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An Electronic Pressure Profile Display System for Aeronautic Test Facilities

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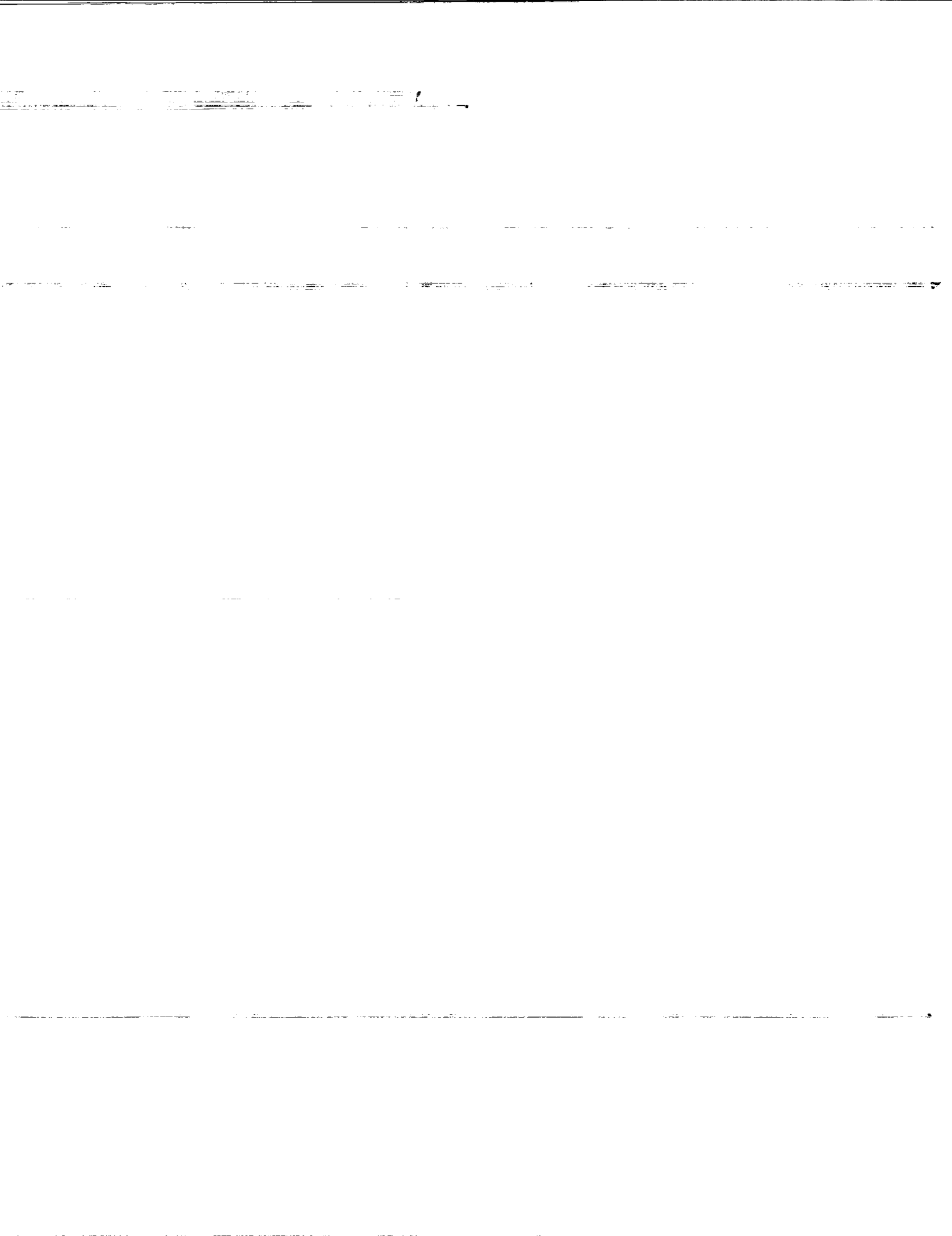*Cleveland, Ohio*

NASA

AN ELECTRONIC PRESSURE PROFILE DISPLAY SYSTEM FOR AERONAUTIC TEST FACILITIES

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ABSTRACT

The NASA Lewis Research Center has installed an Electronic Pressure Profile Display System. This new system provides for the real-time display of pressure readings on high resolution graphics monitors. The Electronic Pressure Profile Display system will replace manometer banks currently used in aeronautic test facilities.

