phase Determination

The parameters derived from curve fitting are given in terms of chart dimensions instead of simulated parameters. The conversion to the desired parameters is accomplished by using scale factor values associated with the tests. The scale factors considered are the following:

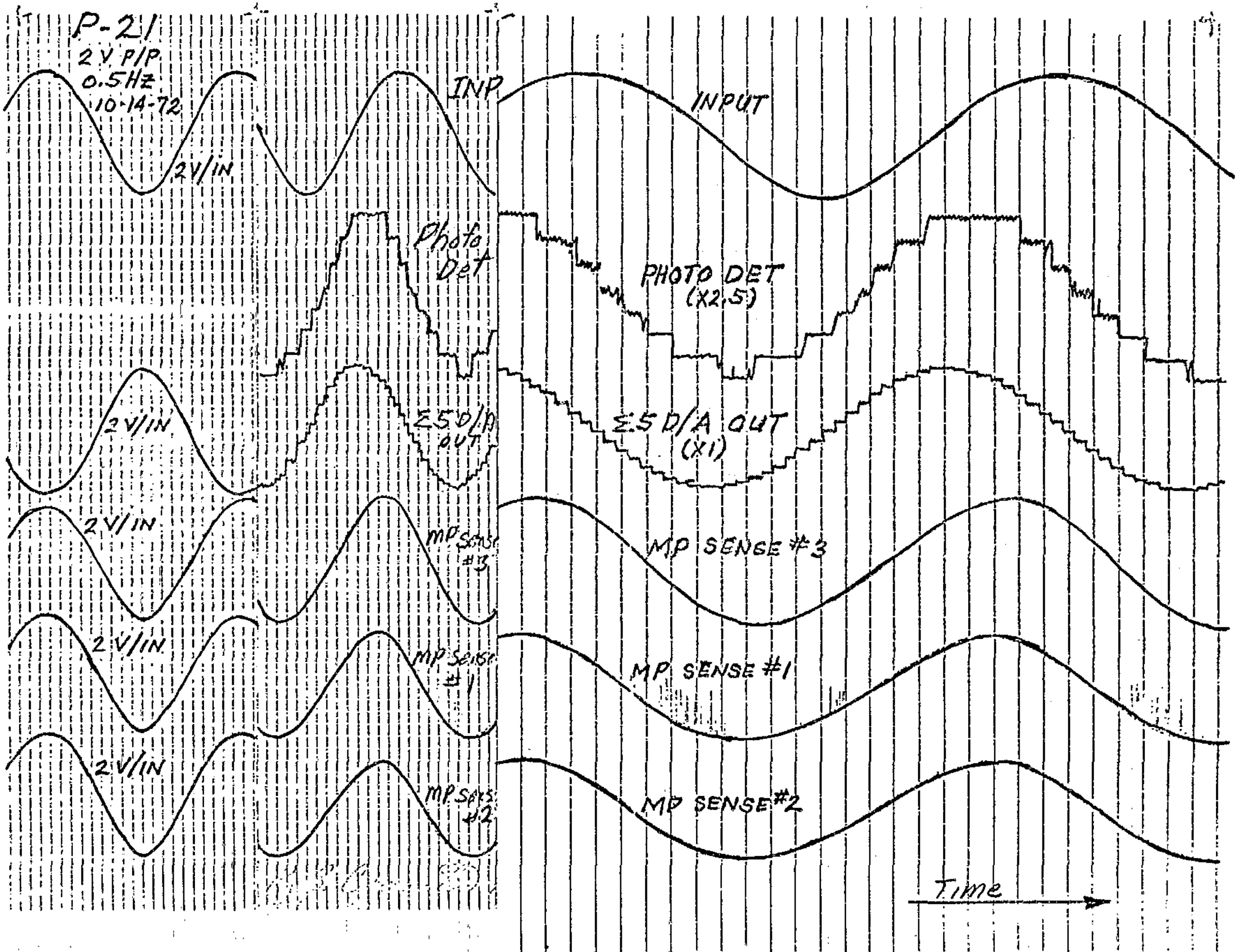


Figure 4. Frequency Response Test Example

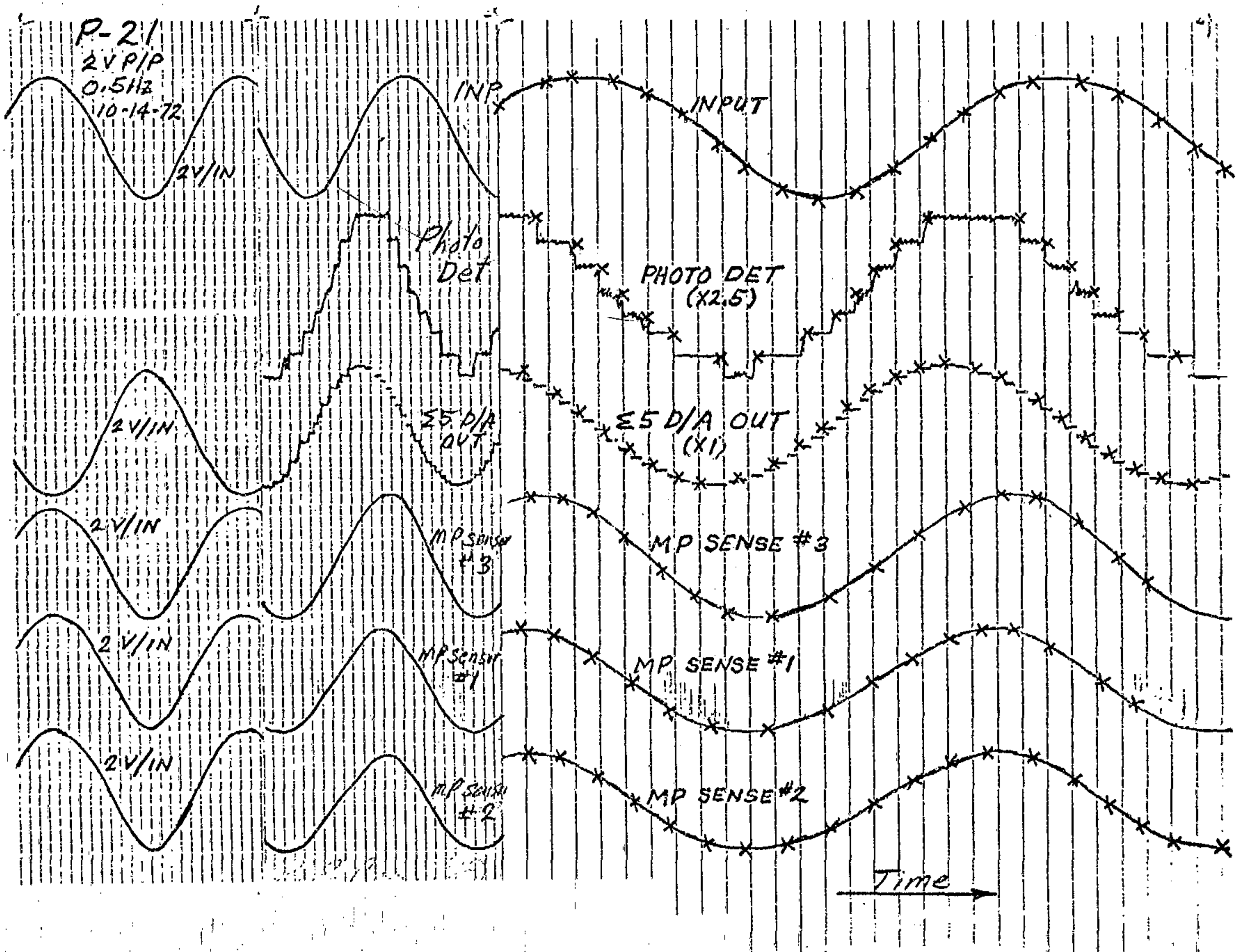


Figure 5. Digitized Points in Frequency Response Test

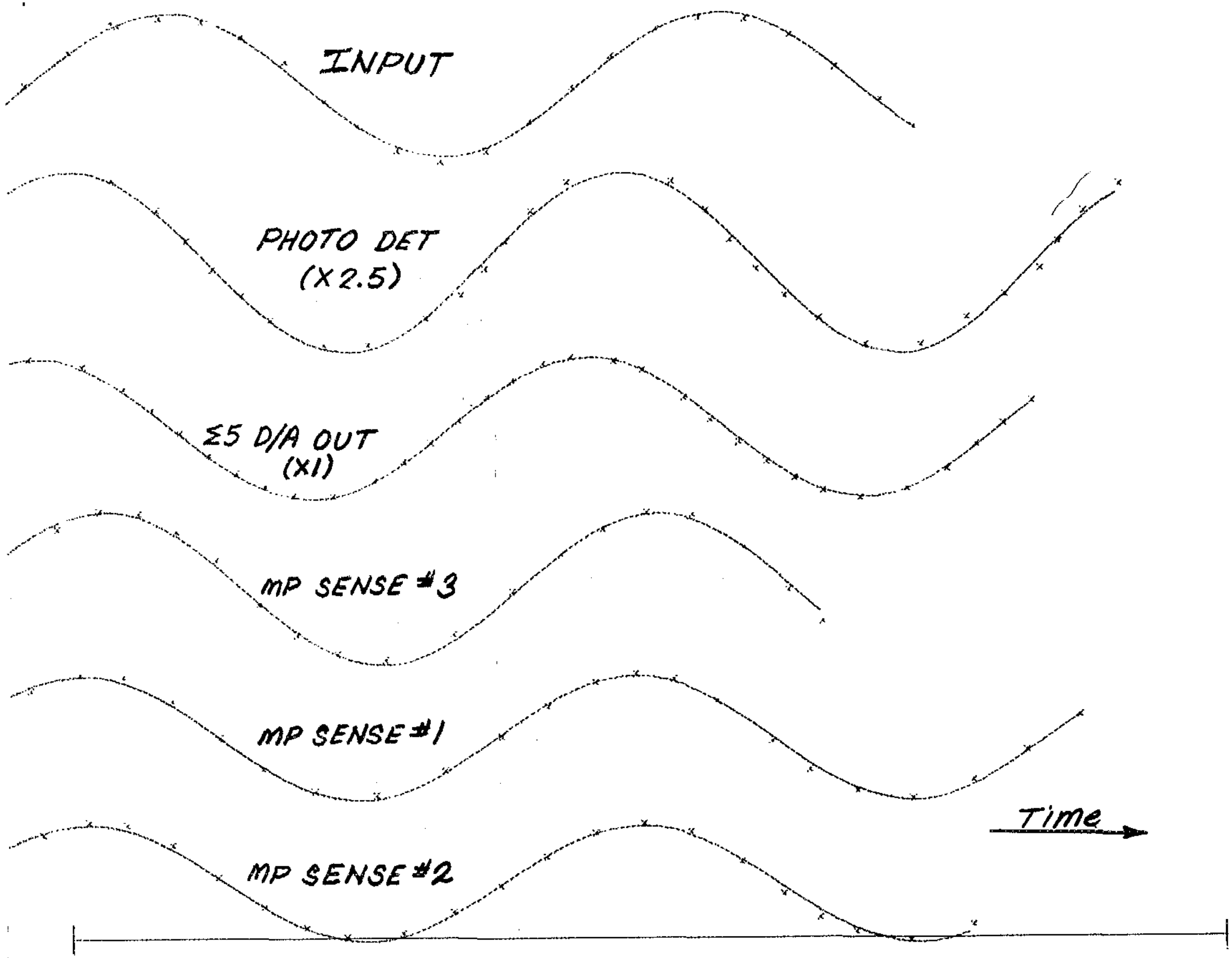


FIGURE 6. CURVE FITTING EXAMPLE

1. Chart rate in inches per second.

2. Calibration input signal amplitude in volts.

3. Conversion factors (e.g. degrees rudder reflection per volt).

4. Photosensor position and spacing.

Bode Plots

The simulated aircraft response data derived from the tests are plotted on log modulus - frequency charts (Bode Charts). These are shown in Figures 7 - 9. The linearized transfer functions derived from the aircraft