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MEASUREMENT OF CASE WALL PRESSURE SIGNATURES IN A TRANSONIC COMPRESSOR USING REAL-TIME DIGITAL INSTRUMENTATION

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Monterey, California

THESIS

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DIGITAL INSTRUMENTATION

by

Gordon Curtis Paige

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Thesis Advisor: R. P. Shreeve

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SYMBOLS AND ABBREVIATIONS

Latin

K_B	Blockage factor
N*	Referred RPM
p	Instantaneous static pressure
$\bar{p}$	Time average static pressure
p_{min}	Minimum pressure
p_a	Ambient static pressure
p_r	Reference static pressure
p_t	Total (stagnation) pressure
q	$1/2\ \rho W^2$
r	Radial distance from compressor centerline
S	Pressure coefficient $\left[\frac{p - p^2}{1/2\ \rho W_2^2}\right]$
W	Flow velocity relative to the rotor
w*	Referred flow rate (lbm/sec)
V	Absolute flow velocity
V_t	"Limiting" flow velocity
X	Non-dimensional velocity (V/V_t)

Greek

β	Flow angle relative to the rotor
Φ	Flow function
Ω	Blade loading parameter (or Ohms)
ξ	Ratio of non-dimensional flow rate to flow function at the case wall

Subscripts

1	Rotor inlet
2	Rotor exit
o	Outer wall
r	Reference
t	Total (stagnation)

Abbreviations

A/D	Analog-to-Digital
TRANSX	Transonic (used in connection with the Transonic Compressor)
txdcr	Transducer

I. INTRODUCTION

The study reported here is part of a program at the Naval Postgraduate School to determine the behavior of the flow in a transonic compressor stage. The purpose is to develop an input into the design method which will account for the three dimensional and periodic nature of the flow. The stage under examination was designed by Dr. M. H. Vavra and installed in the Turbopropulsion Laboratories of the Naval Postgraduate School. The work is sponsored by Naval Air Systems Command, Code 310, through the office of Dr. H. J. Mueller.

In the present work unsteady case wall pressure signatures were measured at the leading edge of the rotor. These measurements required the development of techniques, programs and hardware that are of general application in the program of real-time measurements in the transonic compressor.

Considerable work has been done in the area of unsteady pressure measurements in turbomachines. Recently, H. B. Weyer [Ref. 1] and H. E. Gallus [Ref. 2] reported their experiences in the use of fast response transducers in measuring wall static and flow total pressures. Weyer has also devoted time to the solution of the problem of measuring true time average pressures. These references provide an excellent review of the subject and a source of references for the study reported here.

Real-time measurement of pressures has been possible only with the advent of the ultra-miniature, high response, semiconductor transducers such as the Kulite used in this study. The transducer was coupled with a computer controlled, analog-to-digital converter to acquire pressure data at sampling rates of 100 KHz. The data were then automatically transferred to a Hewlett-Packard Model 9830A Calculator system equipped with a disk memory unit for storage, reduction and presentation. Programs were written to present the data in the form of distributions of pressure rise across a single blade space. The measurements from eighteen consecutive blade spaces so plotted indicated deviations resulting from geometrical non-uniformity and flow unsteadiness. Extension of the procedures to obtain pressure maps from recordings of several transducers is straightforward.

An on-line calibration procedure was used to reduce the transducer output to pressure with the assumption that a concurrent pneumatic measurement of the same axial station was the true time average of the pressure. Further consideration must be given to the measurement of time average pressures of higher compressor speeds.

The results presented in the body of this report represent the first application of a number of new instruments, a sophisticated data system and previously untried experimental techniques. The real-time data system which uses a Hewlett-Packard 21MX computer is described in Appendix A. The general procedures for its operation and use in acquiring data from the transonic compressor are given there. The procedures developed for calibrating and verifying the instrumentation and data system are reported in Appendix B. A flow generator is described which was designed to provide a simulated compressor pressure waveform at up to 10 KHz. The procedure used for reducing the compressor data is given in Appendix C and, lastly, the theoretical calculation of the peak pressure amplitude on the compressor blade is found in Appendix D.

II. TRANSONIC COMPRESSOR

A. DESCRIPTION

The transonic (TRANSX) Compressor Test Rig consists of an air turbine drive unit and an induction section containing a filter, throttle, settling chamber and flow measuring nozzle. Figure 1 shows the TRANSX Compressor assembly. The turbine drive unit supplies 450 HP at 30,000 RPM. The compressor is designed to operate at 30,460 RPM with a relative tip Mach number of 1.5. At the design RPM and tip Mach number, the flow angle is 65° and the pressure ratio is 1.6 at a referred flow rate of 10 lbm/sec. The compressor flow rate is controlled by a rotating throttle plate. The test rig is located in a explosion-proof cell and is operated from a remote console. A complete description of the laboratory facilities and the test rig are given in Refs. [3] and [4].

B. INSTRUMENTATION

In addition to the Kulite transducer which is described in section III, a number of static pressure taps and pneumatic probes are installed in the TRANSX Compressor. Figure 1 shows the general arrangement and location of the static taps along the case wall. Provision is made for the installation of Kulite transducers at stations upstream and through the rotor and stator blading. Each Kulite station is matched by a pneumatic pressure tap at the same axial location but displaced peripherally. A data recording system [Ref. 3] was used to scan and record steady-state pressure and temperature data. The recorded output was on punched paper tape which was then reduced with the HP 9830A system (see Appendix A). These data were used as an adjunct to the transducer information, providing inputs to the reduction program and providing confirmation of the desired operating point prior to data taking.

C. BLADING DESIGN

The rotor blades on the TRANSX compressor are of circular arc design. The pressure side is flat, as indicated by Fig. 2. Table I gives dimensions of the blade at the tip section. The rotor diameter is 11.0 in. and the hub-to-tip ratio is 0.5 at the rotor face.

III. INSTRUMENTATION AND DATA PROCEDURES

A. TRANSDUCER AND MOUNTING

A single Kulite CQL-080-25 fast response pressure transducer was mounted in an epoxy mount flush with the inner case wall of the TRANSX Compressor. Figure 3 shows the axial and peripheral location of the transducer in relation to the static pressure taps used in the data reduction. The static taps identified in Fig. 3 as S7 and S9 are the seventh and ninth static taps, respectively, beginning upstream.

The Kulite, a view of which is shown in Fig. 4, is an ultra-miniature, semiconductor, strain gauge transducer. It has a natural frequency at 125 KHz which allows for sampling of frequencies in the 25 KHz range without undue concern for distortion [Ref. 1]. Table II gives the factory specifications for the transducer.

B. SIGNAL CONDITIONING

The transducer signal was processed by a newly constructed amplifier/signal conditioning unit. Figure 5 shows a schematic diagram of the signal conditioning circuit. Amplification can be varied by changing the gain resistor, R_g. With the 1.56 KΩ resistor which is presently installed, the amplification was approximately 120:1. The signal conditioning unit also served as a junction box for the five-volt bridge power supply. The amplified transducer signal was transmitted to the A/D converter input plug through a sixteen channel junction box. Figure 6 shows the components of the instrumentation system.

C. CALIBRATION

The sensitivity of semiconductor transducers is temperature dependent and therefore the calibration procedure must be carefully considered. A static calibration in which the transducer response is mapped as a function of temperature and pressure can establish basic characteristics. However, since the transducer temperature cannot be measured during application, an on-line method can provide greater accuracy.

Five different calibration and verification procedures were conducted on the Kulite transducer, the instrumentation system and the data system: (i) a static calibration provided baseline data with which to compare the first dynamic measurements and verified the linearity of the transducer; (ii) a controlled temperature test was made in an oil bath to determine the temperature stability; (iii) the sampling rate of the A/D converter and the fidelity of reproduction were verified using a sine wave voltage input; (iv) the periodic Flow Generator (described in Appendix B) was used to verify data taking and handling procedures as well as to provide information on the transducer rise time; (v) finally, the on-line calibration method was used to provide a reduction polynomial for the data taken from the compressor.

Details of the calibration tests and results are given in Appendix B.

D. TEST PROCEDURE

Before recording data, the electronics and the TRANSX Compressor were run for several hours to allow them to stabilize at operating temperature. The real-time data system was prepared by loading the data acquisition and transfer programs as described in Appendix A. The compressor was brought to a desired operating point determined by the computer reduction of steady-state data acquired with the 'B & F' data system [Ref. 3]. The step-by-step procedure for taking a data sample is given in Appendix A. Briefly, the real-time data samples were taken by the 21MX computer and transferred to the 9830A system for storage on a disk memory unit. Concurrently, the 'B & F' data system acquired steady-state data at the same operating point. The reference pressure on the transducer was then changed and the process was repeated. At least three scans at different reference pressures were taken.

E. DATA ANALYSIS AND PRESENTATION

Data acquired and transferred to the 9830A system were reduced using the programs for the 9830A described in Appendix A. The recorded transducer output voltages were reduced to pressures by applying the on-line calibration reduction described in Appendices B and C. The pressure rise above upstream static pressure (S7 in Fig. 3) was first plotted as a function of elapsed time from the first sample. The sampling interval was assumed to be constant and equal to 10 μ sec. The result was as shown in Fig. 7. In this figure the discrete data points are connected by straight lines to emphasize the waveform.

The pressure rise data, shown for example in Fig. 7, were also plotted as a peripheral distribution across a single blade space. The data for one complete revolution of the rotor (18 blades) were plotted as a function of the normalized blade-to-blade distance, using the procedure outlined in Appendix C. The results are shown, for example, in Fig. 8.

IV. RESULTS OF COMPRESSOR TESTS

Unsteady pressure measurements were made in the Transonic Compressor at six operation conditions.

a. 50% Design Speed, Open Throttle

b. 50% Design Speed, Near Surge

c. 50% Design Speed, Surge

d. 65% Design Speed, Open Throttle

e. 65% Design Speed, Partial Throttle

f. 65% Design Speed, Near Surge

Figures 7 through 17 show the results of the tests. Raw and reduced data were stored on the mass memory unit of the HP 9830A. Because of the large quantity of data, it was not feasible to include it in this report. Of the above mentioned results, the data for 50% Design Speed in the surge condition are felt to be inconclusive for reasons which are discussed in the next section.

V. DISCUSSION

The results presented here for case wall static pressure distributions in the TRANSX Compressor are preliminary in nature. More measurements must be made at other axial locations before the pressure signatures can be properly interpreted. However, the data obtained from one transducer at one location successfully verified the instrumentation, programs and the experimental technique required for a complete study involving several channels.

The transducer, signal conditioning circuit and real-time data system performed well. The generation of programs for the data acquisition and transfer was difficult because the microcomputer used a paper tape operating system; however, once programmed, the system was easy to use.

The on-line calibration technique was successful. The procedures for loading the transducer and recording data required less than three minutes for each operating point.

In attempting to interpret the pressure measurements shown in Fig. 7 through Fig. 17, it is important to realize that the transducer was mounted at the leading edge of the rotor, Fig. 3. An inspection showed that as the rotor turned, the sensor surface (0.040" in diameter) was completely covered in the axial direction by some of the blades, but partially uncovered by others. This was due to small differences in the integrally machined blades at the tip section. Thus, part of the variation observed in all the results from one blade passage to another can be attributed to geometrical differences in the blading. In comparison, the effects of a possible deviation in the sample interval from a constant value of 10 μ sec., and a deviation in the rotational speed during one revolution, are thought to be small.

The effect of throttling at 50% of design speed is seen in Fig. 8 and Fig. 10. The distribution of pressure is observed to steepen and the peak pressure to remain unchanged. Design incidence occurs at a throttle condition between the open throttle condition represented by Fig. 8 and the near surge condition represented by Fig. 10. The peak suction condition therefore gives a pressure at the transducer location between 1.2 and 1.6 inches of Mercury below upstream static pressure, or 3.15 to 4.33 inches of Mercury below atmospheric pressure. In Appendix D a value of 5.57 inches was estimated for the peak suction pressure on the blade based on a series of assumptions and on cascade measurements of a different blade shape. The lack of agreement is understandable. It is encouraging, however, to anticipate the measurement and interpretation of data obtained at different axial locations through the blading.

The data obtained in the surge condition (Fig. 11) is of some interest in that the level of pressure is several inches of Mercury above upstream static pressure, and no periodicity is visible in the record. During the data sample, the compressor was surging with a frequency of several cycles per second. The total time for the sample was 0.01 sec. The sample time was therefore too short to indicate transients characteristic of surge.

At 65% of design speed, for which the normalized data plots are shown in Fig. 13, Fig. 15 and Fig. 17, the flow relative to the rotor is estimated to be approximately sonic. The degree of scatter in the data over the first half of the distribution was observed to be consistent with unsteadiness in the trace simultaneously observed on an oscilloscope. In contrast, the reduced scatter over the pressure side of the blade space was consistent with steadiness observed in the oscilloscope trace. The flattened section of the distribution which occurs between 0.3 and 0.4 of the normalized blade-to-blade distance could be the result of shock/case-wall boundary layer interaction. The sharp rise in pressure seen in Fig. 17 at 0.2 of the blade-to-blade distance is thought to be the bow shock resulting from just supersonic relative flow conditions.

Difficulty in measuring the true time average pressure introduced an error of 1% to 2% at the rotor speeds for these tests (Appendix B). This error could become as high as 10%, according to Ref. 1, at higher rotor speeds. The error introduced, however, affects only the absolute level of the pressure and not the quality of the time varying signal.

VI. CONCLUSIONS

The methods developed and applied in the present study, for measuring unsteady static pressures have provided accurate and repeatable results. With the addition of a more accurate determination of the true time average static pressure, real-time pressure signatures can be reconstructed quickly and simply. The potential for the technique lies in the ability to produce pressure "maps" at the case wall. With this goal in mind, future testing should include:

1. Testing with improved techniques for measuring the time average static pressures. A rotating piston such as that described in Ref. 1, or a small sensing orifice which opens into a much larger settling chamber (in order to minimize differences between in and outflow), are two possible methods of approach.

2. Testing throughout the entire range of operation of the compressor with multiple transducers installed. This will provide data across the blade chord and will enable maps to be produced using techniques similar to those described in Appendix C.