The Electronic Pressure Profile Display System consists of an industrial type digital pressure transmitter (DPT) unit which interfaces with a host computer. The host computer collects the pressure data from the DPT unit, converts it into engineering units, and displays the readings on a high resolution graphics monitor in bar graph format. Software was developed to accomplish the above tasks and also draw facility diagrams as background information on the displays. Data transfer between host computer and DPT unit is done with serial communications. Up to 64 channels are displayed with 1 sec update time.

This paper describes the system configuration, its features, and its advantages over existing systems.

INTRODUCTION

The Electronic Pressure Profile Display System was developed to replace existing mercury manometer banks that were used in Lewis Research Center's 8- by 6-Foot Supersonic and 9- by 15-Foot Subsonic Wind Tunnel Complex. The manometer banks were used to obtain pressure profiles of the tunnel compressor and the supersonic tunnel test section. The compressor profile is used to monitor the performance of the compressor and to watch for a dangerous unloading of the compressor stages. The test section profile is used to monitor the position of the shock in the test section. This allows the tunnel operator to keep the shock downstream of the model.

The Electronic Display System was installed during a rehabilitation of the wind tunnel's control room. Reasons to replace the manometers were twofold. The first reason was to eliminate the obvious health hazards involved with a possible mercury spill in the control room. The second reason was that the new control room was designed to be divided to allow secure (classified) tunnel testing in either the 8 by 6 or the 9 by 15 test section. With the old system a duplicate manometer bank for each half of the control room would have been required. The Electronic Display System only requires a second color graphics monitor for display. The system also allows the displays to be custom made for operator requirements. It also allows for the displays to be located closer to the tunnel operators allowing for a more efficient work area.

The Electronic Pressure Profile Display System is a low cost stand alone system, which provides a more convenient method of viewing pressure profiles, while eliminating the hazards of using mercury manometer banks.

GENERAL SYSTEM OVERVIEW

The Electronic Pressure Profile Display System configuration is shown in Fig. 1. The system consists of an industrial type 64 channel digital pressure transmitter (DPT) unit which interfaces with a host computer. It measures pressures by multiplexing between 64 individual pressure transducers. The DPT unit transmits the pressure data to the host computer.

The host computer collects the pressure data from the DPT unit, converts it to engineering units, and displays the data in bar graph format on high resolution graphics monitors. The host computer is also responsible for initiating an on-line calibration of the DPT unit. It accomplishes this by measuring the values of the calibration pressures and transmitting them to the DPT unit along with a calibration command. The calibration pressures are measured using high accuracy analog pressure transducers PT1 and PT2. The DPT unit applies the pressures to its transducers, calculates conversion coefficients, and then transmits the coefficients to the host computer. The host computer uses these coefficients to convert the pressure data into engineering units. Calibration of the DPT unit is done when the system is first initialized. Calibration can also be activated by an operator push-button.

The host computer accomplishes the above tasks by running a custom application program. This program was written in compiled BASIC and consists of an initialization routine, a calibration routine, a data collection routine, and two display routines.

HARDWARE

The DPT unit used for the system is a commercially available industrial type unit manufactured by Pressure Systems Incorporated (model DPT 6400). The DPT unit consists of a 19 in. (48.3 cm) rack mainframe which houses eight transducer modules, each containing eight solid state silicon pressure transducers. For this application 15 psi (103 kPa) differential range modules were used. Each module has an electronic signal multiplexer and a two position pneumatic calibration valve for its transducers. The mainframe also contains the microprocessor control unit, calibration pneumatics, and serial interface unit. Pressure inputs are connected to the rear of the mainframe. Connections for calibration valve shuttle pressure, reference pressure, and calibration pressures are also on the rear of the mainframe. The DPT unit requires 100 psi (690 kPa) gage for the shuttle pressure. Pressures of 4 psi (27.6 kPa) absolute and 27 psi (186 kPa) absolute are used for calibration. Atmosphere is used for the reference pressure. The DPT unit's block diagram is shown in Fig. 2.

