APPLICATION OF INTERACTIVE COMPUTER GRAPHICS

IN WIND-TUNNEL DYNAMIC MODEL TESTING

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SUMMARY

The computer-controlled data-acquisition system recently installed for use with the Langley Research Center transonic dynamics tunnel is described. This description includes a discussion of the hardware/ software features of the system. A subcritical response damping technique, called the combined randomdec/moving-block method, for use in wind-tunnel model flutter testing that has been implemented on the data-acquisition system is described in some detail. Some results using the method are presented and the importance of using interactive graphics in applying the technique in near real time during wind-tunnel test operations is discussed.

INTRODUCTION

The digital computer is finding more and more applications in wind-tunnel testing as existing tunnels seek to update their data-gathering capabilities and as new wind tunnels are constructed having digital data-acquisition systems. The attractiveness of the digital computer in a data-acquisition role, as in most other roles, is its ability to rapidly acquire and process large amounts of data. This capability provides the wind-tunnel test engineer with the ability to examine reduced data on-line and thus the engineer can make better informed judgments as to whether to move to the next test point or repeat the previous test point. Also, computer control and monitoring of analog devices will free the engineer of these routine, yet time-demanding tasks, and give him more time for data analysis.

Presented in this paper is a description of the recently installed computer-controlled data-acquisition system of the Langley Research Center transonic dynamics tunnel, and a discussion of how the interactive graphics capability of this system is being applied to wind-tunnel flutter model studies.

LANGLEY TRANSONIC DYNAMICS WIND TUNNEL

Before describing the computer-controlled data-acquisition system for the Langley transonic dynamics tunnel, it will serve a useful purpose to briefly describe this wind tunnel and the purposes for which it is used. This description will provide a background for placing the data-acquisition system in the proper perspective. The transonic dynamics tunnel is located at the NASA Langley Research Center. An aerial view of the facility is presented in figure 1 along with two drawings which show the general arrangement of the wind tunnel. The tunnel is relatively large with a 4.88-m (16-ft) square test section. The tunnel is capable of continuous operation, and both tunnel speed (Mach number) and pressure (altitude) are continuously controllable. The building shown in the foreground of the photograph provides office space and shop facilities for tunnel personnel. Most of the data-acquisition system equipment is located on the third floor of this building. Some equipment is located in the control room where the test engineer is usually stationed during wind-tunnel operations, and some equipment is located in a setup/ calibration laboratory located on the first floor so that the system can be used in preparing models for subsequent wind-tunnel tests.

The transonic dynamics tunnel is almost totally dedicated to dynamic model testing as opposed to the measurement of static forces and pressures that is done in most wind tunnels. A large number of tests use dynamically scaled aeroelastic models of advanced aerospace systems, including both aircraft and launch vehicles. Some tests are used to provide data on specific configurations while others are of a basic research nature. For the most part, the tunnel tests fall into one of seven categories. A listing of the categories is presented in figure 2. Also shown in the figure is the type of model measurements required, typical number of data channels required, and frequency range of interest. Prior to the installation of the data-acquisition system, each type of test essentially required a unique set of instrumentation. Since a flutter test might be followed by a gust test which, in turn, might be followed by a helicopter test and so forth, a new instrumentation system including signal conditioners, amplifiers, and display and recording equipment had to be set up for each test. This not only resulted in a lengthy setup time for each test, but also meant that tunnel personnel had to be familiar with and expert in the use of many different types of instrumentation. Also, during the tests, considerable effort was necessary to manually adjust such things as amplifier gains to keep data signals within allowable limits. During each test voluminous amounts of information are obtained. Since practically all data reduction was done after the tests were completed, the test engineer had very little reduced data available on-line to guide the conducting of the test.

COMPUTER-CONTROLLED DATA-ACQUISITION SYSTEM

Basic Design Requirements

The purpose of the computer-controlled data-acquisition system is to improve the efficiency of wind-tunnel model testing. Here improved efficiency does not mean that more wind-tunnel tests will be conducted in a given period of time, although the use of the system will undoubtedly expedite some tests, but rather it means that the quality and quantity of the data obtained will be improved. Basically, the system was designed to perform four rather general functions in a manner to be specified and controlled by the test engineer. These functions are (1) automatically adjust amplifier gain and offset to make maximum use of amplifier dynamic range, (2) acquire and format tunnel and model test data and record the information on magnetic tapes, (3) process and display in real-time wind-tunnel parameters, and (4) process and display in real time, or near real time, selected model response data. In performing these four functions it was required that the system be very flexible, or versatile, so that it could be used with all of the seven categories of tests previously mentioned as well as meet the needs of future, different test requirements. Another requirement was that the system would be convenient to use, including being relatively easy to learn how to use. Also, advantage would be taken of man-machine interaction where man's decision-making capabilities are desirable, and yet take advantage of the system hardware/software capabilities to free the test engineer from as many routine tasks as possible.

System Description

In this section the basic components and features of the computer-controlled data-acquisition system will be described. However, no attempt will be made to completely describe the system. For convenience, the data system may be thought of as being composed of five major subsystems which are the Analog Front End Subsystem, Analog-to-Digital Subsystem, Computer Subsystem, Control and Display Subsystem, and Digital Input/Output Subsystem. The interconnection of these five subsystems is illustrated schematically in figure 3. The operation of the system is under the control of the test engineer through the use of appropriate computer software. Provision has been provided in the system for certain hardware status information to be made available to the computer. This information includes such items as analog amplifier gain settings. Also, when suitably programed, the computer can be used to control most of the hardware equipment such as adjusting amplifier gain setting. Data flow paths are shown as solid lines in the figure, command or control signal paths by dashed lines, and status information paths by long and short dashed lines. Analog signals from the wind-tunnel model enter the data system through the Analog Front End Subsystem, which contains signal conditioners, amplifiers, tape recorders, and other analog equipment. In this subsystem, the data are recorded on analog tape for later data reduction (i.e., between wind-tunnel test runs). Selected data are passed from the Analog Front End

Subsystem to the Analog-to-Digital Subsystem where the analog data are converted to digital form and passed to the Computer Subsystem for real-time, or near-real-time, processing. The processed data may be recorded on digital tape and/or displayed for the test engineer's examination by the Control and Display Subsystem; for example, a plot on the graphic display unit screen. Digital data, such as shaft encoder outputs, are input to the computer through the Digital Input/Output Subsystem. The test engineer exercises control of the data system by issuing commands through equipment in the Control and Display Subsystem; for example, typing in a message on a typewriter keyboard.

Analog Front End Subsystem. The Analog Front End Subsystem accepts and processes data signals from transducers located on models mounted in either the wind-tunnel test section or in a model setup/calibration laboratory. This dual input feature allows the data-acquisition system to be used during wind-tunnel testing and in preparing models for subsequent testing. This subsystem provides for transducer excitation, signal conditioning, filtering, signal monitoring, and signal recording. The class of components of this system are similar to those found in most analog systems including amplifiers, filters, tape recorders, and so forth. However, this subsystem has many special characteristics to allow the system hardware components to be monitored and controlled by the digital computer. A simplified block diagram of the subsystem is presented in figure 4, and some of the subsystem components may be seen in the photograph in figure 5. The subsystem, as provided, is a complete 60-channel system. Fifty of these channels are called DC channels and have a frequency-response capability from zero to 20 kHz. These channels are for use with strain-gage-type transducers. Ten of the channels, called AC channels, have a frequency-response capability from 1 to 20 kHz. These channels are for use with piezoelectric transducers. Signal conditioning and excitation are provided for each DC channel. Separate conditioning equipment is provided for the test section and calibration laboratory inputs so that models can be set up in the calibration laboratory while another model is undergoing wind-tunnel testing. Each amplifier is equipped with a computer controllable input source selection switch to select any one of three input sources: test section, calibration laboratory, and calibration bus. The computer can also be used to set amplifier gain, and, for the DC channels, offset control is provided to balance out the zero frequency component of dynamic signals to provide maximum use of the amplifier dynamic range. Each amplifier has dual output channels, one unfiltered and one low pass filtered. The unfiltered output is connected to monitor oscilloscopes and to connector panels for use with other monitor equipment if desired. The filtered data are output to the Analog-to-Digital Subsystem (ADS). Two analog tape recorders are available for recording data, a low band recorder (LB) and an intermediate band recorder (IB). The LB tape unit is primarily for use with low-frequency dynamic data, and the 60 input data channels may be frequency multiplexed in groups of 5 onto 12 of the 14 LB tape recorder channels. The test engineer selects the grouping of the various input channels into the groups of five. The IB tape unit is for use with higher frequency data, and 12 channels of data are recorded simultaneously. A time-multiplexing capability is provided so that different groups of 12 data channels can be selected by the test engineer for sequential

recording. Analog tape recorded data can be played back and input to the computer through the Analog-to-Digital Subsystem (ADS). Additional equipment in this subsystem includes time code generator, time code reader, AC calibration source, and DC calibration source.

Most of the hardware devices in this subsystem can be operated under computer control.

Digital Input/Output Subsystem. The Digital Input/Output Subsystem provides a means of inputing digital information into the computer and a means for the computer to monitor and/or control some of the data system hardware components. This subsystem consists of two major components, the digital multiplexer (DM) and the control signal distributor (CSD). The operation of the DM is controlled by the computer. Most of the digital data input to the computer through the DM is information concerning the status of the data system hardware such as various switch position settings that the computer is required to log, for example, amplifier gain settings. The DM also accepts inputs from the time code generator, shaft encoders, and some spare channels are provided. Although the CSD may be operated manually, it is normally operated under computer control. The CSD receives command words from the computer, decodes these words, and routes command signals to the data system hardware components. For example, command signals from CSD can be used to start and stop the analog tape recorders and adjust the amplifier gains.

Analog-to-Digital Subsystem. The Analog-to-Digital Subsystem is used to convert analog data signal outputs from either the data system amplifiers or playback data from the two analog tape recorders to digital form for computer processing. Some spare input channels are provided to accept data from other sources. The maximum conversion rate is 50 000 samples per second. All incoming data channels are not required to be sampled at the same rate.

Computer Subsystem. The main component of the Computer Subsystem is a XEROX Sigma-5 computer with a 48 000-word memory. Computer peripheral equipment includes a random access storage disk, card reader, card punch, line printer, keyboard printer, digital plotter, and three digital tape units, two nine-track units and one seven-track unit.