3. Development of a 'synchronous sampling' technique. This would involve the use of a trigger pulse to start the sampling procedure at a particular location with respect to the rotor and to allow samples to be taken at one revolution intervals. Samples taken in a synchronous manner would show whether the flow is steady in the frame of the rotor and would eliminate the differences in successive blade passages caused by small differences in the blading geometry.

G	Angle between profile chord and rotor axis	59° 49' 35"
C	Profile chord	2.688
R	Radius of profile contour	16.330
E	Chord with sharp leading and trailing edges	2.911
A	Distance of stack point S from profile chord	.026
T	Maximum profile thickness	.065
ER	Leading and trailing edge radius	.005
X1	Distance of profile edge from S in axial direction	.660
X2	Distance of profile edge from S in axial direction	.696
Y1	Distance of profile edge from S in peripheral direction	1.152
Y2	Distance of profile edge from S in peripheral direction	1.1732
P1	Distance of point LE from S in axial direction	.709
P2	Distance of point TE from S in axial direction	.754
Q1	Distance of point TE from S in peripheral direction	1.245
Q2	Distance of point LE from S in peripheral direction	1.271

Table 1. Blade Tip Profile Dimensions

Table II.

KULITE CQL-080-25

FACTORY SPECIFICATIONS

Rated Pressure	25 psi
Max. Pressure	50 psi
Nominal Output (Rated Pressure)	75 mV
Bridge Excitation Voltage	5 V (7.5V max)
Bridge Impedance	750 Ω
Zero Balance	± 3% Full Scale
Combined Non-Linearity and Hysteresis	± 1.0% Full Scale
Repeatability	0.5%
Compensated Temperature Range	25-80° C
Change of Sensitivity with Temperature	± 2.5% / 100° F
Change of no-load Output with Temperature	± 2% / 100° F
Natural Frequency	125 KHz
g-Sensitivity	Perpendicular: 0.0003%FS/g Transverse: 0.00006%FS/g
Resolution	INFINITE

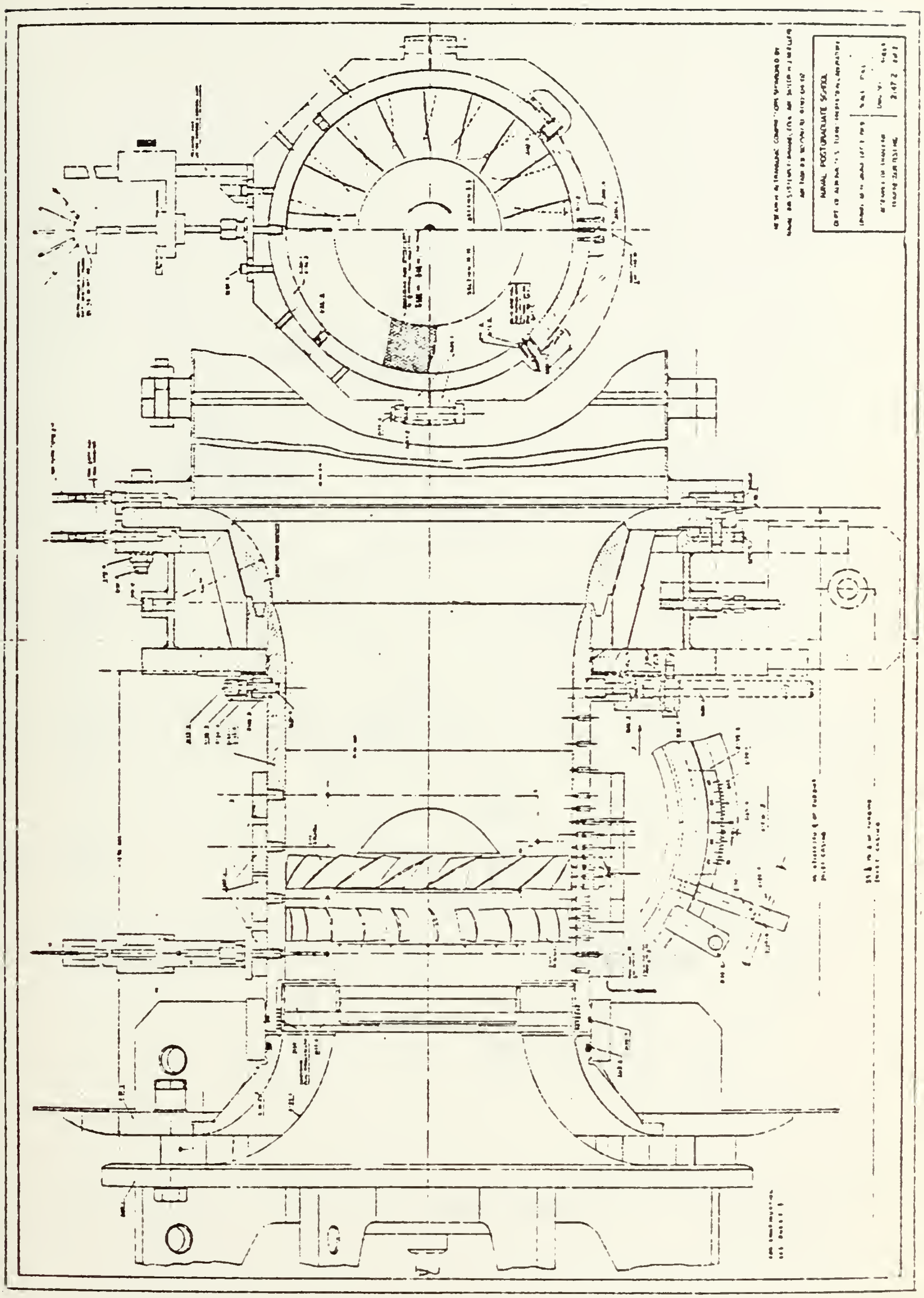

Figure 1. Transonic Compressor Assembly

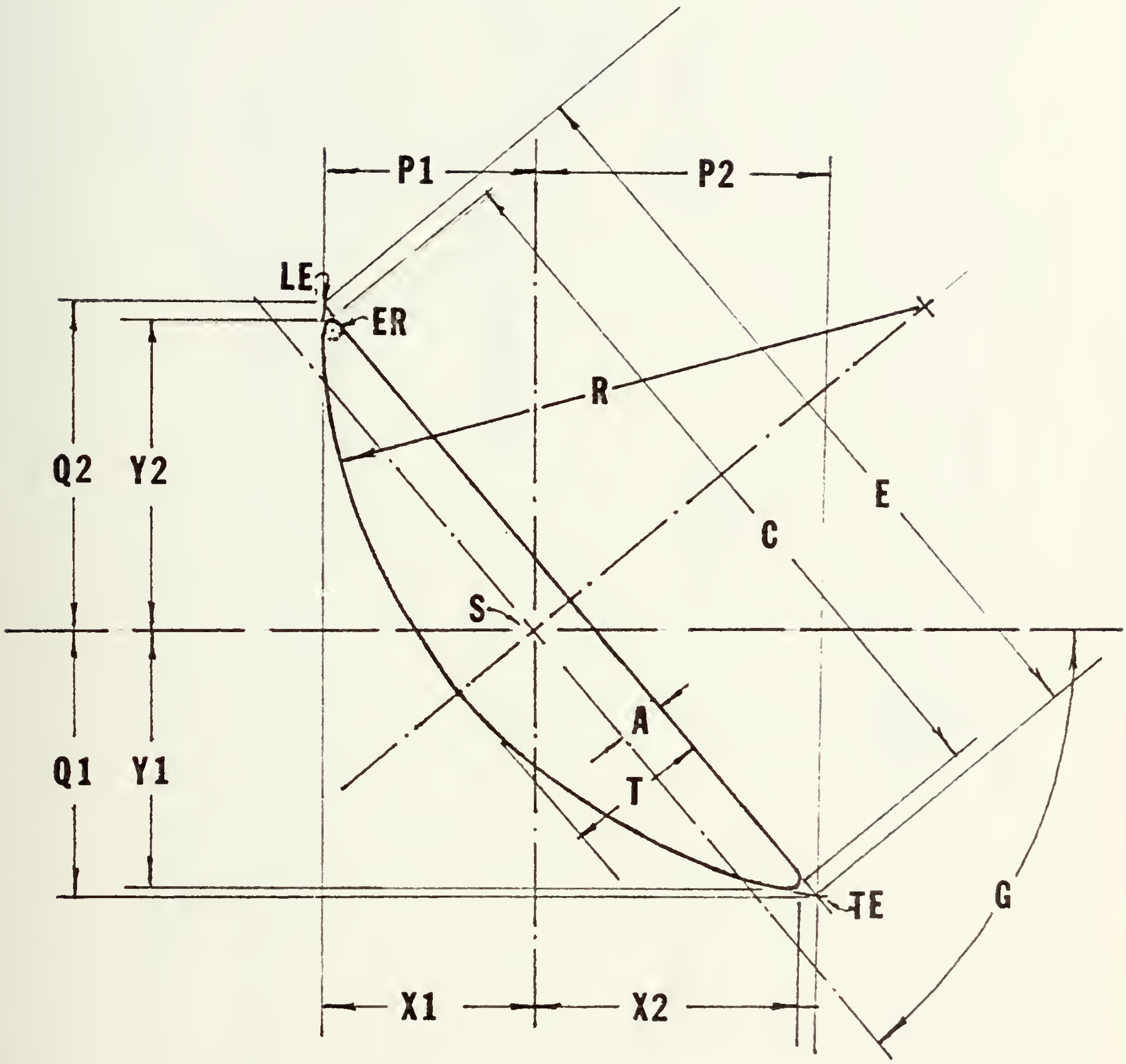

Figure 2. Rotor Blade Tip Profile (See Table I for Dimensions)