On-line calibration is performed by utilizing the integral calibration valve in each transducer module. This valve is moved between a RUN and a CALIBRATE position by applying the shuttle pressure to a cylinder and piston. In the RUN position the calibration valve connects the transducers to the measurement pressures. In the CALIBRATE position the calibration valve manifolds the transducers to a common calibration pressure. When a calibration is activated, the calibration valve is moved to the CALIBRATE position and two accurately measured pressures are sequentially applied to the transducers for a two point calibration. The DPT unit records the voltage reading for each transducer and calculates the conversion coefficients for each transducer. It then transmits the coefficients to the host computer which uses the coefficients to convert the pressure data into engineering units. Communications between the host computer and the DPT unit are by serial communications at 9600 BAUD.

The host computer runs the software which drives the electronic display system. The microcomputer used for this system is an IBM AT compatible rack mountable personal computer. Communications to the DPT unit are through the computer's RS232c serial communications port. An analog to digital conversion card is used to measure the calibration pressures which are monitored by 0 to 5 V high accuracy pressure transducers. The A/D card uses 12 bit resolution for the A/D conversion. The A/D card also has digital inputs and outputs which are used for operator interface via remote push-buttons. The remote push-buttons allow the operator to either initiate a DPT unit calibration or

to obtain a screen copy of the pressure profiles. The screen copy is produced on a dot matrix printer.

The pressure profiles are displayed in bar graph format on high resolution color graphic monitors. The monitors use a 640 pixel wide by 350 pixel high format. A total of 64 colors are available to be used for displaying the profiles. The monitors are driven by a Enhanced Graphics Adaptor card, located in the computer. The Pressure Profile Display System has two monitors being run in parallel from the same graphics card. Each monitor is located remotely at a tunnel operator's station.

Physically, the Electronic Display System is located in the wind tunnel control room. The DPT unit, host computer, and system pneumatics are located in one 19 in. (48.3 cm.) rack (Fig. 3). The display monitors and operator push-buttons are located at the tunnel operator stations (Fig. 4). Overall, the system is compact and uses less space than the old manometer banks.

SOFTWARE

The software that runs the Electronic Pressure Profile Display System is written in compiled BASIC. The program consists of five parts. They are as follows: DPT initialization, DPT calibration, background diagram display, data collection, and data display. The program flow chart is shown in Fig. 5.

The initialization routine sets up communications with the DPT unit. The initialization routine also sets up the following parameters used by the DPT unit:

    RS232c communication parameters - Allows user to set up communication parameters, such as handshaking characters and protocol to be used for data transfer. For this application the format of eight data bits, one stop bit, and no parity is used.

    Output options - Allows user to specify where DPT unit output is to be sent and what order the DPT channels are to be scanned. For this application the DPT output is sent to the serial port and the transducers are scanned sequentially 1 to 64.

    Number of averages to be used - Allows user to specify how many averages are to be taken for each transducer reading. Options of 1, 2, 4, 8, and 16 averages are available per reading. This application uses eight averages per reading.

Other options and parameters are also sent to the DPT unit during this portion of the program. This part of the program is executed during initial system start up.

The calibration routine initiates a two point calibration of the DPT unit. Calibration pressures are measured using the 0 to 5 V analog pressure transducers. The values of the calibration pressures are read into the computer by accessing the

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A/D input port. The values of the span and zero pressures along with a calibration command are then transmitted to the DPT unit. The DPT unit applies the calibration pressures, records the voltage readings, and calculates the conversion coefficients. The coefficients are sent back to the host computer and stored in an array designated for each transducer. A calibration sequence requires 0.2 sec to read calibration pressures, 17.6 sec for DPT unit to calibrate and calculate coefficients, and 14.2 sec for the coefficients to be transferred to the host computer for a total time of 32 sec. The calibration routine is executed on initial boot up of the system or by operator request using a push-button. The calibration push-button input is looked for every data scan. When the DPT unit is calibrating, data is not taken or displayed.