Control and Display Subsystem. The purpose of the Control and Display Subsystem is to provide a means of displaying, in real time, information that has been processed by the computer for the test engineer's examination while the wind-tunnel test is in progress, and to provide a means for the engineer to exercise his control over the data system by issuing instructions to the computer. The main components of this subsystem are the graphic display unit (GDU) which includes a keyboard and light gun, two typewriter units, numeric displays, and constants switches. The GDU may be seen in the left foreground of the photograph presented in figure 6 which shows an interior view of the wind-tunnel control room. A bank of numeric displays may be seen in the center of the photograph. Most of the communications between the test engineer and the computer are made by using the GDU. Information from the computer is displayed on the GDU screen in

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the form of messages or data plots. The engineer issues his commands to the system by using the GDU keyboard. Messages can also be sent and received by using either typewriter. The numeric displays can be used to access particular computer memory locations to display stored data. The constants switches provide a means for the test engineer to change the contents of particular computer memory locations.

System Control Software. The automated data-acquisition system is controlled and operated by the test engineer through the use of a computer software package called Operating Measurements Program (OMP) which operates in conjunction with the standard Sigma-5 computer monitor system. The OMP program may be thought of as a software supervisor which allows the test engineer to exercise control of the system to acquire, display, and analyze wind-tunnel data by using his own software. As a part of the OMP package, a set of user callable subroutines (UCSUBS) have been provided. The basic computer FORTRAN library subroutines are also available for use by the engineer, and this library may be generally thought of as an extension of the UCSUBS. At the time of system delivery, there were 103 of these UCSUBS available. A large number of these subroutines are related to controlling the system hardware; for example, starting a tape recorder. Others are in the analysis category such as generating a Fourier transform. To operate the data system within the OMP framework, the test engineer is required to write a series of FORTRAN language subroutines called first-level user programs, or FLUPS, which access the UCSUBS, basic library subroutines, and/or the input/output services provided within OMP. The FLUPS may be as simple or as complex as necessary to meet the user's requirements. A simple FLUP might be one that starts an analog tape recorder, records data for 10 seconds, and then stops the analog tape recorder. A more complex FLUP might be one that records data on analog tape, rewinds the tape, plays back the tape and digitizes the data, passes the digitized data to the computer, calculates a power spectral density, and displays the result on the GDU. In most instances, the test engineer causes his FLUP to be executed by typing in the FLUP name on one of the three keyboards, typewriter or GDU. Since there are some requirements which are necessary for all wind-tunnel tests, some standard services are built into OMP and it is not necessary that a FLUP be prepared. The determination of wind-tunnel parameters such as Mach number, velocity, density, and so forth, is an example of a built-in service. The OMP program also can be used to assist the engineer in configuring the system hardware during test setup. This is done by the engineer inputting to the computer the desired setting of various hardware device switches. The computer compares the desired setting with the actual setting and advises the engineer of any improperly configured equipment.

FLUTTER TESTING WITH INTERACTIVE GRAPHICS

Flutter is a dynamic instability produced by the coupling of structural inertia and stiffness forces with aerodynamic forces to produce a self-excited, usually increasing in amplitude, sinusoidal oscillation that can lead to catastrophic structural failure. Consequently, flutter must

be taken into account in the design of new aircraft to insure that flutter cannot occur within the normal aircraft operating envelope. Although there are many analytical techniques available for flutter analysis, these techniques are unreliable at transonic speeds where flutter is usually most critical. Therefore, for high-speed aircraft, flutter model studies are relied upon heavily to demonstrate that the aircraft has acceptable flutter characteristics. Important uses of the transonic dynamics tunnel are to perform such flutter clearance studies of new aircraft designs as well as to conduct basic phenomenological flutter research studies. Traditionally, flutter model test procedures have been to treat flutter as an event that either occurs or does not occur. The models are actually taken to the flutter condition, and by varying tunnel parameters (Mach number and dynamic pressure), sufficient flutter points are obtained to define the flutter boundary. A typical flutter boundary in terms of the variation of dynamic pressure with Mach number is shown on the left in figure 7. The variation in wind-tunnel conditions in reaching a typical flutter point is illustrated by the dashed line in the figure. Since flutter is not only hazardous to aircraft but can also cause model structural damage, it would be desirable to obtain the flutter boundary without actually experiencing flutter. This is particularly true since flutter models of specific air-craft configurations are rather expensive, often costing in excess of a hundred thousand dollars. One way to determine the flutter condition with-out actually experiencing flutter is to make subcritical damping measure-ments of the critical flutter mode at various flight conditions and extrapolate to the flutter condition since the damping becomes zero at flutter. For example, referring to figure 7, if the flutter boundary were approached along the dashed line shown on the left and damping measurements made at each of the conditions marked A, B, C, D, and E by analyzing model response data while the tunnel conditions are held constant, then a damping variation as indicated on the right in the figure can be obtained. The flutter condition can then be obtained by extrapolating the damping curve to zero as indicated in the figure. By repeating this process, the entire flutter boundary can be determined. Unfortunately, the obtaining of damp-ing from model response data is not an easy task, and subcritical damping techniques have not been routinely used in the past. A large part of the difficulty has been associated with the inability to reduce, analyze, and display model damping data in near real time so that the damping can be continuously monitored during the approach to the flutter boundary. The installation of the data-acquisition system has now made it practical to apply subcritical damping methods to flutter tests in the transonic dynamics tunnel. One promising technique which is currently under development depends heavily on the use of interactive graphics. This technique will be described in the following discussion.

Subcritical Damping Technique

The subcritical damping technique that has been implemented using the data-acquisition system for use in flutter model testing is a combination of two methods, either of which can be used to determine damping under certain conditions. The first method, called randomdec, is applicable to determining the damping of a system excited by a random force. The second

method, called moving block, requires the model to be excited transiently in order to determine the damping. (Transient response as used here means the free decay following the removal of a discrete excitation force.)

Randomdec method. The randomdec method provides a means of obtaining information about an elastic system by examining the system response to random excitation. A description of the method is presented in reference 1 and only the highlights of the technique will be described here. The randomdec method is illustrated schematically in figure 8. The system response is assumed to be composed of three components: the responses to a step input, to an impulse, and to a stationary random force. The system response to a step force is obtained by an ensemble average of a number of response time segments, since the response to random force and to an impulse average to zero. The averaging process for each time sample is started when the response signal reaches a predetermined level, indicated by Y_0 in the figure. The output of the randomdec analysis has the appearance of a damped sine wave and is referred to as the randomdec signature. From this signature, the system damping and frequency can be obtained. Although the randomdec method has many advantages, the most notable being that it is not necessary to provide external excitation as required by many subcritical damping techniques, its application is not without problems. One difficulty occurs when the system under study has two or more resonances that are relatively close together. This problem can be partially overcome by filtering the response data, but this is not always practical since it implies a certain knowledge of the flutter characteristics beforehand. When the randomdec signature is composed of the response of two or more resonances, beats appear in the signature and make it difficult to obtain the characteristics of any single mode. Some work has been done in applying curve-fitting methods to analytically separate the signature into frequency components. Although this work shows promise, current indications are that effective curve-fitting methods are too slow for near real-time applications such as required for flutter testing.

Moving-block technique. The moving-block technique is a means for obtaining the damping of an elastic system from its transient response. A detailed description of this technique is presented in reference 2. Early applications of the method in rotary-wing stability testing are described in references 3 and 4. The technique is illustrated schematically in figure 9 and may be described briefly as follows: A response signal from the model which has been excited transiently in the mode of interest is first obtained. A Fourier transform of this signal trace is then made to determine the frequency content of the signal, and the analyst selects the model frequency for which the damping calculations are to be made. After optimizing the operator-input frequency to obtain the peak value of the transform nearest the input frequency, a discrete Fourier transform is made with a block of data which is a fraction of the originally collected data block, and the natural log of the amplitude of the discrete transform is taken. A plot of this value against time is constructed by moving the block down the signal trace incrementally one data sample (hence, the name moving block) and repeating the discrete transform, natural log operation until the block reaches the end of the original data sample. If the signal

is a pure damped sine wave, the plot generated will be a curve which oscillates about a straight line. The slope of the straight line determines the damping.

Combined Randomdec/Moving-block technique. Although the moving-block method is suitable for determining damping from transient response time histories, it is not, in general, applicable to flutter model testing since provision for external excitation is not usually provided for in these models. However, there is no difficulty in obtaining a randomdec signature for such models since residual wind-tunnel turbulence provides the required random excitation. Since the randomdec signature may be thought of as a transient response, the randomdec signature can be used to provide the input needed by the moving-block method.

Data System Implementation of

Combined Randomdec/Moving-Block Method

The combined randomdec/moving-block method has been implemented on the automated data-acquisition system by using three FLUPS which are under the direct control of the test engineer. The three subroutines, designated BDRDIN, BDRD, and PKPLOT, are executed serially in the order listed and communicate with one another through labeled common blocks within the OMP program. BDRDIN is used to initialize some parameters; BDRD is used to calculate the randomdec signature; and PKPLOT is used to perform the moving-block analysis to determine the damping and frequency. The GDU is important in the execution of BDRD and PKPLOT. In the BDRD case, a plot of the signature is presented for the engineer's examination so that he can make a judgment as to whether or not the signature is satisfactory and warrants further processing by PKPLOT. In the execution of PKPLOT a large amount of interaction by the test engineer is required. This interaction includes not only the examination of data plots for their acceptability but also requires the engineer to input parameters to be used during the execution of PKPLOT. An intelligent choice of parameter values cannot be made without the engineer being able to examine plots of intermediate results on the GDU screen. The highlights of each of these three FLUPS are discussed in the following three sections.

FLUP BDRDIN. This subroutine essentially initializes a set of parameters to be used by the other two routines. The test engineer communicates with the FLUP through one of the keyboard input devices, usually the graphic display keyboard. Once the FLUP is initialized by typing in the FLUP name, the test engineer responds to queries displayed at the bottom of the GDU screen to input the required parameters. Initially, there are seven parameters required. These parameters are data channel to be analyzed, digital sampling rate, total number of data points to be sampled, number of data points in final randomdec signature, number of ensemble averages, and two parameters associated with converting the digital randomdec signature back to an analog signal for display on a recording oscillograph. The seven parameter values are stored in a labeled common block so that they can be accessed by the other two FLUPS. All seven of

these parameters are needed by BDRD, whereas PKPLOT only needs the sampling rate and the number of points in the signature. Once these seven parameters have been initialized, it is not necessary to execute BDRDIN again unless the engineer wishes to change a parameter, for example, increase the number of ensemble averages. Upon each call to BDRDIN, a table of parameter values selected is tabulated on the line printer to provide a permanent record.

