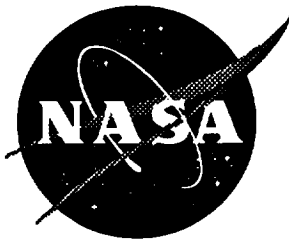NASA Technical Memorandum 109156

Dynamic Stability Instrumentation System (DSIS)

Volume III: User Manual

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Abstract

The paper is an operating manual for the Dynamic Stability Instrumentation System in specific NASA Langley wind tunnels. The instrumentation system performs either a synchronous demodulation or a Fast Fourier Transform on dynamic balance strain gage signals, and ultimately computes aerodynamic coefficients. The dynamic balance converts sting motor rotation into pitch or yaw plane or roll axis oscillation, with timing information provided by a shaft encoder. Additional instruments control model attitude and balance temperature and monitor sting vibrations. Other instruments perform self-calibration and diagnostics. Procedures for conducting calibrations and wind-off and wind-on tests are listed.

Introduction

This document, the third volume of a three-volume set, provides installation, calibration, and operational procedures for the Dynamic Stability Instrumentation System (DSIS). The first volume of the three-volume set describes the DSIS electrical and mechanical hardware and includes electrical schematics and wiring diagrams. The second volume is a software manual that describes the PC software at a functional level and includes information on how to modify the C language code.

The DSIS measures aerodynamic coefficients using a forced model oscillation technique. These coefficients are functions of the forces and/or moments on the oscillating wind tunnel model. This system, which utilizes dual-digital signal processors, replaces an obsolete analog version based on electro-mechanical resolvers. In addition to the Synchronous Demodulation algorithm that was implemented on the analog version, the new system also implements an algorithm based on the Fast Fourier Transform. Reference 1 provides information about both dynamic stability techniques.

The DSIS consists of a double rack of instruments, a remote motor-generator set, two special stings each with motor driven shafts, and specially designed balances which mechanically convert the rotary shaft motion into either a pitch, yaw, or roll motion about the balance oscillation center. The major components in the instrumentation rack include a personal computer (PC), digital signal processor (DSP) microcomputers, computer controlled signal conditioners, function generator, digital multimeter, and an optional Fast Fourier Transform (FFT) Analyzer. These new racks replace original electro-mechanical resolver-based analog instrumentation. The original motor-generator set used to drive the sting drive motor is used in the new system.

DSIS Transportation

Advance preparation is required prior to transportation of the DSIS. The instrumentation rack, shown in figures 1 through 4, has a dimension of 38 inches (D) × 56 inches (W) × 95 inches (H) and weighs approximately 1,200 pounds. Physically moving the DSIS rack from one location to another requires certain precautions. The first precaution is to remove the FFT analyzer (if installed), shown in figure 5, from the rack and have it transported separately. The high cost of this instrument warrants special care. Another precaution is to secure the sliding tracks on which the PC chassis is mounted. The PC is illustrated in figure 6, which also shows a drawer under the PC chassis. The keyboard is supported by this drawer, and it contains the miscellaneous items listed in table 1.

As shown in figure 7, the drawer top is lifted to reveal the items which should be cleared and stored elsewhere prior to shipping. All front panel interconnecting cables shown in figures 8 and 9 should also be removed. The PC mouse cable should be removed from a connector located on a panel beneath the drawer as shown in figure 10. During normal operation, the mouse rests on top of a special shelf attached below the drawer that slides outward to the right as shown in figure 6. The shelf can also slide outward toward the left.

Main Menu Description

The following discussion of PC software assumes the user is familiar with the PC and the DOS operating system. Turn on the PC and change to the "C:\DSP" subdirectory. Deactivate execution of all DOS memory resident and terminate and stay resident (TSR) programs to conserve memory (RAM) space. Start the software by typing "DSP.EXE" and depressing the "Enter" key. When the software is executed, an initial main menu with 14 selections will be displayed on the monitor similar to the one shown in figure 11.

User selections are made by depressing the corresponding numeral key. Depress the "Enter" key to make the selection. Software initialization is performed by selecting one or all of options 5 through 10. Options 1 and 3 are used to start a program, while options 2, 4, and 11 are used for diagnostic purposes. A brief explanation of each option is now given in a sequence for normal usage.

Option 5 controls which computed results are displayed on the monitor. If "immediate" on the sub-menu is selected, then displayed values are passed directly from the DSP microcomputers to the PC. If "averaged" on the sub-menu is selected, then values are averaged and displayed. The user can select the number of values to be averaged in the same sub-menu.

The user can enter calibration constants K_D, K_T, and K_M, defined in Appendix A, by selecting option 6. The prompts listed in figure 12 will be displayed. If the constants are not known a priori, then a procedure for determining them is given in DC Balance Calibration procedure listed below in the Calibration section. Constants for the angle-of-attack sensor and the dimensions for model reference are entered by selecting option 7. The prompts for option 7 shown in figure 13 will be displayed. Model temperature, wind tunnel pressure, and Mach number are entered by selecting option 8. The prompts for option 8 are listed in figure 14.

Both measured and processed data may be stored to disk with default file names. Option 9 allows the user to specify the file names. The user enters a file name for the processed data. This same file name is appended with the letter "c" to create the file name for the measured data.

Prior to the start of tare or wind-on testing, select option 10 to initialize the XY Plotter, which is shown in figure 15. The user will be prompted, as shown in figures 16 and 17, for the constants listed in table 2, which also lists optional choices. The first six constants are calibration values and the last five are XY plotter parameters. The wind-on plot code determines which set of coefficients will be computed and displayed. Refer to tables 3,4, and 5 for lists of wind-on plot codes and the corresponding sets of coefficients.

Option 3 allows the user to change the program running on the DSP microcomputers. A sub-menu, shown in figure 18, will prompt the user for program choice. Refer to table 6 for a list of six different programs available. Once chosen, the main menu will reappear. The chosen program will now be displayed after the "Current program:" message label.

Option 1 downloads the drivers selected in option 3 to the DSP microcomputers and starts execution of numeric processing software on the PC. One of the real-time displays, as shown in figures 19 or 20, will be visible on the monitor.

All of the user selected constants entered by the user for options 3 through 10 are stored in the following disk files: CALIVAL.DAT, TESTVAL.DAT, DCONFIG.DAT, SENS.DAT, TAREVAL.DAT. These files are recalled when the software initially starts and stored to the same disk files when option 0 is selected. All of these constants are maintained unless they are updated. Option 0 terminates DSIS operation and returns PC control back to DOS.

A real-time spectrum of the selected channel is plotted on the monitor by selecting option 2. Option 4 prompts the user as shown in figure 21 for window type, number of points, and which channel to plot for the real-time spectrum. Option 11 displays a real-time measurement of model attitude as illustrated in figure 22. Notice in the figure that a standard deviation is computed and is also displayed. Depress the "Enter" key to return to the main menu. The equations for computing model attitude are given in Appendix B.

Option 12 sends the processed data file or a calibration data file to the printer. The actual file sent is the one specified in option 9 or the one created during calibration. If option 9 has not been selected, then a file with the default name "aaaaaaaa.aaa" is sent.

Option 13 allows the user to initialize all of the different point counters to a value of one. Refer to table 7 for a list of different types of counters and data types. This option is typically not used during normal operation.

Nulling the Signal Conditioners

Background. The DSIS contains a computer controlled multi-channel signal conditioner unit as shown in figure 23. Three signal conditioners are utilized while two others are spares. The unit is accessed by the PC via an IEEE-488 interface, and software hot keys on the PC are provided to control all of the necessary functions. Each signal conditioner has a shielded differential input, an automatically generated DC nulling voltage, and a linear amplification stage. Each signal conditioner has a programmable offset adjustment stage with two full scale ranges: 0.075 V and 1.667 V. The offset is added electronically prior to the gain stage. The software automatically reduces the computed offset by the particular gain setting.

The strain gage bridges are configured for full four-arm bridges (no bridge completion required). Figure 24 illustrates a bridge completion card. Notice in the figure the small configuration jumpers and the calibrate signal resistor pairs. These four resistor pairs can be changed to provide different levels of

calibrate signal voltages. Resistor choices along with the resulting voltages are listed in table 8.

During normal operation, elimination of the DC voltage offset on each of the strain gage bridge signals prior to amplification is required. A precision digital multimeter (2001 DMM), shown in figure 25, is used to monitor the nulling operation. A single rotary switch located on the same panel as the 2001 DMM is used to control input to the 2001 DMM. Accordingly, switch positions are labelled "Displacement," "Pitch," and "Secondary."

Set the 2001 DMM rotary switch to the selection corresponding to the channel being nulled. Standard deviations of all three channels are displayed on the monitor during the nulling operation. Null one signal conditioner at a time. Use the "I," "D," and "G" hot keys to change the gain; the "X," "V," and "Z" keys to change the offset; and the "A" key to select the active signal conditioner. Appendix C lists hot key descriptions.

Throughout this manual, an "active" signal conditioner is one that is addressed by the computer for subse quent commands from the user. Thus, in order to control three different signal conditioners with the same hot keys, only one "active" signal conditioner is recognized by the PC software. The "I" key increments the gain of the "active" signal conditioner, while the "D" key decrements the gain. The "G" key displays a list of gain selections before prompting for a new gain setting. The "X" key activates PC software that commands the active signal conditioner to add 0 VDC as nulling voltage. The "V" key activates PC software that algebraically adds a correction to the current nulling voltage and can be used iteratively as follows in the procedure below. The "Z" key forces the active signal conditioner to auto-null, where the signal conditioner computes its own estimate of the nulling voltage and then algebraically adds that value electronically. This last hot key is used mainly for diagnostic purposes, and not for normal operation.

Access to the DSP microcomputer inputs is provided at the short rack panel shown in figure 9. Connect BNC type cables to the access panel jacks and to the oscilloscope or 2001 DMM. The inputs must not exceed the full scale range of ± 0.8 V.

A maximum possible gain setting should be used to achieve a good signal-to-noise ratio. Signal conditioner gain is limited by the AC portion of the strain gage signal to within ± 0.8V. During wind-on conditions, low frequency oscillations with sufficient amplitude may prevent the user from using gain values above 500. The nulling procedure only

removes the DC portion of the strain gage signal, not the undesired low frequency oscillations.

Real-Time Displays. Doftware resides on the PC and DSP microcomputers that implements two types of numeric processing algorithms in real-time. The first type is based on the FFT, while the second is based on syn chronous demodulation. The second type is the preferred algorithm to use with the DSIS hardware. The user can select either algorithm from main menu option 3, "Change program." Associated with both algorithms is a real-time display on the PC monitor. The FFT display is very similar to the Synchronous Demodulation display; thus only a description for the synchronous demodulation display is now given.

Illustrated in figure 20 is an example of syn-chronous demodulation display. Across the top of the screen is a label for the type of algorithm implemented. Two choices of lowpass digital filter cutoff frequencies are available: 0.25 Hz, and 0.10 Hz. The tradeoff is processing delay versus data accuracy. Also located at the top of the screen is the label "Frequency" with a numeral updated in real-time in units of Hz corresponding to the oscillation frequency. This value is more accurate than the LED display, which is located on the RPM indicator panel, shown in figure 26.

Below the algorithm label are three other labels: "Displacement," "Torque," and "Secondary." These column headings correspond to balance signals. Each row of voltage values listed in the columns below these headings are updated in real-time, and are labelled. The displacement column has its own row labels: "Real (1)," "St. Dev.," "Real (2)," "St. Dev.," and "St. Dev. Avgs." The torque and secondary columns have row labels: "Real," "St. Dev.," "Imaginary," "St. Dev.," " Magnitude," "St. Dev.," and "St. Dev. Avgs."

The displayed value corresponds to the adjacent row label. The label "Real" or "Imag" refers to values passed directly from the DSP microcomputers to the PC. The label "St. Dev." refers to a running standard deviation computed on a fixed number of the DSP passed values. These values should be allowed to "settle" before data is acquired. The label "St. Dev. Avgs." refers to a running standard deviation of the running average of the DSP passed values. The term "running" means that values are continuously being recomputed and updated in real-time. Notice in the bottom of the screen, the label "Averaged data" or "Immediate data" will be displayed. If averaging of the incoming data is performed, then the appropriate label will be displayed and the standard deviation of the averages (and their labels) will be displayed.

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Otherwise, no labels nor values will appear. The "Averaging" label listed at the bottom of the screen is the number of averages of the DSP passed values.

Phase angle information is given below the voltage readings. The phase angles of the torque and secondary signals are displayed in units of degrees relative to the displacement signal. For this reason, notice that displacement has no imaginary or magnitude values listed. Across the center of the screen a blank area is reserved for certain coefficients. Sensitivity, tare, or wind-on coefficients are computed and displayed in real-time if the datacode is 9, 3, or 7, respectively. Equations used to compute all of the different coefficients are listed in appendix A.

Signal conditioner gains and offsets are listed in columns corresponding to the column headings listed previously. The "active" signal conditioner is the one that can be controlled by any of the alphabetic hot keys. The active signal conditioner is indicated by gain and offset values displayed in the color white instead of yellow. Listed under the offset displays are wind tunnel parameters that are computed or entered manually. The number of data points actually stored in a disk file during tare or wind-on testing is displayed next to the label "Ptnum." The label "AoA" refers to model attitude in degrees, and its standard deviation is displayed next to the label "St. Dev." Model attitude equations are listed in Appendix B. Wind-on velocity is displayed next to the label "V." The label "Stored in:" lists the name of the data storage file for formatted data.

Nulling Procedure. The procedure should be performed for all three channels, one channel at a time. The signal conditioners and the oscilloscope are shown in figure 8.

1. On the PC, type "DSP.EXE" and depress the "Enter" key. From the main menu, select option 3, "Change program," and the submenu shown in figure 18 will appear on the monitor. Depress the number "4" for "Synchronous Demodulation," and depress the "Enter" key. Finally, select option 1, "Run program," from the main menu. A display similar to the one shown in figure 20 should be visible on the monitor. The gain and offset display color for the "active" signal conditioner will be white versus yellow for the other two.

2. Select a signal conditioner using the "A" key. Set the switch labelled "Calibrate Enable" on the RPM Indicator panel shown in figure 26 to the "Calibrate Enable" or up position. Select 0 Hz frequency on the HP3325A function generator, also shown in figure 26. Depress the "X" key.

The software will command the signal conditioner to add an offset. The offset value on the PC monitor should verify this operation with a display of 0.0 V. Connect the three balance signals and the G-meter output at the oscilloscope access panel BNC's to the four-channel oscilloscope.

3. Wait approximately 15 seconds for the standard deviation of the selected channel to settle. Depress the "V" key. A prompt "Send iterative offset adjustment?" will be displayed. Answering "No" will force the software to generate the new nulling voltage value equal to the negative of the input voltage. The "input voltage" is the voltage value input to the DSP micro computers. Answer "No" the first time through to generate a starting point for the iteration and to avoid unnecessary iterations. Answer "Yes" on each subsequent pass to force the software to generate the new nulling voltage by subtracting the input from the previous nulling voltage. DC offset error on each of the strain gage bridge signals can be eliminated in less than four iterations.

4. Depress the "I" key to increment the gain of the selected signal conditioner; otherwise depress the "G" key if the desired gain is known a priori. A gain menu with options listed in table 9 will be displayed. Depress the letter key corresponding to the desired gain.

5. Repeat steps 3 and 4 until the highest gain setting is achieved and the standard deviation of the selected channel does not decrease significantly. The selected channel is now nulled.

6. Set the "Calibrate Enable" switch back to the down position to disengage the encoder simulator hardware. The frequency setting on the HP3325A can remain at 0 Hz, since its output is also disengaged by the "Calibrate Enable" switch.

Data Codes

All non-calibration data are identified by a data-code which is defined in table 10. Datacodes can be used to give information about the status of the DSIS hardware. The value of the datacode is a weighted sum of four switch-dependent values as shown in table 11. For example, a wind-on datacode of "7" indicates that bridge power is on (1), the oscillation drive is on (2), and wind is on (4). Thus, $1 + 2 + 4 = 7$. The datacode is displayed on the monitor and an LED display on the motor speed control front panel. Figure 26 is a photograph of the motor speed control front panel.

If the two displays do not agree, or the datacode is one of the undefined values, 4, 5 or 8, then the status of the soft switches is not current. The status of the bridge power and shunt resistor soft switches within the software must be updated by using the "B" key or "U" key to force the signal conditioner to a known state. The oscillation drive switch is located on the motor speed control front panel while the wind-on switch is located on the front of the sting as shown in figure 27. The software monitors these two hard switches using a register on the DAS-20 Multifunction I/O board.

Real-Time Displays and Hot Keys

A "real-time" display is one that provides continuous updates of averaged data from the DSP microcomputers. The software uses three different real-time displays that correspond to different signal processing algorithms. See table 6 for a list of each type of display. Figure 20, "Example of Synchronous Demodulation Display" is a depiction of one of the real-time displays and corresponds to the second type listed in table 6. The phase "real-time execution" refers to the mode of operation of the PC software while one of the real-time displays is active.

The following discussion describes each of the software "hot keys" which are also listed in Appendix C. For all user input to the software program "DSP.EXE," the "Enter" key must be depressed after alphanumeric entry. All of the "hot keys" listed below do not require the "Enter" keystroke. The "F#" function keys provide software flow control while the alphabetic keys mainly control the programmble signal conditioners. These keys are only active whenever the main menu is not displayed.

The "ESC" key terminates real-time execution and returns the user back to the main menu. The "F1" function key displays a help screen that lists function key descriptions as illustrated in figure 28. In this figure, the "A" key option refers to an "active" amplifier which is the same an "active" signal conditioner. The "F2" function key toggles between average or immediate display of data. Averages are always being computed; the displayed values respond more quickly in immediate mode, and are more accurate while in the averaging mode. The "F3" function key sets all calibration, tare, and wind-on data point counters to 1. Depending upon the mode of operation, one of these point counters will be displayed (usually across the bottom of the monitor screen) and updated on the appropriate real-time display.

The "F4" function key is used to compute a new gain normalization value for the active channel. This key is used for daily calibration of the A/D converters on the DSP microcomputers. The "F5" function key is used to select calibration code, and thus change the type of data stored. The "F6" function key is used to enter the sensitivities from the keyboard. The "F7" function key displays a menu of options for manipulating tare data and/or performing tare regressions.

The "F8" function key allows the user to rename the data files. The "F9" function key activates continuous model attitude display. The "F10" function key is used for data acquisition. For any mode of operation, use this key to store mode specific data to the hard disk and plot values on the XY plotter. The "F11" function key displays a menu of DSIS hardware mode configuration options. Commands are sent to all IEEE-488 instruments corresponding to the user selected mode. The "F12" function key is used to print the current data file on the printer.

The "A" key is used to select which signal conditioner is "active" as indicated by highlighted color of gain/offset values on the real-time displays. The "B" key is used to turn bridge power on or off in order to record mode specific zero values. The "C" key records an AC Calibration data point. The hardware must first be configured before this function can be properly used. The "D" key decrements the currently active signal conditioner's gain.

The "G" key displays a list of gain values and corresponding letter codes, and sets the gain of the currently active signal conditioner. The "I" key increments the currently active signal conditioner's gain. The "N" key is used to electrically connect or disconnect the signal conditioners from the bridges. This feature is not normally used in calibration or testing. The "S" key provides a list of shunt calibration resistor pair options to be used for sensitivity data.

The "U" key disconnects or unshunts the shunt resistor pairs from the appropriate bridge. The "V" key is used to send a computed offset, from averaged data passed from the DSP microcomputers to the PC, to thesignal conditioners. The "X" key commands the signal conditioners to add 0 VDC to the balance inputs, and is used once prior to using the "V" key. The "Z" is used instead of the "X," "V" key sequence for nulling the signal conditioners, to command the signal conditioner to determine its own offset. While using this key as a shortcut over the other method, the computed offset does not account for the DSP microprocessor's A/D converters or anti-alias filters, which may add additional offset not accounted for by the signal conditioners.

Theory of Operation

Signal Processing

Force or torque signals from strain gages mounted on the oscillation balance, shown in figure 29, are fed through the connectors at the back of the sting, shown in figure 30, and then passed on to the junction panel, shown in figure 31. Each of the displacement, torque, and secondary strain gage signals from the oscillation balance are initially nulled and amplified by signal conditioners. These new signals are then digitized by analog-to-digital converters on the two DSP microcomputers which reside in the PC. The sampled signals are digitally filtered and, depending upon the user's input, are either synchronously demodulated or passed through an FFT algorithm.

All numeric processing such as error correction, phase computation, and averaging, is performed by both DSP microcomputers and by software running concurrently on the PC. Both the synchronous demodulation and FFT methods require frequency information which originates from a shaft encoder that is mechanically coupled to the oscillation drive sting motor. Digital circuitry located within the PC converts timing information from the shaft encoder to oscillation frequency by periodically dividing counted shaft encoder pulses by a constant.

The pitch balance can be rotated 90° axially and mounted onto the sting to oscillate as a yaw balance. A separate balance is used for roll tests. Procedures are given for pitch and yaw tests. Coefficients associated with each type of test are listed in Appendix A.

Oscillation Drive

A remote motor-generator set provides variable low frequency power to drive the oscillation sting motor. A solid-state electronic solution does not currently exist for this application. The motor-generator set is shown in figure 32. A set of electrical junction boxes is shown residing on a rigid steel platform equipped with castors.

In addition, located on one side of the platform is a synchronous induction motor, a single phase generator, a magnetic clutch, and a three phase generator, all coupled together on the same platform. An end view of this machinery is shown in figure 33. On the far right side of figure 32 is a box labelled "Manual Voltage Adjust." The large black dial can be manually adjusted, and should always be set to 85%. Immediately to the left, a small red box houses one of two power switches. The second is a large handle located on the far left box. Both power switches should be set to the "ON" position for operation of the motor-generator set.

Forced-Oscillation Balance Mechanisms

Principles of operation of the forced-oscillation balance mechanisms are given in reference 2.

Oscillation Frequency

The shaft encoder, coupled to the oscillation motor and shown in figure 34, generates clock signals that are counted by digital hardware. These count values, along with once per revolution information, are processed by special circuitry to yield desired oscillation frequency. The phase of the torque and secondary strain gage signals is computed relative to the displacement signal. Two function generators are used to provide simulated shaft encoder clock signals for calibration and nulling purposes. A hand crank is available to rotate the sting shaft until the oscillation balance is at the desired attitude. The access hole for the hand crank is also shown in figure 34.

Oscillation frequency is controlled by a potentiometer on the motor speed control front panel. On the same front panel, separate switches are available to control oscillation motor power and sting elevation angle. Oscillation frequency is displayed on an LED labelled "RPM Indicator" on a panel below the motor speed control panel.

Model Attitude

Model attitude signals from an angle-of-attack sensor mounted on the sting are filtered by a Kearfott or a Q-Flex signal conditioner, shown in figure 35, and digitized by a 12-bit analog-to-digital (A/D) converter on a DAS-20 multi-purpose I/O board which resides within the PC. The interior of the PC chassis is illustrated in figure 36. Software routines control the I/O board and process the digitized model attitude data. The Up/Down toggle switch located on the motor speed control panel controls a sting attitude motor. This motor is supplied by a 40VDC power supply shown in figure 37.

PC Software

The PC software performs all data acquisition, control, and numeric processing. This software is executed from the DOS prompt and displays a main menu from which all subsequent operations are user selectable. During a typical test, the program downloads a particular set of drivers to the DSP microcomputers depending upon user operational choices. As incoming data is processed by the DSP

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microcomputers and is transferred to the PC, a real-time display is generated on the PC monitor. Displacement, torque, and secondary voltages are averaged and standard deviations are computed. Sensitivity, tare, or wind-on coefficients are computed and updated in real-time. All of these values are displayed and updated automatically. Model attitude, wind tunnel parameters, and signal conditioner gains and offsets are also displayed.

All of the function keys and certain alphabet keys are "pre-programmed" during this real-time mode of operation and perform particular functions. A list of these hot keys and their functions is given in Appendix C and in a help menu display. After data is recorded, the program creates two ASCII data files, one with formatted data and the other with data with informative text. The formatted file contains raw voltages that can be used for off-line analysis. In addition, the program uses four files to store DSIS system configuration, wind tunnel parameters, and additional constants that are unchanged from one test to another. An XY plotter and a laserjet printer provide hardcopy plots and printouts.

Balance Heaters

A separate panel mounted on the top right-hand side of the rack houses the heater controllers needed to maintain constant balance temperature. Two separate heater controllers are available. Each heater controller energizes an electrical heating element located on the forced-oscillation balance. One element is located at the front, or upwind relative to the sting, and the other is located at the rear of the balance. The controllers and heaters must be powered for at least 2 hours prior to any type of calibration or testing.