The main part of the electronic display program is the data collection routine. The host computer sends a scan command to the DPT unit. The DPT unit executes a scan of the 64 pressure transducers and transmits the pressure data back to the host computer. The data received by the computer is in counts. Each pressure reading consists of four ASCII characters. The ASCII high byte is stripped from each character and the program uses the following conversion to convert the readings into actual pressure (psia):

$$PSIA = \{[(B1)4096 + (B2)256 + (B3)16 + (B4)]cts \\ \times (10v/cts)(C1\ PSIA/v)\} + CO$$

where

    Bn byte
    C1 span coefficient
    CO zero coefficient

This conversion is executed for all 64 channels. Engineering units are stored in an array that is used for graphical display. The output option of counts is used so data transmission would only require four characters per reading. Other scan commands were available that transmit the data in actual engineering units. This requires transmission of nine characters per reading, thus doubling data transmission time. It was found that by using the output in counts and making the engineering unit conversion in the computer, faster scan time could be obtained. Time to scan and transmit data for 64 channels is 0.7 sec. Time required to convert 64 readings into engineering units is 0.1 sec. Total data collection time for 64 readings is 0.8 sec.

The display routines of the program use graphics commands to display the data in bar graph format on the high resolution color monitors. The first display routine draws background diagrams (Fig. 6). Diagrams are drawn using graphics commands in BASIC. The diagrams are drawn to relate the pressure bars to the pressure sampling port locations. In this configuration there are two background diagrams. The first diagram is a schematic of the seven stage compressor. This diagram allows the operator to view the pressure profile of the compressor stages. The second diagram is a schematic of the wind tunnel's test section.

This diagram allows the tunnel operator to monitor the shock in the test section by watching the pressure profile. Reference lines are also drawn on diagrams to indicate values of the pressure readings. The time required to draw the background diagrams is 1.7 sec. The background diagrams are only drawn once, when the system is finished calibrating.

The second display routine draws the pressure readings in bar graph format for every data scan. The readings are first scaled into pixels. Drawing resolution is 10 pixels per 1 psia. To prevent screen flicker only the difference between the previous value is added or taken away from the bar. Colors are assigned to the pressure bars to enhance visibility. The nominal time required to draw the pressure bars is 0.25 sec for 64 channels.

User interface with the program is minimal. The Display System was designed as a stand alone system. The operator is able to initiate two functions through push-button inputs. The first function allows the operator to initiate a DPT calibration. The second function allows the operator to obtain a screen copy and data print-out of the pressure profiles. Both of these functions are accomplished in the program by scanning the respective push-button inputs and executing the required routine when a push-button is detected.

The display system has a display rate of ~64 readings per sec, with the following breakdown of time required for each task:

Scanning/collecting data from DPT unit	= 0.7 sec
Converting readings to engineering units	= 0.1 sec
Displaying pressure readings	= 0.25 sec
Total time required for displaying 64 channels	= 1.05 sec

The DPT unit specifies a nominal throughput rate of 60 readings per sec. Thus, the display system update time is limited by the throughput rate of the DPT unit. The update time of once a second was adequate for the application of displaying pressure profiles. System update rate could be improved by using an IEEE 488 parallel communications interface for obtaining data from the DPT unit. The DPT unit has a data throughput rate of 500 readings per sec when the parallel interface option is used. This would increase the display rate of the display system. The IEEE 488 parallel interface option is available for the DPT unit. However, the data collection and transmission routines used in the program would have to be modified.

SYSTEM ACCURACY

Based on the vendor's equipment specifications, the Electronic Pressure Profile Display System accuracy is as follows:

DPT unit   0.25% x 15 psi (103.4 kPa)
              = ±0.038 psi (0.26 kPa)

Transducers used for calibration pressure
measurement   0.05% x 50 psi (344.8 kPa)
              = ±0.025 psi (0.17 kPa)

              ±0.063 psi (0.43 kPa)

This yields a worst case error of ±0.063 psi
(0.43 kPa) in measuring the pressures. However,
the drawing resolution is 10 pixels/psi and pres-
sure bars are displayed to the nearest 0.1 psi
(0.69 kPa). The error in measuring the pressures
is within this drawing resolution. Thus, the
electronic display system accuracy is limited by
the drawing resolution to ±0.1 psi (0.69 kPa).
In this application this was satisfactory since
the desired output was a pressure profile and not
actual pressure readings. In applications where
pressure readings would be required an accuracy
of ±0.063 psi (0.43 kPa) could be obtained.