data are also plotted on these charts. These transfer functions (reference 2) are derived for a 20,000 ft. altitude instead of the 10,000 ft. altitude used in the initial conditions for the frequency response measurements.

The delay in the visual system was also plotted as a function of frequency. These data are shown in Figures 10 - 12.

RESULTS

The aircraft dynamics in pitch show reasonable agreement with the aircraft transfer function. The phase angle at frequencies greater than one cycle shows excessive lag, as can be expected for the digital solution rate of 20 times per second.

The measurements of roll and yaw dynamics indicate a gain considerably less than that given by the derived transfer function. However, the phase lag and the general shape of the amplitude function fits the data points well.

In both roll and yaw, the amplitude response exhibits almost a square-law effect with no corresponding frequency distortion. This trend was noted during the data gathering and several tests were re-run with the same scale factors in order to insure that the gain difference was not caused by scaling errors. No reason has been discovered for this apparent anomaly.

The delay measurements in the visual system indicate that the computer generated display has a 0.1 second maximum limit. Several measurements fall above the maximum limit, but these are attributed to a shortcoming in the photocell technique used for position measurement rather than true delays in the system. A contributing factor is that the maximum chart speed available was only two inches per second.

SUMMARY AND CONCLUSIONS

The frequency response method is a more elaborate technique for determining the transfer function of a simulated aircraft. It was used on the TA-4J operational flight trainer to determine the simulated aircraft dynamics and the visual system delay to a greater accuracy than can be achieved by transient response testing.