FLUP BDRD. The primary purpose of this subroutine is to generate the randomdec signature. This FLUP must be executed by using the GDU keyboard. Initially, the subroutine calculates the mean and root-mean-square values of the output signal from a dynamic response sensor mounted on the model, usually a strain gage or an accelerometer. This information is used by the engineer to select a trigger level for the randomdec signature (Y_0 value shown in fig. 8). Once the engineer has input the desired trigger level to the subroutine by using the GDU keyboard, the model response signal is digitized and passed to the computer for ensemble averaging. Typically, this process takes 1 to 2 minutes, depending on the number of data points in each time segment and the number of averages requested. Upon completion of the averaging process, the engineer is queried by a message on the GDU screen about the type of output he desires. He may select any combination of four options: plot signature on GDU screen, tabulate signature on line printer, plot signature using line printer, or convert digitized signature to analog signature and record on recording oscillograph. Normally, the engineer will select the GDU plot option so that he can examine the character of the randomdec signature. A randomdec signature plot is presented in figure 10. It should be noted that this figure and the subsequent figure that will be used in the PKPLOT discussion were prepared by using hard copy digital plots made by saving on digital magnetic tape the GDU plot vector file. (Such plotting is done after the wind-tunnel test run is completed by operating the computer in the batch mode.) Consequently, the GDU screen display was essentially the same as that shown in figure 10. Note the two computer output messages concerning the type of output desired and the engineer input message 0010 where he selected the GDU plot option in the GDU message area at the bottom of the figure. Since there is no absolute criteria as to what is or is not an acceptable signature, the engineer must be able to examine randomdec signature plots such as shown in figure 10 and decide, based on his judgment and experience, whether the signature is satisfactory. If the signature is not acceptable, the engineer will call BDRDIN and change some or all of the parameters, most commonly the number of ensemble averages, and then repeat BDRD. If the signature is acceptable, the engineer will call PKPLOT to determine the damping.

FLUP PKPLOT. The moving-block procedure is implemented in subroutine PKPLOT which is the most complex of the three subroutines and requires a considerable amount of interaction on the part of the test engineer. Initially, the subroutine accesses the randomdec signature that has been stored in labeled common by BDRD and plots the randomdec signature on the lower left-hand quadrant of the GDU screen as shown in figure 11(a). This plot is essentially a repeat of the plot that can be made by BDRD except in

BDRD the plot covers the entire GDU screen. Once the signature has been plotted, the subroutine uses a fast Fourier transform algorithm to determine the transform of the signature and displays the results in the upper left-hand quadrant of the GDU screen. The GDU screen now appears to the engineer as shown in figure 11(b). Note that the signature plot is retained in the lower left-hand quadrant. At this point the engineer can examine a portion of the Fourier transform in more detail if he desires by using the GDU keyboard to input a frequency range of interest to truncate and expand the frequency scale. The resulting truncated transform is displayed in the lower right-hand quadrant. The GDU screen now appears as shown in figure 11(c). For the example shown in the figure, a frequency range from zero to 50 Hz was selected. The GDU light gun now is enabled so that the engineer can select the frequency of one of the modes of the system, indicated by the peaks in the transform, so that the damping in that mode can be determined. The selected frequency is then optimized, and the moving-block method is applied to the randomdec signature by taking discrete Fourier transforms of the signature at this frequency. The natural logarithm of the transform amplitude is plotted against time in the upper right-hand quadrant on the GDU screen as shown in figure 11(d). It is from this variation with amplitude that the damping is obtained. Notice that there is a more or less straight-line portion near the beginning of the amplitude plot and then an oscillation in the amplitude appears. Such oscillations indicate that the mode being examined has damped out, and the calculations are being influenced by noise and other nearby modes. In some instances large oscillations occur throughout the entire amplitude plot. This is usually caused by too small a block size. A further clue to block size problems is indicated by the optimized frequency being considerably different from the selected frequency. If the amplitude plot does not appear to be satisfactory to the engineer, he can increase the block size by a keyboard entry and determine a new amplitude plot. The amplitude plot shown in figure 11(d) is a satisfactory one. The plot also indicates the need for engineering judgment in determining what portion of the curve should be used in calculating the damping. The engineer makes this judgment and inputs to the computer through the GDU keyboard the start and stop times (zero and 0.200 second were selected for the case shown) for a linear least-square fit to be applied to the amplitude data. This straight-line fit is displayed on the plot as shown in figure 11(d), and the engineer can accept or reject the fit. For the case shown in the figure, an acceptable fit was obtained. However, in this case the engineer would probably want to make some additional fits using different start and stop times since the logarithmic amplitude curve seems to indicate some nonlinear damping characteristics. One choice he would probably make is start and stop times of zero and 0.100 second, respectively. If the fit is rejected, he selects new start and stop times, and repeats the process until a satisfactory fit is determined. If the fit is acceptable, the damping is determined from the slope of the linear fit formula. The damping and frequency are displayed at the bottom of the GDU screen. At this stage in the process, the engineer may want to determine the damping in another mode. He can do this by selecting another input frequency and repeating the frequency optimization and discrete transform process to obtain a new amplitude plot from which the damping can be determined.

It should be pointed out that if the model is equipped with a means for producing a transient response as would be the case with an active control flutter model, an option is provided in PKPLOT for handling this case without first generating a randomdec signature. This amounts to using the moving-block technique alone. Although no applications of this type have been made to flutter tests, PKPLOT alone has been successfully used in some rotorcraft aeroelastic model studies.

Randomdec/Moving-Block Results and Discussion

The combined randomdec/moving-block method has been applied during several wind-tunnel flutter model tests in the transonic dynamics tunnel. One application was to the low-aspect-ratio arrow-wing configuration shown mounted in the wind tunnel in the photograph (fig. 12). These model investigations and companion analytical studies are part of a program to provide basic flutter data on candidate supersonic cruise aircraft configurations. Some subcritical damping results for the arrow-wing configuration are presented in figure 13 in the form of the variation of damping in the critical flutter mode with dynamic pressure and Mach number. It was necessary to plot the damping against both of these parameters since both were being varied as the flutter boundary was approached in a fashion similar to that shown in figure 7. Since this model was actually taken to the flutter condition, it is possible to get a direct comparison of the actual flutter condition and the condition that would have been predicted by extrapolating the subcritical damping measurements. The actual flutter condition is marked by the square symbols on the figure. Note that the extrapolated damping data predict a flutter condition very close to that actually found. The results shown here for the arrow-wing model are similar to those that have been obtained for several other configurations.

Although the combined randomdec/moving-block method is still in a developmental stage and has not yet completely replaced the traditional method of actually determining flutter points in defining the flutter boundary, it is beginning to prove useful in guiding model tests and preventing unexpected, sudden penetrations of the flutter boundary. Results obtained to date indicate that it is reasonable to expect that this method can be developed into a reliable subcritical damping method that will make it possible in many instances to define the flutter boundary without actually obtaining flutter. However, it has become obvious through the applications to date that a key ingredient to the successful application of the technique is the ability of the test engineer to exercise his judgment and experience by being able to interact in near real time by using the graphic display unit.

CONCLUDING REMARKS

The computer-controlled data-acquisition system recently installed for use with the Langley transonic dynamics tunnel has been described. This description has included a discussion of the hardware/software features of the system.

A subcritical response damping technique for use in real-time wind-tunnel model flutter testing that has been implemented on the data-acquisition system has been described in some detail. This technique is called the combined randomdec/moving-block method and its successful application requires that the user be able to interact with the computational process. The graphic display unit has proven to be a useful tool in providing plots of intermediate computational results so that the user can assure not only himself that the process is proceeding satisfactorily but also provides him with needed data so that he can intelligently select parameter values necessary to complete the damping calculations.

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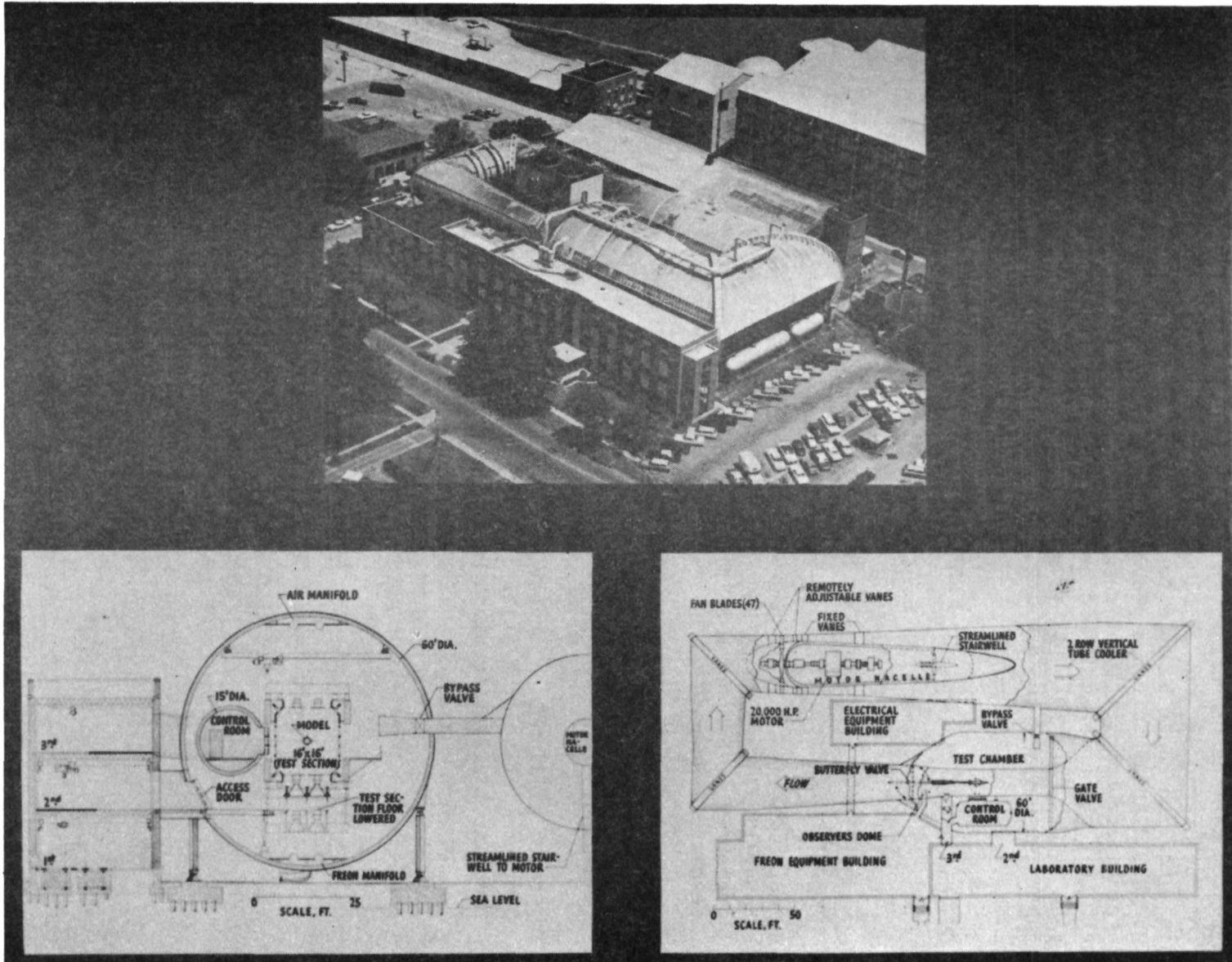
Figure 1.- Langley Research Center transonic dynamics tunnel.