COST

The cost of the Electronic Pressure Profile Dis-
play System is as follows:

DPT unit with 64 channel capability	13 K
Personal computer	2 K
Display monitors (1.5 K each)	3 K
Transducers for calibration pressures (1 K each)	2 K
A/D card	0.5 K
System pneumatics (regulators, vacuum pump, etc.)	0.5 K
TOTAL SYSTEM COST	21 K

This translates into $330 per pressure reading.
This is a relatively low cost when compared to
the potential costs associated with mercury clean
up if a manometer bank were to overflow.

Another benefit of the electronic display system
is the low manpower time required for maintenance.

There is minimal set up time involved with the
system. Once the system is brought on-line it is
left running continuously. The only operator
requirement is to calibrate the system periodi-
cally. This is accomplished as a daily run check-
sheet item and is initiated by pressing the
calibration push-button. The only other periodic
maintenance required is the recalibration of the
pressure transducers used in measuring the cali-
bration pressures. This is done every 6 months
as part of a periodic maintenance checksheet.
Thus, the Electronic Display System requires less
set up and maintenance time as compared to other
pressure display systems.

SUMMARY

The Electronic Pressure Profile Display System
provides a modern state of the art replacement of
manometer bank used for displaying pressure pro-
files in aeronautic test facilities. The system
eliminates the hazards of mercury while adding a
more flexible display system. Displaying the pres-
sure profiles on the graphics monitors presents a
more visible display and enhances the operation
of the facility. The Electronic Pressure Profile
display system is currently being used in the 8-
by 6- and 9- by 15-Foot Wind Tunnels, and is
planned on being used in the 10- by 10-Foot Super-
sonic Wind Tunnel.

In conclusion, the Electronic Pressure Profile
Display System is a major improvement over exist-
ing mercury manometer banks being used in aeronau-
tic test facilities.

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DPT UNIT

15 PSID MODULES

PRESSURE INPUTS

1
2
64

RS-232C

SERIAL COMM. PORT

HOST COMPUTER

A/D CARD

EGA CARD

Digital I/O

SHUTTLE PRESSURE — 100 PSI

REF PRESSURE — ATM

CALIBRATE PRESSURE 1 — 4 PSIA

CALIBRATE PRESSURE 2 — 27 PSIA

PT1

PT2

19" Monitor

8 x 6 Operators Station

Pushbutton Interface Station

CAL   COPY

19" Monitor

9 x 15 Operators Station

Pushbutton Interface Station

CAL   COPY

CABLE TERMINATION ROOM
(19 " RACK)