Installation

Background

This section describes electrical wiring connections for configuration of the DSIS in self-calibration or normal operational modes. Normal operation refers to model attitude calibration, balance calibration, sensitivity testing, tare testing, or wind-on testing. Refer to the cable listing in Appendix D and the junction panel connections listed in table 12 for details. In addition, refer to the cable layout and system block diagram shown in figure 1 on page 78 in NASA TM 109160, "Dynamic Stability Instrumentation System (DSIS) Volume I: Hardware Description."

Operational Procedure

While the sting is being installed into the test section, the DSIS rack is moved into the control room or data room. Cables are run between the test section and the DSIS rack. After the sting is installed, the balance is mounted and sign convention tests are conducted. If the balance is installed and connected properly, then model attitude calibration with a calibration block mounted onto the sting is performed. Next, a series of different calibrations are performed including a balance calibration using the same calibration block. A prepared wind tunnel model then replaces the calibration block to determine sensitivities of the balance. The final steps are tare and wind-on testing, outlined in the Operation section.

Power Connections

The DSIS rack requires 115VAC power line inputs from two separate circuit breaker lines. Located in the bottom right of the DSIS rack is an AC regulator, as shown in figure 10, from which power for certain components is supplied. All of the other components in the DSIS rack run off of unregulated power. See table 13 for a list of power distribution requirements. Located along each side in the back of each rack are two power distribution strips—one regulated and one unregulated. Solicit assistance from local facility coordinators to locate two power receptacles on separate circuit breaker lines within the control room or data room. Connect the two DSIS power cords to the separate circuit breaker lines.

Power Switches

A separate power switch for the regulator and ventilation fans is located inside the right-hand side rack behind the video monitor and is accessible from the right rear door of the rack. The switch looks like a residential light switch as shown in figure 38. All other power switches are located on the front panels of each component, although the motor speed control panel does not have a power switch.

Wind Tunnel Connections

Wiring connections between the DSIS instrumentation rack and all other components/systems external to the rack are made via a recessed junction panel on the left-hand side of the rack. Table 12 lists all of the junction panel connections for wind tunnel operation.

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Calibration

Self-Calibration Connections

For self-calibration, the displacement, torque, and secondary signals are replaced with simulated signals from a function generator. At the rear of the signal conditioners, locate connectors J10, J11, and J12. These "J" connectors are distinct from the "J" connectors in the junction panel. Replace cable C2 with cable C43, cable C3 with cable C44, and cable C4 with cable C45. For normal operation, reconnect cables C2, C3, and C4 toconnectors J10, J11, and J12, respectively. Leave cables C43, C44, and C45 disconnected. The rear of the signal conditioners is shown in figure 39.

Self-Calibration

The process of comparing the DSP inputs and algorithms versus the AC measurement of the 2001 DMM is called self-calibration. A software program called "SELFCAL.EXE" performs this gain normalization over the passband of the system and should be executed once prior to a wind tunnel test. Turn on the HP3245A function generator, shown in figure 35, the HP3325A function generator, and the 2001 DMM. The software will automatically control the function generators, the signal conditioners, and the 2001 DMM. On the PC, type "SELFCAL.EXE" and depress the "Enter" key. Status messages will appear on the monitor to indicate how much longer the process will require. After completion, the DOS prompt will reappear. Follow the directions given above to restore the system configuration back for normal operation.

System Calibration

System calibration consists of the following four types of calibrations: AC, model attitude, balance DC displacement, and balance DC moment/force.

AC Calibration Procedure. AC calibration of the DSIS uses two function generators, one as a reference oscillator, and one as a signal generator. This type of calibration is required because of drift error within the A/D converters on the DSP microcomputers. The procedures are to be performed daily prior to taking data.

1. Disconnect cables C18, C19, and C20 from the input connectors of the signal conditioners, and replace them with cables C43, C44, and C45, respectively. Set the rotary switch on the AC Cal front panel shown in figure 9 from "Normal" to "AC Cal." Turn on the HP3325A and

HP3245A function generators. Set the toggle switch on the RPM Indicator panel to the "Calibration Enable" position.

2. On the PC, start the software "DSP.EXE." When the main menu appears, select option 3, "Change program." Next, select option 6 "Calibration" fromthe prompt "Download which program to DSP boards?" Depress "Enter" to return to the main menu. Select option 1, "Run program," and depress "Enter." A display similar to the one shown in figure 19 will appear.

3. Depress the F11 key and select "Calibration Mode" using the numeral "2" key. The HP3245A and HP3325A function generators, and the 2001 DMM are now configured via the IEEE-488 bus.

4. Depress the "C" key to record calibration data. Record several data points and vary the frequency/amplitude on the HP3245A Channel B over the ranges specified in table 14. A regression will be computed when the last data point is recorded.

5. Depress the F11 key and select "Normal Mode" using the numeral "1" key. Store the results by terminating the program using the ESC key and then 0, "Exit Program."

6. Disconnect cables C43, C44, and C45 from the input to the signal conditioners, and replace them with cables C18, C19, and C20.

7. The regression results are then manually extracted from the data file (using any mathematical software package) and entered via the keyboard back into the program during the next execution of the DSP.EXE. The regression results are used for error correction.

Model Attitude Calibration Procedure. The following procedure for calibrating the inertial sensor that measures model attitude is listed below. Appendix B lists the equations for computing the model attitude.

1. Mount the calibration block onto the balance as shown in figure 29 and set up an independent means of measuring the model attitude, such as an inclinometer positioned on top of the calibration block.

2. Set the rotary switch labelled "Test Points" on the main interface front panel to position "4" to route the output of the model attitude signal to the BNC connector labelled "Scope" on the

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oscilloscope accesspanel. Connect the 2001 DMM to this BNC connector.

3. Manually adjust the hand crank to position the drive shaft in the sting so that the calibration block is set at 0 degrees (as measured by the inclinometer). If the pitch balance is being used, the locking pin should be inserted and used during the calibration.

4. Then adjust the model attitude offset potentiometer labelled "Zero" on the main interface front panel until the 2001 DMM measures 0 VDC. Lock the potentiometer in place. Drive the sting to the largest expected angle, but make sure the output signal does not exceed ± 0.50 VDC to avoid saturating the A/D converter.

5. On the PC, execute the program "AOACAL.EXE" to perform model attitude calibration. The DAS-20 board digitizes the output signal with 12-bit resolution. The software prompts the operator to enter the independent AoA measurement manually on the keyboard.

6. Use the toggle switch labelled "Up/Down" on the motor speed control panel to reposition the calibration block for each new measurement. A manual regression on the collected data yields the necessary calibration constants.

7. When executing the DSP.EXE program, these calibration constants can be entered manually via the keyboard after prompting by the main menu option 7, "Input AoA accelerometer constants and reference dimensions." Figure 13 is an example of the different prompts for main menu option 7.

DC Balance Calibration. Two types of DC balance calibration are described: displacement and moment/force. For the case of displacement calibration, the hand crank is employed to manually rotate the oscillation drive shaft such that the balance deflects the internal spring which causes an output of the displacement strain gage bridge. For moment/force calibration, the procedure requires loading the balance through the calibration fixture with known weights. In both cases, the resulting output is measured by the DSP microcomputers.

The desired calibration constants are K_D(radian/V), K_T(ft-lb/V), and K_M(lb/V or ft-lb/V), and are defined in Appendix A. These constants are used in subsequent data reduction procedures. Once these constants are determined, there is no need to repeat these procedures again. The software main menu option 6 allows the user to enter these con-

stants manually. Bridge shunting is part of this calibration procedure. The positive calibrate voltage ($V_{SHUNT\,CAL}$) is produced by a pair of shunt resistors connected via relays across opposite arms of the strain gage bridge circuit. A negative calibrate voltage is produced by connecting the resistor pair across the opposite bridge arms. Shunt resistor pairs are located on bridge completion cards, which plug into a slot in the front panel of each signal conditioner. The bridge completion cards also have switches to reconfigure the bridge circuits. Table 8 lists the possible selections for bridge shunt resistor pairs and resulting calibrate voltages.

An example of the DC calibration display is shown in figure 19. A real-time display with three columns should appear with the title "DC Calibration." Column one displays the running averages of the calibration data in real-time. The second column shows the standard deviations of the data in the first column. The third column displays the last data zeros recorded. Initially, this column displays all zeros. The top row contains the displacement reading from the first channel of the first DSP microcomputer. The next row down contains the moment or torque reading from the second channel on the same DSP microcomputer. The displacement is also measured by the second DSP microcomputer, and resulting values are displayed in the third row from the top. The fourth row contains the secondary or moment reading.

Data point, zero point, shunt point, and calcode numbers are displayed in the lower left corner of the display in figure 19. The point number displayed is always one more than the actual number of points taken. The "Calcode = 11" shown indicates that a shunt resistor pair is connected to the bridge. Refer to table 15 for calcode data types and descriptions.

Depress the "F5" key to prompt the user to change the calcode to a value of 10 for calibration zero or 12 for calibration data. The "S" key will display a submenu, shown in figure 40, and will prompt the user for a shunt resistor selection. There are four types of shuntingavailable, with provision to shunt across adjacent bridge arms. Thus, one pair of resistors can be shunted one of two ways to yield a positive or negative calibrate signal voltage. The user should select the resistor pair that results in the desired calibrate signal for the selected gain. This selection should yield a calibrate signal less than the DSP input limits. The selected resistors are now connected across the bridge. The DC Calibration real-time display will reappear; notice that calcode is automatically changed to "11," and "Shunt Option" will indicate the shunt resistor selection. The other

channels should be shunted in a similar fashion at this time.

Depress the "U" key while the real-time calibration display is visible to disconnect all of the selected shunt resistor pairs and change calcode to 10. Depress the "F5" key in order to change calcode to 12. Use the "F10" function key to record or store the current voltage readings "marked" by the calcode. The prompt "Is this the last data point?" will appear. Answer either "yes" or "no." A second prompt will ask the user to enter a new sting angle or calibration weight from the keyboard. The values entered will then appear as "Last Independent Data" when the display in figure 19 returns.

After several calibration steps have been performed, a linear regression will be performed on the stored data when the user responds to "Is this the last data point?" with "yes." Regression results are then stored and displayed on the monitor screen as indicated by "regression results here" in figure 19. Remember that the "F1" function key displays a help screen when any real-time display appears on the monitor.

DC Displacement Calibration Procedure. The procedure for displacement calibration follows. The description given is for aerodynamic model tests involving the use of a pitch balance. Two operators are required to perform this procedure—one in the test section and one at the DSIS instrumentation rack. Modifications to this procedure for calibrating a roll balance are subsequently discussed.

1. Install the calibration block on the balance.

2. Software selections assume user has already initialized the software. From the main menu, select "Change program" and then select "DC Calibration." The monitor should display information in the real-time calibration format shown in figure 19.

3. The PID heater controllers are located on the top right side of the DSIS rack and are shown in figure 25. The labels "Front" and "Rear" refer to balance heater locations. Push-button controls are used to adjust the temperature settings. Now depress the appropriate push-buttons to adjust the temperature set-points for the front and rear balance heaters. Now adjust the upper and lower temperature limits for each controller. Depress the two white power buttons for each balance heater controller and also set the red power switches on the balance power supplies to the "On" position. The thermal time constant of the balance/model system is approximately 30 minutes, and therefore it is recommended that

a warm-up time of up to 2 hours be allowed prior to calibration or test. During the warm-up period, the controllers may occasionally exceed temperature set-points and sound alarms or even shut themselves off temporarily. No corrective action by the user is necessary should these events occur.

4. Depress the "A" key, then the "1" key to select the displacement signal conditioner. Set the gain to 1 using the "G" key, then the "E" key. Verify that the locking pin is removed from the balance. Set the speed control potentiometer located on the motor speed control front panel for the motor-generator set to zero. Turn on the motor-generator set shown in figure 32. Check for proper direction of rotation which is marked on the set as shown in figure 33. Turn the motor speed control potentiometer until the calibration block oscillates between 3 to 6 Hz. Check each test or condition listed in table 16 and make any corrections. Now decrease oscillation frequency to zero and turn off the motor-generator set.

5. Install the calibration block on the balance, as shown in figure 29, with the locking pin in place. Mount the inclinometer on top of the calibration block and drive the sting attitude mechanism until the inclinometer measures 0 degrees. Remove the locking pin and manually adjust balance displacement deflection to full scale using the hand crank. Use the hand-held digital multimeter (DMM), shown inside the drawer in figure 7, to measure balance displacement output voltage at the front panel BNC labelled "Displacement." Rotate the hand crank until the DMM achieves a maximum positive voltage. Select signal conditioner gain so that the voltage is less than 0.8 V. This is the maximum gain setting for this signal conditioner for subsequent DC calibration steps. Write down the maximum voltage level corresponding to this maximum gain setting. This voltage information will be used in the next step. Now adjust the hand crank until the displacement signal is at 0 (zero) V.

6. Iteratively select a gain and shunt resistor option pair to generate a calibrate voltage within +/− 0.10 V to the full scale voltage recorded in step 5. Do not exceed the full scale voltage of +/− 0.8 V. Set the rotary switch next to the 2001 DMM to measure the output DC voltage of the displacement amplifer. Monitor the displacement signal on the 2001 DMM while performing this process. Use the "S" key to select a shunt resistor pair, the "I" key to increment the selected signal conditioner's gain, and the "D" key to decrement the gain. This

process may involve some iteration between shunt resistor and gain selections. Keep the gain fixed for the rest of this calibration. Disconnect the shunt resistor pair using the "U" key. Write down the final choice of shunt resistor pair for subsequent full scale and sensitivity checks.

7. Adjust the hand crank until the balance displacement signal on the hand-held DMM measures 0 V. Depress the "F5" key to set the calcode to 10. When the standard deviation of the displacement signal has decreased to a steady minimum value at least two or three orders of magnitude less than the displacement voltage signal, record the calibration zero on the disk file using the "F10" key. A submenu shown in figure 41 will prompt the user for the type of calibration to be performed. Depress the numeral "1" key to choose displacement calibration. This prompt will only appear when the first data point is recorded.

8. Select shunt option using the "S" key, then select the shunt resistor pair determined in step 6. A shunt calibrate signal now appears at the DSP microcomputer inputs. After the standard deviation has settled, record a shunt calibrate reading using the "F10" key. Remember that "F10" records and stores mode specific data. Now disconnect the shunt resistor pair from the displacement bridge using the "U" key. Depress the "F5" key, then the "1" key to change the calcode to 12.

9. Use the hand crank to increase the balance deflection to a value approximately 20 percent of full scale. Wait approximately 20 seconds for the standard deviation to "settle." Depress the "F10" key to record data, and enter the model attitude measurement manually from the keyboard. Repeat this step for model deflection values of 40 percent, 60 percent, 80 percent, and 100 percent of full scale. Then record data as the model deflection is decreased by 20 percent each time back to 0 degrees. Repeat step 7 to take another calibration zero.

10. Repeat step 8 to record a shunt calibrate signal measurement. Depress the "F5" key to set the calcode to 12. Repeat step 9, only decrement model deflection by 20 percent each time until 100 percent negative full scale is achieved. Then record data as the model deflection is increased by 20 percent each time back to 0 degrees.

11. Repeat step 7 again to record a final calibration zero. Key in "Yes" to the prompt "Is this the last data point?" in order to compute a linear regression of the static deflection data. Results will be displayed on the monitor and stored in a disk file.

12. The slope "m" from the regression is used to compute K_D manually using the formula listed in Appendix A. The DC displacement calibration procedure is now complete. Depress the "ESC" key to return to the main menu. Maintain power on the balance heaters in order to be at thermal equilibrium for the moment/force calibrations.

Modifications to Procedure for Roll Balance. The procedure remains the same as for pitch/yaw tests. No mechanism (locking pin) exists to lock the roll balance at 0° displacement in roll. Note that hand crank adjustment changes roll angle (displacement). An inclinometer mounted on the calibration block measures roll angle in the side plane. The heater thermal time constants may be different for the roll balance since it has a different mass than the pitch/yaw balance. Finally, the sensitivity K_{ROLL} replaces K_D in the equations listed in Appendix A.

Moment/Force DC Calibrations. Repeat the DC displacement calibration steps 2 through 12 to calibrate both the primary and secondary moment/force channels. However, instead of using balance attitude as the independent variable, deadweights applied to the calibration block are used as the independent variable.

Moment/Force DC Calibration Procedure. The following procedure is applied to both moment/force channels. It is assumed that these calibrations are performed after the displacement calibration has been completed. Pitching moments are used to calibrate moment or torque, while rolling or yawing moments or normal force are used to calibrate secondary or normal force. Displacement channel gain is fixed at the value determined from the displacement calibration procedure for both moment and force calibrations.

1. Attach calibration pitch (roll) moment arms to the calibration block. Place knife edges in the end grooves of the pitch (roll) arms, apply weight hangers and pans, and add one-half of full scale normal weight to each pan. Pitch (roll) calibration is done with constant normal force.

2. Software selections assume user has already initialized the software. From the main menu, select "Change Program" and then select "DC Calibration." The monitor should display information in the real-time calibration format shown in figure 19.

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3. Use the hand crank to level the calibration block until the displacement signal on the DC Calibration real-time display indicates zero. Set the 2001 DMM rotary switch to "Torque" for moment calibration or "Secondary" for force calibration. Connect one end of cable C35 to the oscilloscope access panel BNC connector labelled "Displacement," and the other to the hand-held DMM. While deadweights are transferred between the two weight pans in the following steps, rotate the hand crank as necessary to maintain zero displacement output. Make this adjustment prior to taking each calibration datum on the PC.

4. Remove the locking pin from the balance. Use the Up/Down toggle switch located on the motor speed control front panel to position the calibration block to 0 degrees in pitch. Manually transfer all of the weights to the weight pan to produce a positive pitch (roll) signal. Select a maximum signal conditioner gain setting to achieve a full scale torque (secondary) output. Do not exceed 0.8 V on any signal conditioner output. A negative full scale value is achieved by transferring all of the weights to the other weight pan. Maintain this full scale gain setting throughout the rest of the calibration.

5. Place one-half of the total weight on each of the weight pans. Now select a shunt resistor pair using the same iterative method as in DC displacement calibration step 6. Write down this shunt resistor pair selection for later use. Depress the "F5" key to select a calcode of 10.

6. When the standard deviation of the torque (secondary) signal has settled to a value at least two or three orders of magnitude below the torque (secondary) signal, use the "F10" key to record and store to disk a calibration zero. A menu will prompt the user for the type of calibration to be performed. Depress the numeral "2" key to choose torque calibration or "3" key to choose secondary calibration. This prompt will only appear when the first data point is recorded.

7. Select shunt option using the "S" key, then select the shunt resistor pair determined in step 5. A shunt calibrate signal now appears at the DSP microcomputer inputs. When the standard deviation has settled, depress "F10" to record and store shunt calibrate data. Use the "U" key to disconnect the torque (or secondary) bridge shunt resistor pair. Depress the "F5" key, then the "1" key to change the calcode to 12.

8. Transfer sufficient weight to increase the weight distribution to a value approximately 20 percent of full scale. Wait approximately 20 seconds for the standard deviation to "settle." Depress the "F10" key to record data, and enter the moment or force weight data manually from the keyboard. Repeat this step for weight distributions of 40 percent, 60 percent, 80 percent, and 100 percent of full scale. Then record data as the weight is decreased by 20 percent each time back to equal distribution. Repeat step 7 to take another calibration zero.

9. Repeat step 7 to record a shunt calibrate signal measurement. Depress the "F5" key to set the calcode to 12. Repeat step 8, only decrement weight distribution by 20 percent each time until 100 percent negative full scale is achieved. Then record data as the weight distribution is increased by 20 percent each time back to 0 degrees.

10. Repeat step 6 again to record a final calibration zero. Key in "Yes" to the prompt "Is this the last data point?" in order to compute a linear regression of the static weight data. Results will be displayed on the monitor and stored in a disk file.

11. The slope "m" from the regression is used to compute K_T (K_M) manually using the formula listed in Appendix A. The DC moment (force) calibration procedure is now complete. Depress the "ESC" key to return to the main menu.

Operation

Sensitivity Tests

The following test procedure is used to determine sensitivities S_Θ, S_T, and S_M, required for all tare tests and wind-on tests. These sensitivity values, computed using the equations in Appendix A, are determined for the calibration block and for the model. Once determined, these sensitivity values will be automatically stored on a disk file when the software terminates and retrieved when the software is restarted. Main menu option 6 "Set Calibration Constants" allows the user to change the sensitivity values. The software automatically recomputes the attenuations A_Θ, A_T, and A_M if the user changes signal conditioner gain. Sensitivity zeros are marked using a datacode of 1, while sensitivity data are marked by a datacode of 9.

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Sensitivities Test Procedure. The procedure for determining the sensitivities is now given.

1. Rotate the sting drive shaft manually and visually check for proper clearances between the balance and sting to avoid fouling. Turn on the balance heaters as outlined in DC displacement calibration step 3. Allow sufficient warm-up time for the balance/model to reach the desired set-point temperature.

2. Use the hand crank to set pitch (roll) displacement at 0 degrees relative to the balance. Use the Up/Down toggle switch located on the motor speed control front panel to set model attitude at 0 degrees. Start "DSP.EXE" software and select option 3 from the main menu. From the submenu displayed, select "Synchronous Demodulation" with either lowpass filter (0.25 Hz or 0.1 Hz). After the main menu reappears, depress the numeral "1" key. The monitor should have a display similar to the one shown in figure 20. Perform the DC nulling procedure on all three signal conditioners.

3. Depress the "A" key to select an "active" signal conditioner. Depress the "G" key to select the same gain determined during the calibration procedure. Repeat this step for the other two signal conditioners. Depress the "F2" key to alternate between "averaged" or "immediate" data display mode. Wait for the standard deviation of the averaged values to become less than at least two orders of magnitude below the averaged values. Depress the "F10" key to record and store the sensitivity zero on the disk file.

4. Depress the "A" key to select an "active" signal conditioner. Depress the "S" key to select the same shunt resistor pair determined during the calibration procedure. Repeat this step for the other two signal conditioners. After the standard deviations of the averaged values have settled, depress the "F10" key to record and store these sensitivity values to the disk file.

5. Depress the "U" key to disconnect the bridge shunt resistor pairs. The sensitivity constants will disappear from the display. If the program is terminated, the sensitivity constants are retained in the user-named data storage file. Sensitivity constants are also retained in system memory, if a tare test is performed next without exiting from this program.

Tare Tests

A tare is a wind-off frequency sweep about the wind-off resonance frequency. This frequency is also known as velocity resonance. Data points are taken at the resonance frequency and at lower and higher frequencies. A tare is performed to determine the mechanical properties of the system. The mechanical properties are needed for the wind-on data reduction. In particular, we have to determine the balance spring constant, the model inertia, and the mechanical damping for arthe primary moment channel. The last two of these items will change as a result of changes to the model configuration. The balance spring constant should not change. The repeatability of the spring constant is one measure of how well the system is working. Similar terms have to be determined for the secondary channel.

The model is mounted on the balance and the model remains unchanged for subsequent wind-on tests. If the model configuration changes, then a new tare is taken prior to any wind-on testing. Tare values T1, T2, M1, and M2 are displayed and updated in real-time on the monitor and are defined in appendix A.

Figure 42 is a tare data submenu display. The first option allows the user to correct one or more data points, while the second option eliminates a selected data point. If necessary, these options should be selected prior to computing a regression, or option 3. Option 4 allows the user to select between the two different data sets that exist for each tare test. Option 5 returns the user back to the real-time display.

Tare Test Procedure. The procedure for tare testing with model oscillation in the pitch plane is now given. There are no basic differences between the tare test procedures in using the pitch balance versus the roll balance. This procedure assumes that sensitivities have been determined. Yaw and Roll oscillation tests follow the same procedure below.

1. If testing is conducted using the Unitary Plan Wind Tunnel (UPWT) sting, then insert the high pressure air nozzle into the hole located in the bottom of the oscillation motor housing as shown in figure 43. This air flow replaces the flow during wind-on conditions that cools the oscillation motor. Thepressure setting on the air supply regulator should be set to about 50 percent of full scale. Remove the locking

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pin from the pitch balance. Use the hand crank to set the calibration block or model to 0 degrees attitude. Make sure the balance temperature is constant at the set point value.

2. Connect the oscilloscope to the oscilloscope access panel BNC's and select the "Torque" setting on the 2001 DMM switch panel. Software selections assume user has already initialized the software. Main menu option 10 will command the XY Plotter to draw two axes for subsequent plots of tare data. From the main menu, select "Change program" and then select "Synchronous Demodulation." The monitor should display information in the real-time display format shown in figure 20.