TYPE OF TEST	MEASURAND	NUMBER OF CH	TRANSDUCER TYPE	FREQUENCY RANGE
BUFFET	ACCELERATION FLUCTUATING AERODYNAMIC PRESSURE	60	DYNAMIC PRESSURE CELLS PIEZOELECTRIC ACCELEROMETERS	5-20 KHZ
FLUTTER	STATIC FORCE ACCELERATION DYNAMIC FORCE MODEL PARAMETERS	50	STRAIN GAGE SERVO ACCELEROMETERS STRAIN GAGE ACCELEROMETERS	0-200 HZ
DECELERATOR	STATIC FORCE ACCELERATION DYNAMIC FORCE	13	STRAIN GAGES STRAIN GAGE ACCELEROMETERS	0-200 HZ
GUST LOADS	STRAIN ACCELERATION MODEL PARAMETERS	39	RESOLVERS STRAIN GAGES POTENTIOMETERS DIFFERENTIAL TRANSFORMERS PIEZOELECTRIC ACCELEROMETERS	0-50 HZ
GROUND-WIND LOADS	ACCELERATION MODEL PARAMETERS STATIC BENDING MOMENT DYNAMIC BENDING MOMENT	25	STRAIN GAGES POTENTIOMETERS SERVO ACCELEROMETERS STRAIN GAGE ACCELEROMETERS PIEZOELECTRIC ACCELEROMETERS	0-100 HZ
ROTORCRAFT	STATIC FORCE ACCELERATION DYNAMIC FORCE	32	STRAIN GAGES STRAIN GAGE ACCELEROMETERS	0-200 HZ
STATIC AERODYNAMICS	STATIC FORCE STATIC PRESSURE	48	STRAIN GAGES PRESSURE CELLS SCANNER VALVE CONTROLLER	0-5 HZ

Figure 2.- Types of wind-tunnel model tests and instrumentation requirements.
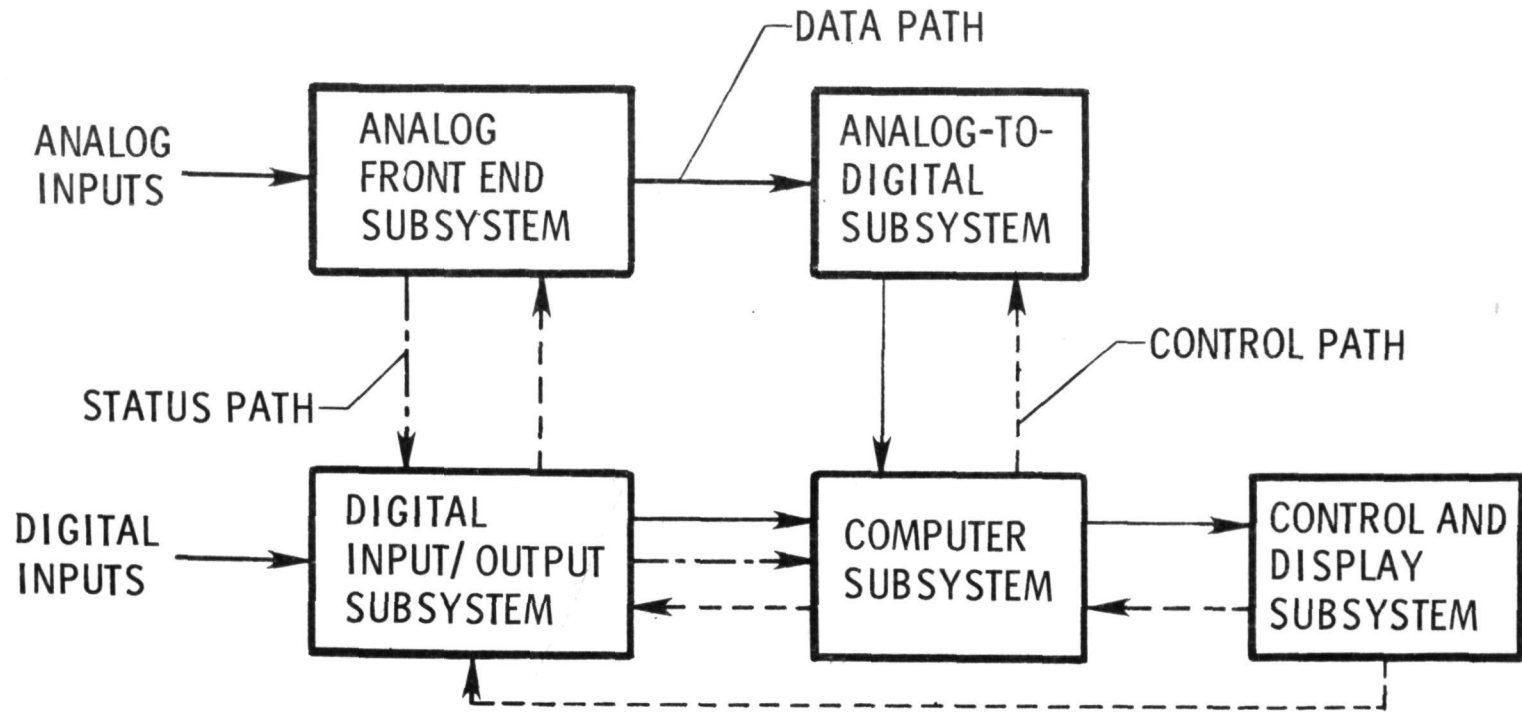
Figure 3.- Simplified block diagram of data-acquisition system.
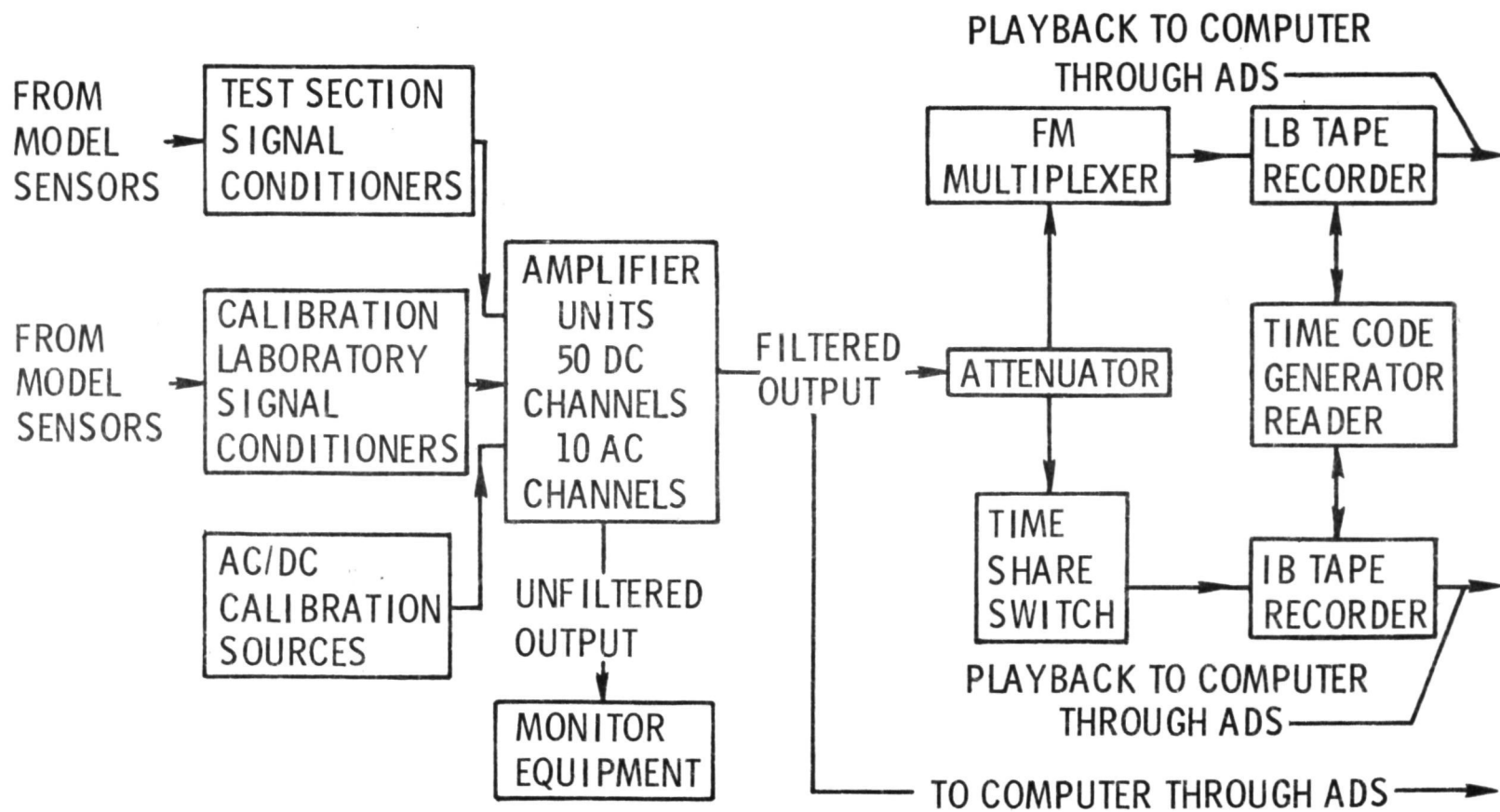
Figure 4.- Simplified block diagram of analog front end subsystem.
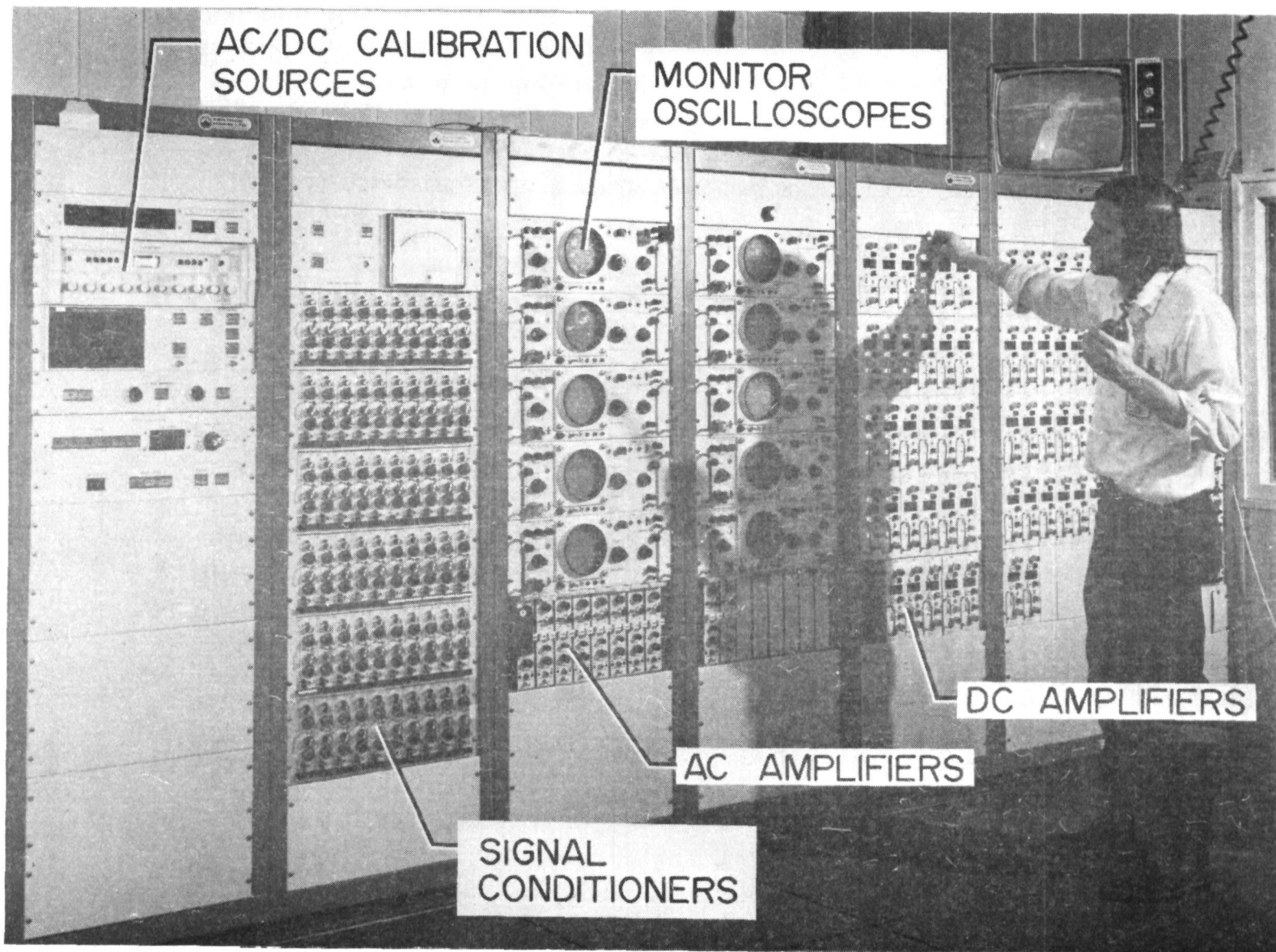
Figure 5.- Photograph of analog front end subsystem equipment.