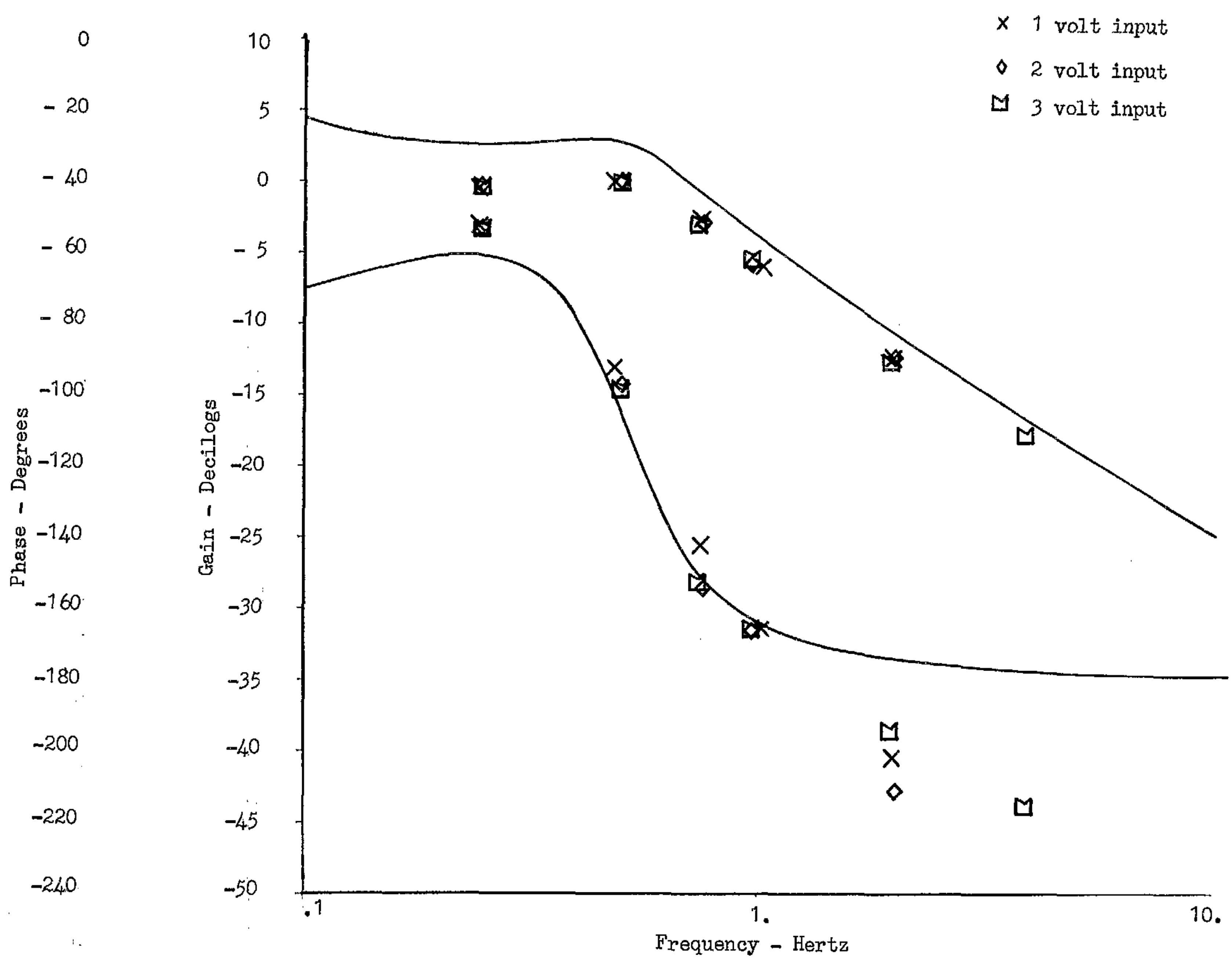


Figure 7. Bode Plot of Pitch Axis Response.