3. Set the Calibrate Enable switch to the "Up" position. This forces the shaft encoder simulator board to send simulated encoder pulses to the tachometer board. On the HP3325A function generator, select square wave output at 24576 Hz. The frequency value displayed on the monitor (upper right-hand corner) and on the RPM Indicator LED display should be 3.0000 Hz. Set the frequency output on the HP3325A to 0 Hz. Both displays should change to 0 Hz.

4. Set the gain on each of the three signal conditioners to 1 by using the "A" key to select signal conditioner and the "G" key to set the gain. Set the motor speed control potentiometer located on the motor speed control panel to 0. Select the "On" position for the motor-generator set switch, which is also located on the motor speed control panel. Rotate the motor speed control potentiometer until the model is oscillating in the range from 3 to 6 Hz. Set the gain of each signal conditioner to the value used during the sensitivity tests. Increase the gain using the "I" key if possible without exceeding the 0.8 VDC limit. Null each signal conditioner using the procedure previously described. Once nulling is complete for all three signal conditioners, set the Calibrate Enable switch to the "Down" position. Use the oscilloscope or 2001 DMM to measure the DSP microcomputer input voltages. Do not let them exceed the ±0.8 Volts full scale limit.

5. Determine the resonant frequency by slowly adjusting the motor speed control potentiometer in small increments until the real component of torque goes to zero. Pause between each incremental adjustment to allow the standard deviations to settle. When the resonant frequency is achieved, turn off bridge power by using the "B" key. Record a datacode = 2 tare zero data point by depressing the "F10" key.

6. Turn on bridge power using the "B" key and maintain the resonant frequency by making careful corrections with the motor speed control potentiometer. At the resonant frequency, wait for the standard deviations to settle. Record a datacode = 3 tare data point by depressing the "F10" key. Two additional data points at the resonant frequency are usually recorded during a tare run--one in the middle of the frequency sweep and another one at the end of the sweep. The tare values will be displayed and updated on the monitor while datacode = 3.

7. Decrease the gain of the torque and secondary signal conditioners one setting by depressing the "D" key. Increase the oscillation frequency by about 1 Hz above the resonant frequency by adjusting the motor speed control potentiometer. Using the "A" key to select signal conditioner and the "I" key to increment gain, increase torque and secondary signal conditioner gains while monitoring the oscilloscope and/or 2001 DMM to achieve a maximum signal level within the ±0.8 Volt limits. Wait for the standard deviations to settle and record another tare data point by depressing the "F10" key. The XY Plotter will plot the computed tare values on each of the two tare plots.

8. Record at least six additional tare data points, 3 above and 3 below resonance by repeating step 7. Do not record tare data below 1.0 Hz, and depending on the model, avoid excessively high frequencies. At frequencies below 1 Hz, the oscillation becomes non-sinusoidal. High frequencies of oscillation can excite the sting bending frequency. The g-meter output can be monitored on the oscilloscope to check for this "bad" data condition. Sting bending violates the assumption of oscillation in only a single degree of freedom.

9. Turn off bridge power using the "B" key, and leave the model oscillating at resonance. Record a final datacode = 2 tare zero data point using the "F10" key. Rotate the speed control potentiometer to zero. Once the model is motionless, turn off the motor-generator set.

10. Select the tare regression submenu by depressing the "F7" key. A submenu is provided as shown in figure 42. Select option 3, "Compute Linear Regression." The XY Plotter plots a computed regression line. Select option 4, "Load [upper/lower] tare data set." Then select option 3 again to compute and draw the other regression line. Tare values are stored in disk files prior to program termination.

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Data Reduction. For any testing that involves pitch oscillation, use the equations listed in Appendix A. These equations are used to reduce the tare data. A linear regression of the real component of torque divided by displacement, T_R/Θ or T1, versus the square of the angular frequency, ω^2 yields the first two tare values. The value at $\omega^2 = 0$ is the spring constant, K_{SPRING}, of the balance and the slope is the moment of inertia (variable name is Inertia) of the model. The average of the plotted values at the resonant frequency is C_{TARE} or T2.

The secondary component is plotted in a similar manner to determine the slope and intercept. A linear regression on the real component of moment or secondary divided by displacement, M_R/Θ or M1, versus the square of the angular frequency, ω^2, is computed and plotted. The value at $\omega^2 = 0$ is the normal force produced by the mechanical spring in the balance, or Amr. The negative slope is the mass moment of the model, Bmr. The average of the plotted values at the resonant frequency is MC_{TARE} or M2.

Wind-on Tests

Wind-on data is normally recorded only at the resonant frequency over a range of model attitude values to obtain the most accurate measurement of aerodynamic damping. Wind-on data can be recorded at other frequencies if desired. This type of testing would determine the effect of frequency on the aerodynamic damping. This is usually a small effect unless there is separated flow with associated time lags on the model. For any type of testing, do not record wind-on data below a frequency of 3 Hz as the model motion can depart from an ideal sinusoidal form because of the low torque output of the drive motor and the aerodynamic loads on the model.

The equations listed in Appendix A are used by the on-line computation performed by the DSP microcomputers and the PC. There are three sets of four coefficients that can be displayed on the monitor, one set at a time as selected by the user during software initialization. The displayed values are also saved to disk files during data acquisition. The wind-on plot code, a parameter requested from the user during software initialization, determines which set of coefficients are computed and displayed. For pitch testing, yaw testing, or roll testing, see tables 3, 4, or 5, respectively, for wind-on plot codes, and descriptions of the three sets of coefficients.

Wind-on Procedure. The procedure for wind-on testing with model oscillation in the pitch plane is now given. This procedure assumes that sensitivities have already been determined. When powered down,

the oscillation drive does not stop such that the model is oriented in a known position. Sensitivities must be recorded at 0 degrees model attitude, and adjusting the model attitude requires use of the hand crank by an operator in the wind tunnel.

1. After wind-on flow is established in the tunnel, start and initialize the software. Set the motor speed control potentiometer to zero. Turn on the motor-generator set. Rotate the motor speed control potentiometer until the model oscillates at 3 to 6 Hz. The monitor should be similar to the display shown in figure 20. If the datacode = 6, then depress the "B" key to turn on the power to the bridges.

2. Verify that model temperature is constant at the desired temperature settings on the heater controllers. The wind-on resonant frequency usually differs from the wind-off (tare) resonant frequency because of the effect of the aerodynamic spring. Adjust the speed control potentiometer to achieve the resonant frequency. Carefully null each of the signal conditioners.

3. Turn off bridge power to the balance channels using the "B" key, but leave the model oscillating at the resonant frequency. Set the gain of the threesignal conditioners to the tare testing values. When the standard deviations have settled, record a datacode = 6 wind-on zero data point using the F10 key. For checkout purposes, a wind-on shorting plug can be used on the wind-on switch cable (C61) connector (J12) located in the junction panel on the left side of the DSIS rack.

4. Turn on bridge power using the "B" key. Note that datacode = 7 and the selected wind-on coefficients are displayed and updated on the monitor. Maintain the resonant frequency by slowly adjusting the motor speed control potentiometer.

5. Wait for the standard deviations to settle, then null each of the signal conditioners. Depress the "I" key to increment gain and the "A" key to select signal conditioner channels. Increase torque and secondary gains to maximize each signal. Displacement gain should remain at the tare testing value. Monitor each output using the oscilloscope and/or the 2001 DMM to prevent overloading the DSP inputs. When the standard deviations have settled, record a datacode = 7 wind-on data point. Record additional data points above and below resonance by adjusting the speed control potentiometer and using the F10 key. Normally at least two data

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points are recorded at each model attitude. The software will use the equations listed in appendix A, display the computed coefficients, and plot them on the XY Plotter.

6. Change the model attitude by using the Up/-Down toggle switch. Rotate the speed control potentiometer to achieve resonance at the new model attitude. The gain of all three channels may need to be adjusted in order to prevent overloading the DSP inputs. Now repeat step 5 for each new model attitude.

7. Turn off the bridge power using the "B" key, but leave the model oscillating at resonance. Record a final datacode = 6 wind-on zero data point using the F10 key.

8. Notify wind tunnel operators to shut down the wind tunnel. Rotate the motor speed control potentiometer to zero. Turn off the motor-generator set. Depress off-line and form-feed buttons on the laser printer for a hard copy of the data. Depress the ESCkey to return to the main menu, then the numeral 0 key to exit the software.

Table 1. Miscellaneous Items in Computer Drawer

Key for PC Panel Lock, Hand-held Multimeter
Wind-on Shorting Plug for Junction Panel Connector J12
BNC T and Barrel Connectors, XY Plotter Pens

Table 2. User Input for Main Menu Option 10

Value	Description
K_{SPRING}	y-intercept of linear regression on T_R/Θ
Inertia	negative slope of linear regression on T_R/Θ
C_{TARE}	average value at resonance of $T_I /(\omega \Theta)$
Amr	y-intercept of linear regression on M_R/Θ
Bmr	negative slope of linear regression on M_R/Θ
$M_I /\omega\Theta_{TARE}$	average value at resonance of $M_I /(\omega \Theta)$
wind-on plot code	a value from 1 to 6
wind-on symbol code	a value from 1 to 4
x-scale*	XY Plotter: x-axis units per inch, both plots
y1-scale*	XY Plotter: y-axis units per inch, top plots
y2-scale*	XY Plotter: y-axis units per inch, bottom plots
xmin	XY Plotter: x-axis starting value, both plots
xmax	XY Plotter: x-axis stopping value, both plots

*Only these values are requested when tare plotting is chosen.

Table 3. Pitch Testing Coefficients

Wind-on Plot Code	Coefficient	Parameter Description
1 or 2	$C_{m_q} + C_{m_{\dot\alpha}}$	damping in pitch
	$C_{m_\alpha} - k^2 C_{m_{\dot q}}$	oscillatory longitudinal stability
	$C_{N_q} + C_{N_{\dot\alpha}}$	normal force due to pitch rate
	$C_{N_\alpha} - k^2 C_{N_{\dot q}}$	normal force due to pitch displacement

Table 4. Yawing Test Coefficients

Wind-on Plot Code	Coefficient	Parameter Description
3 or 4	$C_{nr} - C_{n\dot\beta}\cos\alpha$	damping in yaw
	$C_{n\beta}\cos\alpha + k^2 C_{n\dot r}$	oscillatory directional stability
	$C_{lr} - C_{l\dot\beta}\cos\alpha$	rolling moment due to yaw rate
	$C_{l\beta}\cos\alpha + k^2 C_{l\dot r}$	effective dihedral

Table 5. Rolling Test Coefficients

Wind-on Plot Code	Coefficient	Parameter Description
5 or more	$C_{lp} + C_{l\dot\beta}\sin\alpha$	damping in roll
	$C_{l\beta}\sin\alpha - k^2 C_{l\dot p}$	rolling moment due to roll displacement
	$C_{np} + C_{n\dot\beta}\sin\alpha$	yawing moment due to roll rate
	$C_{n\beta}\sin\alpha - k^2 C_{n\dot p}$	yawing moment due to roll displacement

Table 6. Algorithm Selections and DSP Microcomputer Programs

Display	Algorithm	DSP Microcomputer Program
FFT	Fast Fourier Transform	Enhanced FFT
		Stand Alone FFT @250
		Stand Alone FFT @125
Synchronous Demodulation	Synchronous Demodulation	Synchronous Demodulation 0.25Hz filter
		Synchronous Demodulation 0.1Hz filter
Calibration	Synchronous Demodulation	Calibrate

Table 7. Main Menu Option 13 Counters

Counter	Data Type
ptnum	stored data counter (wind-on, tare, shunt, or zero)
windoncount	wind-on data
tarecount	tare data
calpoint_d	DC calibration data
calpoint_s	DC calibration shunt data
calpoint_z	DC calibration zero data

Table 8. Shunt Resistor Selections*

Shunt Type	Resistor Pair (Ω)	Calibration Voltage (mVDC)	Software Selection
+1	50K	+17.378	1
-1	50K	-17.378	2
+2	100K	+8.7195	3
-2	100K	-8.7195	4
+3	150K	+5.8197	5
-3	150K	-5.8197	6
+4	200K	+4.3673	7
-4	200K	-4.3673	8

*Computed Calibration Voltages assume 5.00 VDC Bridge Power

Table 9. Signal Conditioner Gain Selections

Gain Value	Software Selection
1	E
2	F
5	G
10	H
20	I
50	J
100	K
200	L
500	M
1000	N
2000	O
5000	P
10000	Q

Table 10. Datacode Values

Data Type	Datacode
Sensitivity zero	1
Sensitivity data	9
Tare zero	2
Tare data	3
Wind-on zero	6
Wind-on data	7
Undefined	4, 5, or 8

Table 11. Datacode Switches

Switch	Weight
Bridge power	1
Oscillation	2
Wind-on	4
Shunt resistor	8

Table 12. Junction Panel Connections

System/Component	Connector
Secondary	J1
Torque	J2
Displacement	J3
Temperature Sensors	J4
Heaters	J5
Motor-Generator	J6
Model Attitude Sensor	J7
Shaft Encoder	J8
G-meter	J9
Sting Attitude	J10
Sting Attitude Limits	J11
Wind-on Switch	J12

Table 13. Rack Power Distribution Requirements

Unregulated	Regulated
Heater Controllers	RPM Indicator Chassis
Oscilloscope	Kearfott or Q-Flex Signal Conditioner
40 V Power Supply	Main Interface Chassis
Rack Fans	Motor Speed Control Chassis
XY Plotter	Signal Conditioners
AC Regulator	PC and Monitor

Table 14. Calibration Full Scale Ranges

Frequency Range	Amplitude Range
2 Hz to 20 Hz	-0.8 V to +0.8 V

Table 15. Calcode Descriptions

Calcode	Description	Software Action
10	Calibration Zero	Must be recorded first, gets subtracted from data
11	Calibration Shunt	Used for full scale checks in later procedures
12	Calibration Data	Regression performed on this data yields K values

Table 16. Sign Conventions

| Test or Condition	Test Result	Corrective Action
Motor-Generator direction of rotation	Marked on Motor-Generator	Reverse polarity of power leads for motor
Increasing frequency of oscillation	Real part of Torque (T_R) decreases	Change sign of T_R
Apply hand damping to calibration block (front or rear)	Imaginary part of Torque (T_I) increases	Change sign of T_I
Pitch Testing: hand damping is ap plied ahead of the pitch center	Imaginary part of secondary (M_I) normal force increases	Change sign of M_I
Yaw Testing: hand damping is applied ahead of the pitch center and above the roll axis	Imaginary part of secondary (M_I) rolling moment increases	Change sign of M_I
Roll Testing: hand damping is applied ahead of the pitch center and above the yaw axis	Imaginary part of secondary (M_I) yawing moment increases	Change sign of M_I

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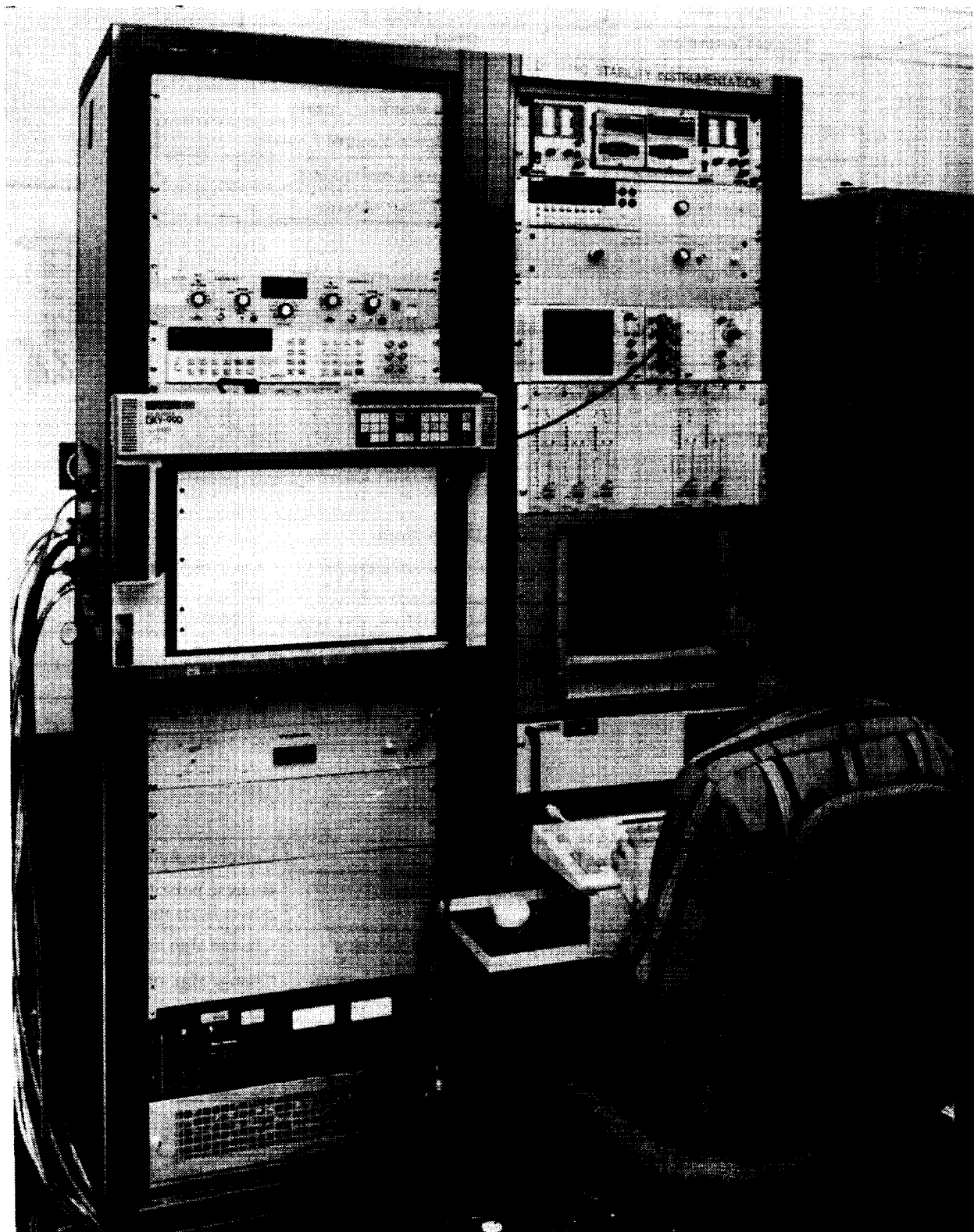
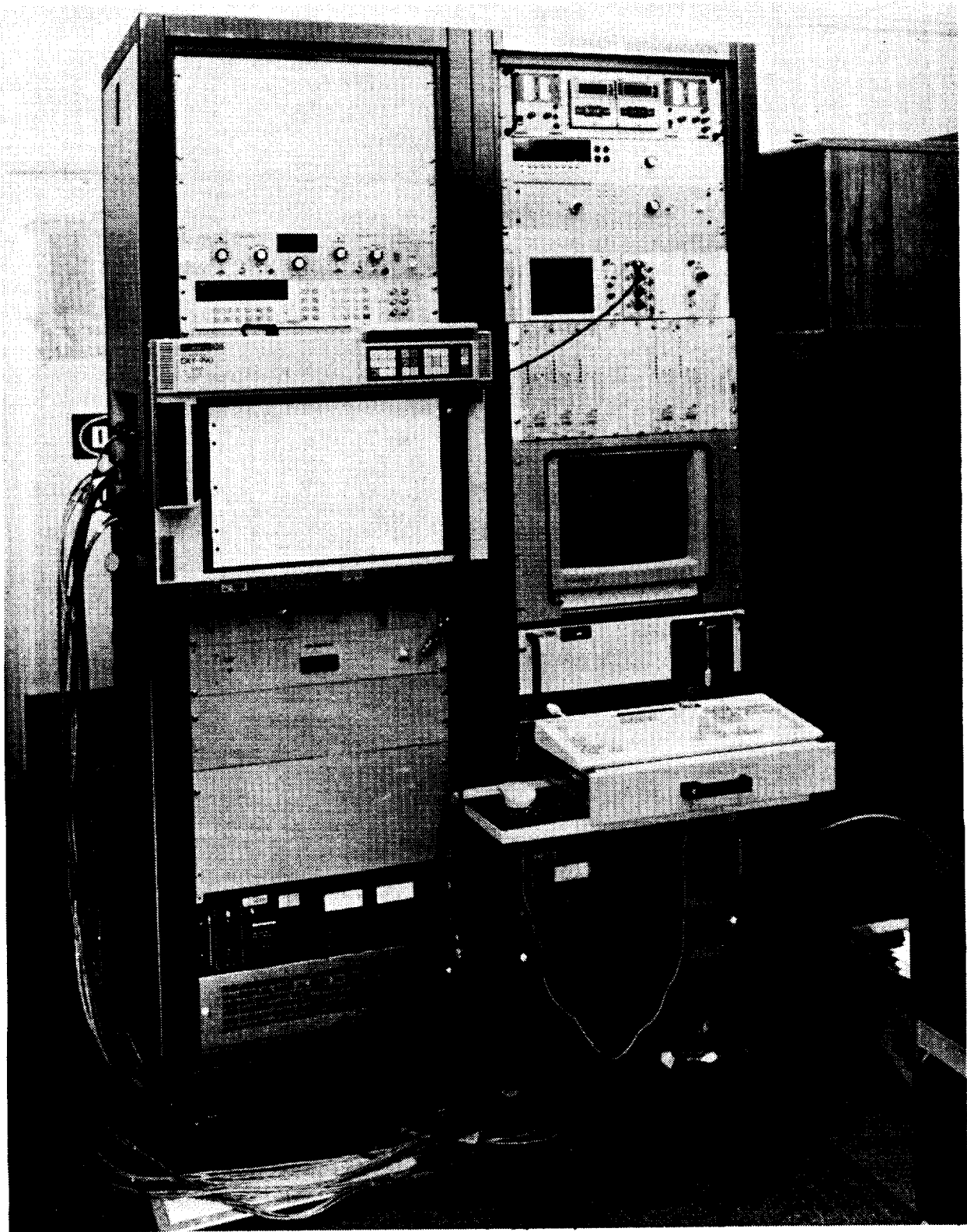Figure 1. Photograph of DSIS with User Seated Before PC

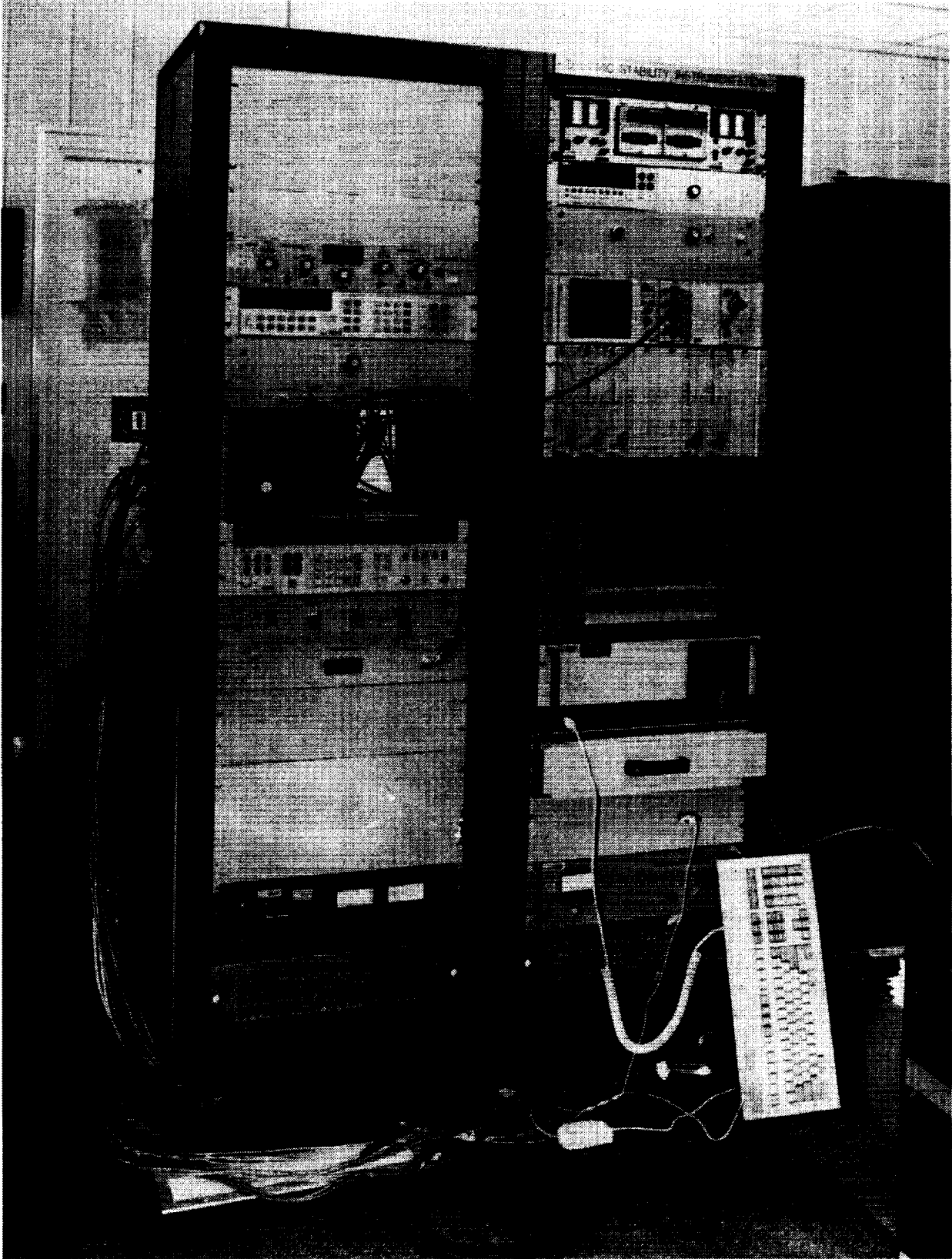Figure 2. Photograph of DSIS Front Panel with XY Plotter Mounted