OPERATOR'S CONSOLES

FIGURE 1. – ELECTRONIC PRESSURE PROFILE DISPLAY SYSTEM.
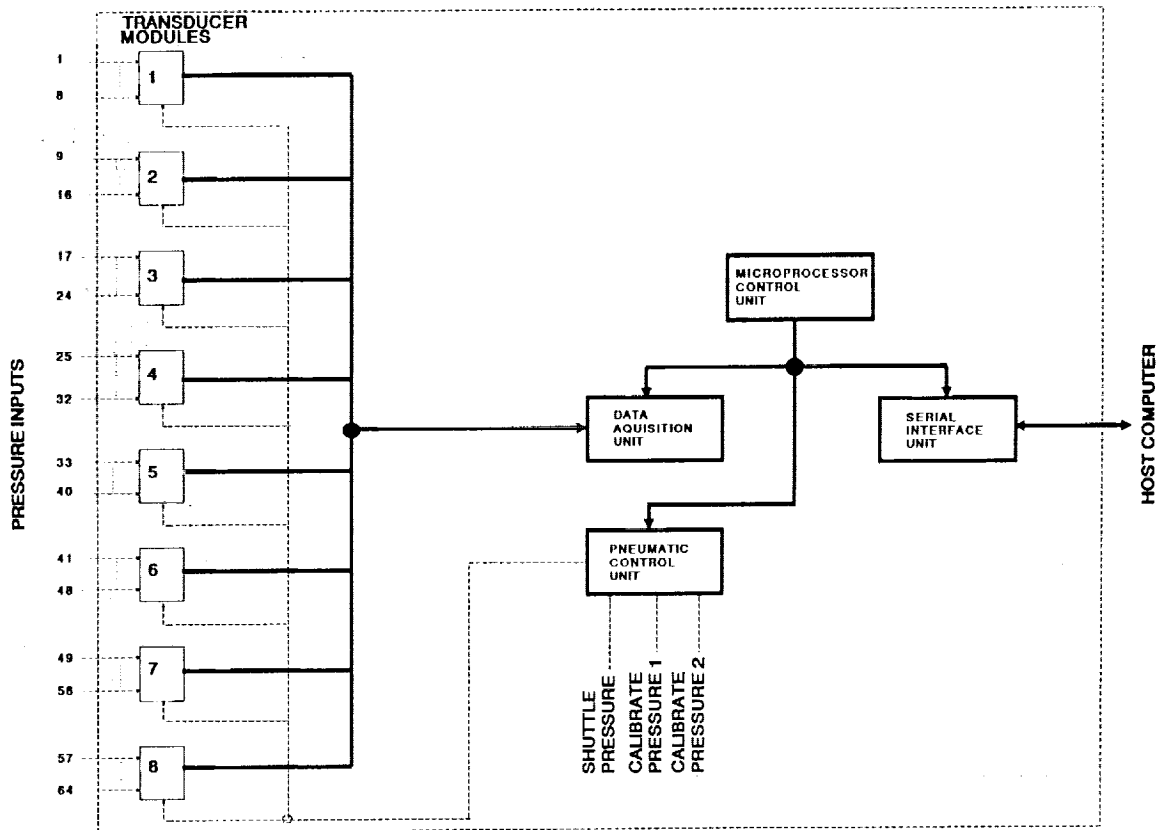
FIGURE 2. - DPT UNIT BLOCK DIAGRAM.

FIGURE 3. - DPT UNIT, COMPUTER, AND SYSTEM PNEUMATICS.

FIGURE 4. - DISPLAY MONITOR AND OPERATOR PUSHBUTTON STATION. (LOCATED TOP CENTER OF
PHOTOGRAPH).