NUMERIC DISPLAYS

GRAPHIC
DISPLAY
UNIT
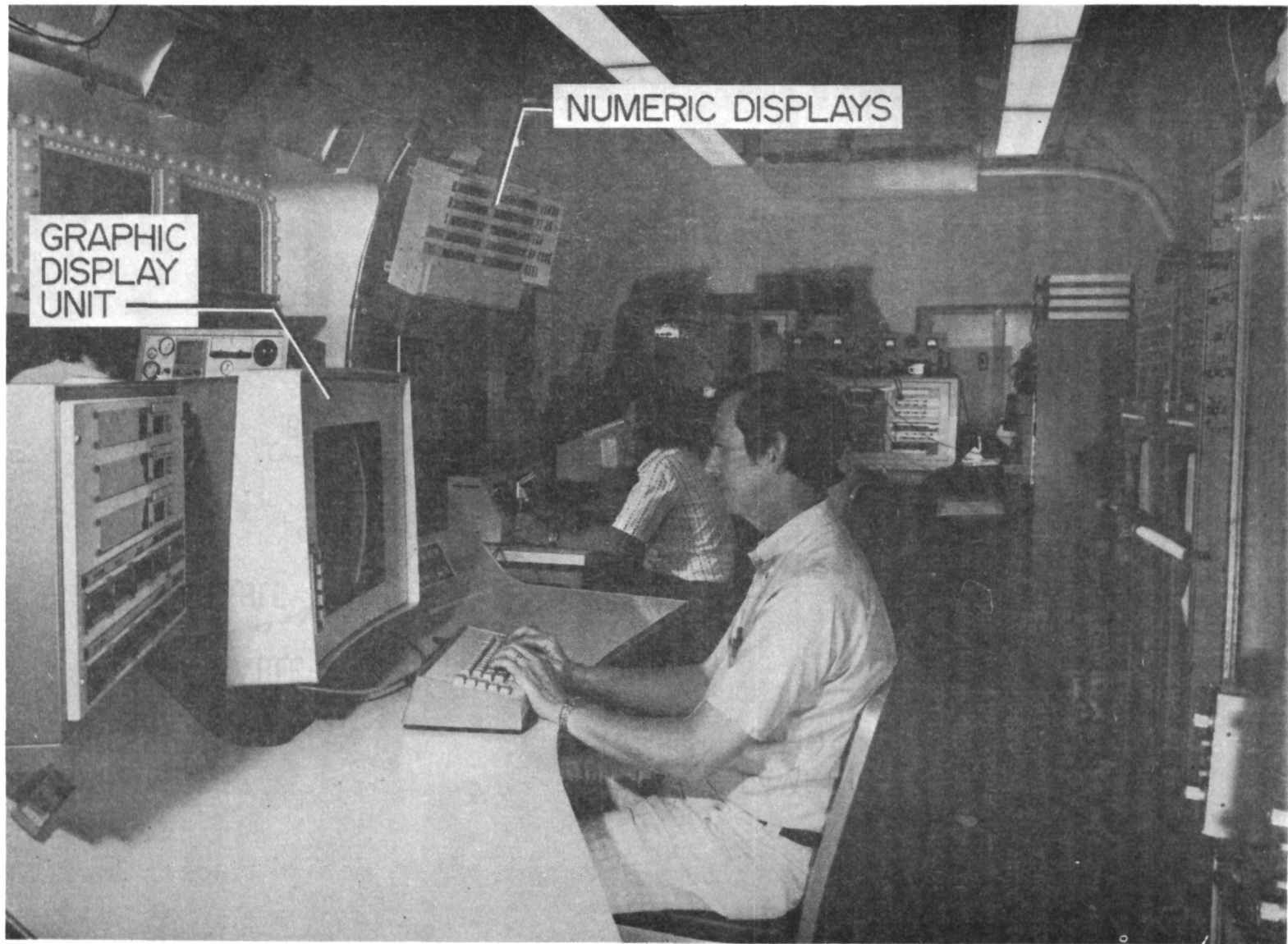
Figure 6.- Interior view of wind-tunnel control room.
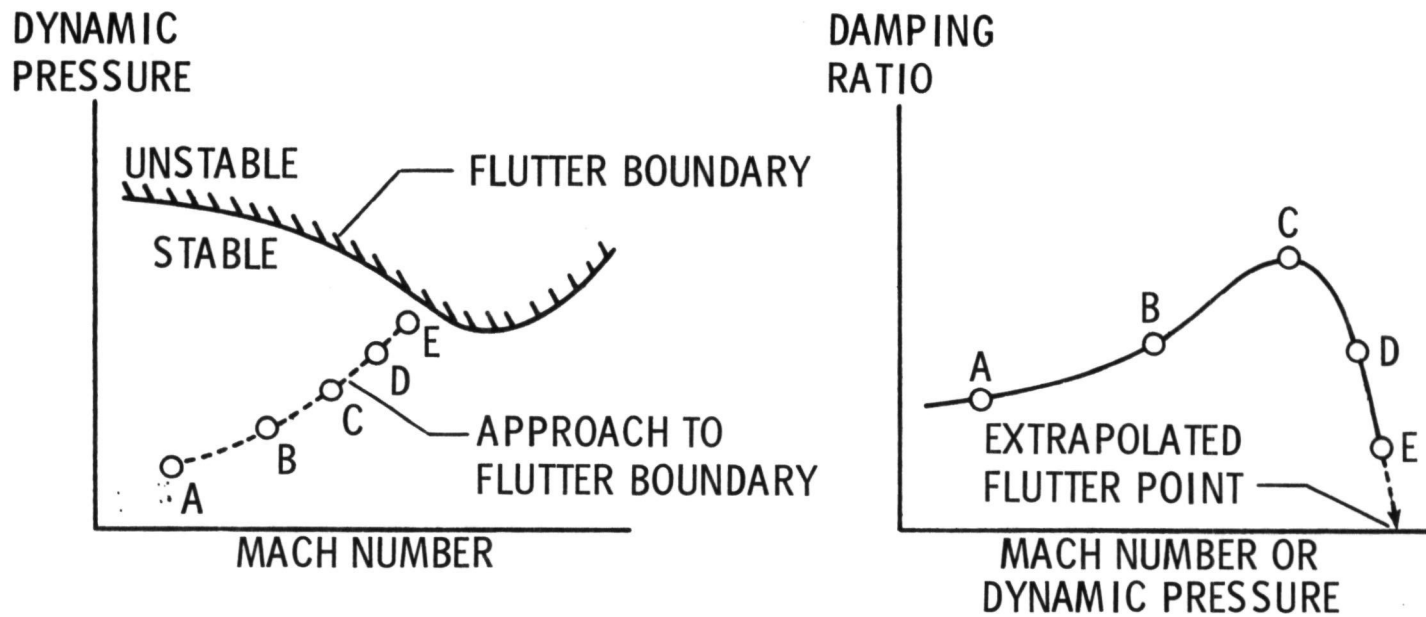
Figure 7.- Typical flutter boundary and subcritical damping variation.