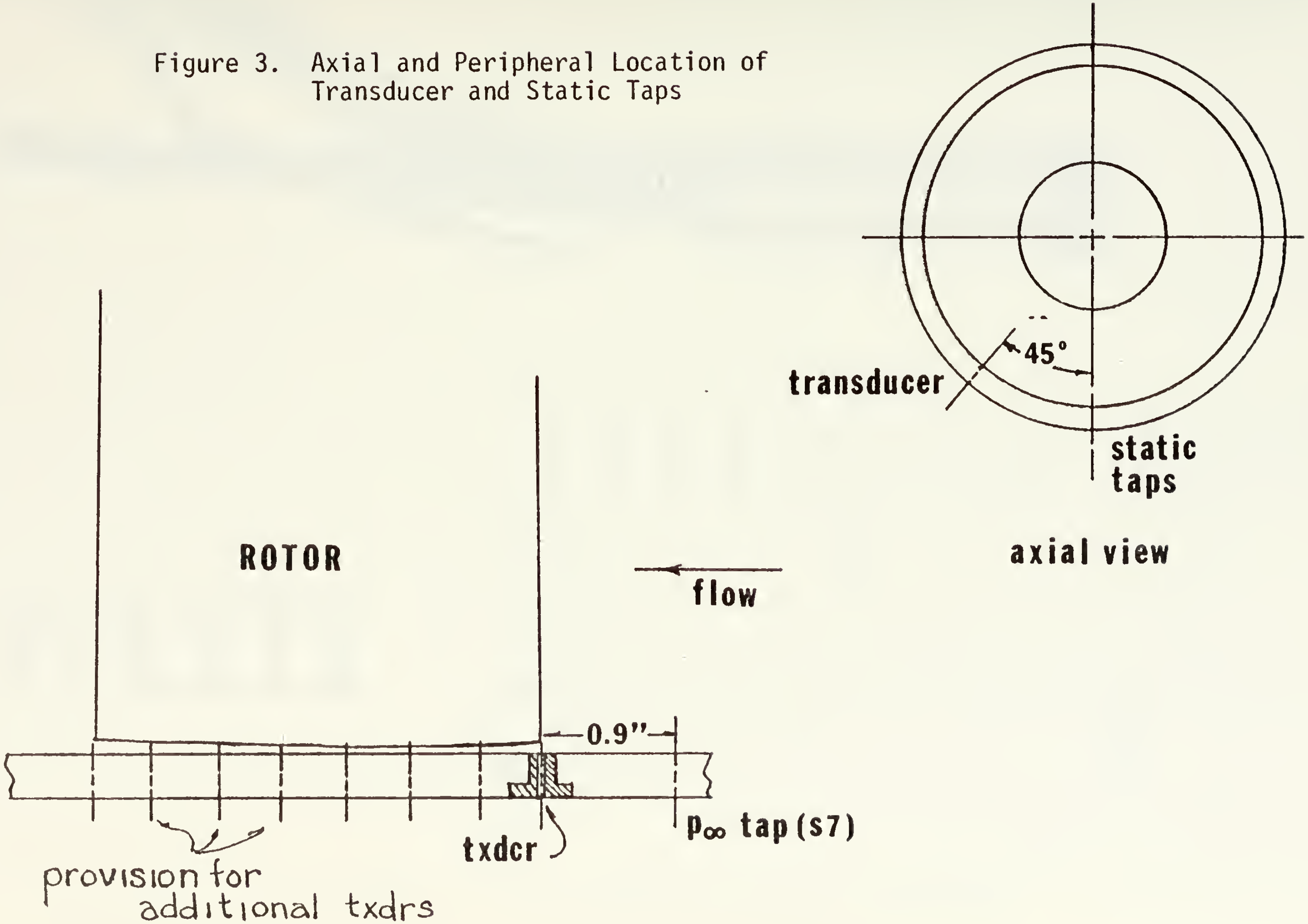

Figure 3. Axial and Peripheral Location of Transducer and Static Taps

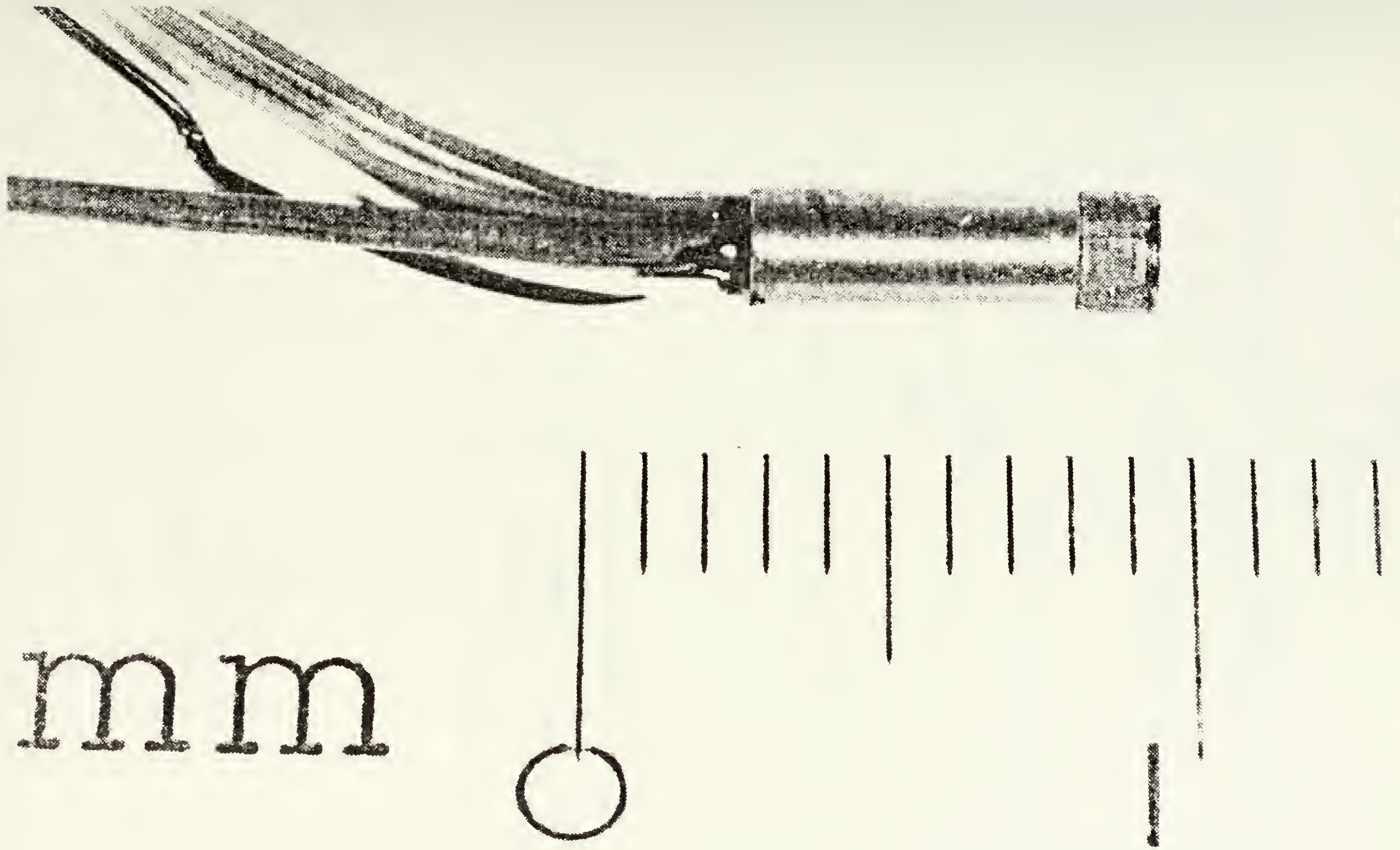

Figure 4. Kulite CQL-080-25 Pressure Transducer

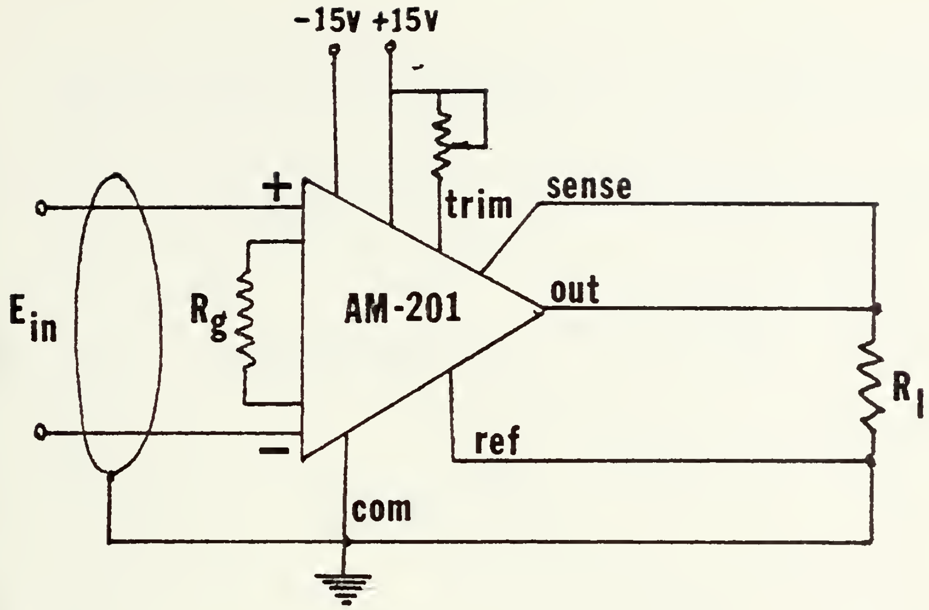

Figure 5. Schematic of the Signal Conditioning Circuit

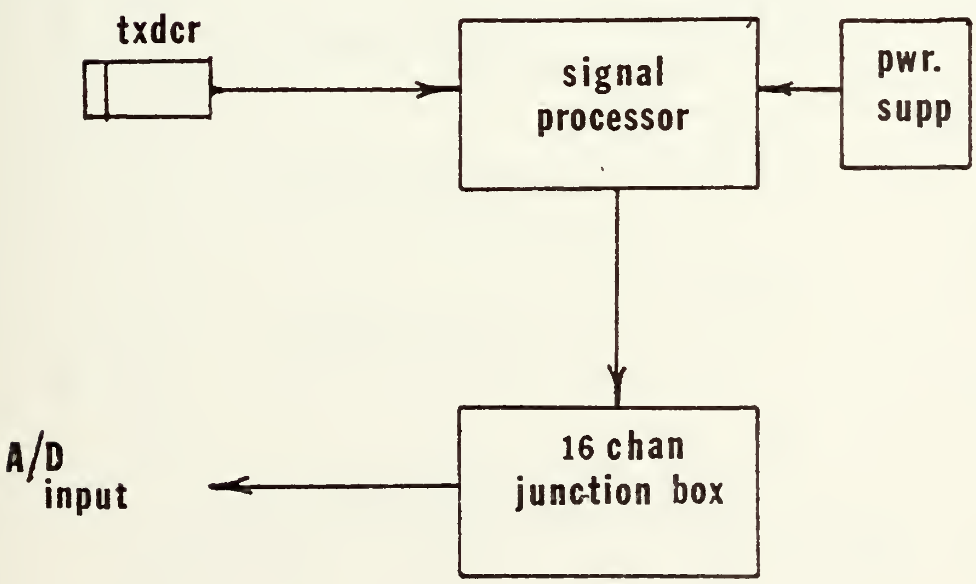

Figure 6. General Arrangement of the Instrumentation System Components

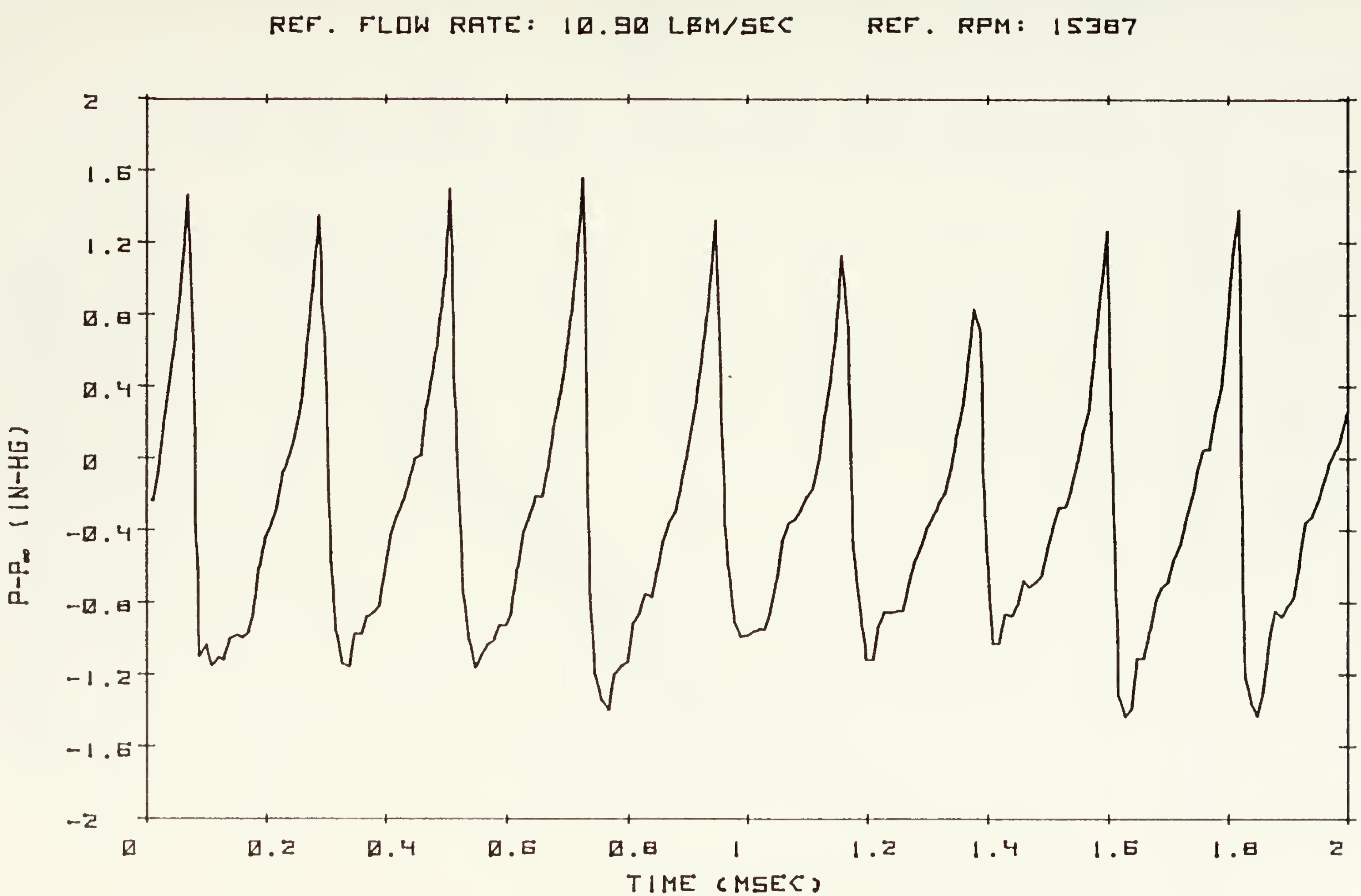

Figure 7. Case Wall Pressure Signature (Open Throttle, 50% Design Speed)

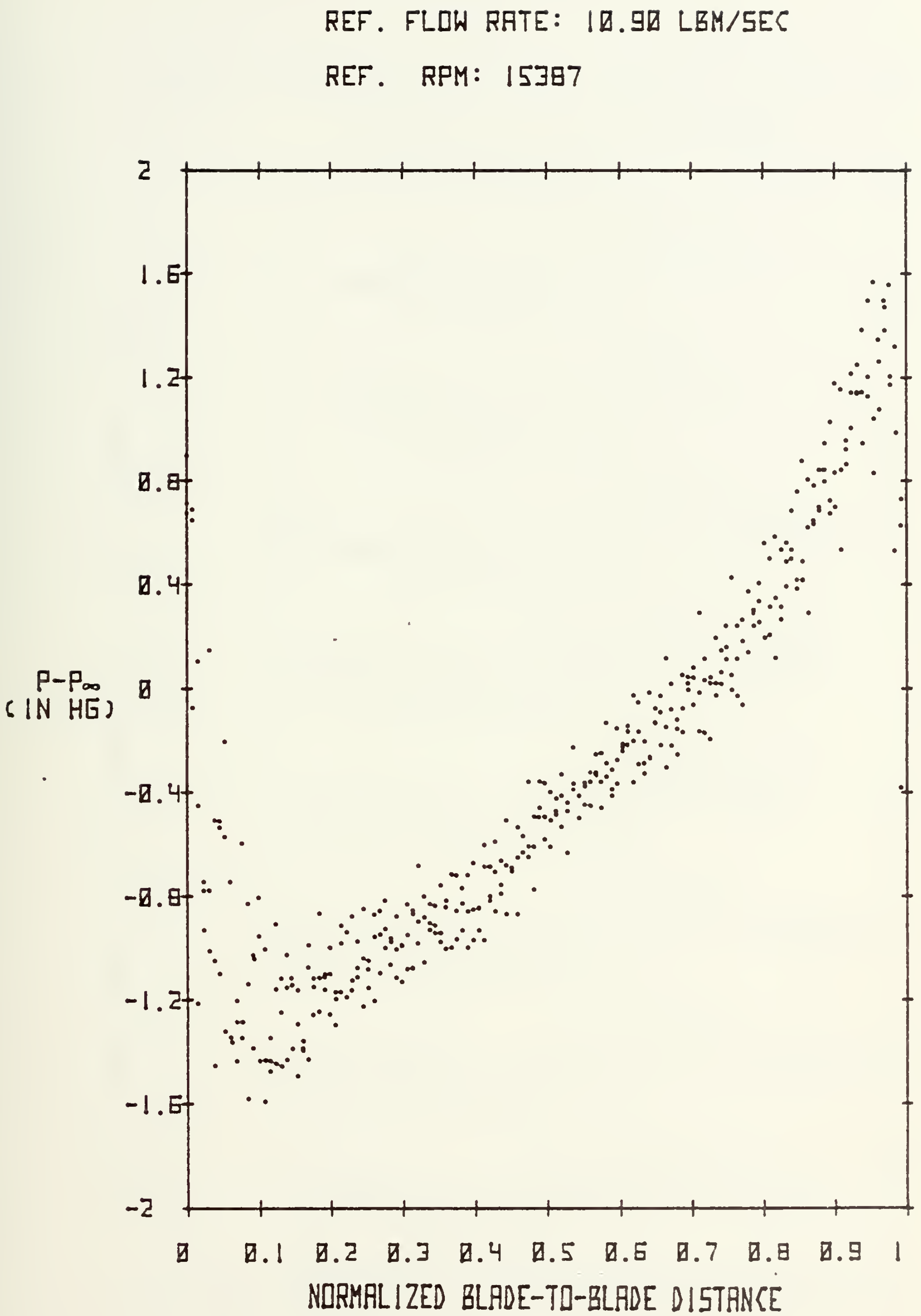

Figure 8. Pressure Distribution Across a Blade Space
(Open Throttle, 50% Design Speed)