Figure 3. Photograph of DSIS Front Panel with FFT Analyzer Removed
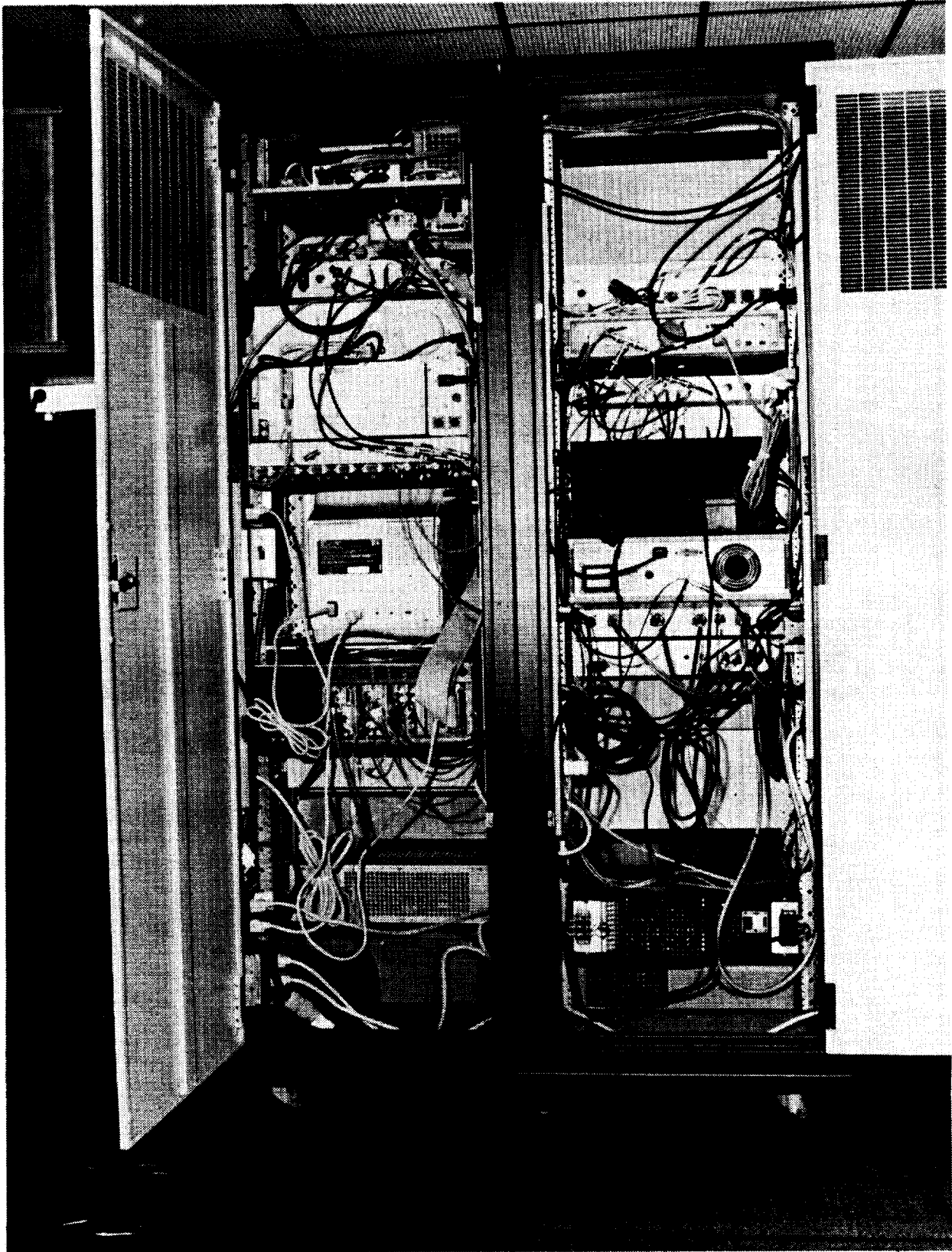
24

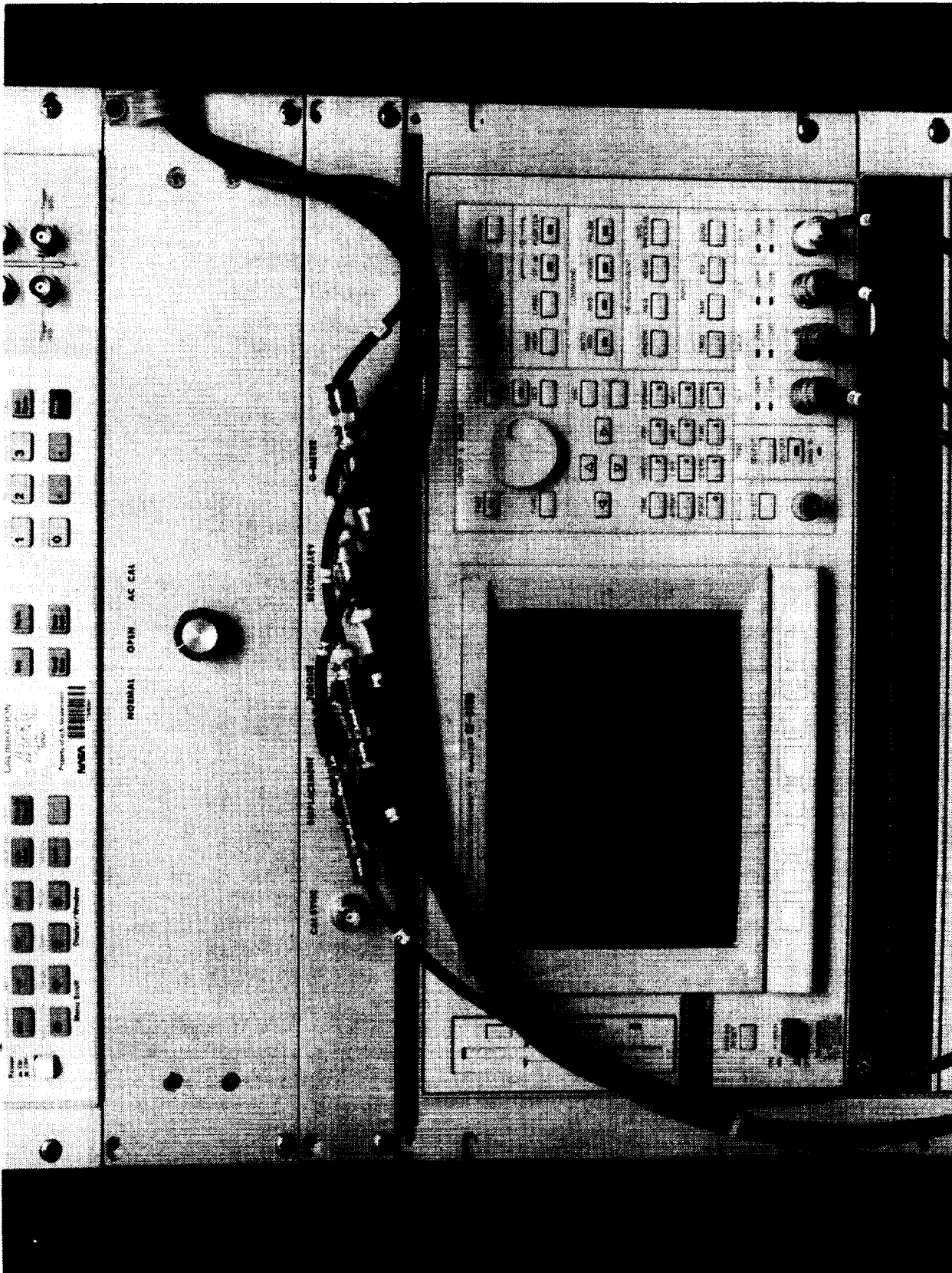Figure 4. Photograph of DSIS Rear with Doors Open

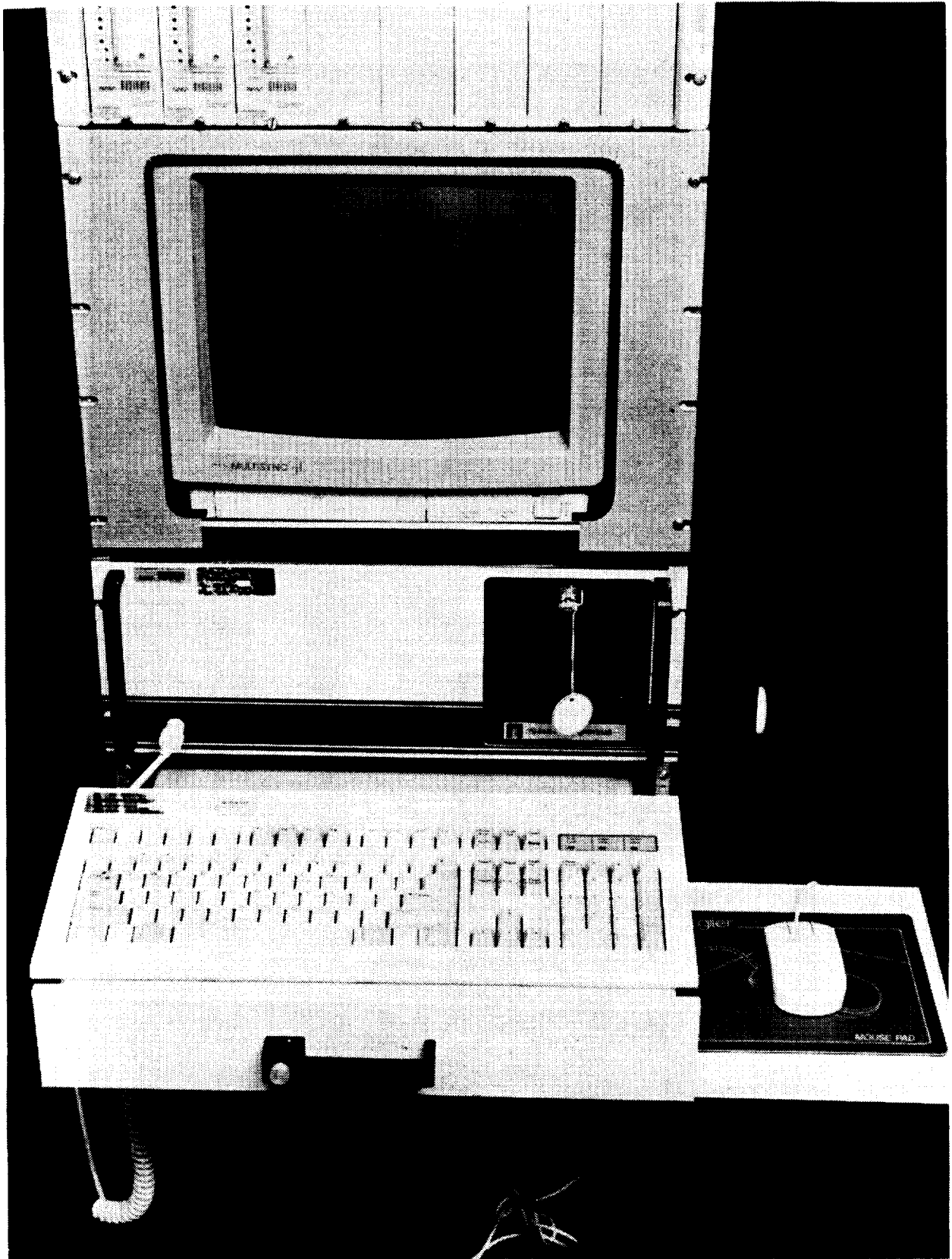Figure 5.   Photograph of FFT Analyzer Front Panel.

Figure 6. Photograph of Personal Computer with Keyboard on Accessories Drawer
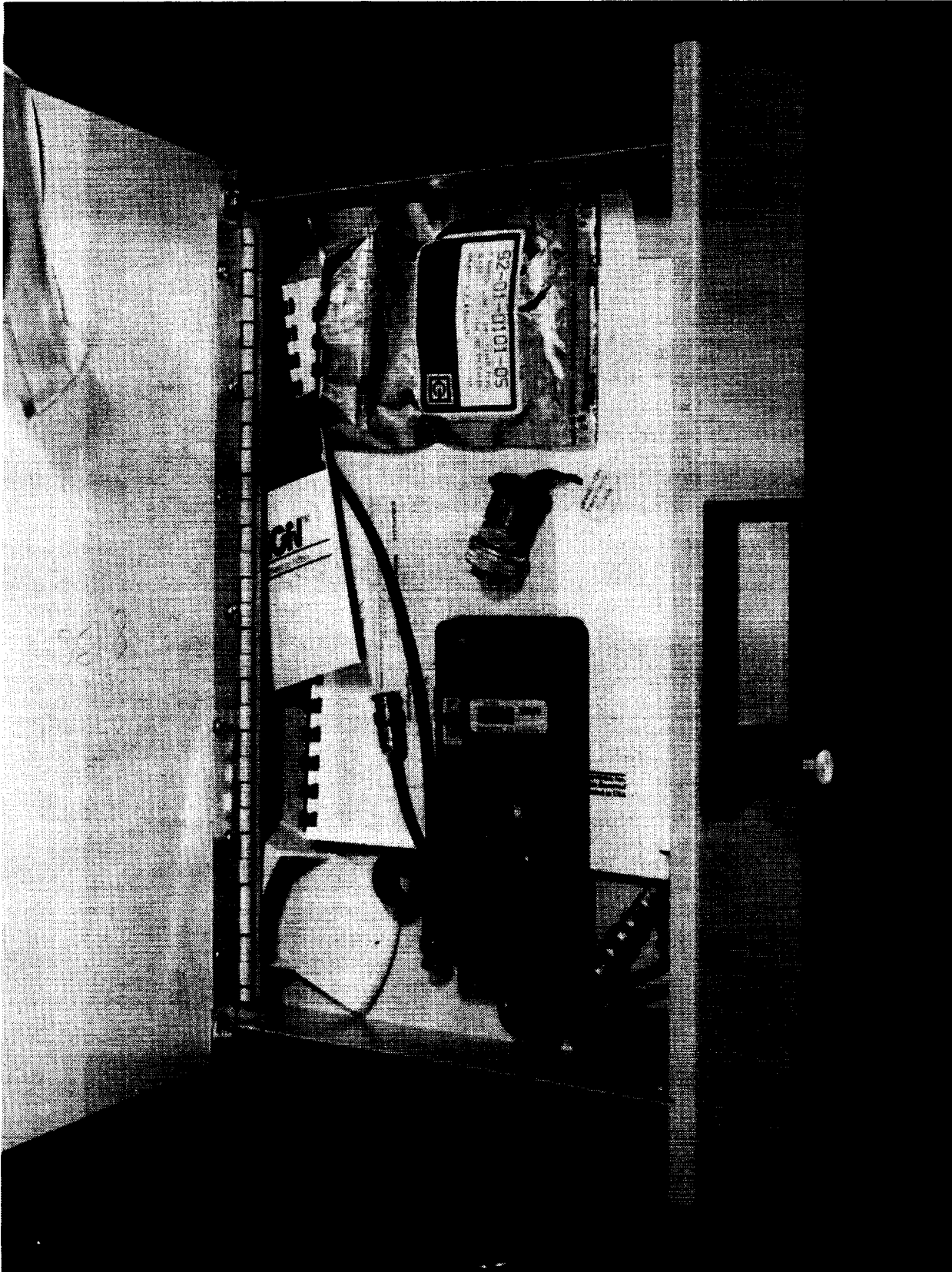
Figure 7. Photograph of Accessories Drawer Opened.
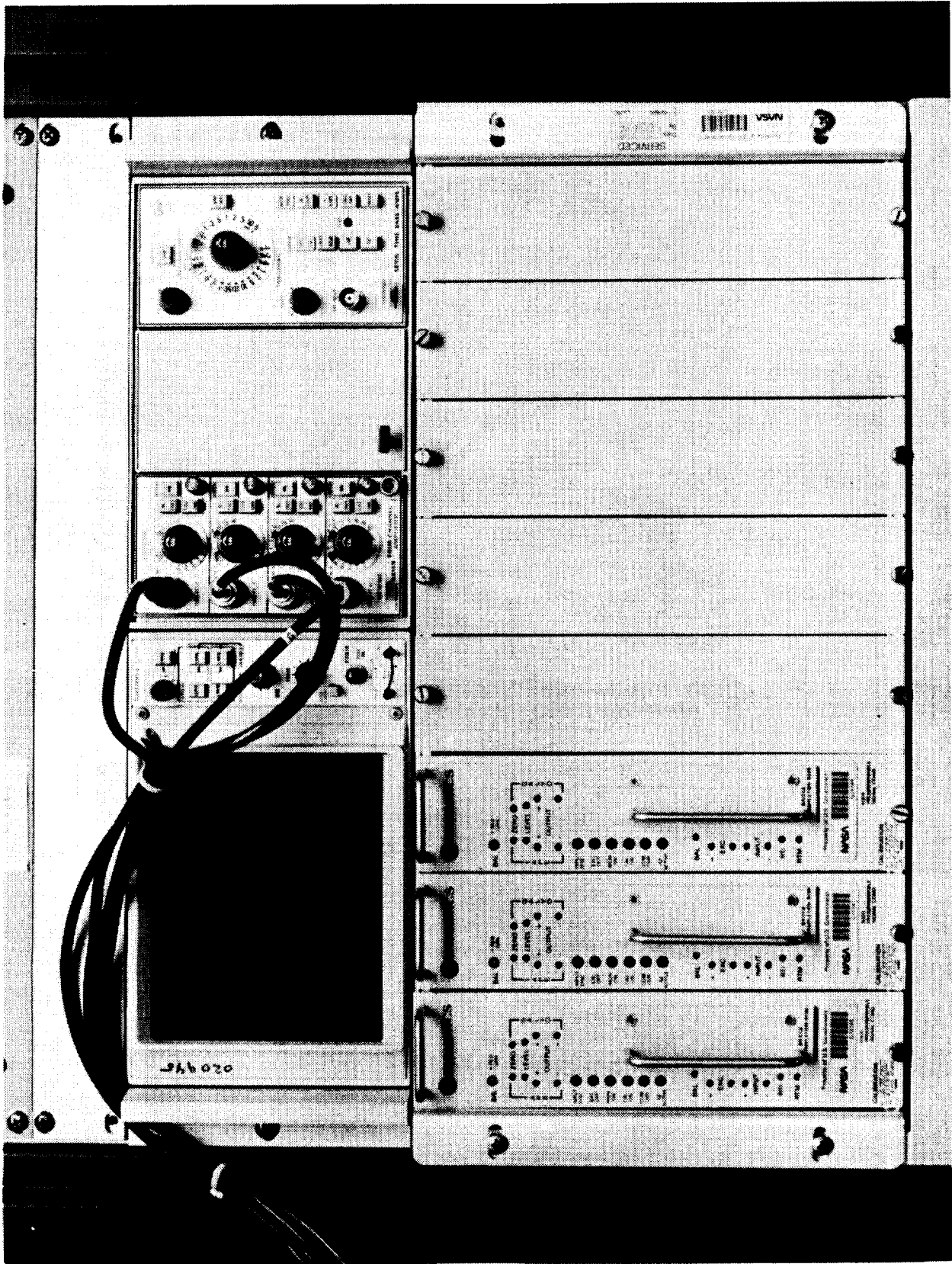
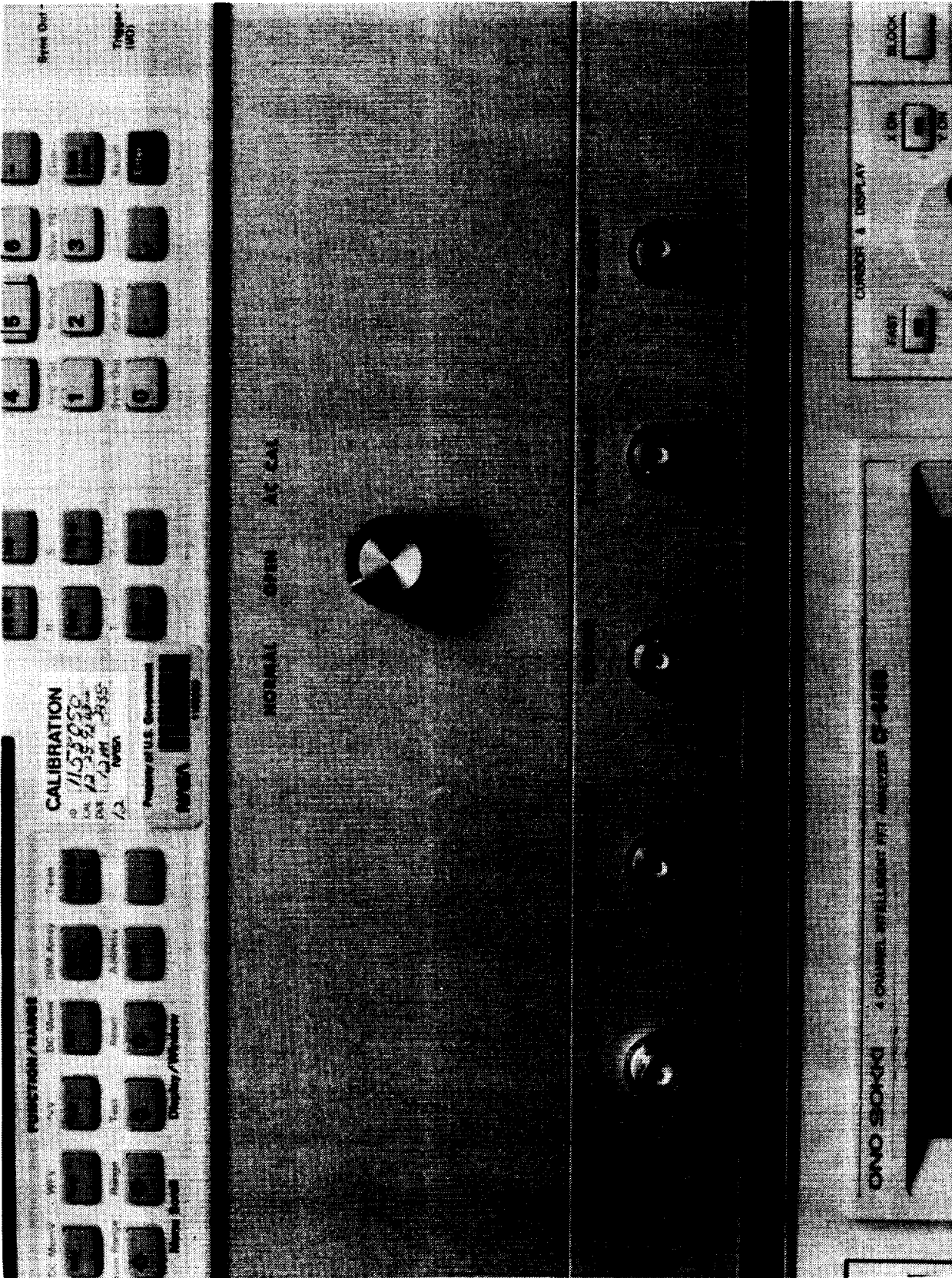Figure 8.   Photograph of Oscilloscope and Signal Conditioner Front Panels.