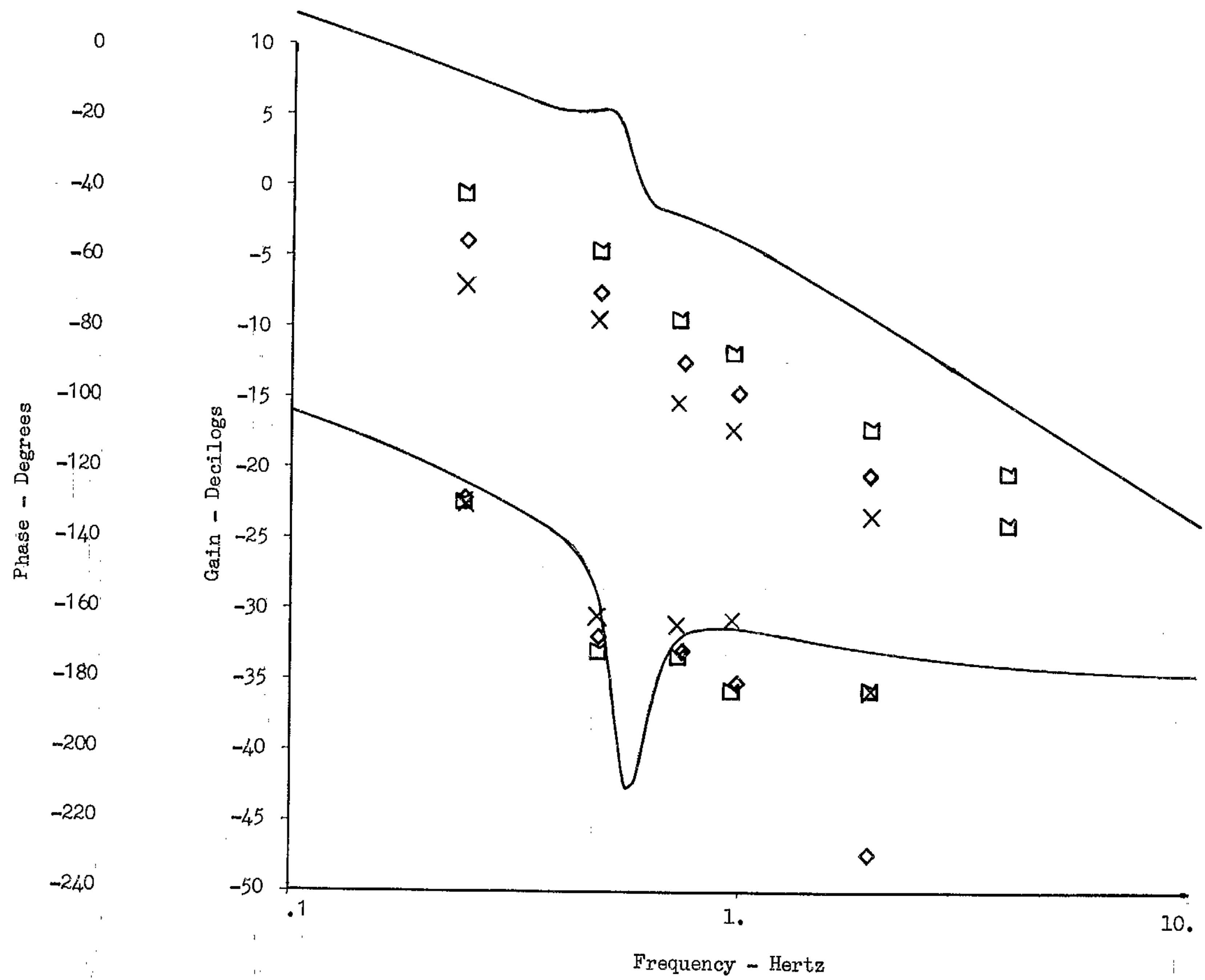


Figure 8. Bode Plot of Roll Axis Response.