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                    ┌─────────────────┐
                    │ INITIALIZATION  │
                    │    ROUTINE      │
                    └─────────────────┘
                             │
                             ▼
                    ┌─────────────────┐
                    │  CALIBRATION    │
                    │    ROUTINE      │
                    └─────────────────┘
                             │
                             ▼
                    ┌─────────────────┐
                    │   BACKGROUND    │
                    │  INFO. DISPLAY  │
                    │    ROUTINE      │
                    └─────────────────┘
                             │
                             ▼
                    ┌─────────────────┐
                    │     DATA        │
                    │  COLLECTION     │
                    │    ROUTINE      │
                    └─────────────────┘
                             │
                             ▼
                    ┌─────────────────┐
                    │     DATA        │
                    │   DISPLAY       │
                    │    ROUTINE      │
                    └─────────────────┘
                             │
                             ▼
                    ┌─────────────────┐
                    │     CHECK       │
                    │  PUSHBUTTON     │
                    │    INPUTS       │
                    └─────────────────┘
                             │
                             ▼
   ┌──────────┐           ╱   ╲
   │  PRINT   │  ◄─ YES  ╱ HARD ╲
   │  SCREEN  │          ╲ COPY ╱
   │ ROUTINE  │           ╲   ╱
   └──────────┘            ╲ ╱  NO
                            │
                            ▼
                          ╱   ╲
                         ╱CALIBRATE╲
                  YES    ╲       ╱    NO
                          ╲     ╱
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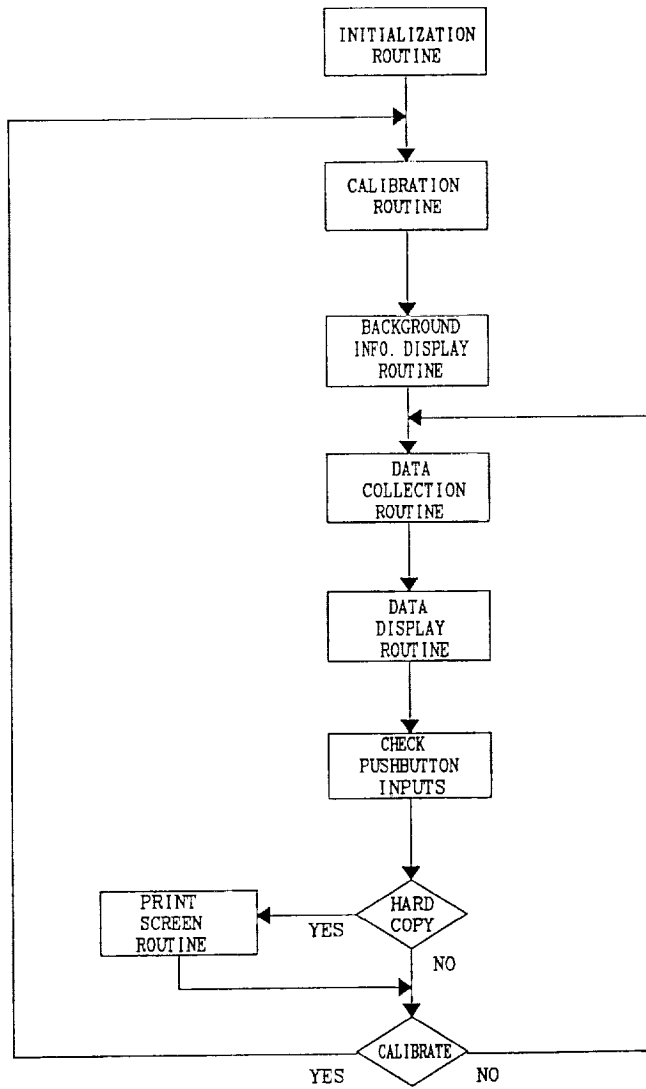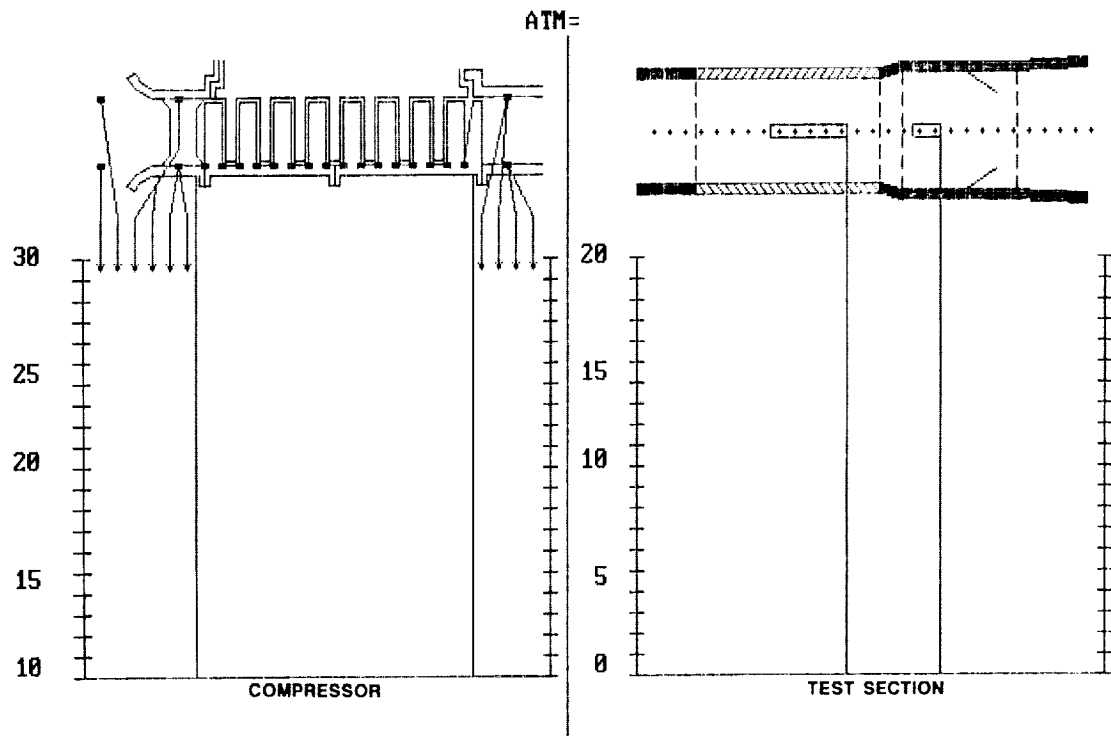
FIGURE 5. – PROGRAM FLOW CHART.