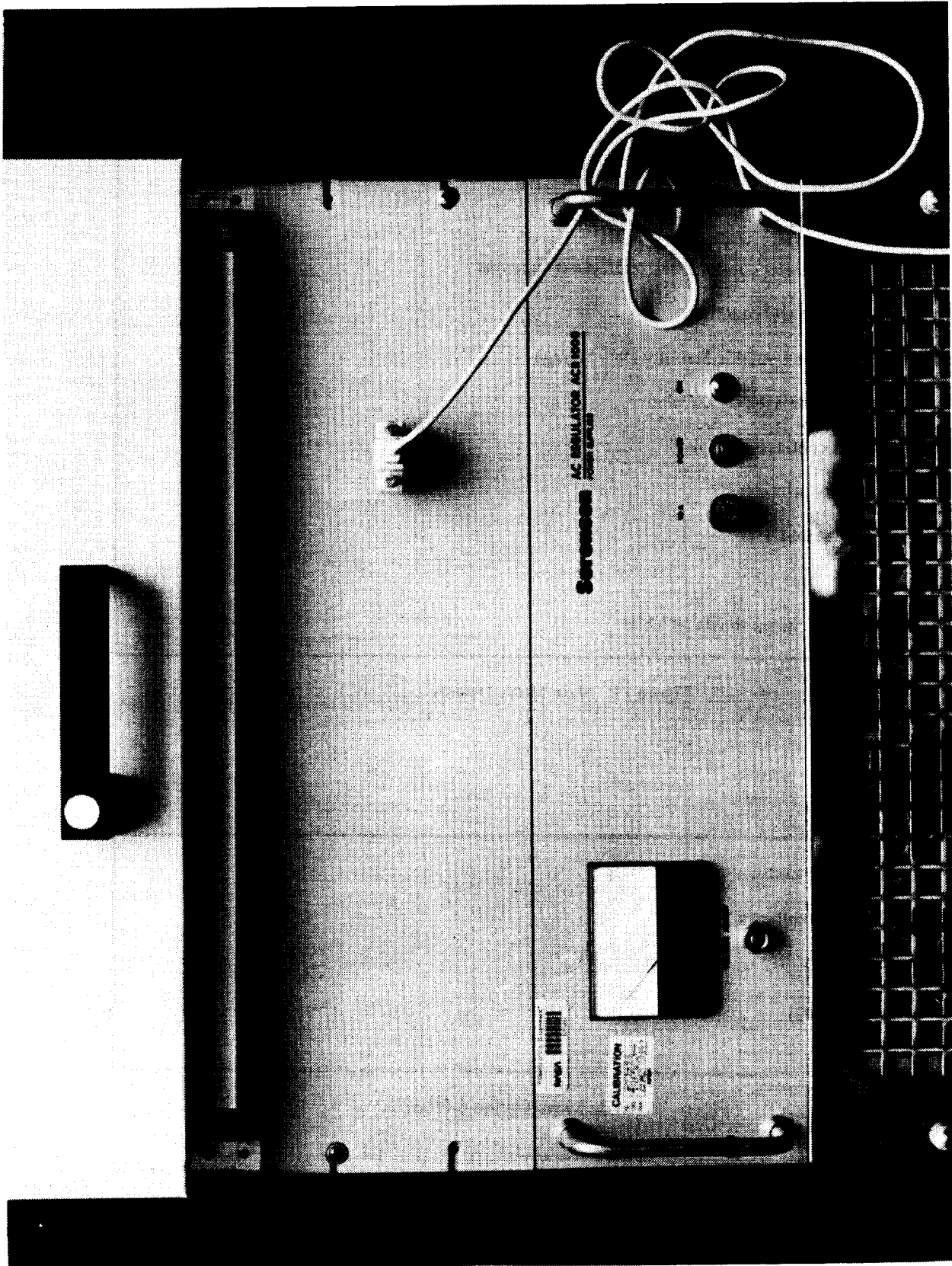Figure 9.   Photograph of AC Cal Front Panel, Oscilloscope Access Panel.

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Figure 10. Photograph of Mouse Cable Connector and AC Regulator Front Panels.
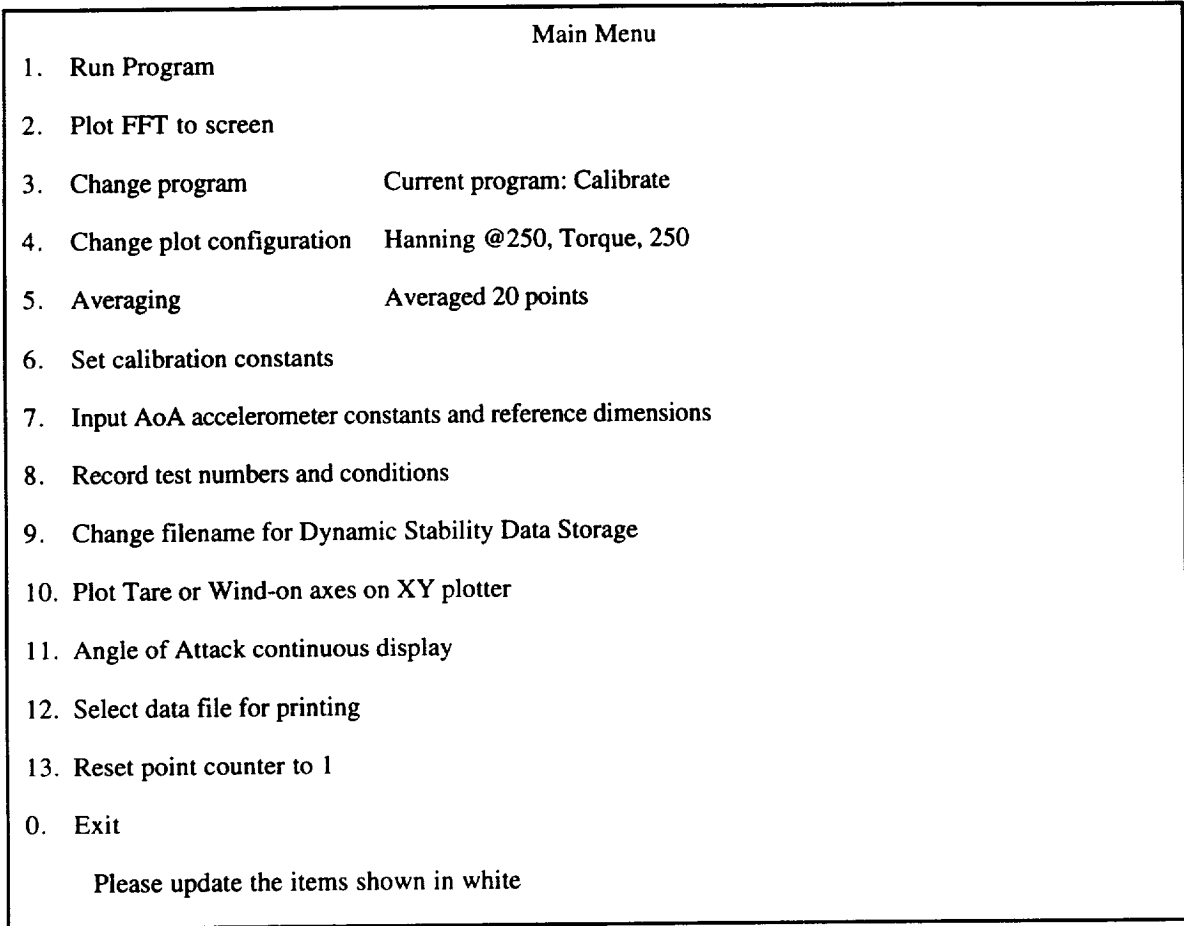
```
                              Main Menu
   1.  Run Program

   2.  Plot FFT to screen

   3.  Change program          Current program: Calibrate

   4.  Change plot configuration   Hanning @250, Torque, 250

   5.  Averaging                Averaged 20 points

   6.  Set calibration constants

   7.  Input AoA accelerometer constants and reference dimensions

   8.  Record test numbers and conditions

   9.  Change filename for Dynamic Stability Data Storage

  10.  Plot Tare or Wind-on axes on XY plotter

  11.  Angle of Attack continuous display

  12.  Select data file for printing

  13.  Reset point counter to 1

   0.  Exit

          Please update the items shown in white
```

Figure 11. Main Menu Display

```
Please input calibration constants.

Enter p for value in parentheses.

k  displacement (0.011970) :
k  torque (9.640998):
k  secondary (24.479999) :
```
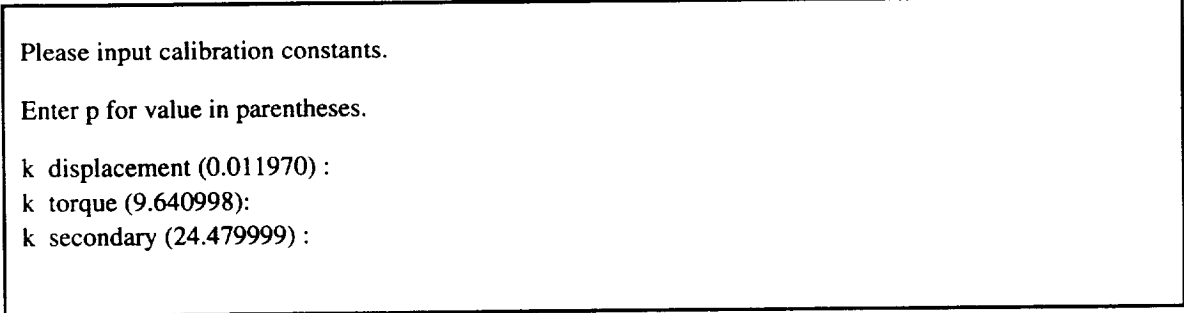
Figure 12. Main Menu Option 6 Prompts

Enter p to accept value in parentheses

Please input

AoA Alpha sensitivity in g/volt (0.0929):
AoA Alpha bias in volts (0.11926):
AoA Alpha offset in degrees (−0.606):
Delta Alpha −> sting to model in degrees (4.310):
Reference length—B in feet (2.80):
Reference area—S in feet^2 (1.1180):

Figure 13. Main Menu Option 7 Prompts

Please enter the following data...

Enter p to accept value in parentheses

Test number (1)...
Tare or Wind-on Run number (1)...
Calibration moment arm length (13.6)...
Calibration number (1)...
Temperature in °F (150.0)...
Pressure in lb/in^2 (20.01)...
Mach number (3.50)...
UpWT AoA flow angle correction (0.13)...

Model inverted? yes=1 no=0 (0)...

Do you want to enter sensitivities from the keyboard?

Sensitivity 1...

Sensitivity 2...

Sensitivity 3...

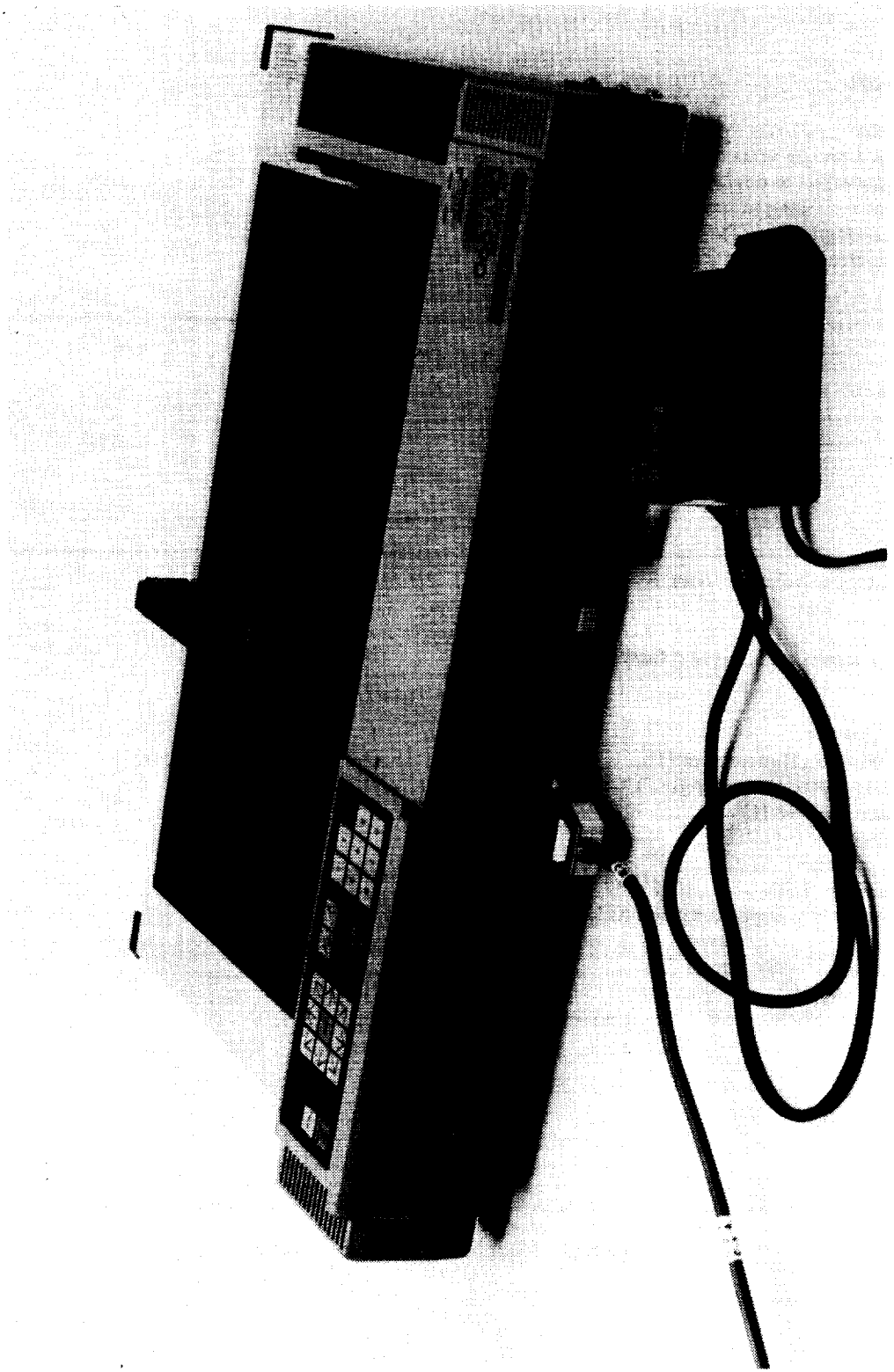Figure 14. Main Menu Option 8 Prompts

Figure 15. Photograph of XY Plotter.

You can return to the main menu without plotting axes, but first you must enter constants and scaling factors.

Type 'w' or 'W' for wind-on, or 'T' or 't' for tare....

Please input the following values for tare plot:

x-scale (200)...
y-scale upper plot (400)...
y-scale lower plot (400)...

Turn on XY plotter, load paper. Press ENTER to continue.

Else hit 'R' or 'r' to return without plotting axes.

Now plotting tare axes...

Figure 16. Main Menu Option 10 Tare Plot Prompts

You can return to the main menu without plotting axes, but first you must enter constants and scaling factors.

Type 'w' or 'W' for wind-on, or 'T' or 't' for tare....

Enter p to accept value in parentheses.

Please enter the following values...

Kspring in ft-lb/rad (168.000)...

Inertia in slug-ft^2 (0.24400)...

C$_{tare}$ (0.0130)...

AMR (857.00)...

BMR (0.1720)...

(MJ/WD) tare (−0.3610)...

K$_{spring}$ = 168.00 ft-lb/rad	Inertia = 0.244 slug-ft^2
C$_{tare}$ = 0.0130	AMR = 857.00
BMR = 0.1720	(mj/wd) tare = −0.3610

Enter the wind-on plot code (1)...
Enter the wind-on symbol code (1)...
Enter the x-scale factor (2)...
Enter the upper y-scale factor (0.1)...
Enter the lower y-scale factor (0.2)...
Enter the minimum × value (-4)...
Enter the maximum × value (20)...

Turn on XY plotter, load paper. Press ENTER to continue.

Else hit 'R' or 'r' to return without plotting axes.

Now plotting wind-on axes...

Figure 17. Main Menu Option 10 Wind-on Plot Prompts

```
Download which program to DSP boards?


Enter number:
1. Enhanced FFT
2. Stand alone FFT sampled @250Hz
3. Stand alone FFt sampled @125Hz
4. Synchronous Demodulation, 0.25 Hz filter
5. Synchronous Demodulation, 0.10 Hz filter
6. Calibration
```

Figure 18. Main Menu Option 3 Submenu

```
DC Calibration                                    Sat Aug 04 11:29:27 1990

              Reading (VDC)    Std. Dev. (VDC)    Last Zero (VDC)

Displacement (0):   0.23456      0.002312          0.00000

        Torque:     0.71093      0.000433          0.00000

Displacement (1):   0.23457      0.001987          0.00000

     Secondary:     0.02985      0.034324          0.00000



                        (regression results here)


Data Point Number 1
Zero Point Number 2       Last Independent Data:  2.00000
Shunt Point Number 2
Calcode = 11              Shunt Option  =  6
```

Figure 19. Example of DC Calibration Display

Synchronous Demodulation 0.25 Hz filter			Frequency 3.0000	
	Displacement		Torque	Secondary
Real (1)	0.01295	Real	0.09351	0.00233
St. Dev.	0.0012109	St. Dev.	0.0006529	0.0085358
Real (2)	0.01296	Imaginary	0.00175	0.00194
St. Dev.	0.0009476	St. Dev.	0.0023226	0.0000347
StDev Avgs	0.0013227			
	Magnitude	0.09353	0.00303	
	St. Dev.	0.0023304	0.0043312	
	St. Dev. Avgs.	0.0003225	0.0008254	

Phase angle 109.147 56.935
(Displacement-Channel)
St. Dev. 0.0467064 0.0196846

(Sensitivity, Tare, or Wind-on Coefficients here)

Gains: 1 1 1
Offsets: 0.0123878 0.0002327 0.0003756
Temp: 114.00°F Pressure: 14.805 psi Ptnum = 1 AoA: 0.20
Mach: 0.80, Q: 626.5663 psi, V: 895.3229 ft/sec St.Dev: 0.00
Averaging 20 Averaged data Stored in: aaaaaaaa.aaa

Figure 20. Example of Synchronous Demodulation Display

```
Choose a plot...

1. Flattop window @250
2. Hanning window @250
3. Hanning window @125

How many points in FFT plot?
Enter number:

1. 250
2. 500


Plot which channel?

Enter:

1. Displacement
2. Torque
3. Secondary
```

Figure 21. Main Menu Option 4 Prompts

```
Angle of Attack


AoA = 12.5°

AoA voltage reading = 0.48371 V

Standard Deviation in voltage reading = 0.075492 V

Press ENTER to return.
```
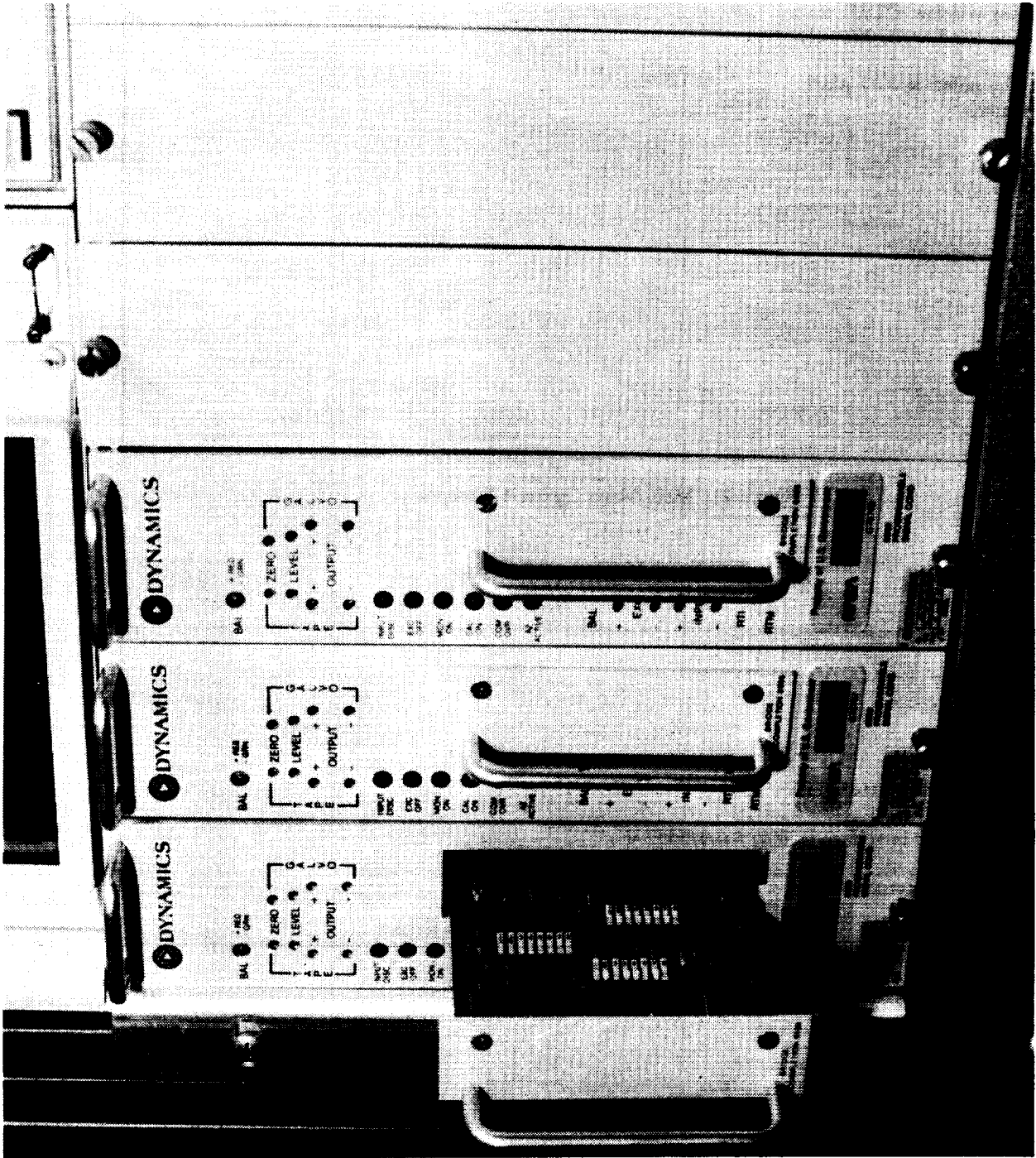
Figure 22. Model Attitude Continuous Display

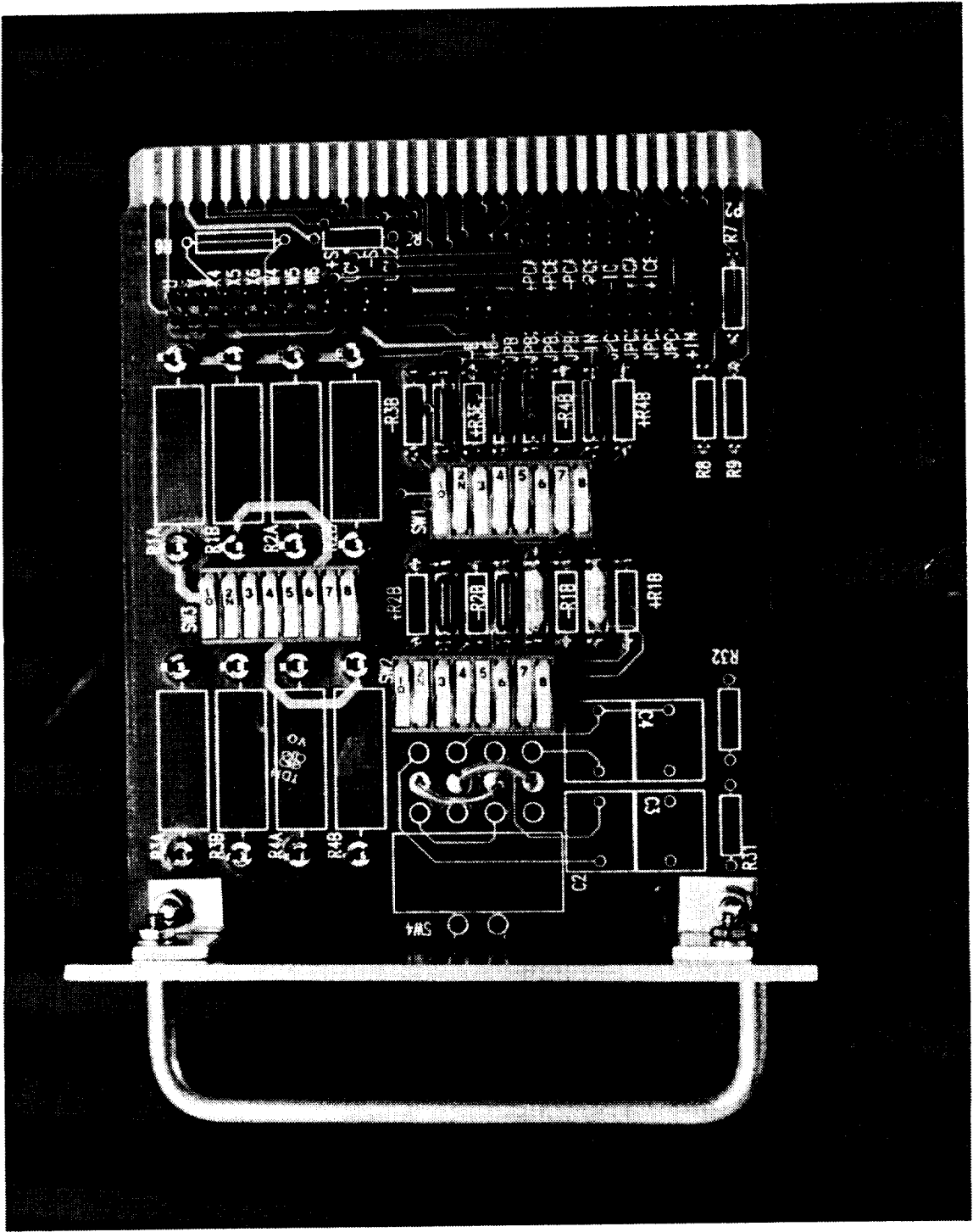Figure 23. Photograph of Signal Conditioner with Bridge Completion Card.