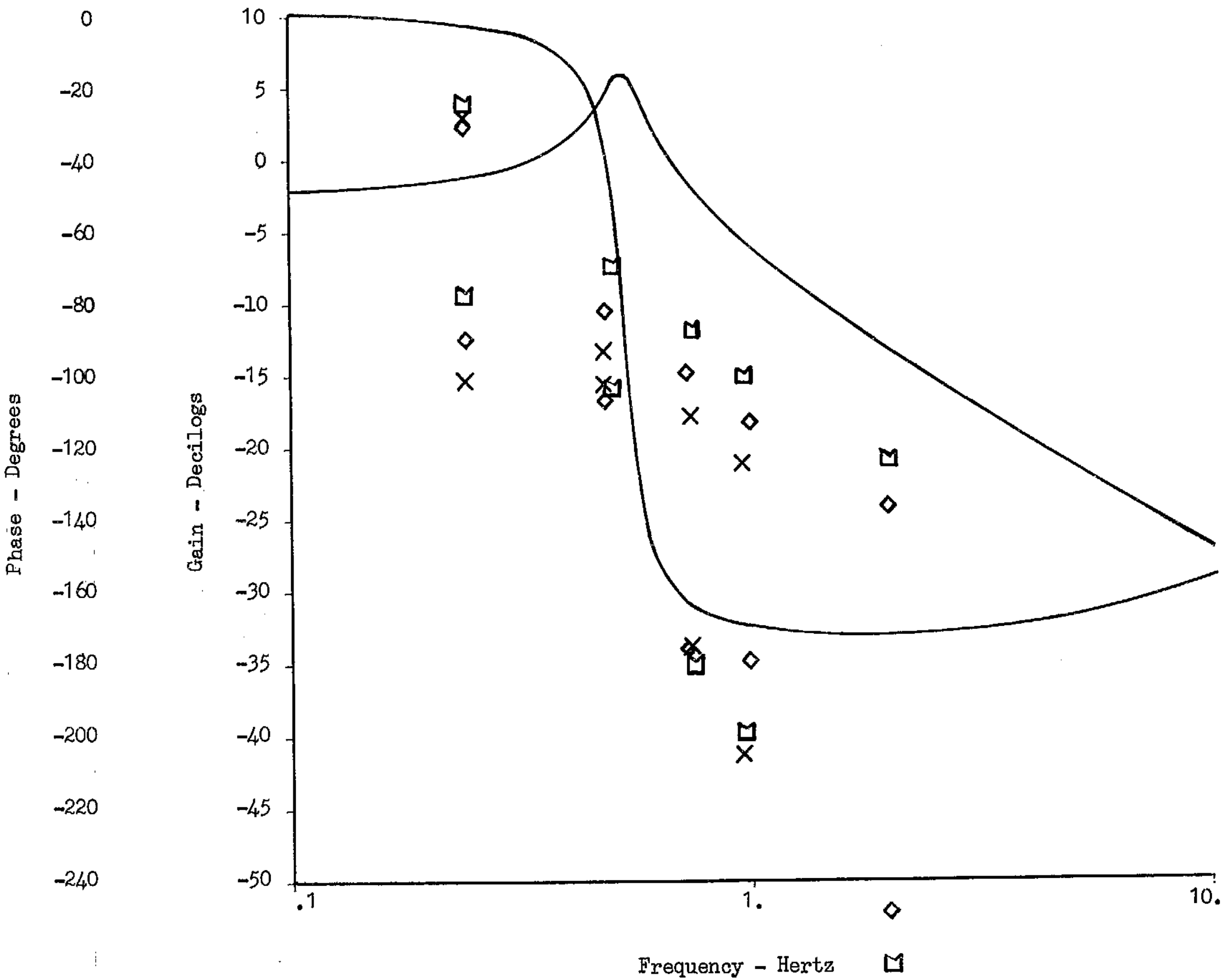


Figure 9. Bode Plot of Yaw Axis Response.

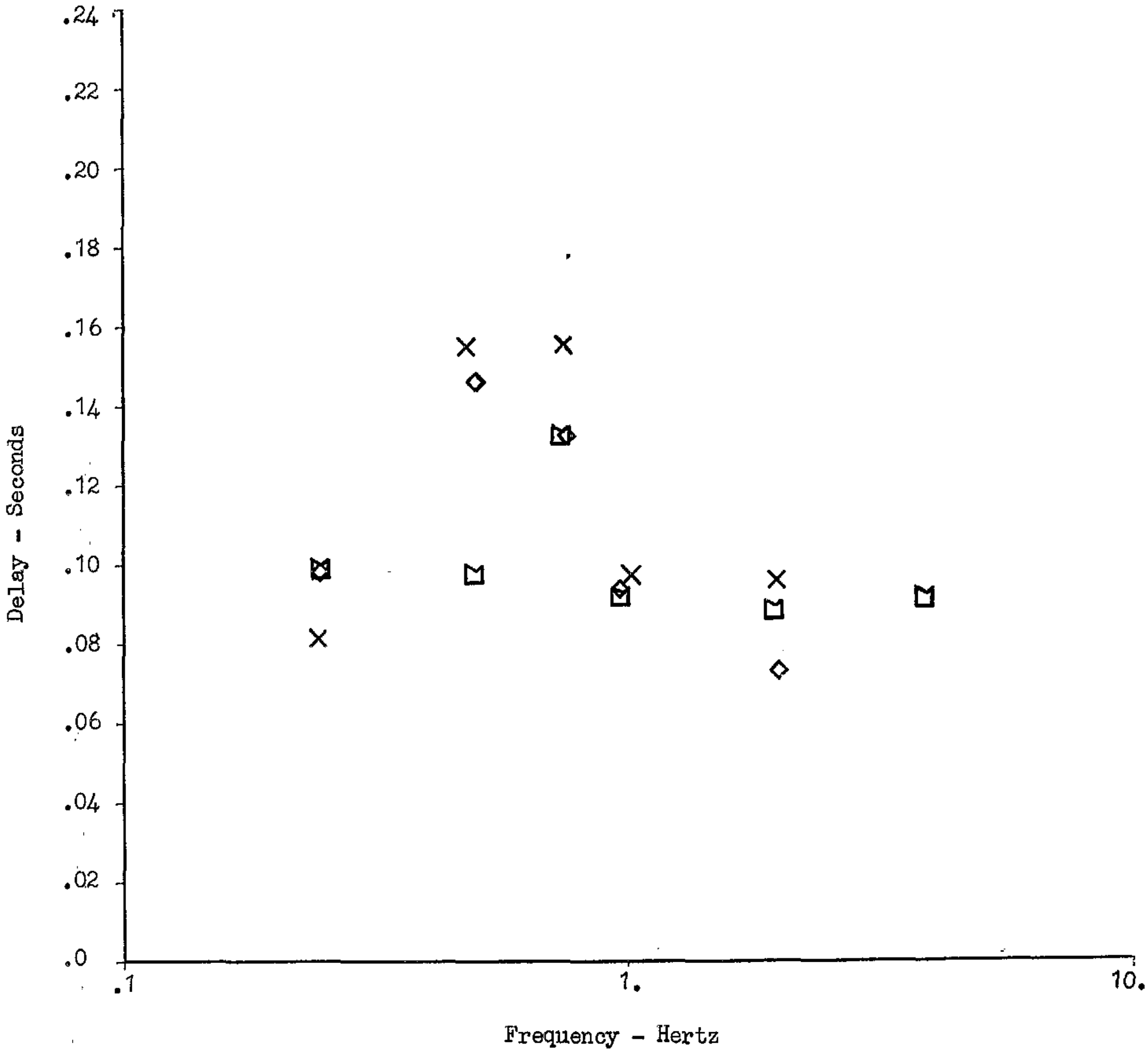


Figure 10. Visual System Delay in Pitch Axis.