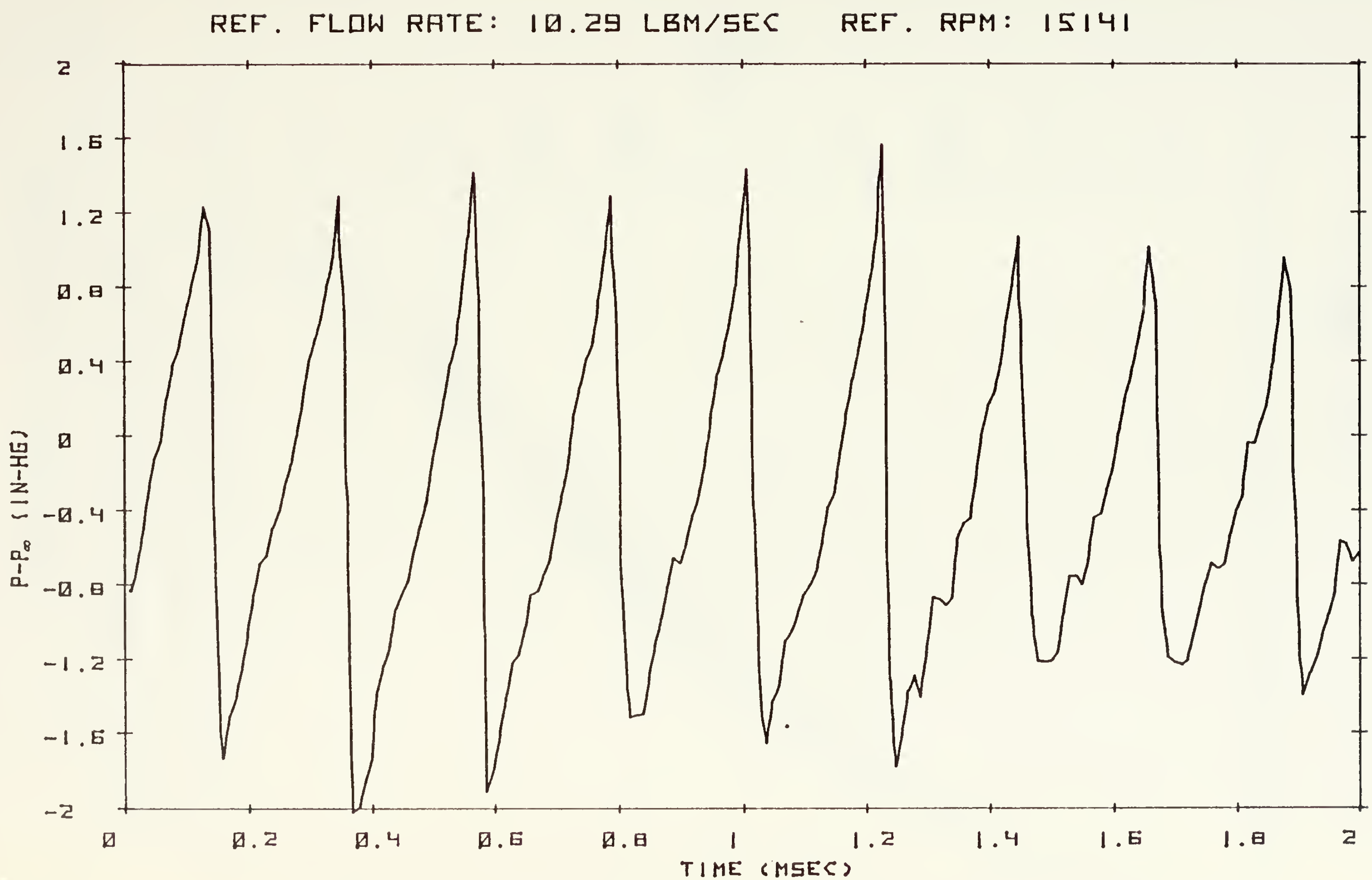

Figure 9. Case Wall Pressure Signature (Near Surge, 50% Design Speed)

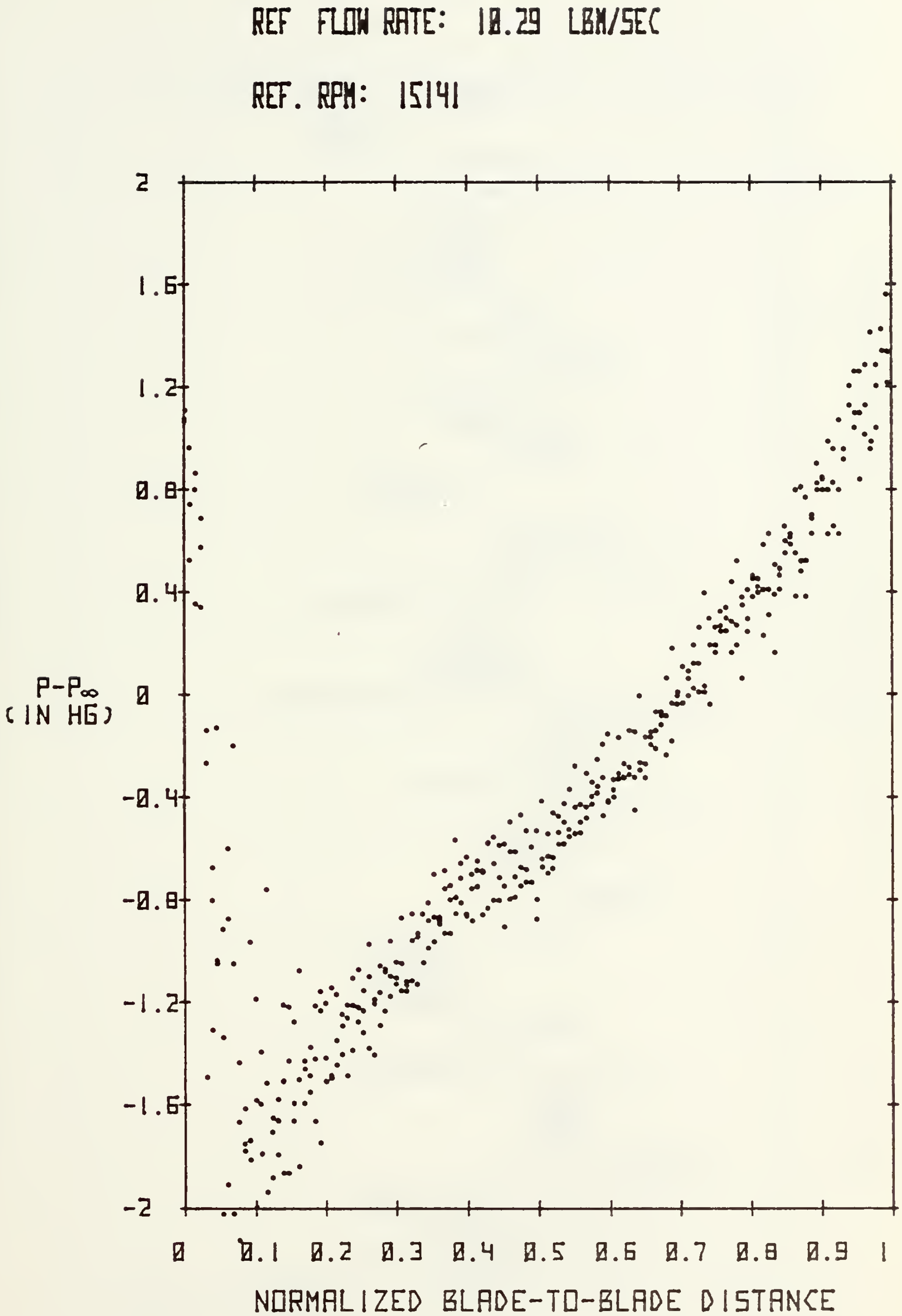

Figure 10. Pressure Distribution Across a Blade Space (Near Surge, 50% Design Speed)

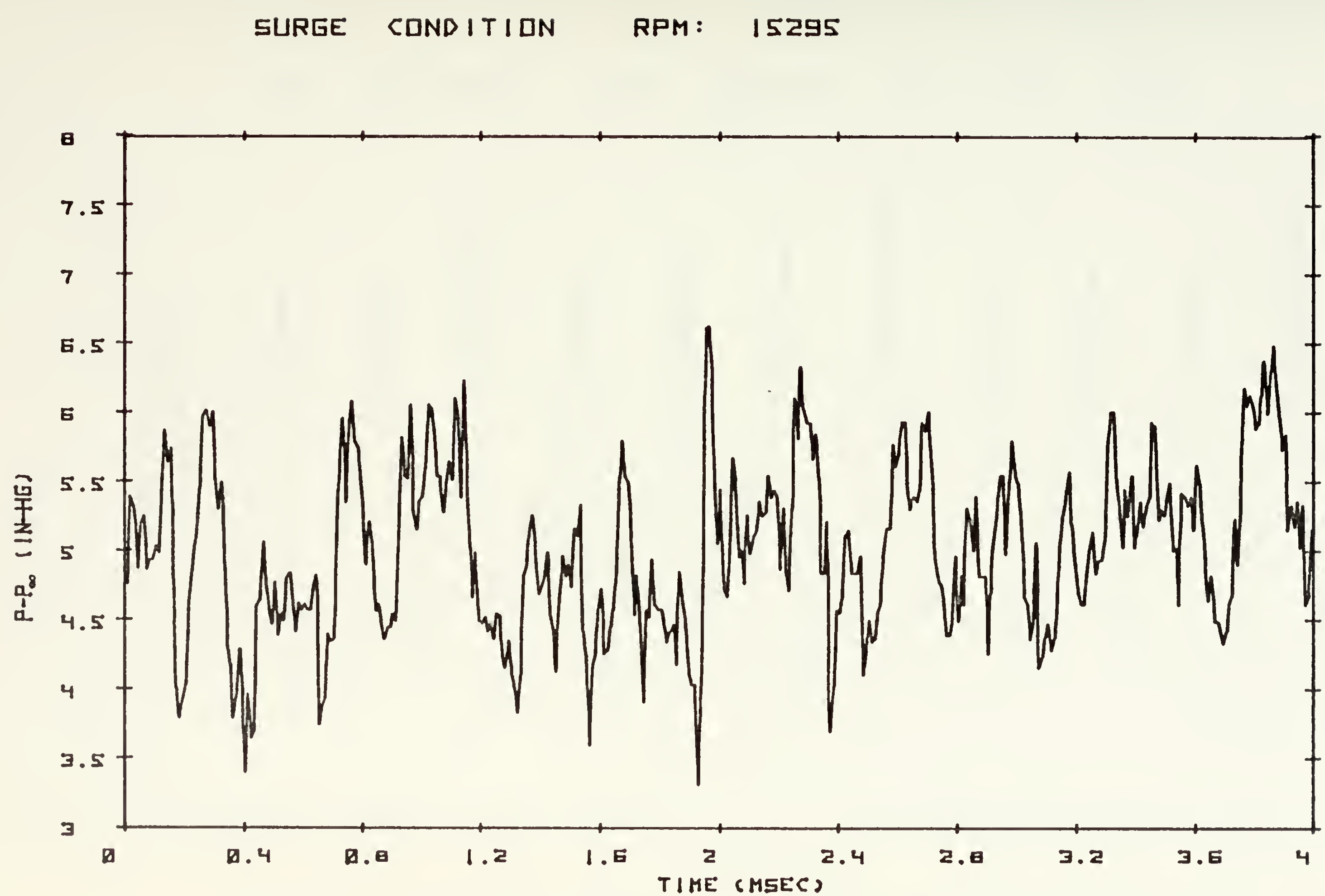

Figure 11. Case Wall Pressure Signature (Surge, 50% Design Speed)