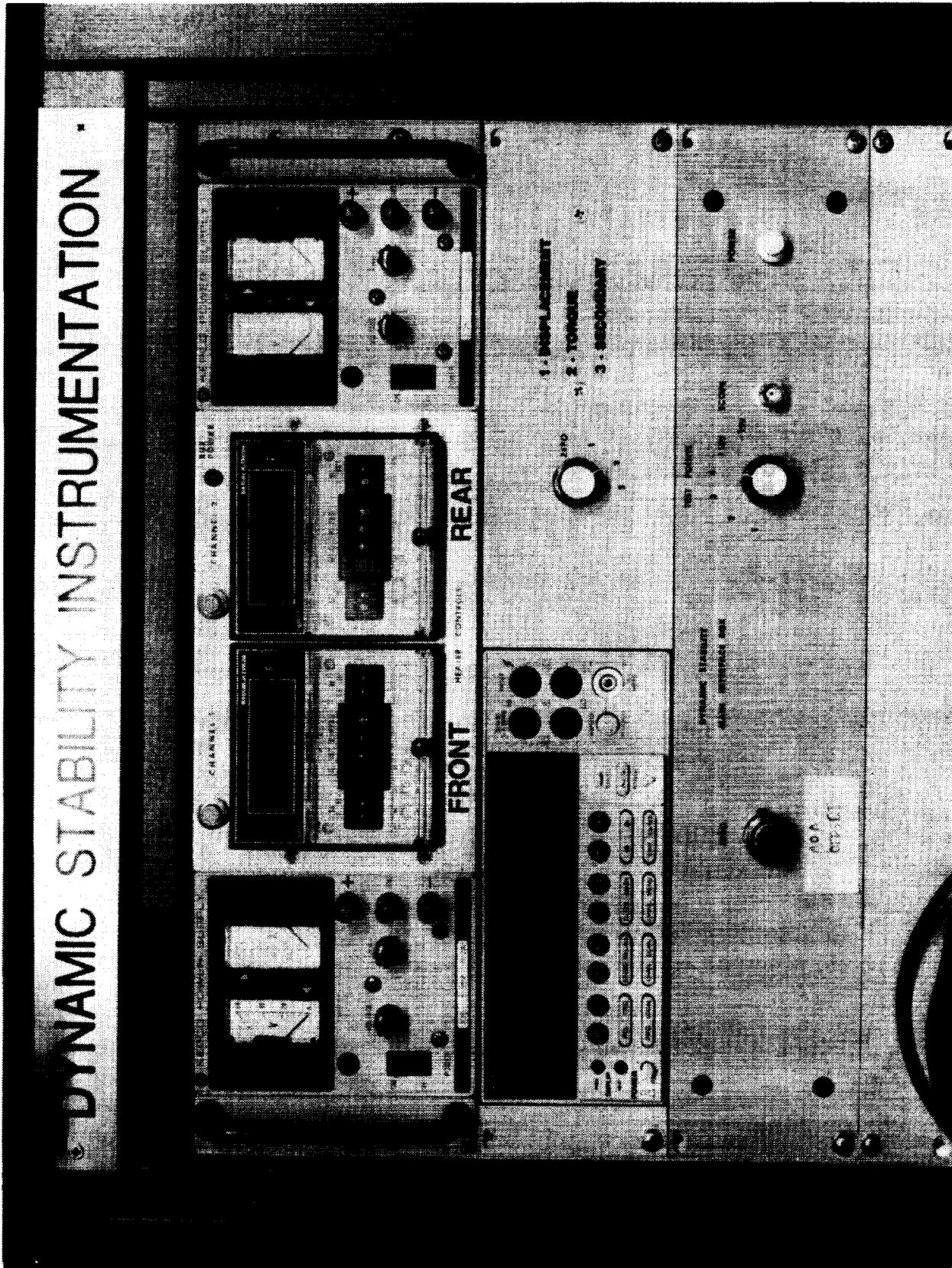Figure 24. Photograph of Bridge Completion Card.

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Figure 25. Photograph of Heater Controller, 2001 Digital Multimeter, and Main Interface Box Front Panels.
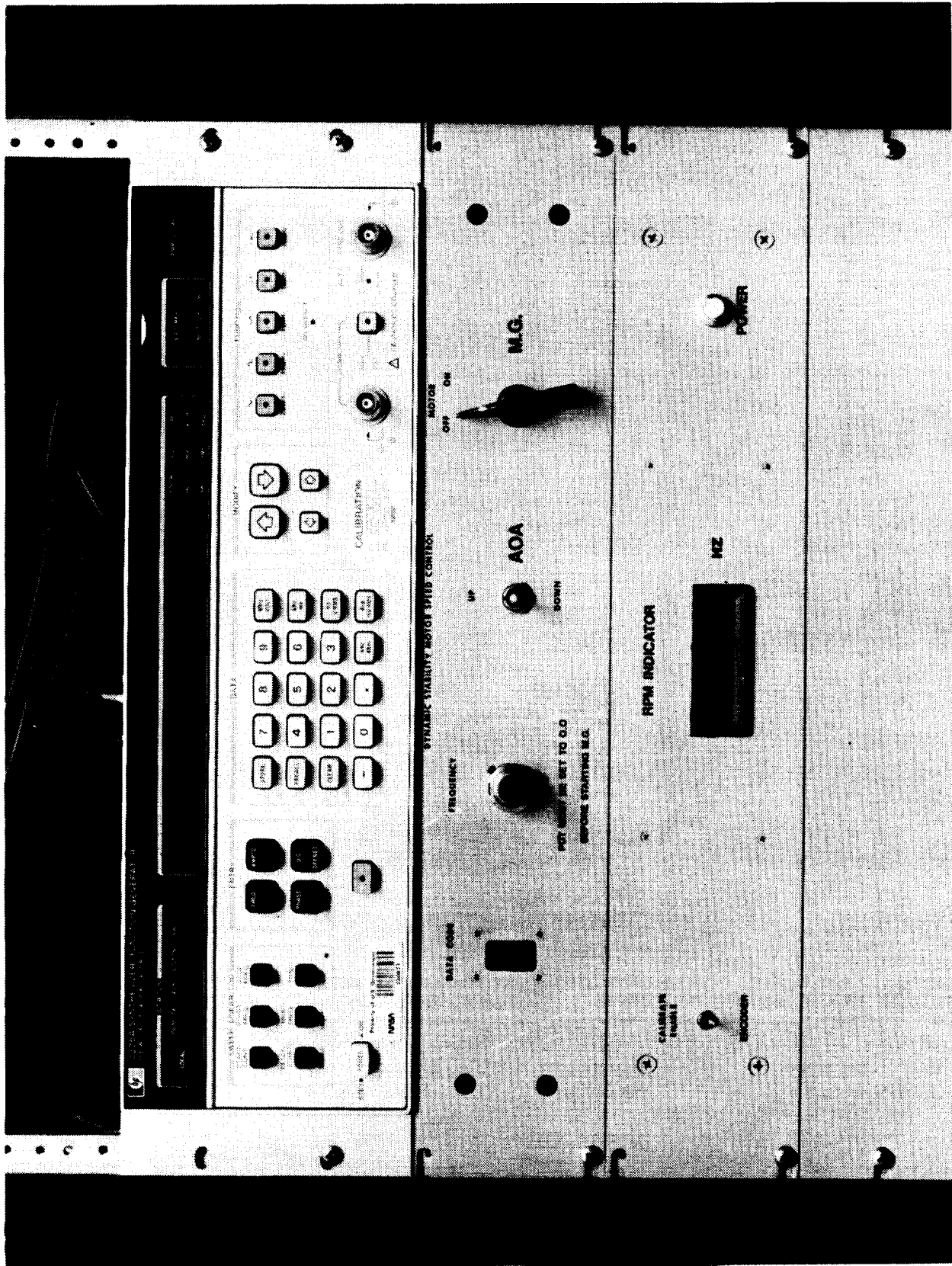
Figure 26. Photograph of HP 3325A, Motor Speed Control, and RPM Indicator Front Panels.
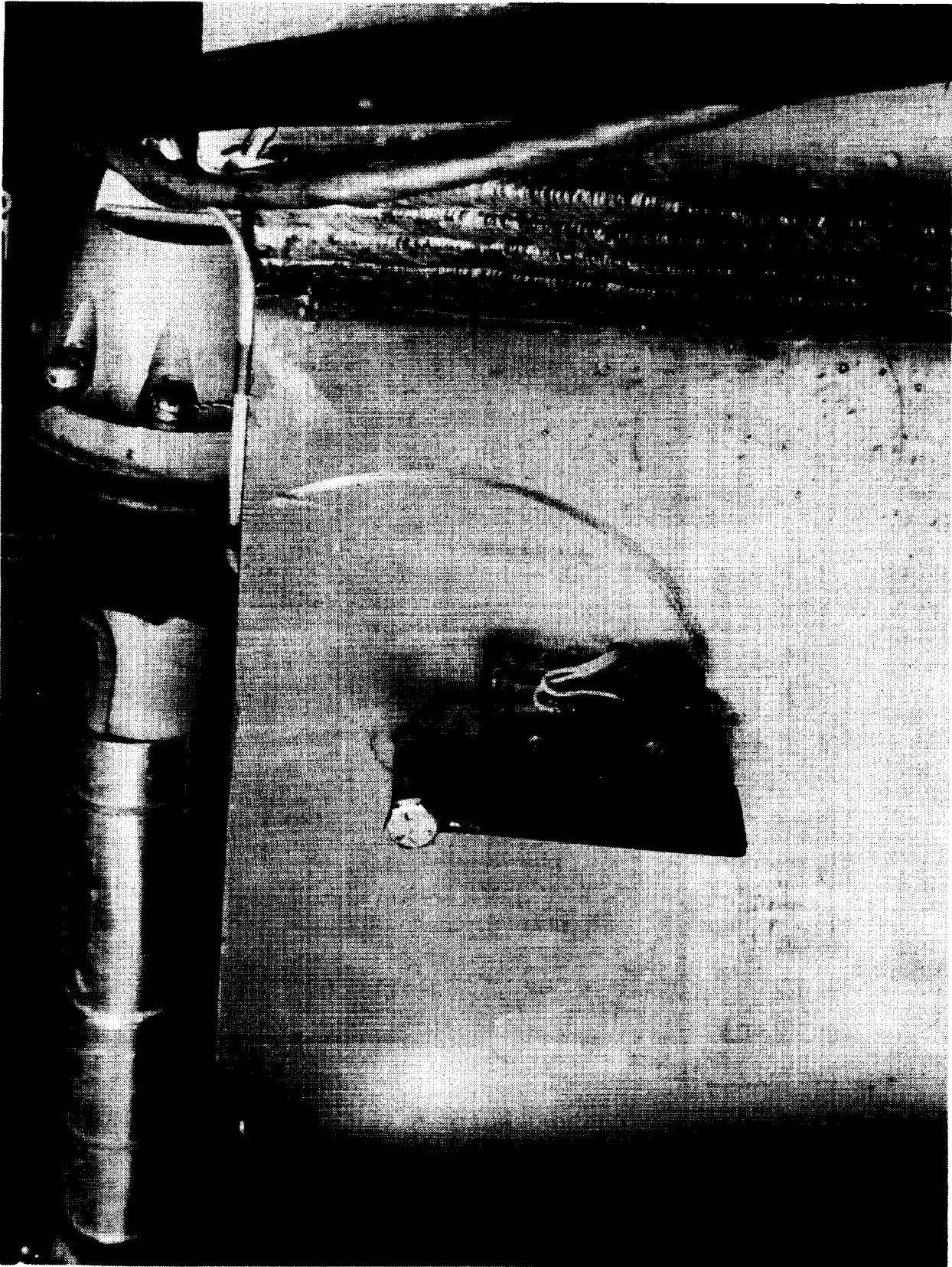
Figure 27. Photograph of Sting with Close-up of Wind-on Switch.

On-line User Information

F1   On-line Help
F2   Averaged or Immediate
F3   Reset Point Counters
F4   Gain Normalization
F5   Change Calcode
F6   Input Sensitivities
F7   Tare Regression
F8   Data File Name?
F9   AoA Display
F10   Take Data
F11   2001 DMM Control
F12   Select Data File to Print
A#   Select amplifier (#)
B#   Bridge power (O) n / of (F)
G   Set Gain
S   Shunt calibrate resistor
I   Increment Gain
U   Un-Shunt calibrate resistor
D   Decrement Gain
N   Connect/Disconnect input
X   Send offset = 0V
V   Send computed offset
Z   Amp computes offset
ESC   Return to Main Menu

Press Enter to leave this help screen

Figure 28. Hot Key Menu Display
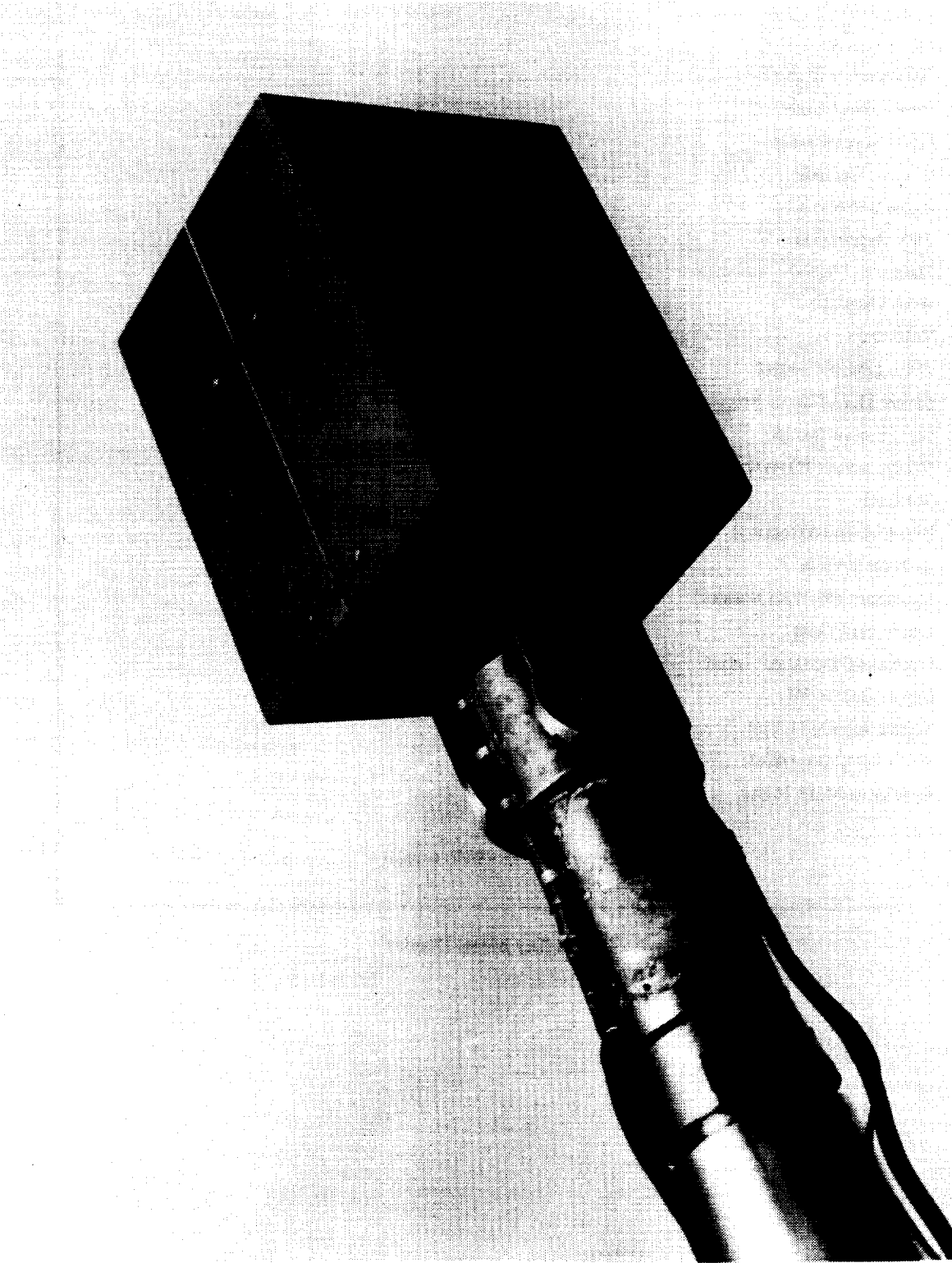
Figure 29. Photograph of Sting with Calibration Block Mounted.
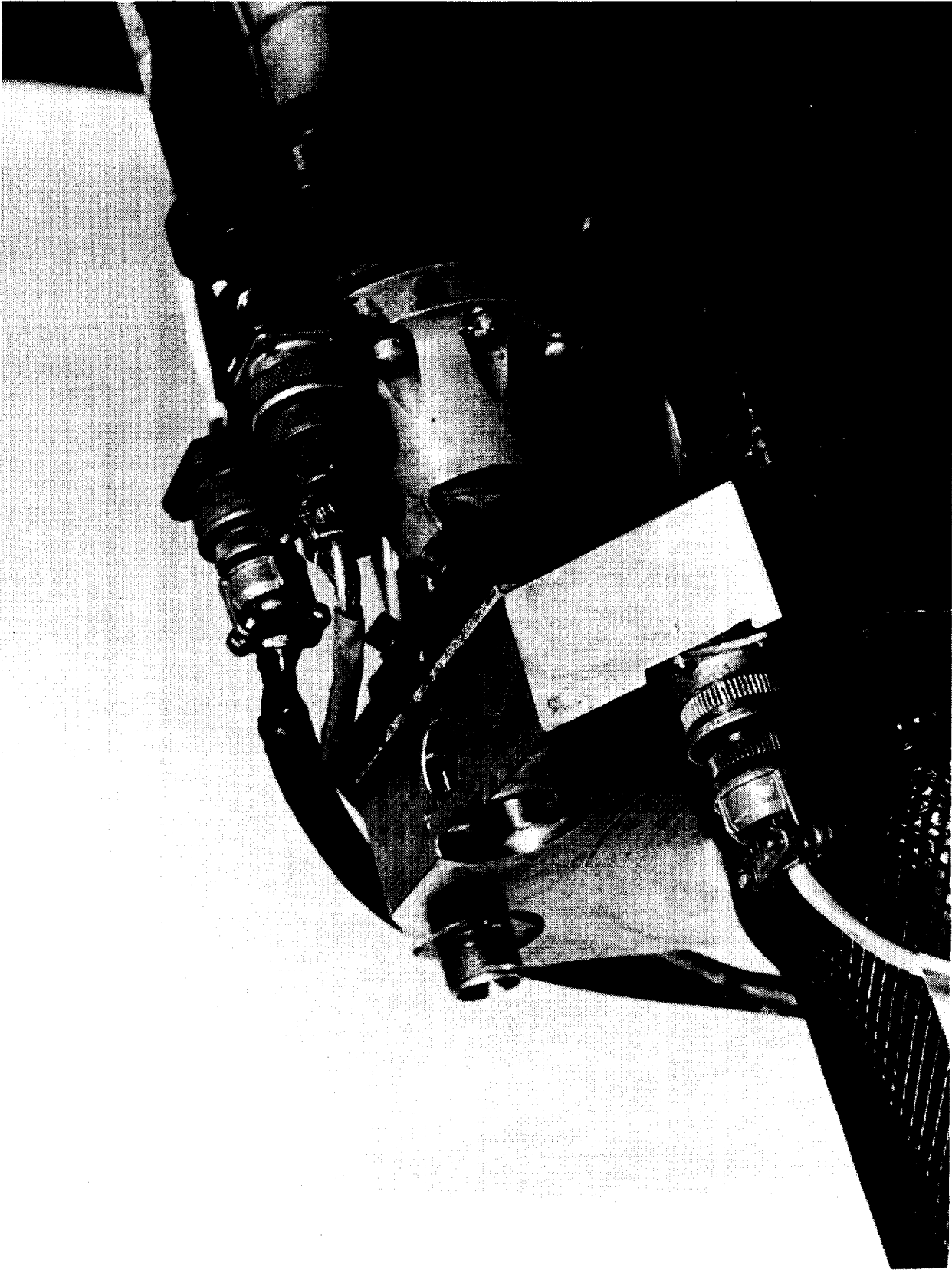
Figure 30. Photograph of Sting Connectors.

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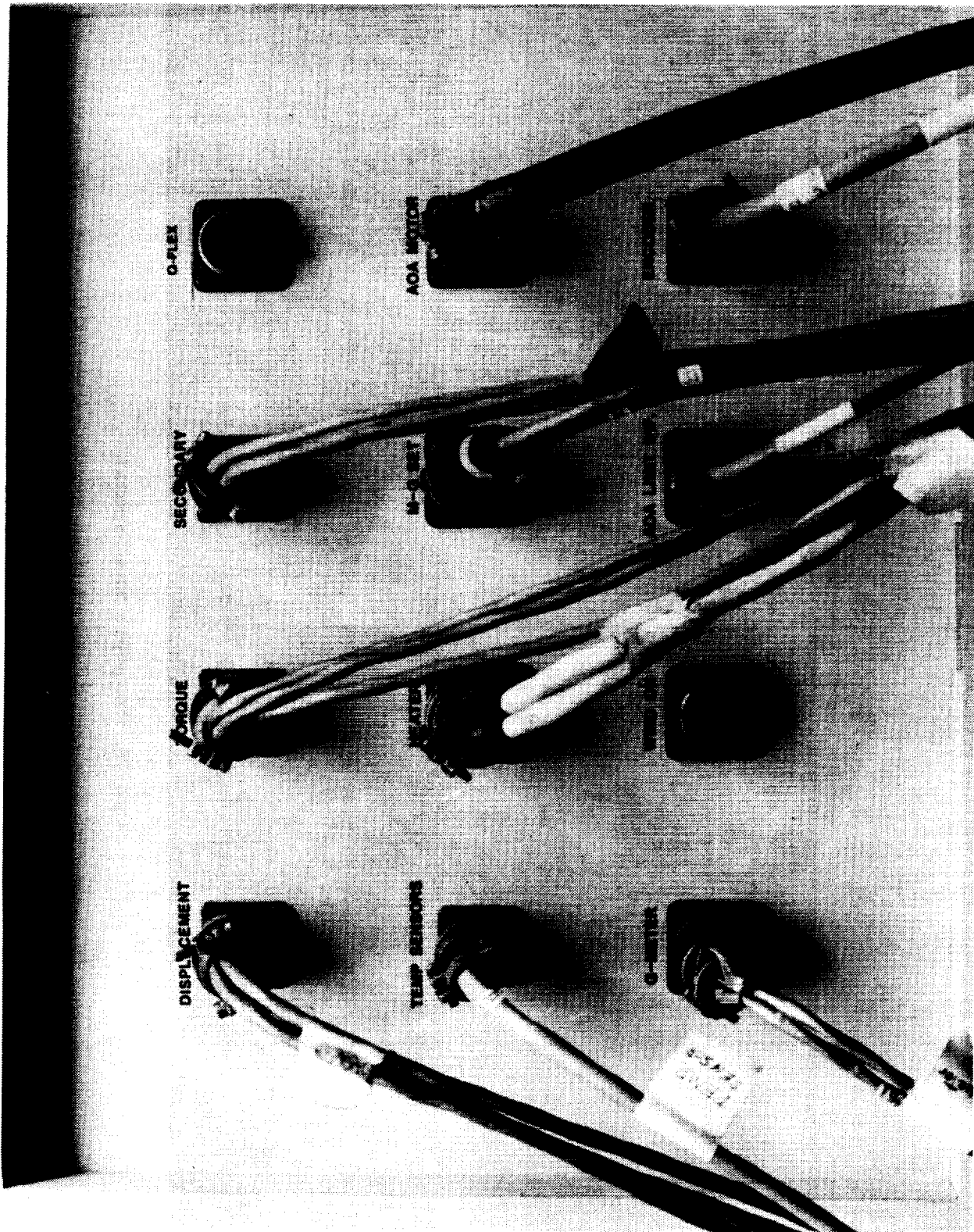
Figure 31. Photograph of Junction Panel Connectors.