RESPONSE y(t)

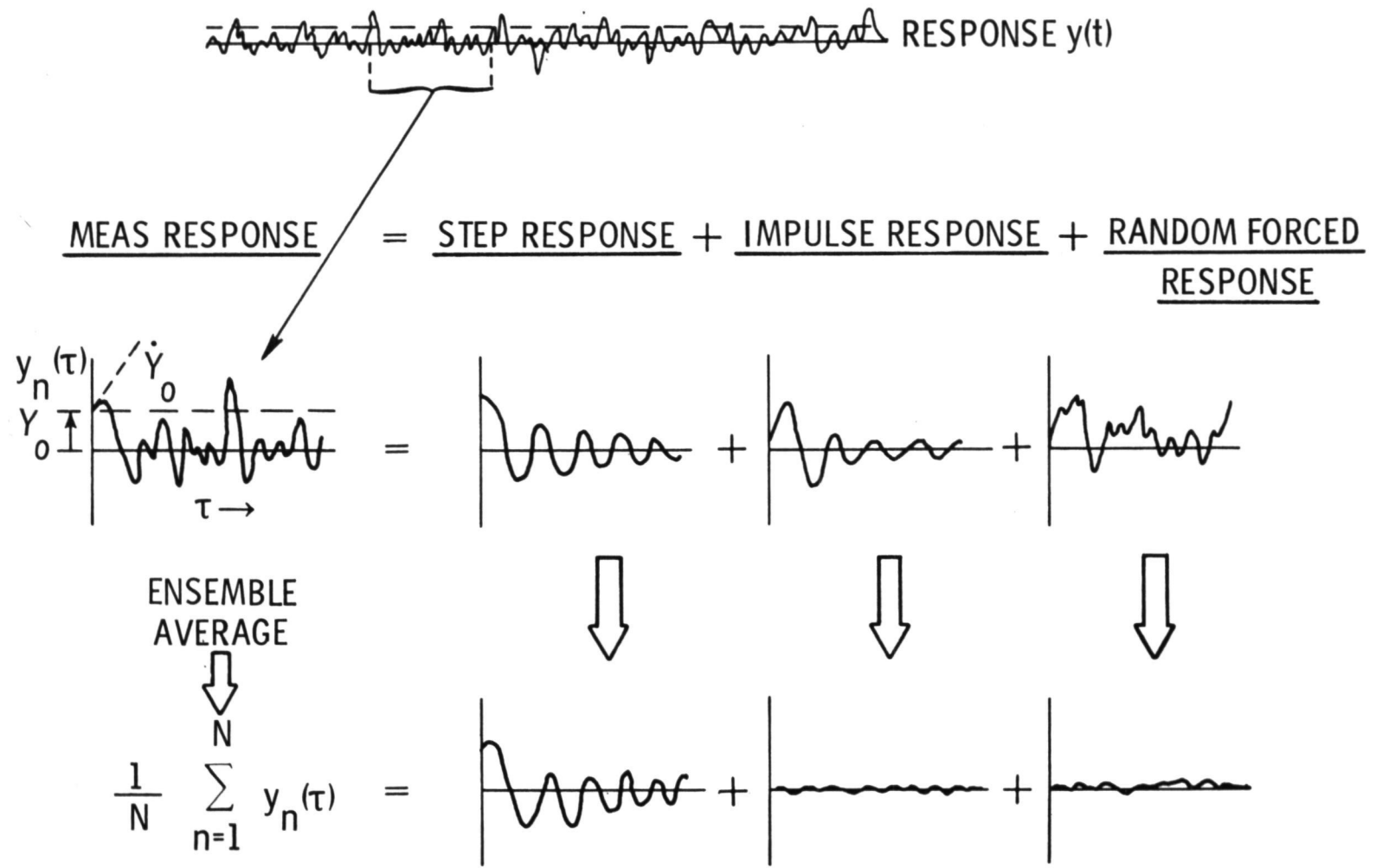MEAS RESPONSE = STEP RESPONSE + IMPULSE RESPONSE + RANDOM FORCED RESPONSE

$$\frac{1}{N} \sum_{n=1}^{N} y_n(\tau) =$$

ENSEMBLE AVERAGE

Figure 8.- Randomdec schematic illustration.
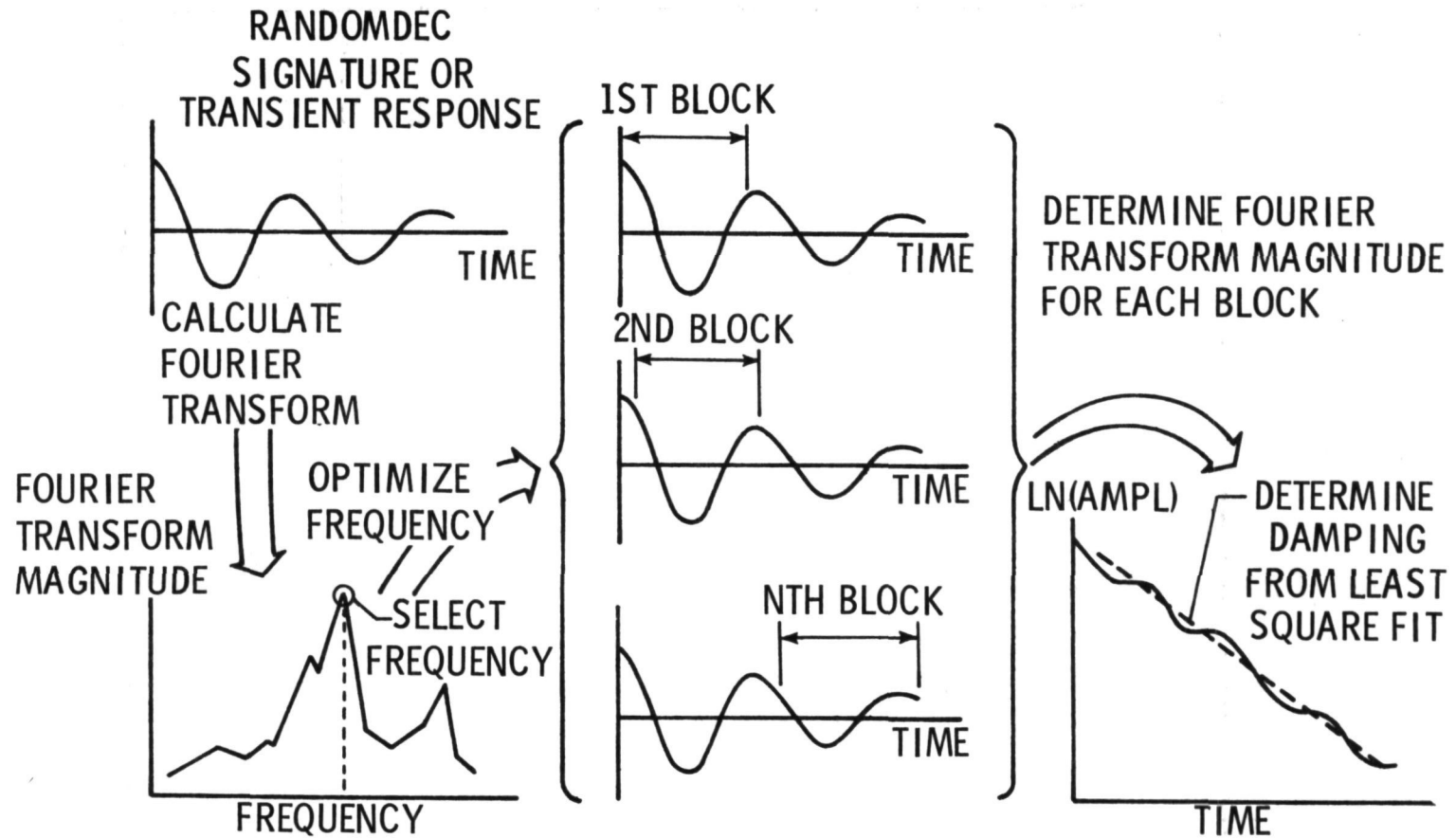