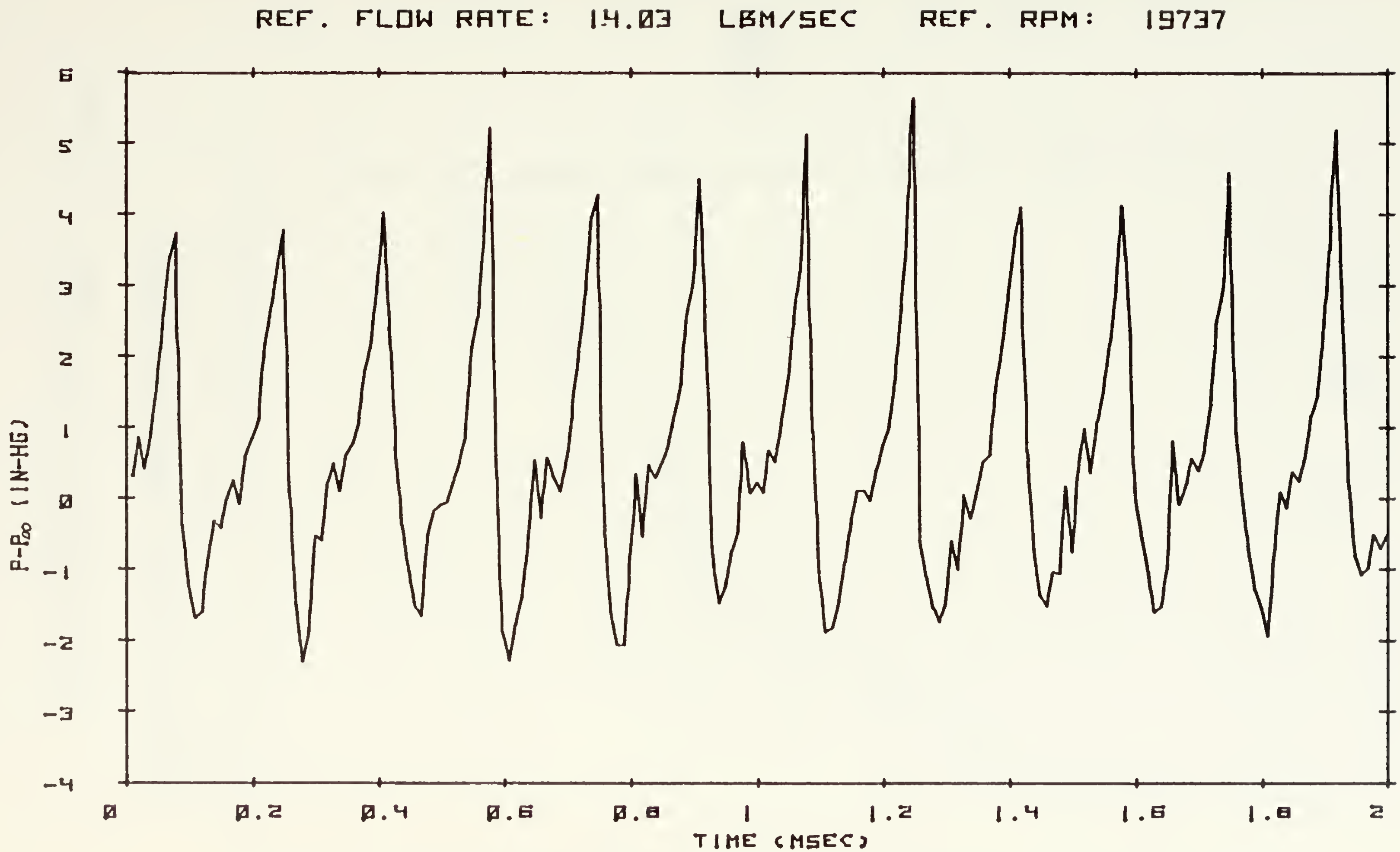

Figure 12. Case Wall Pressure Signature (Open Throttle, 65% Design Speed)

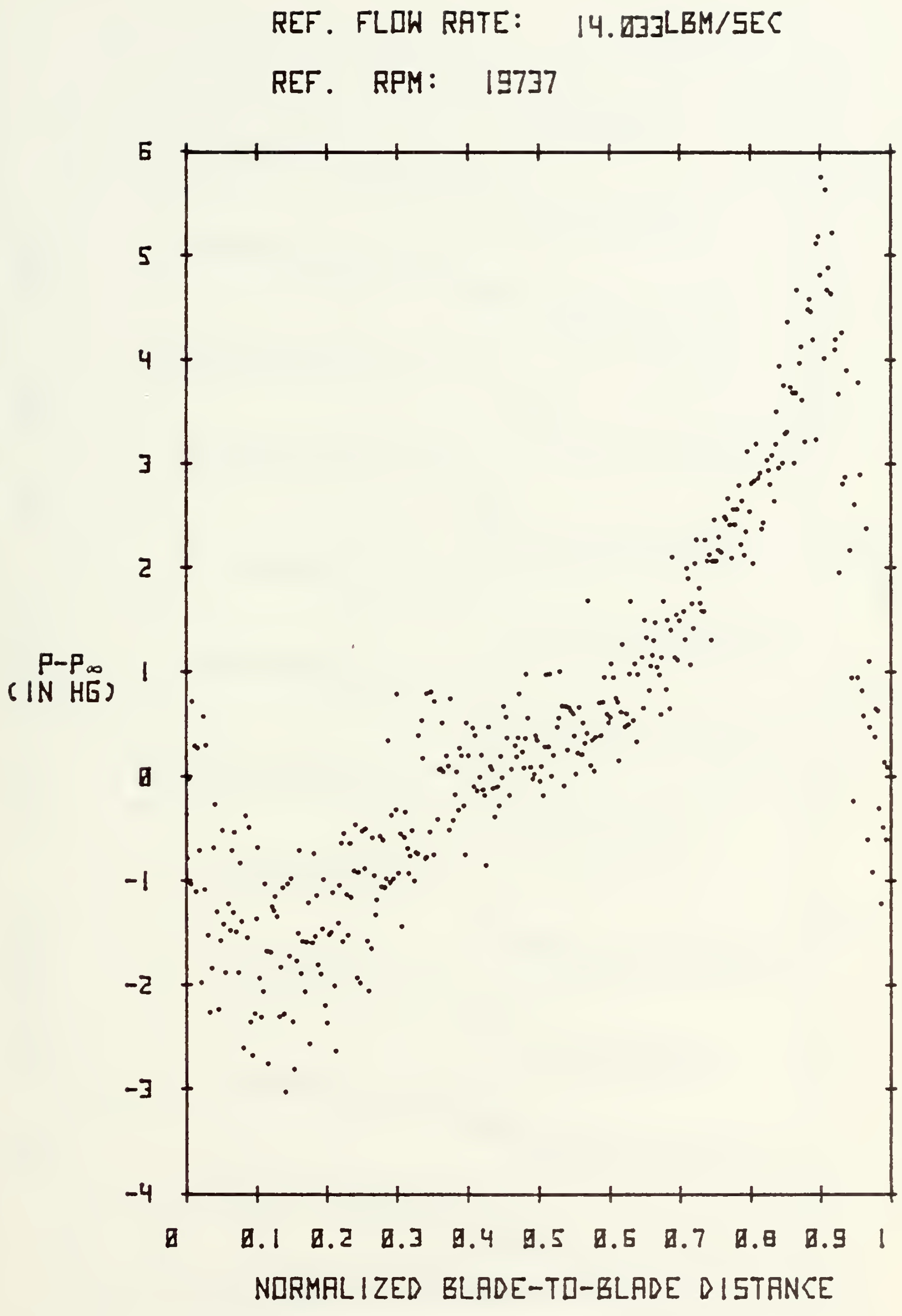

Figure 13. Blade Space Pressure Distribution
(Open Throttle, 65% Design Speed)

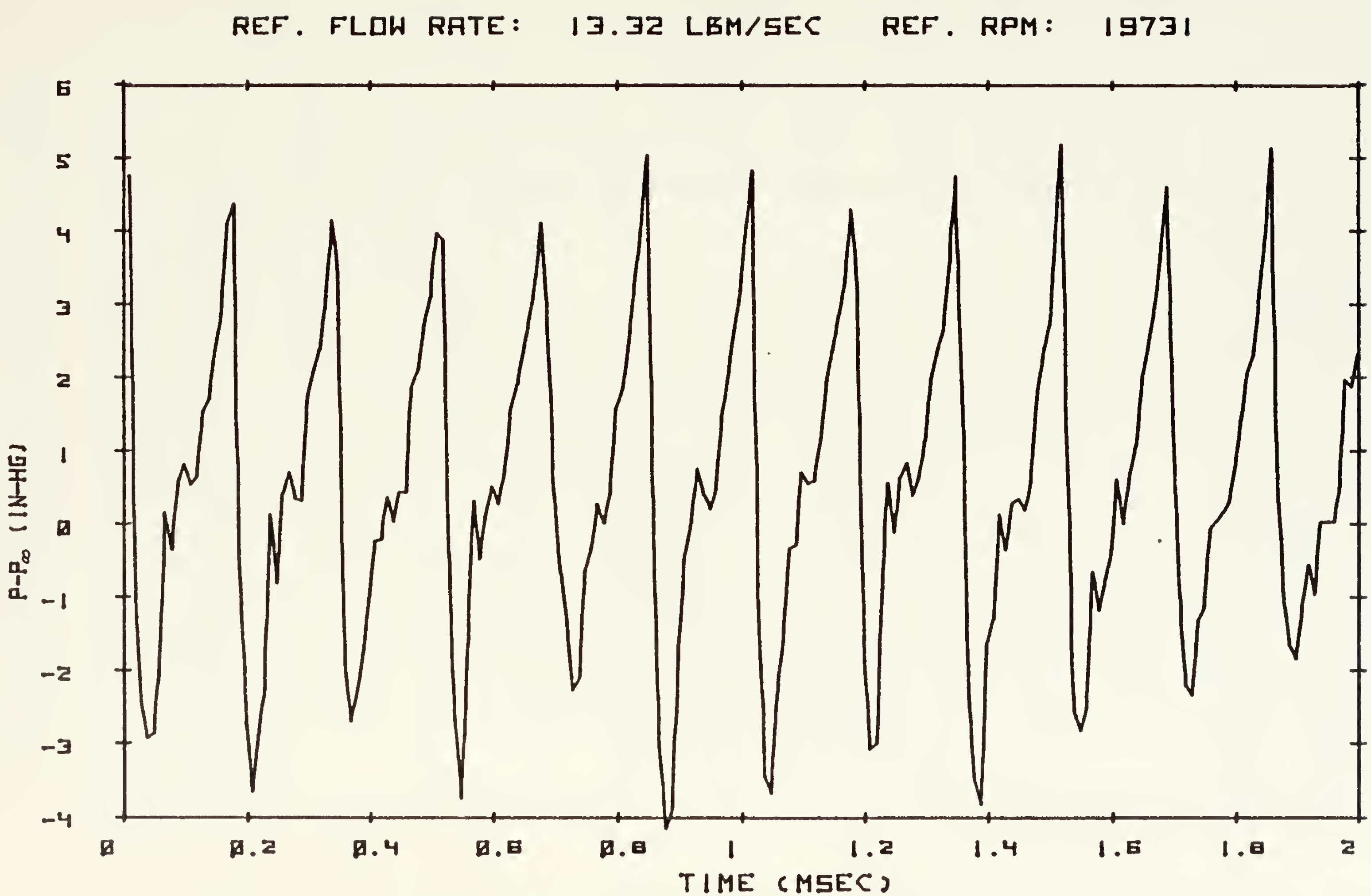

Figure 14. Case Wall Pressure Signature (Partial Throttle, 65% Design Speed)

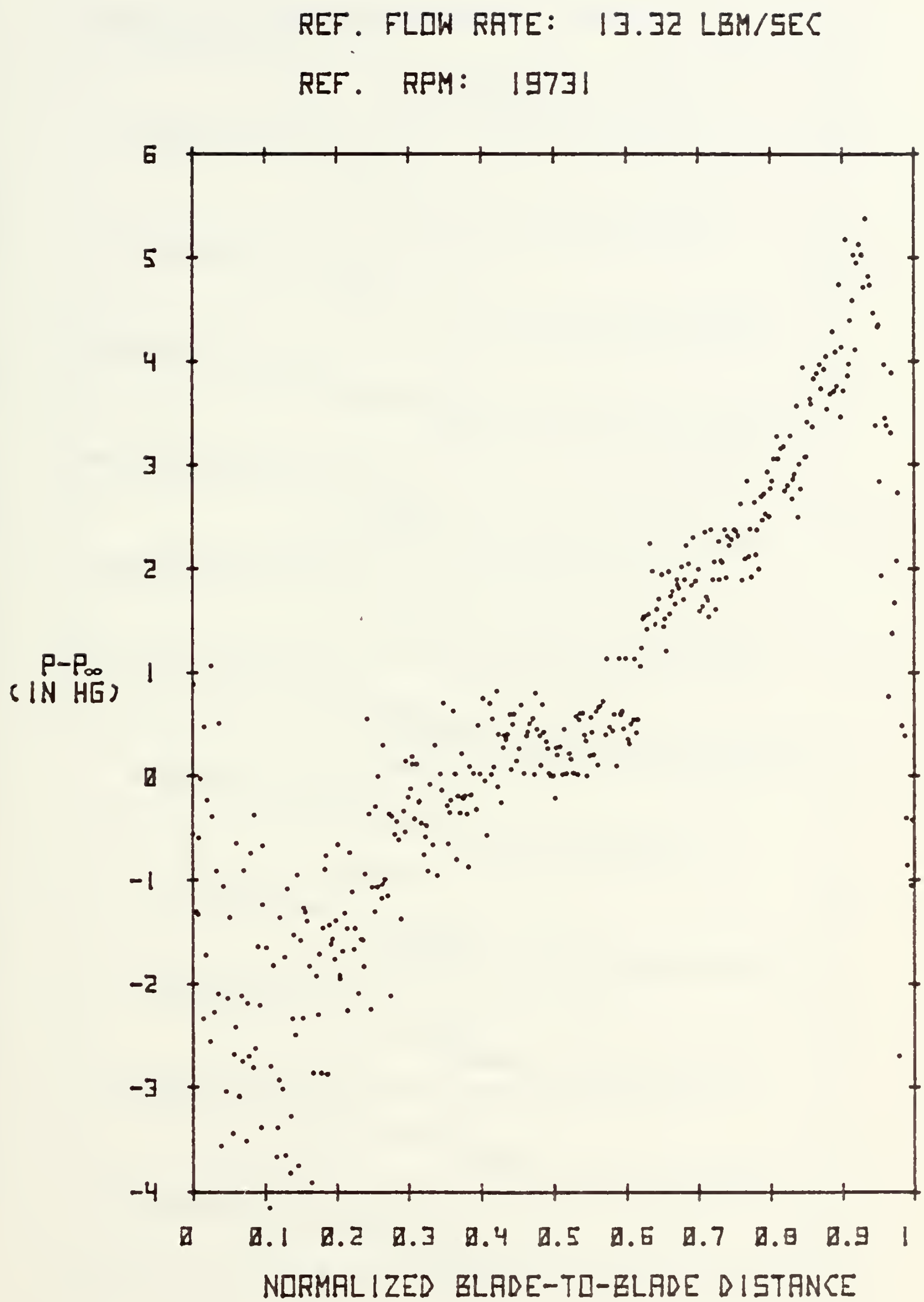

Figure 15. Blade Space Pressure Distribution (Partial Throttle, 65% Design Speed)