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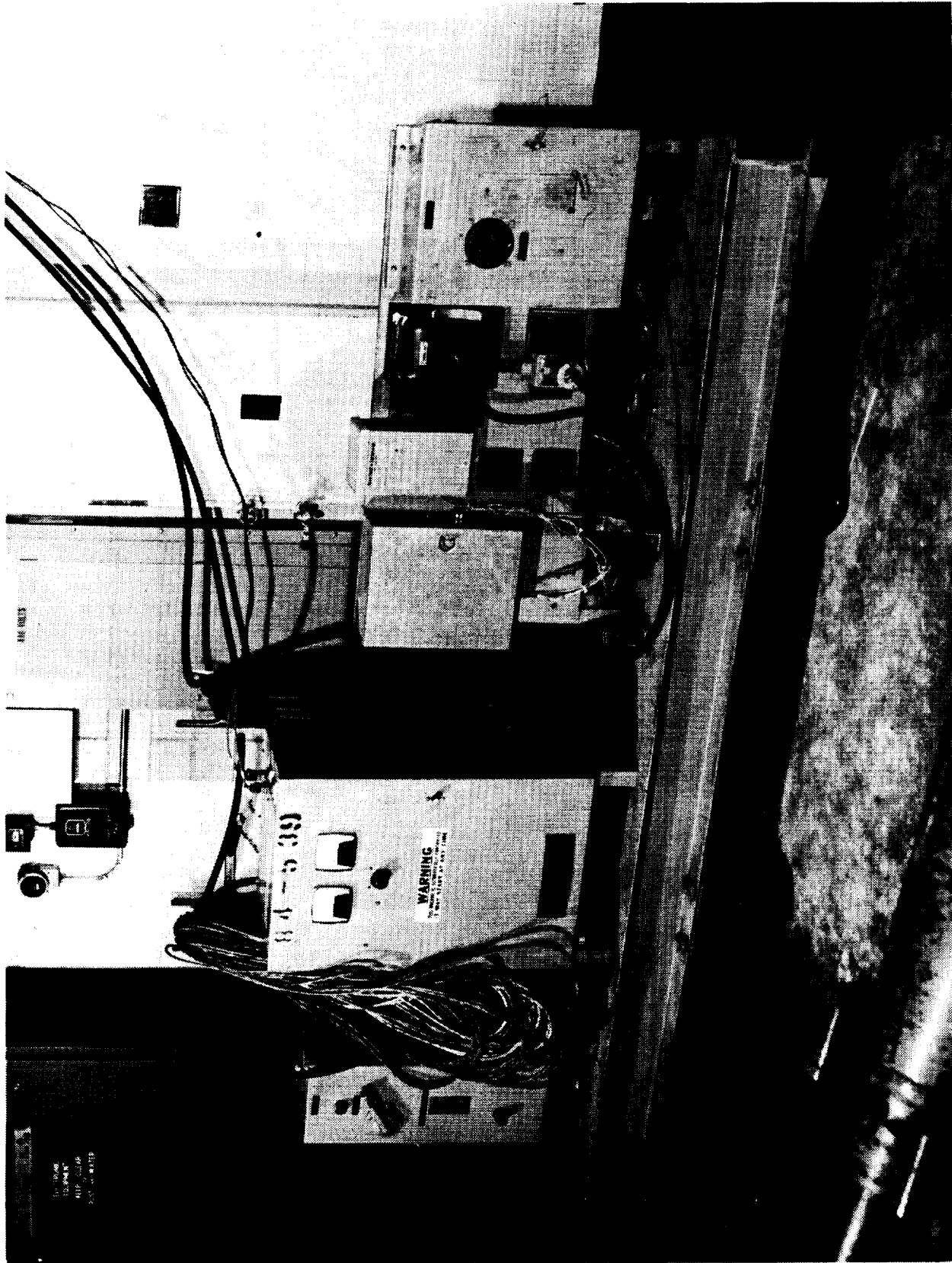
Figure 32. Photograph of Motor-Generator Set.
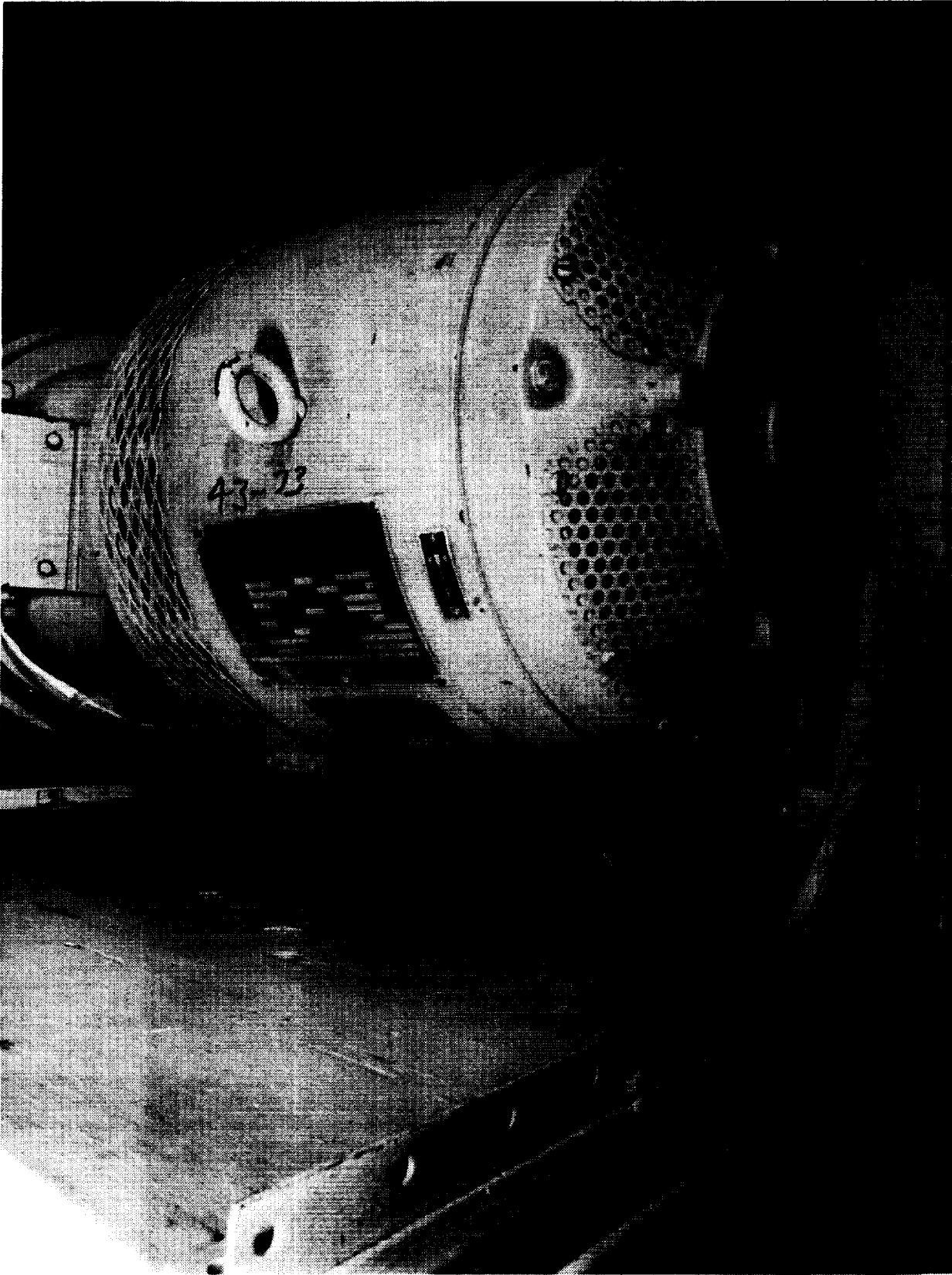
Figure 33. Photograph of Generator with Rotation Arrow.
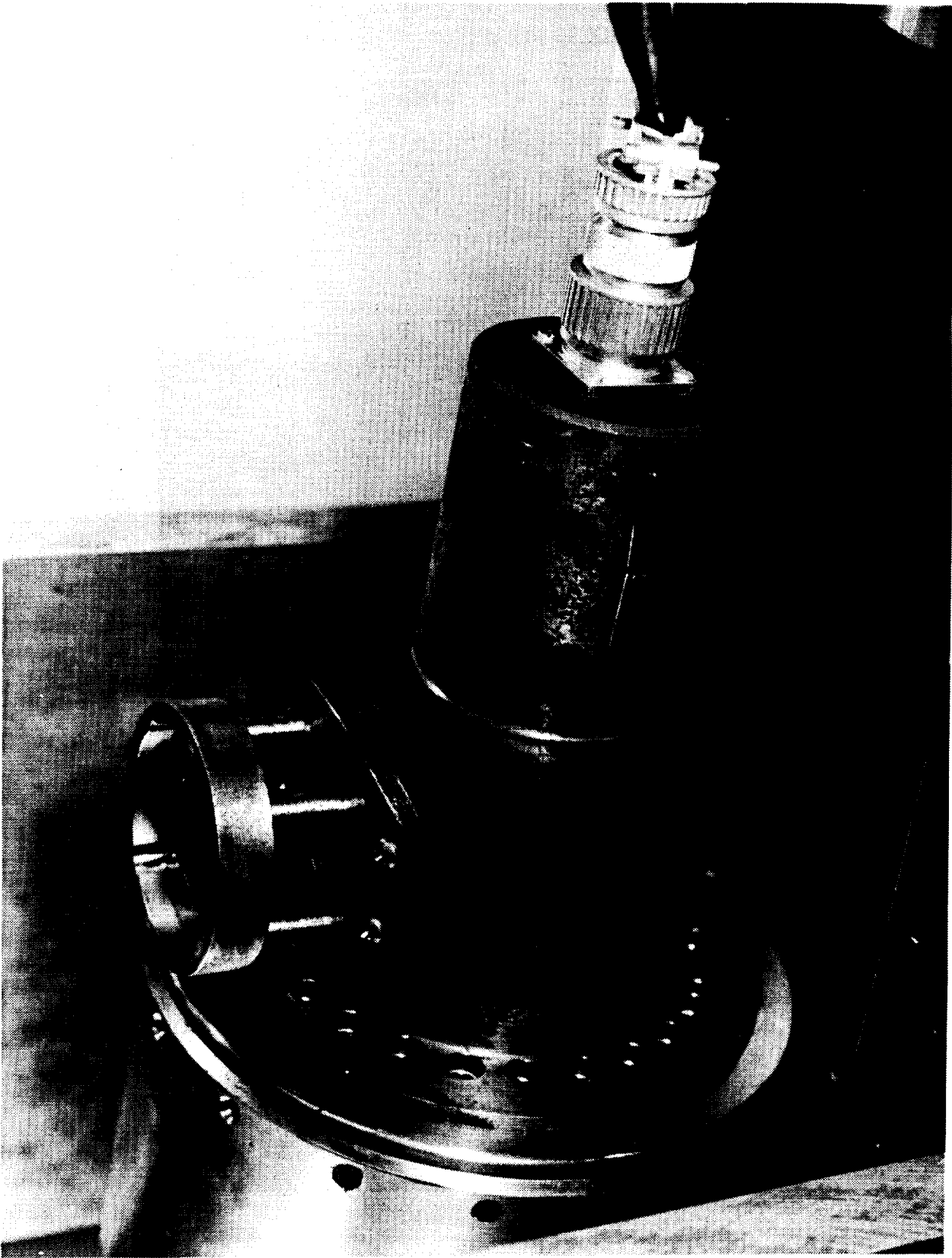
Figure 34. Photograph of Shaft Encoder and Hand Crank Access.
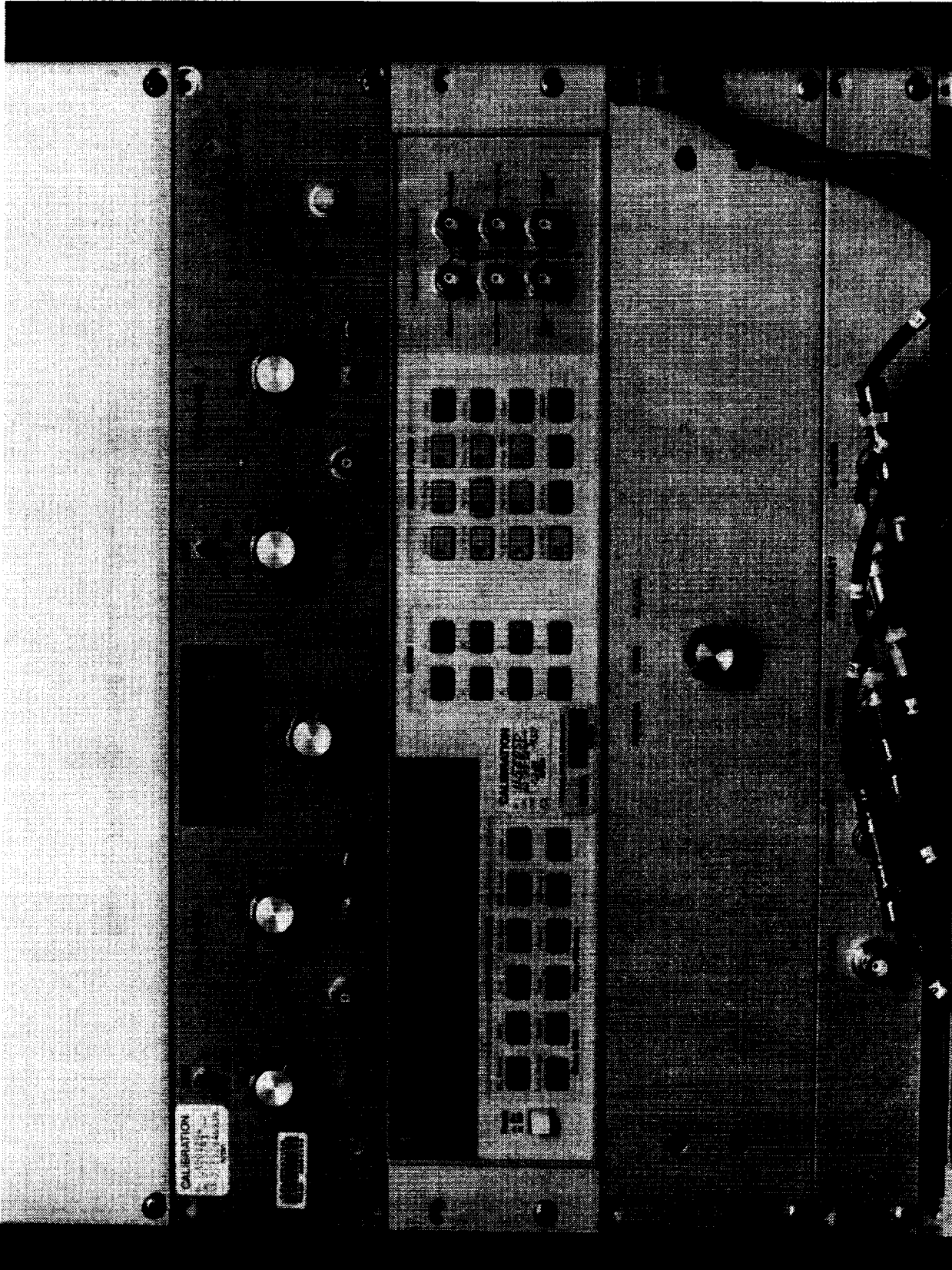
Figure 35. Photograph of Kearfott Signal Conditioner, HP 3245A, AC Cal, and Oscilloscope Access Panels.
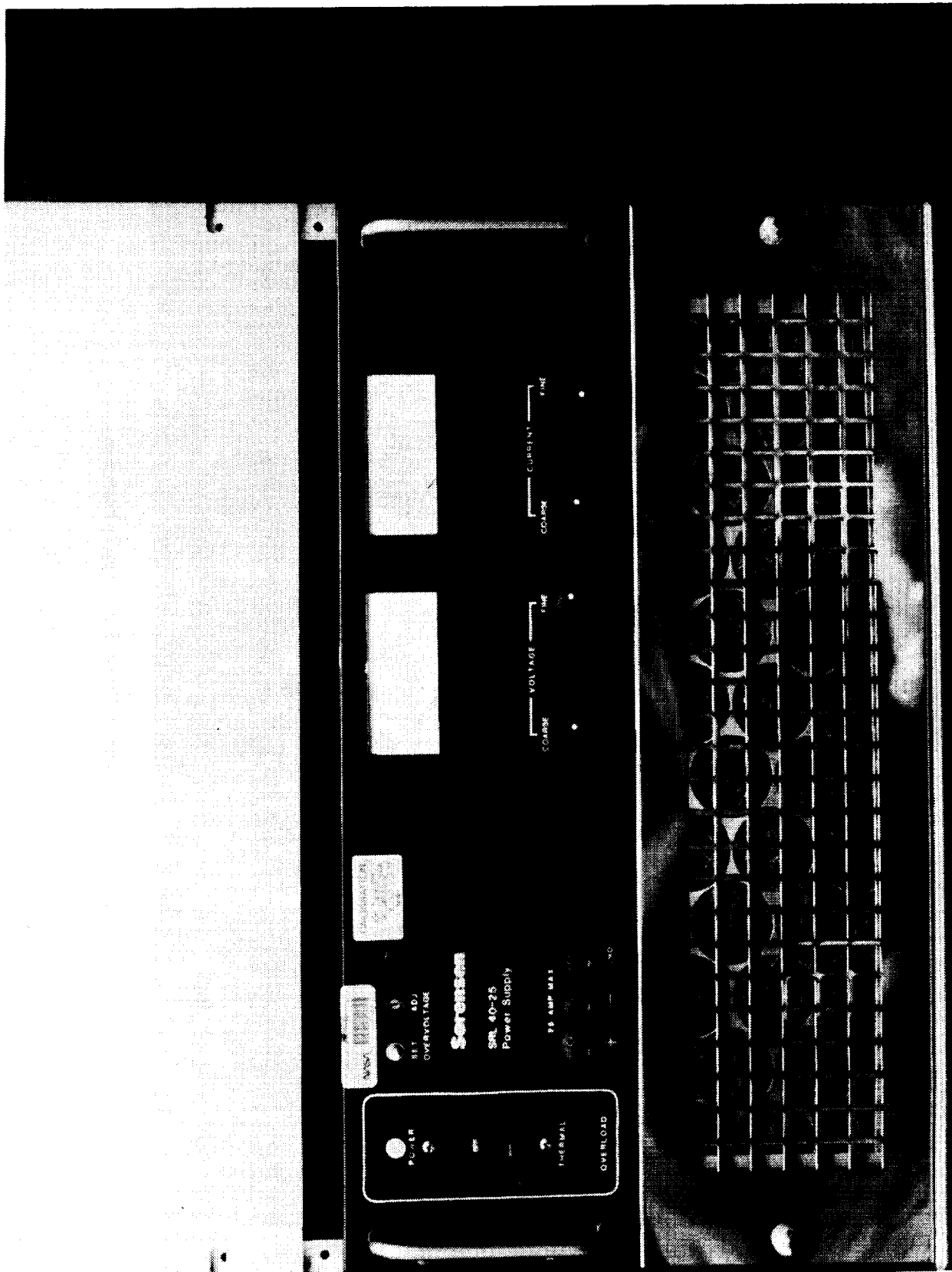
Figure 36. Photograph of Personal Computer Chassis Interior.

Figure 37. Photograph of 40VDC Power Supply Front Panel.
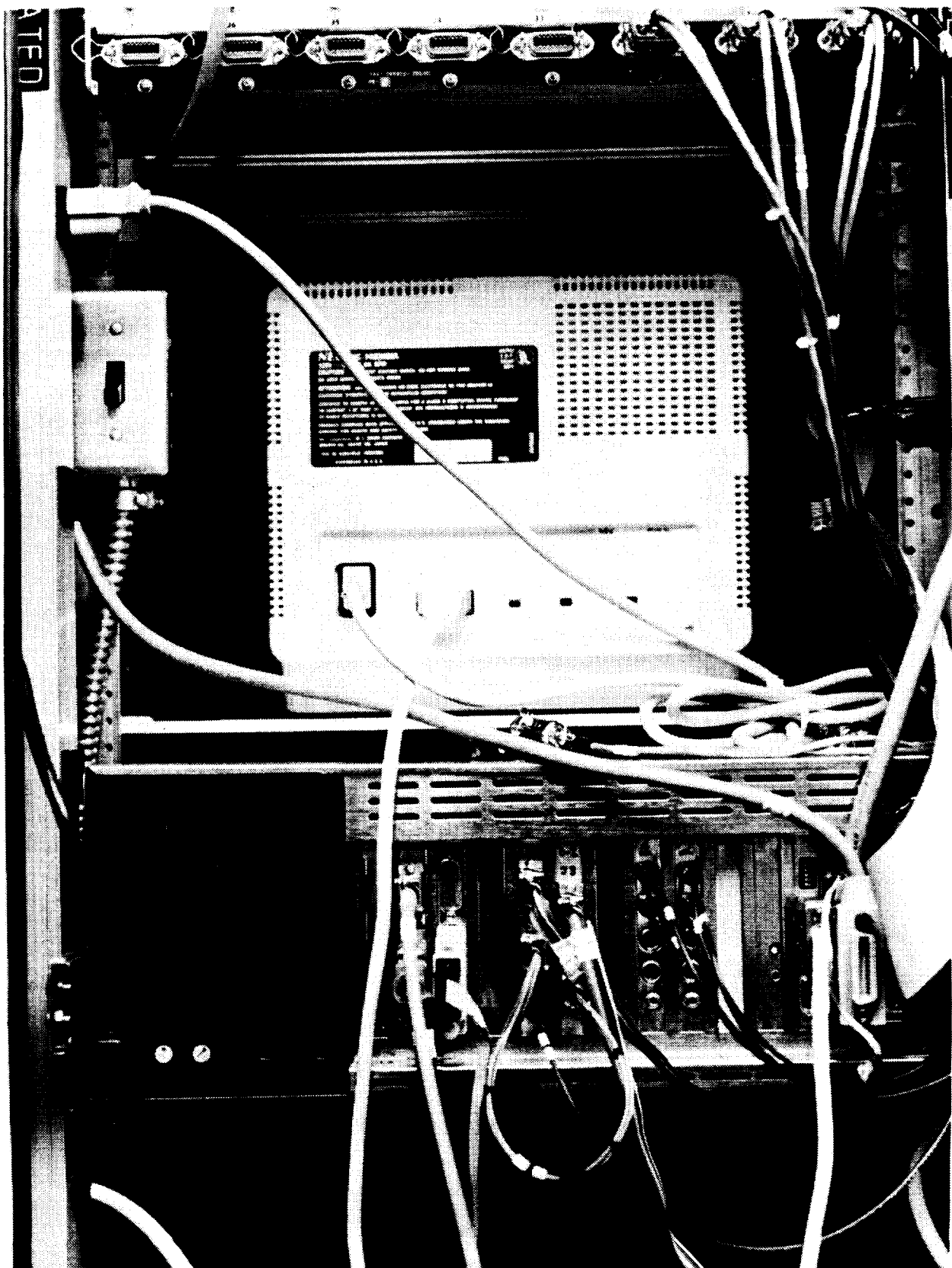
Figure 38. Photograph of PC Rear Panel and Power Switch
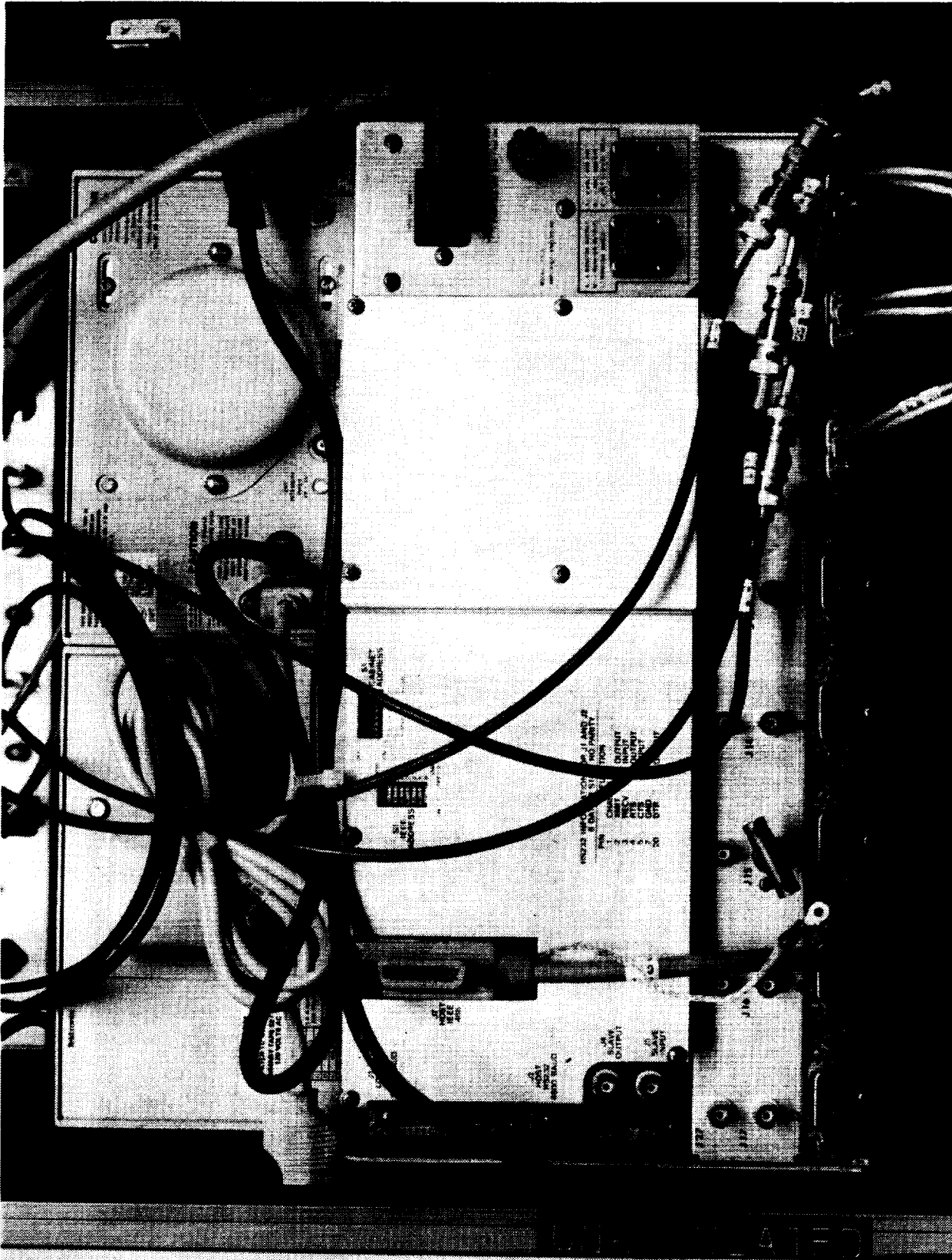
Figure 39. Photograph of Oscilloscope and Signal Conditioner Rear Panels.

```
Select:  −1 . . . 1  (50K)      +1 . . . 2
         −2 . . . 3  (100K)     +2 . . . 4
         −3 . . . 5  (150K)     +3 . . . 6
         −4 . . . 7  (200K)     +4 . . . 8 >>>
```