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FIGURE 6. - PRESSURE PROFILE DISPLAY BACKGROUND DIAGRAMS.
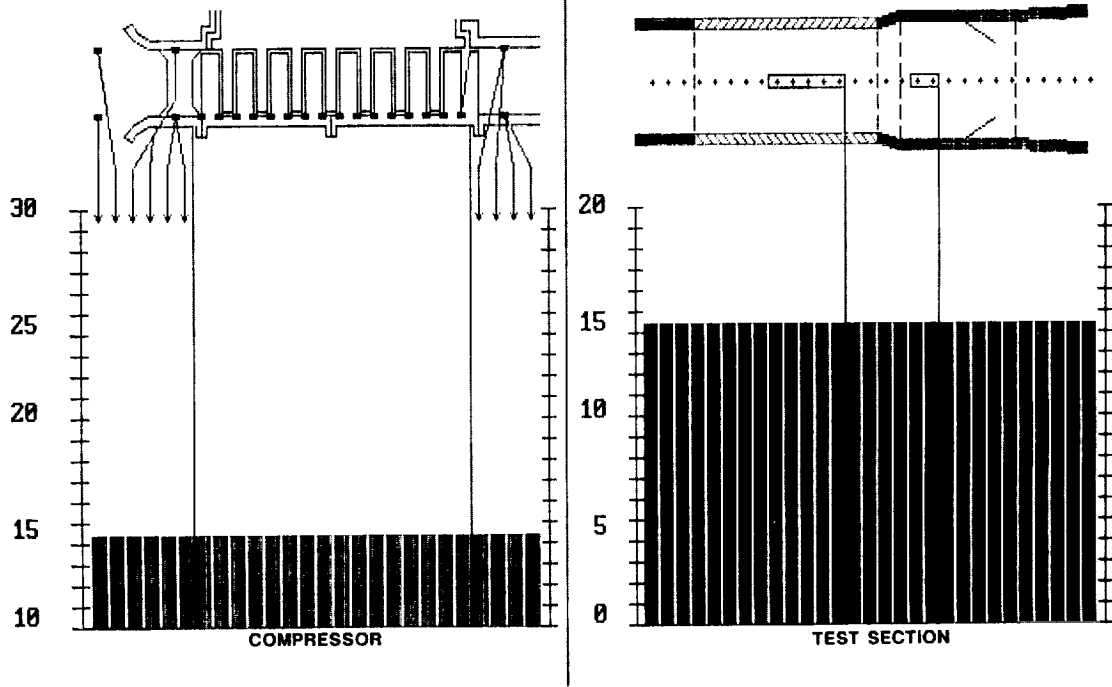
FIGURE 7. - PRESSURE PROFILE DISPLAY FOREGROUND PRESSURE BARS.

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16. Abstract

The NASA Lewis Research Center has installed an Electronic Pressure Profile Display system. This new system provides for the real-time display of pressure readings on high resolution graphics monitors. The Electronic Pressure Profile Display system will replace manometer banks currently used in aeronautic test facilities. The Electronic Pressure Profile Display system consists of an industrial type Digital Pressure Transmitter (DPT) unit which interfaces with a host computer. The host computer collects the pressure data from the DPT unit, converts it into engineering units, and displays the readings on a high resolution graphics monitor in bar graph format. Software was developed to accomplish the above tasks and also draw facility diagrams as background information on the displays. Data transfer between host computer and DPT unit is done with serial communications. Up to 64 channels are displayed with one second update time. This paper describes the system configuration, its features, and its advantages over existing systems.

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