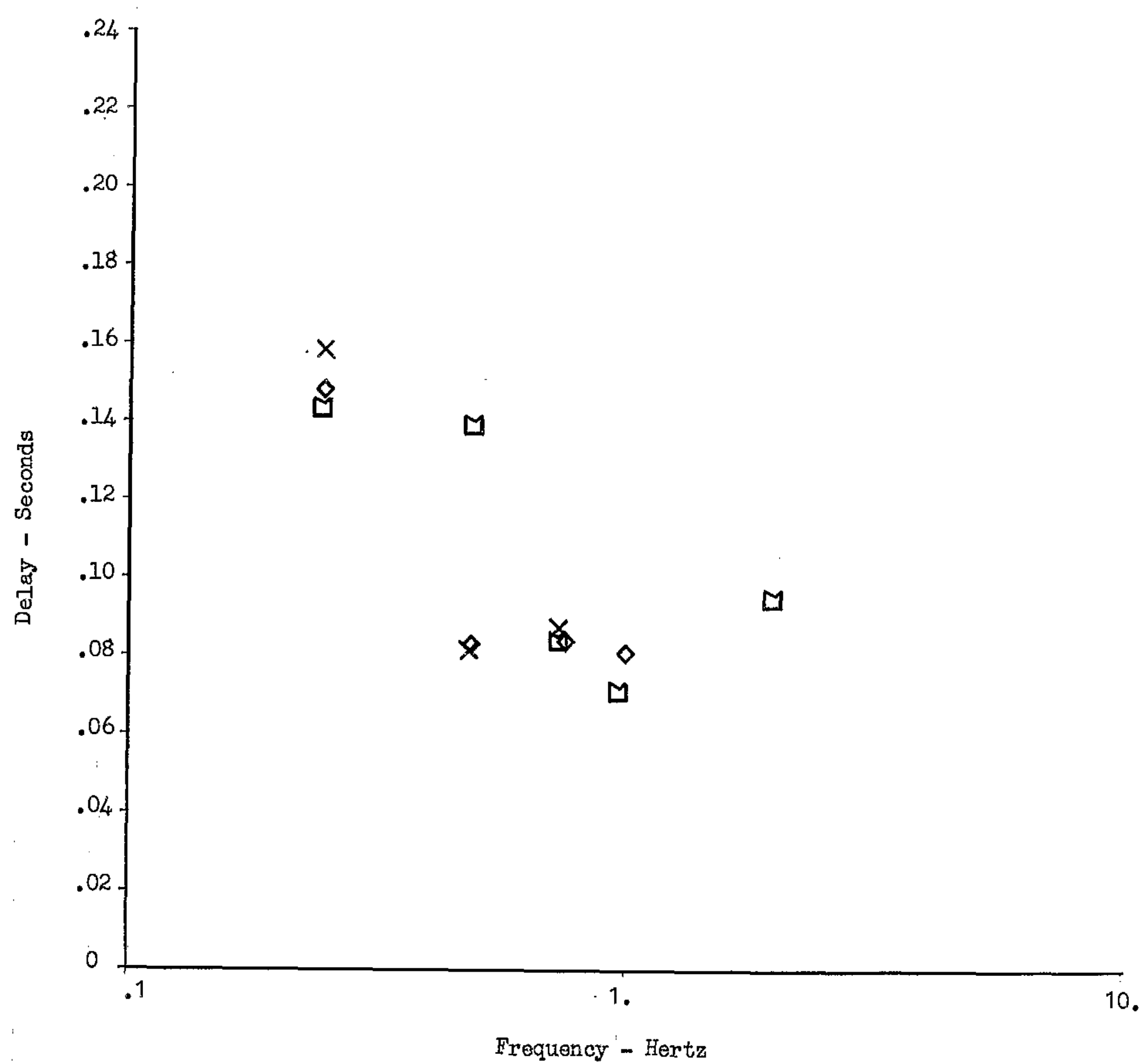


Figure 11. Visual System Delay in Roll Axis.