Figure 9.- Moving-block schematic illustration.
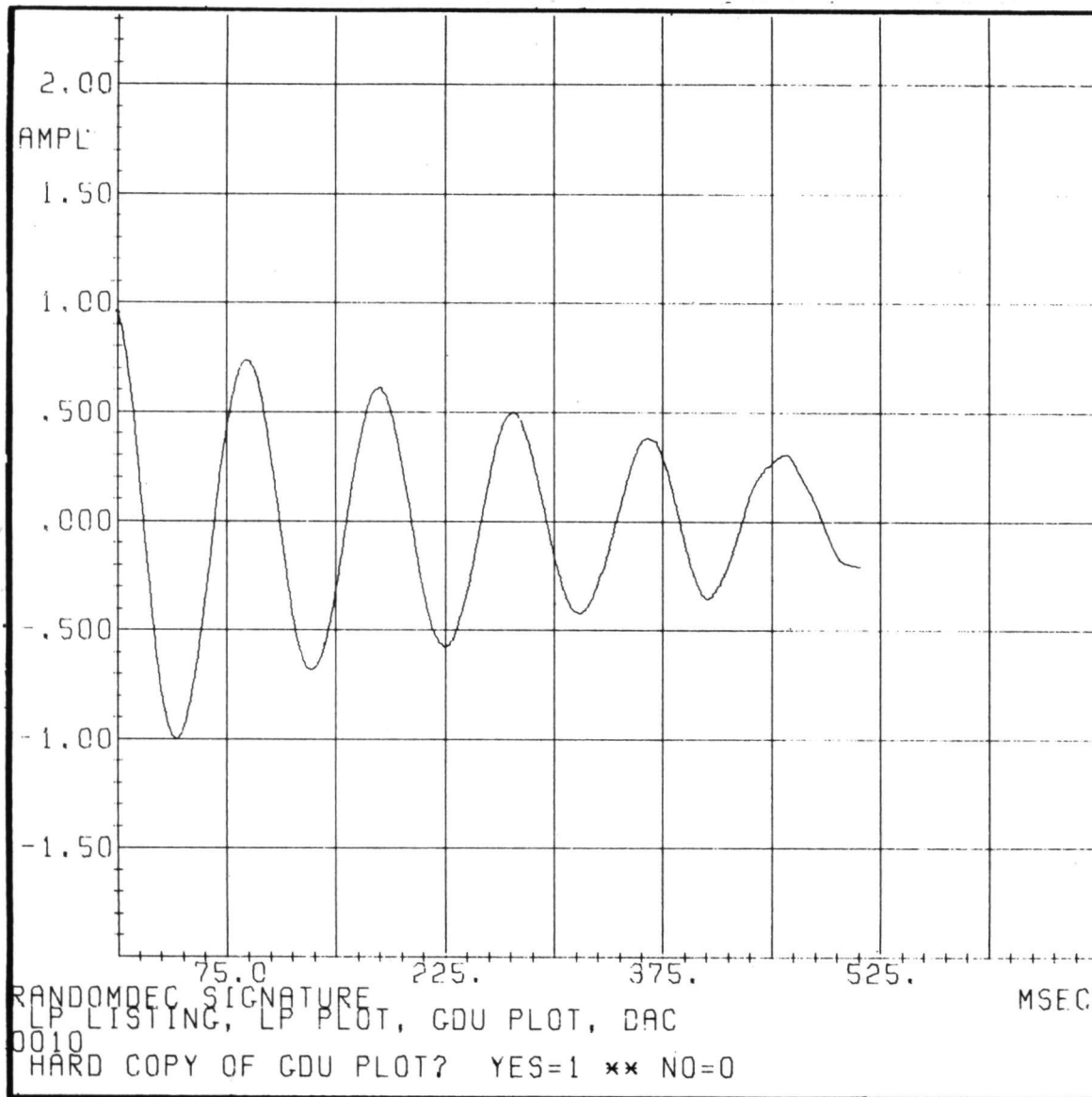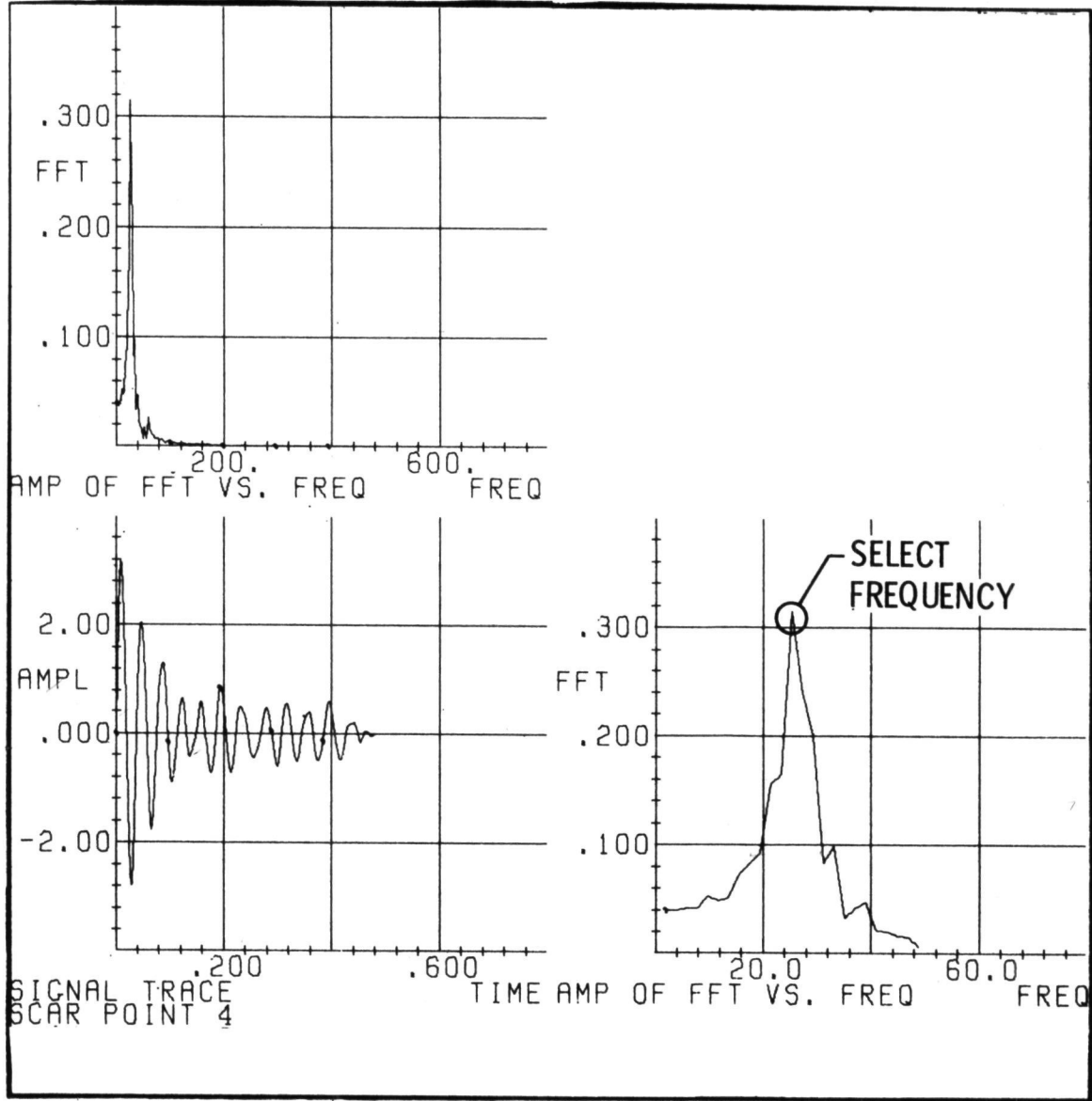
Figure 10.- Graphic display unit plot of randomdec signature.
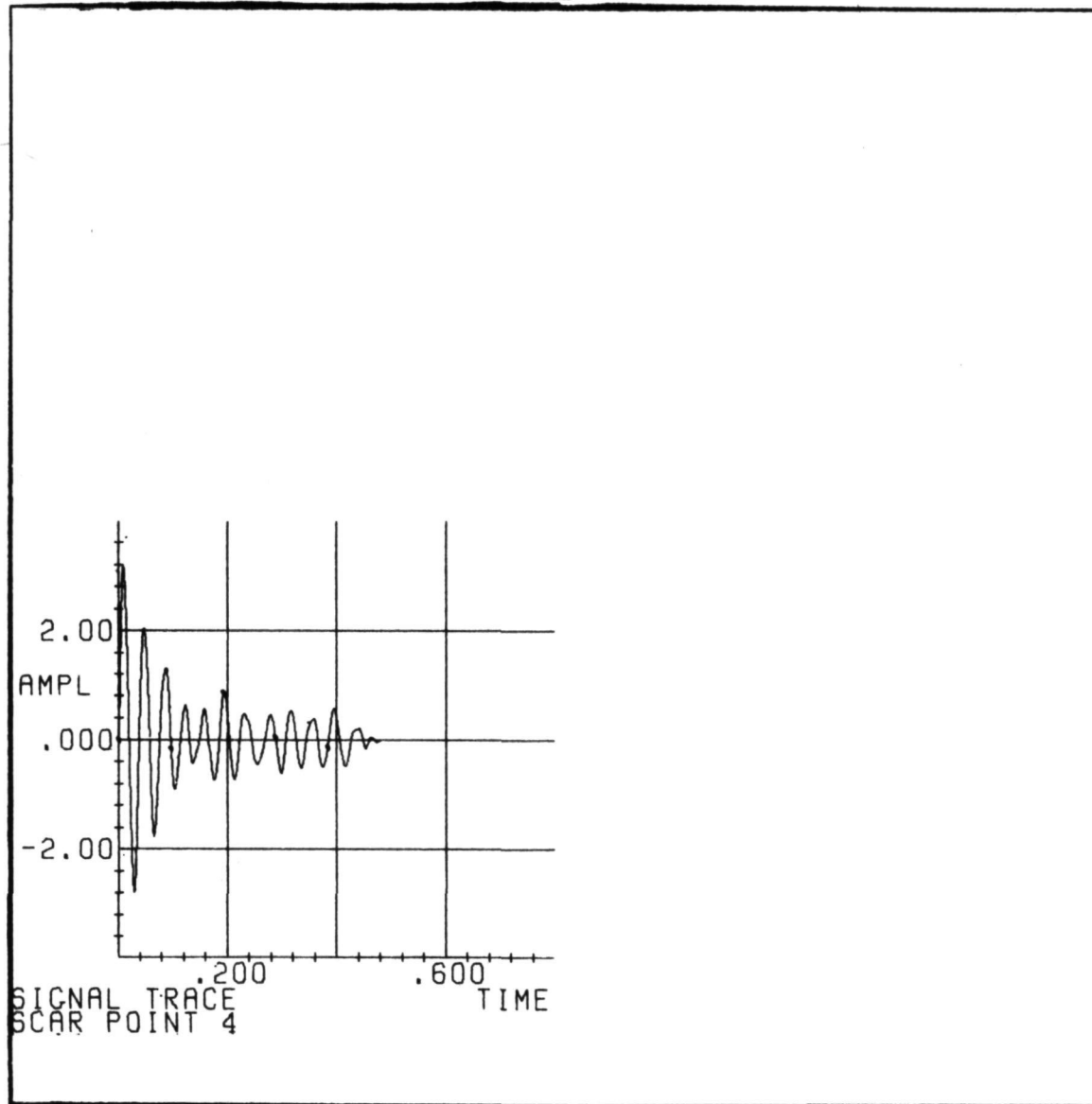
(a)   Randomdec signature.