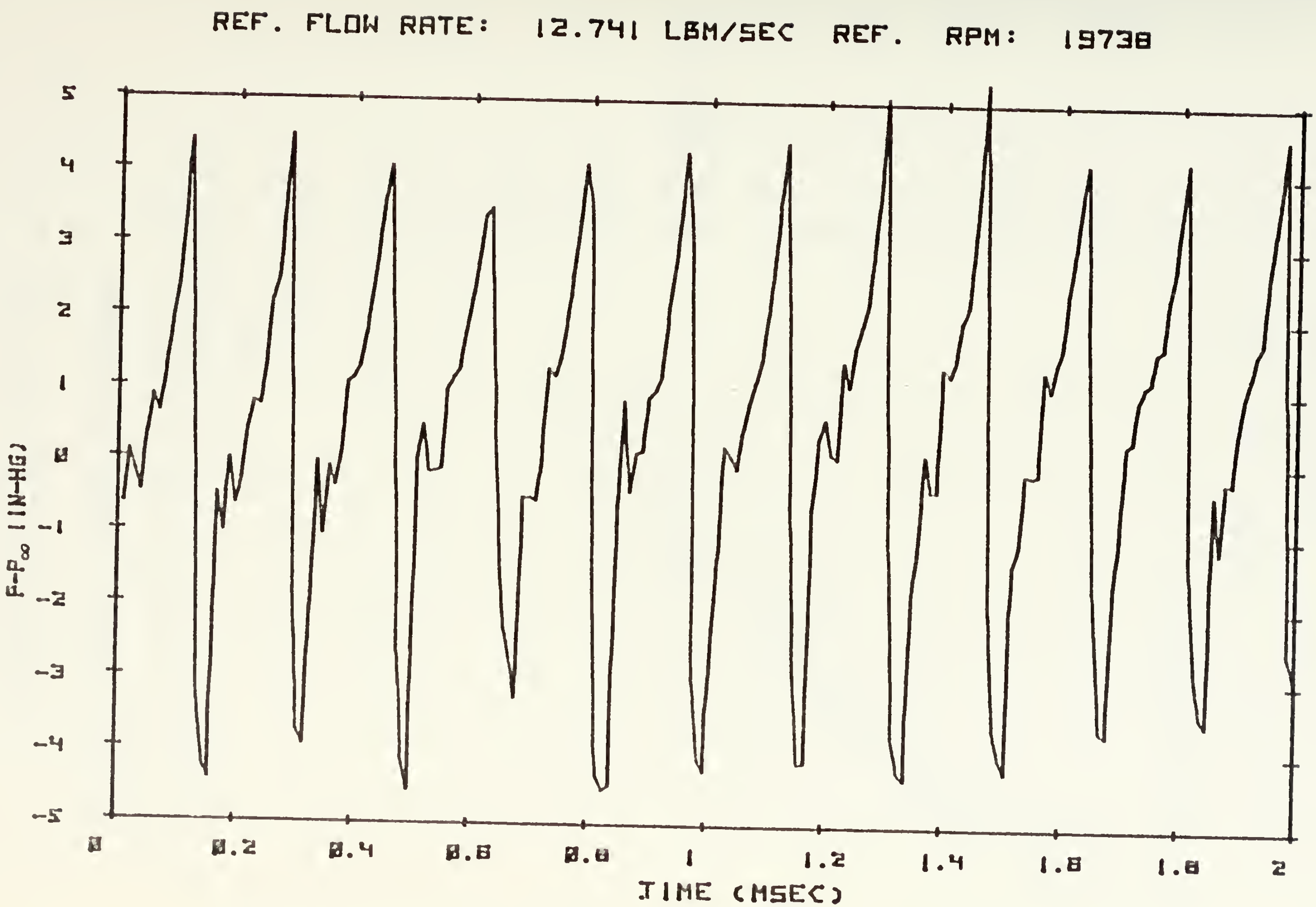

Figure 16. Case Wall Pressure Signature (Near Surge, 65% Design Speed)

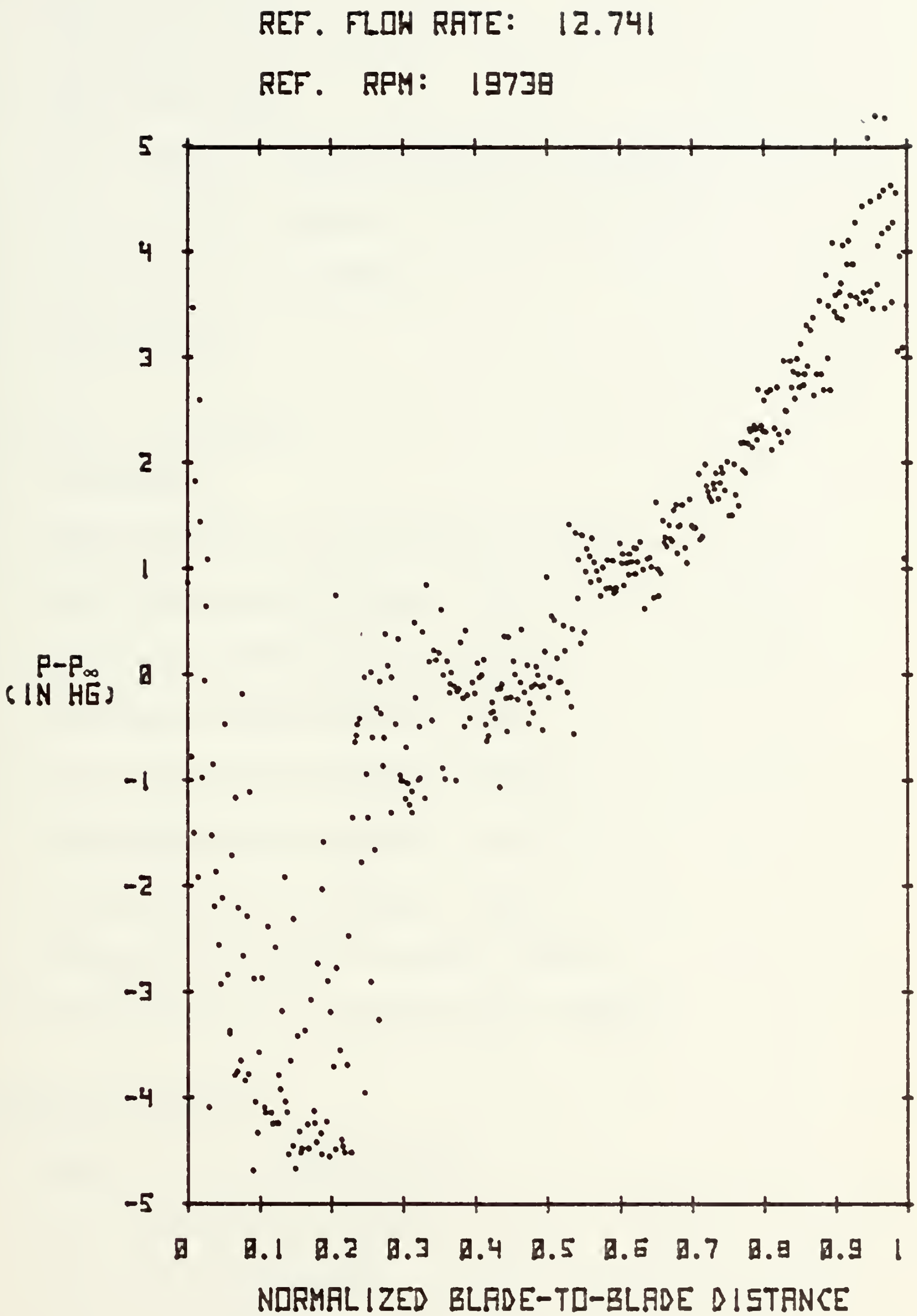

Figure 17. Blade Space Pressure Distribution (Near Surge, 65% Design Speed)

APPENDIX A: REAL-TIME DATA ACQUISITION

Appendix A: Real-Time Data Acquisition

A.1 Real-Time Data System

A.1.1 Introduction The Components of the Real Time Data System are shown in Fig. A-1. The System consists of Hewlett-Packard components including a Model 21MX Micro-Programmable Calculator with peripherals and a Mass Memory Unit. The complete system, with its associated software, acquires and digitizes data at a throughput rate of 100 KHz. The samples are then transferred to the 9830A and recorded on the Mass Memory Disk. Data reduction and plotting are carried out using the 9830A and its peripherals. The complete system, therefore, performs the separate functions of data acquisition, transfer, storage and offline reduction as described in the following paragraphs.

A.1.2 Data Acquisition Up to sixteen channels of analog input voltages in the range of ± 1.0 volts can be sampled and recorded by the A/D converter under the control of the 21MX computer. The acquisition process is governed by the built-in features of the A/D converter and by the programs which can be written for the 21 MX.

A.1.2.1 A/D Converter The HP 5610A Analog-to-Digital Converter (Ref A-1) is designed to convert analog voltages into ten data BIT's at the maximum throughput rate of 100 KHz. Two fundamental modes of operation can be used: SEQUENTIAL - in which all 16 channels are scanned in numerical order and RANDOM in which a single preselected channel is scanned repeatedly. Variations within these two basic modes are also possible which allow for externally supplied sequencing pulses and for externally controlled sample timing. The system currently operates in either the internally sequenced mode (mode 5) or in the "Free Run" Random mode (mode 4). In "Free Run" the A/D converter operates on its own internal timer at the 100 KHz rate.

The A/D digitizes data using a method of successive approximations. That is, a known test voltage is compared with the sample voltage beginning with 1/2 full scale (0.5v in the present system) and a decision is made whether the test voltage is high or low. The comparisons continue, halving the range each time until the machine accuracy is reached. For a resolution of ± 1.0 volts to 10 BIT's the accuracy of the A/D converter is 1/512 = 1.95mV. A full description of the successive approximations method is found in the Operating Manual (Ref. A-1). The frequency response of the system is limited by the aperture time of the A/D converter, which is 50 nanoseconds.

A.1.2.2 <u>The HP 21MX Computer and Control Program</u> The 21MX is a fast micro-programmable computer that uses 128 basic instructions and currently has 16K words of memory. Complete specifications are given in Ref. A-2.

Detailed operating procedures are described in section A3. Here, a general description is given of the role of the computer and its software in obtaining data samples from the A/D converter. The combination of hardware and computer software constitute the Real-Time data system (Ref. A-3).

To the computer, the A/D converter is simply an Input/Output (I/O) device. The control program calls a subroutine (L5610) which sends a 16 BIT "Command word" to the A/D and accepts, in return, a 16 BIT "data word" which is stored in an array defined in the program. The calling parameters specify the mode of operation, channel to be scanned and the number of samples to be taken. The control program then separates the "data word" into a 10 BIT data value and a 6 BIT address (channel number).

The only significant difference between the A/D converter and any other I/O device is the speed of data transfer. In order to satisfy the 100 KHz sample rate, the data are transferred by Direct Memory Access (DMA), to successive memory locations in the computer as they are received (Ref. A-2).

The control program "KATE" was written in HP Fortran. The program is described in section A2. "KATE" performs four functions:

1) Control of data acquisition from the A/D converter

2) Separation of the "address word" and the "data word"

3) Conversion of data from binary code to the equivalent decimal voltage

4) Transfer to the computer's output location for reading by the 9830A.

An absolute, binary coded punched paper tape has been obtained using the Fortran compiler and Basic Control System, so that in order to prepare the data system only a single tape need be loaded (Section A3.2). The operator controls the data system from the teletype keyboard, responding to requests for inputs and receiving messages when actions are completed.

A.1.3 Data Transfer and Storage Data transfer and storage are initiated in the 21MX control program. The 9830A is connected to an I/O slot in the computer via an eight BIT duplex register and an interface card. The transfer into the I/O buffer is performed by a WRITE (6,xxx) command. The 9830A transfer program "TRANS" reads this I/O location with an ENTER (1,xxx) command. Data are transferred to the 9830A one value at a time. Once the entire transfer sequence is complete, program "TRANS" writes the data array onto the Mass Memory storage unit at the next available record of file "DATAX". Total time to scan a single channel 1000 times and to transfer the data onto the disk is about 60 sec.

Before data can be stored on the Mass Memory, a file must be opened. Instructions governing file size and structure are given in Ref. A-4 and A-5.

A.1.4 <u>Data Reduction</u> Data Reduction is carried out on the 9830A. The master reduction program is "TRNSXI" which will call or "CHAIN" with the other programs necessary.

Data reduction involves reading a specified record of raw data from the memory, applying the on-line calibration discussed in Appendix B, storing the array of reduced data and printing or plotting the results. The reduced data are stored in file "DATA-P" in the same numbered record as the corresponding raw data are stored in file "DATAX". Output of the reduced data is performed through program "OUTPUT" which can be accessed automatically by "TRNSX1" or separately by a 'GET "OUTPUT"' command. In either case program "OUTPUT" reads file "DATA-P" and prints and/or plots the reduced data. Details of the operations of these programs can be found in section A2.

A.2 Description of Programs

A.2.1 <u>Introduction</u> Programs for the acquisition, handling, and reduction of data have been written in two languages: HP Fortran for the 21 MX computer and HP BASIC for the 9830A programmable calculator. Reference A-4 and Ref. A-6 provide information for programming in these languages. Table III lists the programs that are stored on disk identified as PL-004 "Transonic Compressor" and gives a brief description of their purpose. In the following sections, for each program, an explanation of the variables and instructions on operation of the program are given, followed by a program listing. Due to its complexity, a flowchart has been included for program "KATE" (Fig. A2). Detailed instructions for the operation of program "KATE" are contained in section A3.2.

A.2.2 Data Acquisition Fortran Program "KATE" This is the primary control program for the 21 MX and A/D converter. A flowchart is shown in Fig. A-2. Detailed operating procedures for this program are included in section A.3.2.