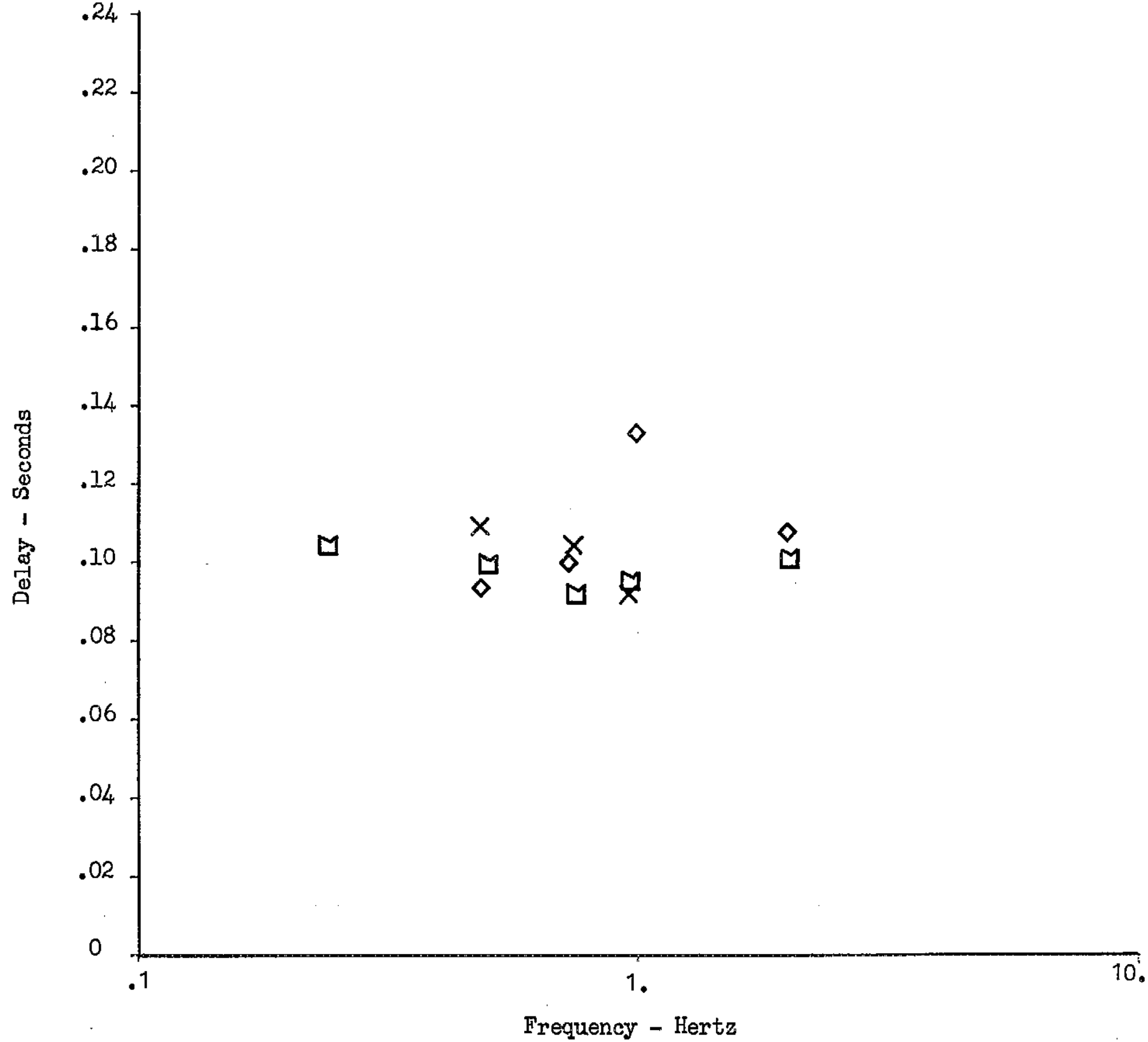


Figure 12. Visual System Delay in Yaw Axis.

The data shows some anomalies. However, the discrepancies do not seem to be detrimental to the performance of the simulator, so the causes and cures were not pursued. This test and analysis method is being used on the F-4E aircraft simulator in the Computer Laboratory. Results of this testing should be available in 1974.

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5. Contract N61339-72-C-0192, CDRL Item A005 Final Test Report, Computer Generated Image System.

ABOUT THE AUTHORS

MR. LEONARD D. HEALY was born in New Orleans, Louisiana on November 17, 1930. He received the B.E.E. degree from Georgia Tech, the S.M.E.E. degree from MIT, and the Engineer degree from Stanford University in 1951, 1957, and 1961, respectively. He is currently completing the requirements for the PhD degree at the University of Florida.

Mr. Healy has more than 20 years experience as an engineer and scientist. At MIT Lincoln Laboratory from 1954 to 1957 he was responsible for the magnetic drum and radar input subsystems for the Whirlwind I computer. At the Lockheed Missile and Space Company's Palo Alto Research Facility from 1957 to 1962 he was responsible for the design and testing of several general-purpose digital computers. He also designed a real-time system for processing telemetry data for missile test and check-out.

From 1962 to 1964, he was a member of the Advanced Technology Staff at the Martin Company. During that time, he was Project Engineer for the design and construction of a general-purpose digital computer with special features for real-time applications and also acted as Head of the Logic Design Section of the Computer Department. From 1965 to 1968 he was a Senior Research Scientist at Martin where he conducted research projects in simulation and evaluation of missile guidance systems.

Since 1968, Mr. Healy has been an Electronics Engineer in the Computer Laboratory at the Naval Training Equipment Center. In that position, he provides technical direction of projects within the laboratory and consultation to other organizations. He spent the year 1971-1972 at the University of Florida on a long-term training assignment.

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Mr. Cooper has 17 years experience as an engineer. He was employed by IBM from 1957 to 1961 where he was responsible for the design and development of special purpose hardware interfacing with standard digital computer equipment. At Martin-Marietta Corporation from 1961 to 1967 he was responsible for the design and testing of digital computer input/output systems.

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