Figure 40. Calibrate Resistor Selection Submenu

```
Displacement Channel 0/1 ................1
Secondary Moment/Force...................2
Torque...................................3
Please enter the type of calibration........"


Is this the last data point?  (y  or  Y,   n  or  N)
```

Figure 41. DC Calibration Submenu

```
Please choose an option.

Amend data point .......................1
Omit  data  point..........................2
Compute linear regression ............3
Load upper tare data set................4
Exit.....................................5
```

Figure 42. Tare Data Submenu

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Figure 43. Photograph of UPWT Sting with Cooling Air Nozzle Placement.

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Appendix A

Aerodynamic Coefficient Equations

All of the equations for computing the necessary constants, tare values, and wind-on coefficients are given.

Constants. Equations for the constants based on the results of a linear regression of the static balance voltages are given below.

$$K_D = m(\text{degrees/volt}) * \text{Pi (radians)}/180 \text{ (degrees)} * \cdots$$
$$V_{\text{SHUNT-CAL}} \text{ (volts per calibrate signal)} \quad (1)$$

where m is the slope of the regression and $V_{\text{SHUNT-CAL}}$ is the bridge output voltage due to the shunt calibration resistor pair.

$$K_T = m * Ma * UC * V_{\text{SHUNT-CAL}} \quad (2)$$

where m is the regression slope in units of kilogram-inch per volt (since the weights are in kilograms), Ma is the moment arm length (inches), and UC is the units conversion factor (0.2491 N-meter/Kg-inch).

Equation (2) has units Newton-meter per calibrate signal (that can be converted to the desired Foot-Lb per calibrate signal). K_M is computed the same way as K_T.

Sensitivities. The equations for computing the sensitivity constants are given below.

$$S_T = K_D / [(V_{\Theta S} - V_{TZ}) A_\Theta] \quad (3)$$
$$S_T = K_T / [(V_{TS} - V_{TZ}) A_T] \quad (4)$$
$$S_M = K_M / [(V_{MS} - V_{MZ}) A_M] \quad (5)$$

where K_D, K_T, and K_M are calibration constants determined from the calibration phase, $V_{\Theta S}$ is the amplified displacement shunt voltage, V_{TS} is the amplified torque shunt voltage, V_{MS} is the amplified secondary shunt voltage, and $V_{\Theta Z}$, V_{TZ}, and V_{MZ} are instrument zero voltages. Also,

$A_\Theta = 10000 /$ gain of the displacement signal (6)
    conditioner

$A_T = 10000 /$ gain of the torque signal (7)
    conditioner

$A_M = 10000 /$ gain of the secondary signal (8)
    conditioner.

Tare Values. Measurements of amplified strain gage signals are made and used to calculate tare values T1, T2, M1, and M2 as shown in the equations below.

$$T1 = T_R / \Theta \quad (9)$$

$$T2 = T_I / (\omega \Theta) \quad (10)$$
$$M1 = M_R / \Theta \quad (11)$$
$$M2 = M_I / (\omega \Theta) \quad (12)$$

where:

$$\Theta = S_\Theta A_\Theta (V_\Theta - V_{\Theta Z}) \quad (13)$$
$$T_R = S_T A_T (V_{TR} - V_{TRZ}) \quad (14)$$
$$T_I = S_T A_T (V_{TI} - V_{TIZ}) \quad (15)$$
$$M_R = M_M A_M (V_{MR} - V_{MRZ}) \quad (16)$$
$$M_I = M_M A_M (V_{MR} - V_{MIZ}) \quad (17)$$

$\omega = 2 \pi f$, f is oscillation frequency, and the following voltage readings from:

V_Θ = displacement channel
V_{TR} = real component of torque
V_{TI} = imaginary component of torque
V_{MR} = real component of secondary
V_{MI} = imaginary component of secondary

and the following zero voltage readings from:

$V_{\Theta Z}$ = displacement channel
V_{TRZ} = real component of torque
V_{TIZ} = imaginary component of torque
V_{MRZ} = real component of secondary
V_{MIZ} = imaginary component of secondary.

Linear regressions performed on the T1 and M1 tare values with respect to squared oscillation frequency, ω^2, yield the constants needed for real-time wind-on damping coefficient display. These constants and other required constants are described below.

Real-time Constants. The following constants are used in subsequent computations.

Θ = amplitude of angular displacement in pitch
K_{Spring} = y intercept of linear regression on T1
Inertia = negative slope of linear regression on T1
C_{Tare} = average value at resonance of T2
Amr = y intercept of linear regression on M1
Bmr = negative slope of linear regression M1
$M_I /\omega\Theta_{\text{Tare}}$ = average value at resonance of M2

For yaw oscillation tests, the equations given for pitch testing apply with the following changes. Substitute Ψ for Θ in all tare and wind-on equations. For roll oscillation tests, the equations given for pitch testing apply with the following changes. Substitute Φ for Θ in all tare and wind-on equations. Thus, Ψ becomes the amplitude of angular displacement in yaw, and Φ becomes the amplitude of angular displacement in roll.

As with tare testing, components are determined from voltages, gains, and sensitivities by the following equations (listed again for convenience) and the same defini tions apply.

$$\Theta = S_\Theta \, A_\Theta \, (V_\Theta - V_{\Theta Z}) \tag{18}$$

$$T_R = S_T \, A_T \, (V_{TR} - V_{TRZ}) \tag{19}$$

$$T_I = S_T \, A_T \, (V_{TI} - V_{TIZ}) \tag{20}$$

$$M_R = S_M \, A_M \, (V_{MR} - V_{MRZ}) \tag{21}$$

$$M_I = S_M \, A_M \, (V_{MR} - V_{MIZ}) \tag{22}$$

Pitch Tests. For pitching tests, the following parameters are needed for computing the final coefficients.

$$\tan \eta = T_I \, / \, T_R \tag{23}$$

$$(K\text{-}I \, \omega^2)_{Run} = T_R \, / \, \Theta \tag{24}$$

$$C_{Run} = T_I \, / \, (\omega \, \Theta) \tag{25}$$

$$(K\text{-}I \, \omega^2)_{Tare} = (K\text{-}I \, \omega^2) \tag{26}$$

where C_{Tare} is the Average of values at tare resonant frequency. In addition,

$$(K\text{-}I \, \omega^2)_{Aero} = (K\text{-}I \, \omega^2)_{Run} - (K\text{-}I \, \omega^2)_{Tare} \tag{27}$$

$$C_{Aero} = C_{Run} - C_{Tare} \tag{28}$$

$$\tan \varsigma = M_I \, / \, M_R \tag{29}$$

$$(Amr\text{-}Bmr \, \omega^2)_{Run} = M_R \, / \, \Theta \tag{30}$$

$$MC_{Run} = M_I \, / \, (\omega \, \Theta) \tag{31}$$

$$(Amr\text{-}Bmr \, \omega^2)_{Tare} = Amr - Bmr \, \omega^2 \tag{32}$$

where MC_{Tare} is the average of values at the tare resonant frequency.

$$(Amr - Bmr \, \omega^2)_{Aero} = (Amr - Bmr \, \omega^2)_{Run} - \cdots$$
$$(Amr - Bmr \, \omega^2)_{Tare} \tag{33}$$

$$MC_{Aero} = MC_{Run} - MC_{Tare} \tag{34}$$

$$k = (\omega \, b) \, / \, (2 \, V) \tag{35}$$

where k is the reduced frequency parameter, ω is the frequency value at which wind-on data were recorded, b is reference length of the model (mean aerodynamic chord for pitch and wing span for yaw and roll), V is the free stream velocity, q_∞ is the free-stream dynamic pressure, q_∞ is the pitch rate, S is the model reference area, and α is the model attitude.

Final pitch computations:

$$C_{m_q} + C_{m_{\dot\alpha}} = \frac{-2VC_{Aero}}{q_\infty S b^2} \tag{36}$$

$$C_{m_\alpha} - k^2 C_{m_{\dot q}} = \frac{-\left(K - I\omega^2\right)_{Aero}}{q_\infty S b} \tag{37}$$

$$C_{N_q} + C_{N_{\dot\alpha}} = \frac{-2VMC_{Aero}}{q_\infty S b} \tag{38}$$

$$C_{N_\alpha} - k^2 C_{N_{\dot q}} = \frac{-\left(Amr - Bmr\omega^2\right)_{Aero}}{q_\infty S} \tag{39}$$

Yaw Tests. For yaw oscillation tests, the following equations are used instead.

$$\tan \lambda = T_I \, / \, T_R \tag{40}$$

$$(K\text{-}I \, \omega^2)_{Run} = T_R \, / \, \Psi \tag{41}$$

$$C_{Run} = T_I \, / \, (\omega \, \Psi) \tag{42}$$

$$(K\text{-}I \, \omega^2)_{Tare} = K\text{-}I \, \omega^2 \tag{43}$$

where C_{Tare} is the average of values at tare resonant frequency, and

$$(K\text{-}I \, \omega^2) \,_{Aero} = (K\text{-}I \, \omega^2)_{Run} - (K\text{-}I \, \omega^2)_{Tare} \tag{44}$$

$$C_{Aero} = C_{Run} - C_{Tare} \tag{45}$$

$$\tan \gamma = M_I \, / \, M_R \tag{46}$$

$$(Amr\text{-}Bmr \, \omega^2)_{Run} = M_R \, / \, \Psi \tag{47}$$

$$MC_{Run} = M_I \, / \, (\omega \, \Psi) \tag{48}$$

$$(Amr\text{-}Bmr \, \omega^2)_{Tare} = Amr - Bmr \, \omega^2 \tag{49}$$

where MC_{Tare} is the average of values at tare resonant frequency.

$$(Amr - Bmr \, \omega^2) \,_{Aero} = (Amr - Bmr \, \omega^{22})_{Run} - \cdots$$
$$(Amr - Bmr \, \omega^{22})_{Tare} \tag{50}$$

$$MC_{Aero} = MC_{Run} - MC_{Tare} \tag{51}$$

where r is the yaw rate, and β is the angle of sideslip. Final yaw computations:

$$C_{nr} - C_{n\dot\beta} \cos \alpha = \frac{-2VC_{Aero}}{q_\infty S b^2} \tag{52}$$

$$C_{n\beta} \cos \alpha + k^2 C_{n\dot r} = \frac{-\left(K - I\omega^2\right)_{Aero}}{q_\infty S b} \tag{53}$$

$$C_{lr} - C_{l\dot\beta} \cos \alpha = \frac{-2VMC_{Aero}}{q_\infty S b^2} \tag{54}$$

$$C_{l\beta} \cos \alpha + k^2 C_{lr} = \frac{-\left(Amr - Bmr\omega^2\right)_{Aero}}{q_\infty S b} \tag{55}$$

Roll Tests. For roll oscillation tests, the following equations are used instead of the pitch equations.

$$\tan \sigma = T_I / T_R \qquad (56)$$
$$(K\text{-}I\ \omega^2)_{Run} = T_R / \Phi \qquad (57)$$
$$C_{Run} = T_I / (\ \omega\ \Phi\ ) \qquad (58)$$
$$(K\text{-}I\ \omega^2)_{Tare} = K\text{-}I\ \omega^2 \qquad (59)$$

where C_{Tare} is the average of values at tare resonant frequency, and

$$(K\text{-}I\ \omega^2)_{Aero} = (K\text{-}I\ \omega^2)_{Run} - (K\text{-}I\ \omega^2)_{Tare} \qquad (60)$$
$$C_{Aero} = C_{Run} - C_{Tare} \qquad (61)$$
$$\tan \varepsilon = M_I / M_R \qquad (62)$$
$$(Amr\text{-}Bmr\ \omega^2)_{Run} = M_R / \Phi \qquad (63)$$
$$MC_{Run} = M_I / (\ \omega\ \Phi\ ) \qquad (64)$$
$$(Amr\text{-}Bmr\ \omega^2)_{Tare} = Amr - Bmr\ \omega^2 \qquad (65)$$

where MC_{Tare} is the average of values at tare resonant frequency.

$$(Amr - Bmr\ \omega^2)_{Aero} = (Amr - Bmr\ \omega^2)_{Run} - \cdots$$
$$(Amr - Bmr\ \omega^2)_{Tare} \qquad (66)$$

$$MC_{Aero} = MC_{Run} - MC_{Tare} \qquad (67)$$

where p is the roll rate. Final roll computations:

$$C_{lp} + C_{l\dot\beta} \sin \alpha = \frac{-2VC_{Aero}}{q_\infty Sb^2} \qquad (68)$$

$$C_{l\beta} \sin \alpha - k^2 C_{l\dot p} = \frac{-\left(K - I\omega^2\right)_{Aero}}{q_\infty Sb} \qquad (69)$$

$$C_{np} + C_{n\dot\beta} \sin \alpha = \frac{-2VMC_{Aero}}{q_\infty Sb^2} \qquad (70)$$

$$C_{n\beta} \sin \alpha - k^2 C_{n\dot p} = \frac{-\left(Amr - Bmr\omega^2\right)_{Aero}}{q_\infty Sb} \qquad (71)$$

In each listing of equations, notice that the right-hand side of each of the final four computations for each of the three types of testing is similar. The software takes advantage of this similarity by keeping track of each type using the wind-on plot code. Thus, depending upon type of test, the software computes the values and labels them on the monitor and in the data files accordingly.

Appendix B

Model Attitude Equations

Model attitude is measured by an inertial sensor (accelerometer) mounted inside the model. Calibration constants $(\alpha_{SENS}, \alpha_{BIAS}, \alpha_{OFFSET}, \alpha_{DELTA})$ are provided with the Kearfott or Q-Flex signal conditioner chassis, and entered manually into the software "DSP.EXE" during initialization. The signal from the Kearfott or Q-Flex chassis passes to a gain and offset circuit inside the main interface chassis. A fixed gain and user adjustable offset scales and shifts the voltage signal to match the full scale range of a 12-bit A/D located on the DAS-20 board. The software takes the A/D converter count value during each update cycle. The software automatically corrects for wind-on conditions, but the user has to enter the model configuration information. Equations for computing model attitude are listed below:

$$\alpha_{VOLTS} = [\text{A/D converter counts}] * 10.0 / 4096 \qquad (72)$$

$$A1 = \alpha_{SENS} * (\alpha_{VOLTS} - \alpha_{BIAS}) \qquad (73)$$
$$A2 = (\ 180.0 / 3.1415926\ ) * \text{asin}\ (A1) \qquad (74)$$
$$A3 = A2 - \alpha_{OFFSET} - \alpha_{DELTA} \qquad (75)$$

If wind-on conditions, then:
$$AoAval = A3 + \text{flow\_angle} \qquad (76)$$

If the model is inverted, then:
$$AoAval = - [A3] \qquad (77)$$

If both wind-on and inverted model, then
$$AoAval = \text{flow\_angle} - A3 \qquad (78)$$

where α_{VOLTS} = digitized angle of attack sensor voltage, α_{SENS} is the angle of attack sensitivity in volts, α_{BIAS} is the angle of attack bias in volts, a_{OFFSET} is the calibration offset in degrees, α_{DELTA} is the sensor misalignment indegrees, A1, A2, A3 are all intermediate values, flow_angle is the wind tunnel flow angle within test section in degrees, and AoAval is the model attitude.

Appendix C

Function Key Descriptions

The function and letter keys are only active when the main menu is not displayed.

ESC   This key terminates real-time execution and returns control back to the main menu.

F1   This function key displays a Help screen which lists all function keys and their functional assignments.

F2   Use this function key to toggle between average or immediate display of data. Averages are always being computed; the display responds more quickly in immediate mode.

F3   This function key sets all calibration, tare, and wind-on data point counters to 1.

F4   This function key is used to compute a new gain normalization value for the active channel.

F5   Use this key to select calibration code and thus change the type of data stored.

F6   Use this key to enter the sensitivities from the keyboard.

F7   This key displays a menu of options for manipulating tare data and/or performing tare regressions.

F8   This function key provides the user with an opportunity to rename the data files.

F9   This function key is used to activate a continuous display of the measured AoA value, along with measurement statistics.

F10   For any mode of operation, use this key to store mode specific data to the hard disk and plot values on the XY plotter. Since the mode of operation is known, the data is "tagged" appropriately.

F11   This key displays a menu of DSIS hardware mode configuration options. Commands are sent to all IEEE-488 instruments corresponding to the user selected operational mode.

F12   Use this key to print the current data file on the printer.

A   Select which signal conditioner is "active" as indicated by highlighted color of gain/offset displays.

B   Use this key to turn bridge power on or off in order to record mode specific zero values.

C   This key records an AC Calibration data point. The hardware must first be configured before this function can be properly used.

D   This key decrements the currently active signal conditioner's gain.

G   This key displays a list of gain values and corresponding letter codes, and sets the gain of the currently active signal conditioner.

I   This key increments the currently active signal conditioner's gain.

N   Use this key to electrically connect or disconnect the signal conditioners from the bridges. This feature is not normally used in calibration or testing.

S   This key provides a list of shunt calibration resistor pair options to be used for sensitivity data.

U   This key disconnects or unshunts the shunt resistor pairs from the currently active signal conditioner's bridge.

V   Use this key to send a computed offset (from averaged data passed from the DSP micro-computers to the PC) to the signal conditioners.

X   This key commands the signal conditioners to add 0 VDC to the balance inputs, and is used once prior to using the V key.

Z   Instead of the X, V key sequence for nulling the signal conditioners, use this key to let the signal conditioner determine its own offset.

Appendix D

Cable Listing

Cable #	From	To	Signal
C1	2001 DMM	signal conditioner-J7	signal conditioner commands
C2	signal conditioner-J10	main interface-IB1	displacement
C3	signal conditioner-J11	main interface-IB2	torque
C4	signal conditioner-J12	main interface-IB3	secondary
C5	AC calibration box-DP1 out	oscilloscope access panel	displacement
C6	AC calibration box-T out	oscilloscope access panel	torque
C7	AC calibration box-S out	oscilloscope access panel	secondary
C8	AC calibration box-DP1 out	DSP #1-1	displacement
C9	AC calibration box-S out	DSP #2-2	displacement
C10	AC calibration box-T out	DSP #1-2	torque
C11	AC calibration box-DP2 out	DSP #2-1	secondary
C12	Kearfott box-VM	main interface-IB4	Kearfott signals
C14	RPM indicator-J1	DSP interface-J3	clock signals
C15	g-meter out	oscilloscope access panel	g-meter
C16	heater controller +15v	junction panel-J9	g-meter power
C17	RPM indicator-J3	Shaft encoder simulator board-J3	shaft encoder signals
C18	junction panel-J1	signal conditioner-J0	displacement
C19	junction panel-J2	signal conditioner-J1	torque
C20	junction panel-J3	signal conditioner-J2	secondary
C21	junction panel-J4&J5	heater controller-front	power & sensor
C22	junction panel-J4&J5	heater controller-rear	power & sensor
C23	junction panel-J7	Kearfott	Kearfott signals
C24	junction panel-J8	RPM indicator-J2	shaft encoder signals
C25	junction panel-J10	motor speed controller-MC4	AOA motor control
C26	junction panel-J11	motor speed controller-MC3	limit switches
C27	junction panel-J6	motor speed controller-MC1	Motor-Generator control
C28	28V power supply	motor speed controller-MC2	+/- 28VDC
C29	junction panel-J8	shaft encoder	encoder signals
C30	main interface-IB14	DAS-20	datacode & AoA
C31	temperature sensors	junction panel-J4	temperature sensors
C32	junction panel-J12	motor speed controller-MC6	wind-on signal
C33	main interface-IB15	motor speed controller-MC5	datacode signals
C34	PC serial-COM1	plotter-serial in	plotter signals
C35	Oscilloscope access panel	Hand-held multimeter	nulling voltages
C36	DSP interface-J4	Shaft encoder simulator board-J2	shaft encoder signals
C37	HP 3325A sync out	Shaft encoder simulator board-J1	8192/rev
C38	IEEE-488 card	2001 DMM	DMM commands
C39	RPM indicator-J4	HP 3245A-TB1	1/rev
C40	2001 DMM	HP 3245A-HPIB	function generator comma
C41	PC parallel-LPT1	Laser Jet	hardcopy
C42	PC serial-COM2	mouse	user input
C43	signal conditioners-J0	HP 3245A-ch A out	displacement calibration
C44	signal conditioners-J1	HP 3245A-ch B out	torque calibration
C45	signal conditioners-J2	HP 3245A-ch B out	secondary calibration
C46	HP 3245A frequency ref.	HP 3325A ref. out	function generator sync
C47	O'Scope access panel cal sync	HP 3325A sync out	simulated encoder
C48	2001 DMM sw panel-KP1	main interface-IB12	displacement
C49	2001 DMM sw panel-KP3	main interface-IB9	torque
C50	2001 DMM sw panel-KP2	main interface-IB7	secondary
C51	AC calibration box-HPB in	HP 3245A ch B out	AC calibration
C52	AC calibration box-DP1 in	signal conditioner-J10	displacement 1
C53	AC calibration box-DP2 in	main interface-IB10	displacement 2

C54	AC calibration box-T in	signal conditioner-J11	torque
C55	AC calibration box-S in	signal conditioner-J12	secondary
C56	AC calibration box-K in	2001 DMM switch panel-KP0	2001 DMM select
C57	AC calibration box-K out	2001 DMM-input	shaft encoder signals
C58	PC video output	monitor	video
C59	AoA drive motor	junction panel-J10	AoA motor drive
C60	AoA limit switches	junction panel-J11	AoA limit switches
C61	Wind-on switch	junction panel-J12	wind-on signal

*2 required

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