Variable Assignments

IDAY IMO IYEAR	-	Date
ITEST	-	Identification number for the test being run.
IRUN	-	Identification number of the current data scan. This value is incremented by one each time new data is taken.
IMODE	-	Mode of operation for the A/D converter (4 or 5).
ISCAN	-	Number of scans on any given channel. Used in random Mode only.
ISIG	-	Continue signal.
ISTAT	-	Status variable used by the computer to determine whether the A/D converter has finished sampling the channels and ready to transfer data back to the computer. It is set to -1 initially and becomes +1 when this operation is complete.

IBUFF(1600)	-	Array containing the 'data words' returned from the A/D converter.
IADRS(16)	-	Array containing the channel addresses.
DATA(1600)	-	Array containing the decimal voltages.
INO	-	Total number of scans to be made; equal to the number of scans/channel multiplied by the number of channels.
ILIM	-	An internally generated 'DO' loop limit used to conform to a particular output format.
FSVOL	-	Full Scale Voltage, ± 1.0 in the present system.
ISPCE	-	Internally generated 'DO' loop limit used for formatting purposes.

A.2.3 Data Transfer Basic Program "TRANS" This is the Data Transfer and storage program for the HP 9830A. The program reads data BITS from the 21MX and transfers the array to the Mass memory. "CONT 520" allows a printout in either of two formats depending upon the mode of operation of the A/D converter when the data was taken.

Files: REC# - contains a value representing the total number of runs whose data is stored on the disk (1 RECORD).

DATAX - raw data storage. 13 records are required to store one run (1300 RECORDS).

Arrays & Variables: DS(16,102) - Data storage array. Data is stored in the following manner:

Mode	Type Scan	Order Of Data Entry (Ref. A-6)
4	single chan	((D(I,J),I=1,16),J=1,101)
5	sequential	(D(I,1),I=1,16)- Channel #
		((D(I,J),J=2,101),I=1,16)

The last column (102) is reserved for additional data that can be entered from the keyboard or as part of the data transfer. Present assignments for D(I,102) are:

I	"TRANS" Notation	Definition	Entry Point
1	I1	TEST #	Transferred
2	I2	RUN #	Transferred
3	I3	DAY	Transferred
4	I4	MONTH	Transferred
5	I5	YEAR	Transferred
6	I6	MODE	Transferred
7	I7	#SCAN/CHAN	Transferred
8	-	CHAN#(random)	Transferred
9	P(K)	P-REF	Keyboard
10	M(K)	P_m	Keyboard
11	S(K)	time avg. emf	Keyboard
12	X(1)	k_o	Calculated
13	X(2)	k_1	Calculated
14	N	RPM	Keyboard
15	P7	UPSTREAM STATIC PRESS	Keyboard

Other Variables:

N1 - Total number of runs (stored in REC#). Incremented by one at the end of the program.

N2 - Next record available for data storage. Determined from the relation: N2=N1*13+1

Operation

1. Enter GET "TRANS"
2. Enter RUN
    a. The program is now awaiting data at statement 9Ø
    b. When data has been read and transferred the program will automatically recycle back to line 6Ø and wait for more data.
3. If a printout of raw data is desired, enter STOP, then enter CONT 52Ø.
    a. After completion of printout the program will recycle back to line 6Ø.

A.2.4 Data Transfer Basic Program "TRNSXI" This is the main data reduction program in the HP 9830A. In addition to performing the initial integration and calculation of the time average voltage, it controls the programs which subsequently determine the polynomial coefficients for the voltage-pressure calibration, apply the reduction polynomial, plot and print the reduced data and convert the reduced data into a pressure distribution across a single blade space.

"TRNSX1" performs a 'trapezoidal rule' integration of the raw voltages and, dividing by the number of samples, converts this information into a time average voltage. The reference pressure, mean pressure and RPM are also entered from the keyboard in this program.

Variable Assignments

DS(16,102)	-	raw data storage array
N(2)	-	2 element array containing the record numbers to be reduced.
S1	-	summing variable for the integration routine.
S(2)	-	storage array for the time average voltages.
P(2)	-	storage array for reference pressures.
M(2)	-	storage array for mean static pressures.
R(2)	-	storage array for RPM's

A.2.5 Data Analysis Basic Program "COEFF" This program is 'chained' from TRNSX1 and calculates the data reduction polynomial coefficients by a solution of the matrix equation A x - B where:

All variables are as previously defined.

A.2.6 Data Analysis Basic Program "REDUCE" REDUCE applies the reduction polynomial resulting from COEFF. The process of applying a linear polynomial to each of more than 1000 data points can be a very lengthy process on the 9830A.

The operator should not be surprised of the reduction portion of the program takes in excess of five minutes.

Variable Assignments

CS(16,102) - storage array for the reduced data.

The remainder of the variables are as previously defined.

A.2.7 Data Analysis Basic Program "OUTPUT" This program prints and/or plots the reduced data. If plotting is desired it is necessary to ready the plotter. A STOP is provided following the request to "INPUT RECORD #", during which time the plotter can be set up. After the reduced data has been read from file "DATA-P", the command 'ENTER Ø TO SUPPRESS PRINTOUT', allows the printout of the reduced data to be bypassed. Any other entry than 'Ø' results in the data being printed.

The plotting routine is intentionally general to allow flexibility in choosing the scale of the plot. The limits of the 'X' and 'Y' axes are input from the keyboard. X-MAX should be the number of milliseconds of data to be plotted (less than or equal to 10mSec). Entering Y-MIN = -2 and Y-MAX = +2 provides a suitable scale for data taken at the 100 Hz rate.

Variable Assignments

N1 - record number of the data to be reduced.

X1 - X-MAX

Y1 - Y-MIN

Y2 - Y-MAX

The remainder of the variables are as previously assigned.

A.2.8 Data Analysis Basic Program "BLADE" This program produces a pressure distribution across a single balde space. Data is plotted as points across the nondimensional 'blade-to-blade' scale. Data is plotted for a specified number of points. The number can be adjusted to represent eighteen blades, or one revolution of the compressor at the particular compressor speed for which the data was taken.

When readying the plotter, the paper should be placed with the long side vertical for best results.

Variable Assignments

- t - elapsed time throughout the blade space
- T2 - blade passing period
- K1 - number of the data element representing the first maximum.

All remaining variables are as previously assigned.

A.2.9 Calibration Test Basic Program "STATIC" This program in the HP 9830A acquires and stores static calibration data from the 21MX. The number of data points to be taken is input from the keyboard and the program cycles through the specified number without further attention from the operator. This frees the operator to take data in another room if necessary, controlling the program from the keyboard of the teletype. After entry of the data from the 21MX, the corresponding pressure values are entered at the 9830A keyboard. The data is then stored in the desired record of file "STAT".

Program KATE is used to acquire data and to transfer the data from the 21MX to program "STATIC" in teh HP 9830A. Ten SCANS/CHAN should be entered when requested at the teletype.

Variable Assignments

- S(10) - storage array for ten scans of the data.
- A(20,2) - storage array for the average of the ten scans and the corresponding pressure. Up to 20 data points can be taken.
- S1 - summing variable for the ten data scans.
- N1 - Number of record in which data is to be stored.

A.2.10 Calibration Analysis Basic Program "S/CAL" This program is for the reduction of the static pressure calibration data taken by program "STATIC". Data is read from a selected record of file "STAT" and a least-squares polynomial curve fit is determined (up to degree three). The data and a curve represented by the calculated polynomial can then be plotted. Other keyboard entries are self explanatory and the plotting instructions are similar to those discussed for program "OUTPUT".

Variable Assignments

- N1 - Degree of least squares fit.
- N2 - Number of data points to be fit.

The remainder of the variables are as previously described.

Fig. B-3 is a representative output from this program.

TABLE A1

NAME	REMARKS
KATE	(FORTRAN IV) 21MX DATA ACQUISITION AND CONTROL PROGRAM ACQUIRES DATA BITS FROM A/D CONVERTER, CONVERTS TO DECIMAL VOLTAGES AND TRANSFERS TO 9830
TRANS	(BASIC) 9830 DATA TRANSFER PROGRAM READS DATA FROM 21MX AND STORES IN MASS MEMORY. PRINTS RAW DATA IF DESIRED (FILES: DATAX, REC#)
TRNSX1	(BASIC) MAIN DATA REDUCTION PROGRAM READS RAW DATA FROM DISC. CALCULATES CALIBRATION POLYNOMINAL. CONVERTS VOLTAGES TO PRESSURES AND STORES REDUCED DATA. (FILES: DATAX, DATA-P)
OUTPUT	(BASIC) PRINT & PLOT ROUTINE PRINTS AND/OR PLOTS REDUCED DATA (FILES: DATA-P)
BLADE	(BASIC) REDUCES DATA TO A PRESSURE MAP ACROSS ONE BLADE SPACE (FILES: DATA-P)
STATIC	(BASIC) 9830 STATIC DATA TRANSFER PROGRAM READS STATIC CALIBRATION DATA FROM 21MX AND STORES IN MASS MEMORY (FILES: STAT)
S/CAL	(BASIC) STATIC CALIBRATION REDUCTION PROGRAM PLOTS STATIC CALIBRATION DATA (PRESS VS. EMF). FITS CURVE BY LEAST SQUARES METHOD & PLOTS THIS CURVE - PRINTS LEAST SQUARES COEFFICIENTS. (FILES: STAT)

Data Acquisition Fortran Program "KATE"

```
FTN,B,L,A
      PROGRAM KATE
C THIS PROGRAM CONTROLS DATA ACQUISITION AND TRANSFER
C FROM THE 21MX & A/D CONVERTER TO THE 9830A AND DISK.
C DATA AQUIRED WILL BE TRANSFERRED AUTOMATICALLY.
C TTY PRINTOUT OF RAW DATA IS AVAILABLE IF DESIRED.
C INPUTS REQUIRED FROM THE KEYBOARD ARE EXPLAINED AT
C THE BEGINNING OF PROGRAM EXECUTION....GCP 5/15/76
      DIMENSION IBUFF(1600),IADRS(16),DATA(1600)
      WRITE(2,900)
  900 FORMAT(10X,"KEYBOARD INPUTS REQ'D:"/,12X,"MODE:4=
     1SINGLE CHANNEL"/,17X,"5=SEQUENTIAL"//,10X,"#SCANS/CHAN
     2 SHOULD BE MULTIPLE OF 5"//,10X,"CONTINUE SIGNAL:"
     3/,12X,"0....RESTART PROGRAM"
     4/,12X,"1....START DATA AQUISITION"
     5/,12X,"2....TTY PRINTOUT OF LAST DATA"
      WRITE(2,906)
   10 WRITE(2,901)
  901 FORMAT("INPUT DATE...DAY MONTH YEAR")
      READ(1,902)IDAY,IMO,IYEAR
  902 FORMAT(3I2)
      WRITE(2,903)
  903 FORMAT("INPUT TEST# & RUN#")
      READ(1,*) ITEST,IRUN
   11 WRITE(2,904)
  904 FORMAT(ENTER MODE AND # OF SCANS/CHAN")
      READ(1,*) IMODE,ISCAN
      FSVOL=1.
      IF(IMODE-4)1000,200,12
   12 WRITE(2,905)
  905 FORMAT("ENTER CONTINUE SIGNAL")
      READ(1,*) ISIG
      IF(ISIG-1)10,20,55
   20 INO=16*ISCAN
      CALL L5610(10B,IMODE,0,IBUFF,INO)
      ISTAT=-1
   30 CALL L5610(10B,ISTAT)
      IF(ISTAT) 30,40
   40 L=1
      DO 50 I=1,16
      IADRS(I)=IAND(IBUFF(I),17B)
      DO 50 J=I,INO,16
      DATA(L)=FSVOL*FLOAT(IAND(IBUFF(J),177700B))/32768.
   50 L=L+1
```

```
C TRANSFER SECTION (SEQUENTIAL)
C
  906 FORMAT (3/)
      WRITE(6,907) ITEST,IRUN,IDAY,IMO,IYEAR,IMODE,ISCAN
  907 FORMAT(5I2,I1,I5)
      L=1
      DO 130 I=1,16
      WRITE(6,912) IADRS(I)
      DO 130 J=1,ISCAN
      WRITE(6,913) DATA(L)
      L=L+1
  130 CONTINUE
      GO TO 12
C
C PRINTOUT (SEQUENTIAL)
C
   55 WRITE(2,908) IDAY,IMO,IYEAR,ITEST,IRUN
  908 FORMAT("DATE:",I2,"/",I2,"/",I2,//,"TEST:",I3,2X,"RUN:
     1 ",I2)
      WRITE(2,906)
      N=8*ISCAN
      WRITE(2,909) (IADRS(I),I=1,8)
  909 FORMAT(8I8)
      DO 60 J=1,ISCAN
      ILIM=J+7*ISCAN
   60 WRITE(2,910) J,(DATA(I),I=J,ILIM,ISCAN)
  910 FORMAT(I3,1X,8(F6.3,2X))
      WRITE(2,906)
      WRITE(2,909) (IADRS(I),I=9,16)
      DO 70 J=1,ISCAN
      ILIM=J+N+7*ISCAN
      K=N+J
   70 WRITE(2,910) J,(DATA(I),I=K,ILIM,ISCAN)
      WRITE(2,906)
      GO TO 12
C
C RANDOM MODE SECTION
C
  200 WRITE(2,911)
  911 FORMAT("INPUT CHANNEL NUMBER")
      READ (1,*) ICHAN
  205 WRITE(2,905)
      READ(1,*)ISIG
      IF(ISIG-1)10,206,235
  206 INO=ISCAN
      CALL L5610(10B,IMODE,ICHAN,IBUFF,INO)
      ISTAT=-1
  210 CALL L5610(10B,ISTAT)
      IF(ISTAT) 210,220
  220 IADRS=IAND(IBUFF,17B)
      DO 230 I=1,ISCAN
      DATA(I)=FSVOL*FLOAT(IAND(IBUFF(I),177700B))/32768.
  230 CONTINUE
```

```
C TRNASFER SECTION (RANDOM)
C
      WRITE(6,907) ITEST,IRUN,IDAY,IMO,IYEAR,IMODE,ISCAN
      WRITE(6,912) IADRS
  912 FORMAT (I3)
      DO 310 I=1,ISCAN
      WRITE(6,913) DATA(I)
  913 FORMAT(F6.3)
  310 CONTINUE
      GO TO 205
C
C PRINTOUT (RANDOM)
C
  235 WRITE(2,906)
      WRITE(2,908) IDAY,IMO,IYEAR,ITEST,IRUN
      WRITE(2,906)
      WRITE(2,914) IADRS
  914 FORMAT(10X,"CHANNEL:",I3)
      WRITE(2,906)
      ISPCE=ISCAN/5
      DO 240 I=1,ISPCE
      ILIM=I+4*ISPCE
      WRITE(2,915) (DATA(J),J=I,ILIM,ISPCE)
  240 CONTINUE
  915 FORMAT(5F10.4)
      WRITE(2,906)
      GO TO 205
 1000 WRITE(2,916)
  916 FORMAT("IMPROPER MODE....4 OR 5 ONLY")
      GO TO 11
      END
      ENDS
```