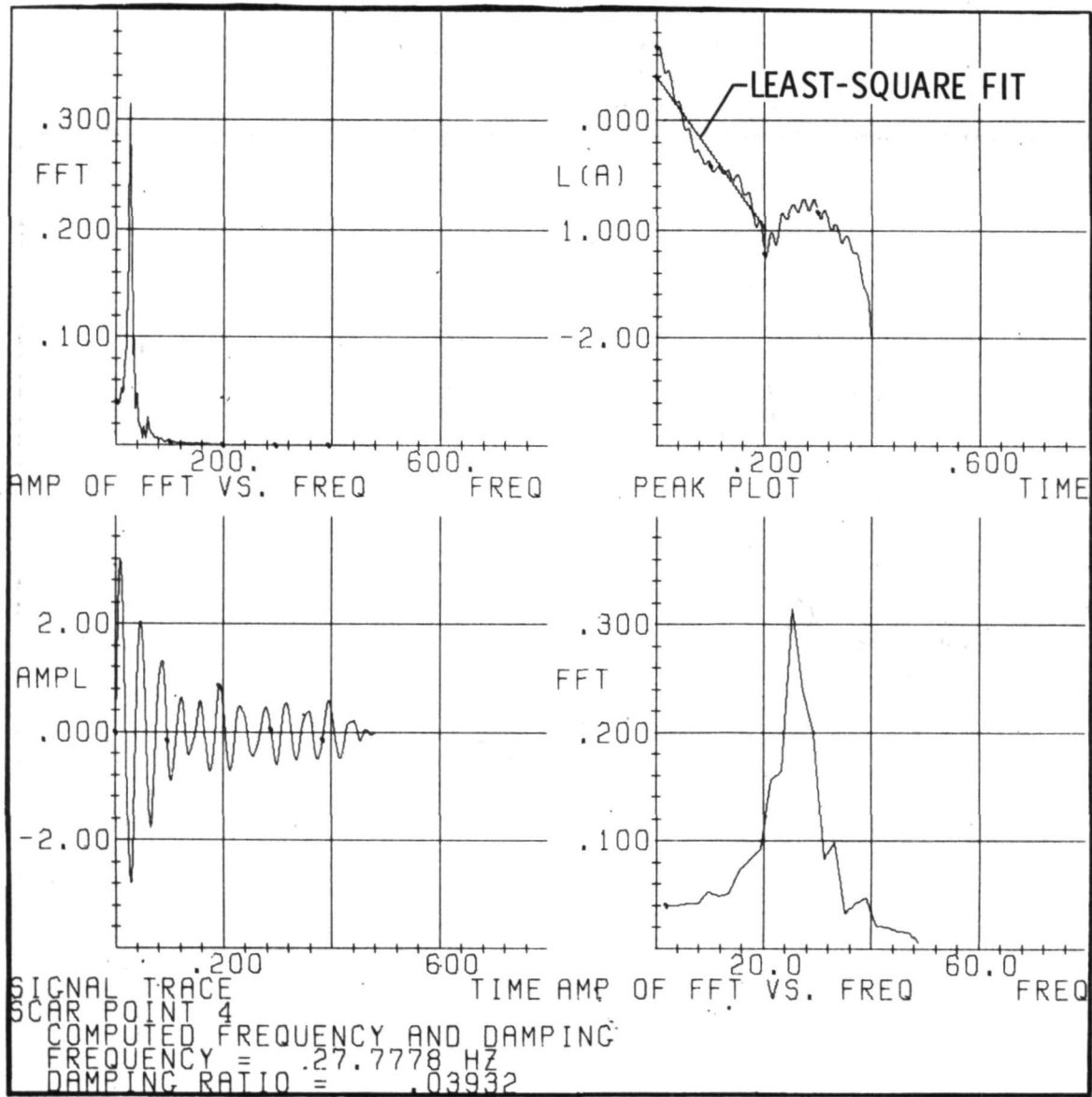Figure 11.- Graphic display unit plot displays.
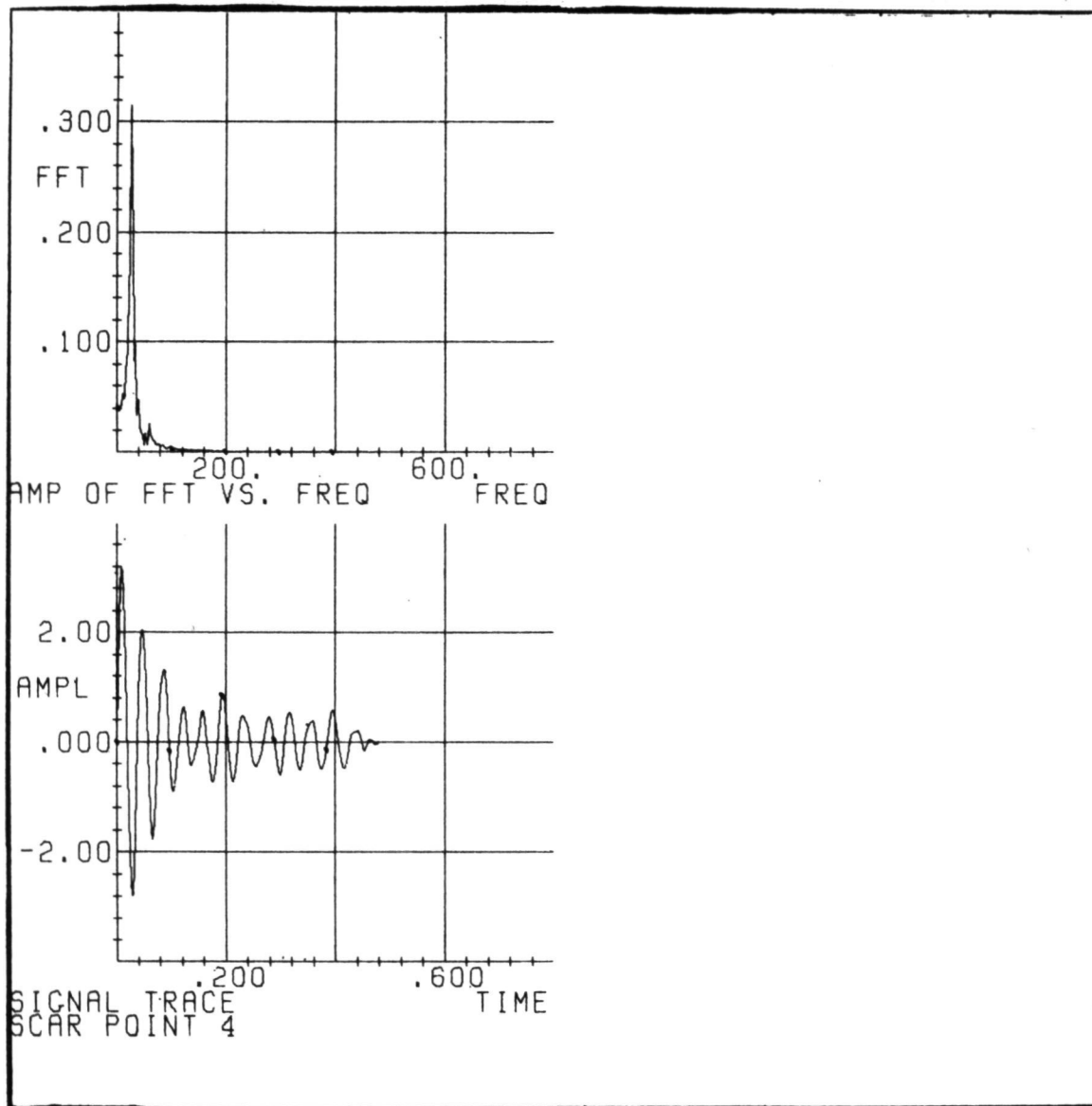
(b)   Fourier transform amplitude.

Figure 11.- Continued.

(c)   Expanded Fourier transform.

Figure 11.- Continued.

(d) Logarithmic amplitude.

Figure 11.- Concluded.

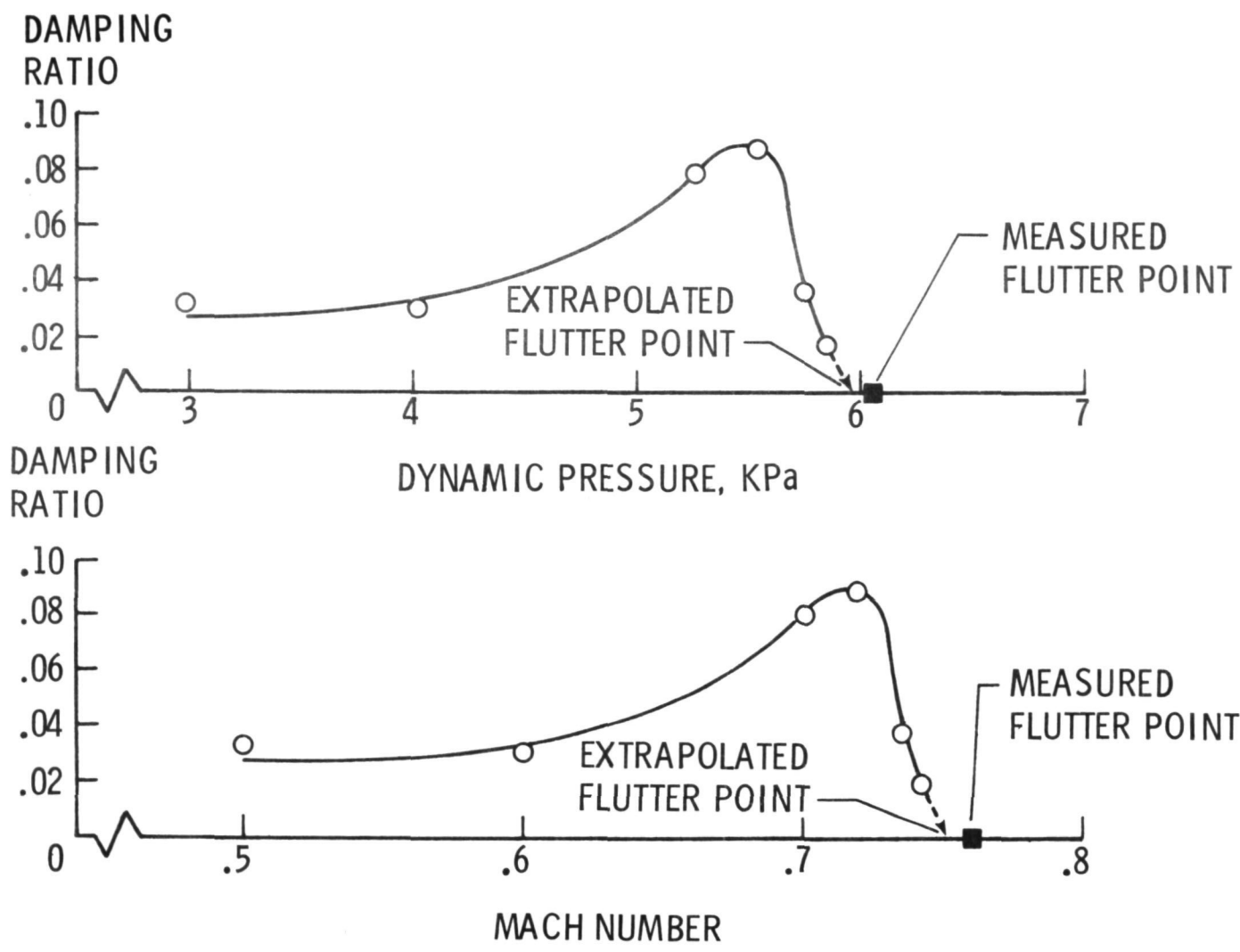Figure 12.- Photograph of arrow-wing model mounted in wind tunnel.

Figure 13.- Randomdec/moving-block subcritical damping results for arrow-wing configuration.