Data Transfer BASIC Program "TRANS"

```
[illegible]
[illegible]
30 REM [illegible]
40 WAIT 2
50 FILES [illegible]
60 READ #1[illegible]
70 DIM D[16,130]
80 MAT D=ZER
90 ENTER (1,100 [illegible]
100 FORMAT 5F2.0,F[illegible]
110 IF I6=4 THEN 2[illegible]0
120 IF I6=5 THEN 150
130 DISP "MODE NO. IS WRONG";[illegible]
140 STOP
150 I8=I7+1
160 FOR I=1 TO [illegible]
170 FOR J=1 TO [illegible]
180 ENTER [illegible]
190 FORMAT [illegible]
200 NEXT [illegible]
210 NEXT I
220 GOTO [illegible]
230 ENTER [illegible]
240 K=1
250 FOR [illegible]
260 FOR J=1 TO [illegible]
270 ENTER [illegible]
280 K=K+1
290 IF K[illegible] THEN [illegible]
300 NEXT [illegible]
310 NEXT [illegible]
[illegible] D[1,[illegible]]=[illegible]
[illegible] D[2,[illegible]]=[illegible]
[illegible] D[3,[illegible]]=[illegible]
[illegible] D[4,[illegible]]=[illegible]
[illegible] D[5,[illegible]]=[illegible]
[illegible] D[6,[illegible]]=[illegible]
[illegible] D[7,[illegible]]=[illegible]
[illegible]
[illegible]
[illegible]
[illegible] PRINT [illegible]
[illegible] PRINT
[illegible] WRITE [illegible]
[illegible] FORMAT [illegible]
[illegible] PRINT [illegible]
[illegible] READ [illegible]
[illegible]
[illegible]
[illegible]
510 REM [illegible]
[illegible]
[illegible]
[illegible]
[illegible] FORMAT [illegible]
```

```
5[illegible]0 PRINT
570 L=1
580 FOR I=[illegible] STEP 10
590 FOR J=1 TO 10
600 FOR K=1 TO [illegible]
610 WRITE (15,620) [illegible]
620 FORMAT (A8)
630 L=L+1
640 NEXT K
650 PRINT
660 NEXT J
670 PRINT LINE
680 IF L [illegible]
690 NEXT I
700 GOTO [illegible]
710 REM------SEQUENTIAL MODE------
720 WRITE (15,"[illegible]"
730 FORMAT [illegible]
740 FOR I=1 TO 8
750 WRITE (15,"[illegible]
760 FORMAT (F2.0)
770 NEXT I
780 FOR J=2 TO 10
790 WRITE (15,[illegible]
800 FORMAT (F5.0)
810 FOR I=1 TO 8
820 WRITE (15,[illegible]
830 NEXT I
840 PRINT
850 NEXT J
860 PRINT LINE
870 FOR [illegible]
880 WRITE (15,[illegible]
890 NEXT I
900 FOR [illegible]
910 WRITE (15,[illegible]
920 FOR I=9 TO 12
930 WRITE (15,[illegible]
940 NEXT I
950 PRINT
960 NEXT J
970 PRINT LINE
980 GOTO [illegible]
990 END
```

Data Analysis BASIC Program "TRNSX1"

```
10 REM----***TRNSX1***-----------[illegible]----
20 REM-----MAIN DATA REDUCTION PROGRAM.-------------------
30 REM---READS RAW DATA FROM DISC, CALCULATES,
40 REM---CALIBRATION POLYNOMIAL, CONVERTS [illegible]
50 REM---AND STORES REDUCED DATA.
60 DIM D[16,102],C[15,102],A[3,2],S[2] [illegible]
61 DIM N[2]
70 FILES DATA[illegible]
80 MAT C=ZER
90 FOR K=1 TO 2
100 DISP "INPUT SEL #";K;
110 INPUT N[K]
120 NEXT K
130 FOR K=1 TO 2
140 READ #1,N[K]
150 MAT READ #1;D
160 S1=-(D[1,1]+D[7,63])/2
170 L=1
180 FOR J=1 TO 102
190 FOR I=1 TO 16
200 S1=S1+D[I,J]
210 L=L+1
220 IF L>D[7,10[illegible]] THEN 250
230 NEXT I
240 NEXT J
250 S[K]=S1/(D[7,1[illegible]]-1)
260 D[11,102]=S[K]
270 PRINT
280 PRINT [illegible]
290 PRINT [illegible]
300 DISP [illegible]
310 INPUT P[K]
320 P[K]=P[K][illegible]
330 DISP "INPUT [illegible]
340 INPUT R[K]
350 M[K]=R[K][illegible]
360 NEXT K
370 CHAIN [illegible]
400 STOP
410 END
```

Data Analysis BASIC Program "COEFF"

```
10 REM------COEFF------------------
20 REM---DETERMINES CALIBRATION COEFFICIENTS
30 A[1,1]=1
40 A[2,1]=1
50 A[1,2]=S[1]
60 A[2,2]=S[2]
70 B[1]=(M[1]-P[1])
80 B[2]=(M[2]-P[2])
90 MAT A=INV(A)
100 MAT X=A*B
110 FOR K=1 TO [illegible]
120 READ #1,N[K]
130 MAT READ #1,D
140 D[9,102]=P[K]
150 D[10,102]=M[K]
160 D[11,102]=S[K]
170 D[12,102]=X[1]
180 D[13,102]=X[2]
190 READ #1,N[K]
200 MAT PRINT #1,D
210 NEXT K
220 PRINT
230 PRINT "CALIBRATION COEFFICIENTS;"
240 PRINT "       X0=";D[12,102]
250 PRINT "       X1=";D[13,102]
260 PRINT
270 CHAIN "[illegible]",10,10
280 END
```

Data Analysis BASIC Program "REDUCE"

```
10 REM----*REDUCE*----[illegible]
20 REM---REDUCES DATA USING CALIBRATION COEFFICIENTS
30 REM---DETERMINED BY 'COEFF'.
40 FOR L=1 TO 3
50 READ #1,N[L]
60 MAT READ #1;D
70 K=1
80 FOR J=1 TO 101
90 FOR I=1 TO 16
100 C[I,102]=C[I,102]
110 C[I,J]=FNA(D[I,J])
120 C[I,J]=C[I,J]+F[L]*[illegible]
130 K=K+1
140 IF K>D[7,102] THEN 170
150 NEXT I
160 NEXT J
170 READ #2,N[L]
180 MAT PRINT #2;C
190 NEXT L
200 GET "OUTPUT",10,10
210 DEF FNA(X)
220 Z=D[15,102]*X-D[12,[illegible]]
230 RETURN Z
250 END
```

Data Analysis BASIC Program "OUTPUT"

```
10 REM-----OUTPUT----------------------
20 REM---PRINTS &/OR PLOTS REDUCED DATA [illegible]
30 REM---FILE:DATA-P.
40 DEG
50 FILES DATA-P
60 DIM D[16,102]
70 MAT D=ZER
80 DISP "INPUT RECORD #";
90 INPUT N1
100 READ #1,N1
110 MAT READ #1;D
120 DISP "ENTER 0 TO SUPPRESS PRINTOUT";
130 INPUT Z1
140 IF Z1=0 THEN 390
150 PRINT
160 WRITE (15,170)D[1,102] [illegible]
170 FORMAT 5X,"REDUCED DATA [illegible]
180 WRITE (15,190)D[3,102],D[4,102],D[5,102]
190 FORMAT 2X,"DATE: ",F3.0,"  ",F3.0,"  ",F3.0
200 WRITE (15,210)N1
210 FORMAT 3X,"DATA FROM FILE:"DATA-P" ; RECORD # ",F5.0
220 WRITE (15,230)D[2,102]
230 FORMAT "CHANNEL:",F3.0
240 PRINT
250 L=1
260 FOR I=1 TO 91 STEP 10
270 FOR J=1 TO 16
280 FOR K=I TO I+9
290 WRITE (15,300)D[J,K]
300 FORMAT F8.3
310 L=L+1
320 NEXT K
330 PRINT
340 NEXT J
350 PRINT LIN2
360 IF L>D[7,102] THEN 390
370 NEXT I
380 REM----PLOTTING SECTION------
390 DISP "INPUT X-MAX";
400 INPUT X1
410 DISP "INPUT Y-MIN,Y-MAX";
420 INPUT Y1,Y2
430 SCALE -0.1*X1,1.1*X1 [illegible]
440 XAXIS Y1,0.1*X1,0,X1
450 YAXIS 0,0.1*(Y2-Y1),Y1,Y2
460 XAXIS Y2,0.1*X1,0,X1
470 YAXIS X1,0.1*(Y2-Y1),Y1,Y2
480 PEN
490 Y=1.05*Y1-0.05*Y2
500 FOR J=0 TO X1 STEP 0.1*X1
510 PLOT J,Y,0
520 CPLOT -2,0
530 LABEL [illegible]
540 NEXT J
550 X=0.065*X1
```

```
560 FOR [illegible]
570 PLOT [illegible]
580 IPLOT 4,-0.5
590 LABEL [illegible]
600 NEXT J
610 PEN
620 PLOT -1.08[illegible]
630 LABEL [illegible]
640 PEN
650 PLOT 0.45[illegible]
660 LABEL [illegible]
670 PEN
680 K=1
690 FOR J=1 TO 10[illegible]
700 FOR I=1 TO 1[illegible]
710 X=1E-0[illegible]
720 IF [illegible] THEN [illegible]
730 PLOT [illegible]
740 K=K+1
750 IF X>D[illegible] THEN 7[illegible]
760 NEXT I
770 NEXT J
780 PEN
790 PLOT 0.[illegible]
800 LABEL [illegible]
810 FORMAT [illegible]
820 PEN
830 PLOT [illegible]
840 LABEL [illegible]
850 PEN
860 PLOT [illegible]
870 LABEL [illegible]
880 PEN
890 DISP "CONT-[illegible] FOR ANOTHER RUN"
900 STOP
910 CHAIN [illegible]
920 STOP
930 END
```

Data Analysis BASIC Program "BLADE"

```
10 REM----**BLADE**------------------
20 REM---PROGRAM TO PLOT [illegible]
30 REM---ACROSS A SINGLE BLADE SPACE
40 DIM D[16,102],A[22]
50 DEG
60 FILES DATA-P
70 DISP "INPUT RECORD #";
80 INPUT N1
90 READ #1,N1
100 MAT READ # 1;D
110 DISP "INPUT COMPRESSOR RPM";
120 INPUT D[1,102]
130 T2=39[illegible]/10*0.01
140 R=0
150 T=0
160 K=1
170 FOR J=1 TO 101
180 FOR I=1 TO 16
190 IF D[I,J]<R THEN 220
200 Y1=K
210 R=D[I,J]
220 K=K+1
230 T=T+1E-02
240 IF K>D[7,101] THEN [illegible]
250 IF T>T2 THEN 280
260 NEXT I
270 NEXT J
280 REM----PLOTTING SECTION-----
290 DISP "INPUT Y-MAX";
300 INPUT Y1
310 DISP "INPUT [illegible]";
320 INPUT Y1,Y2
330 DISP "INPUT [illegible]";
340 INPUT H
350 SCALE -0.[illegible]
360 XAXIS Y1,0.1*[illegible]
370 YAXIS [illegible]
380 XAXIS [illegible]
390 YAXIS [illegible]
400 PEN
410 [illegible]=1.05*Y1-0.05*Y2
420 FOR J=0 TO [illegible] STEP [illegible]
430 PLOT J,Y,0
440 CPLOT -2,0
450 LABEL [illegible]
460 NEXT J
470 [illegible]
480 FOR [illegible]
490 PLOT [illegible]
500 CPLOT 0,-0.[illegible]
510 LABEL [illegible]
520 NEXT [illegible]
530 PEN
540 PLOT [illegible]
550 LABEL [illegible]
560 LABEL [illegible]
```

```
570 PEN
580 PLOT 0.45*X1 1.1*Y1-0 1*Y2 0
590 LABEL (*,1.2,1.5,0;H)"%/S"
600 PEN
610 K=1
620 T=0
630 FOR J=1 TO 101
640 FOR I=1 TO 15
650 IF K<X1+1 THEN 730
660 T1=T/T2
670 PLOT T1,D(I,J),-2
680 PEN
690 T=T+0.01
700 IF T<T2 THEN 730
710 T3=T-T2
720 T=T3
730 K=K+1
740 IF (P-K.[illegible]) THEN 770
750 NEXT I
760 NEXT J
770 PEN
780 PLOT 0.1*X1,1.2*Y2-0.[illegible]
790 LABEL (800,1.1,1.5,0,4)[illegible]
800 FORMAT "TRANSONIC COMPRESSOR TEST",[illegible]
810 PEN
820 PLOT 0.1*X1,1.15*Y2-0.15[illegible]
830 LABEL (840,1,1.5,0,4)[illegible]
840 FORMAT "RUN:",F2.0,3X,"F-REF:",[illegible]
850 PEN
860 PLOT 0.1*X1,1.1*Y2-0.[illegible]
870 LABEL (880,1.1,1.5,0,4)[illegible]
880 FORMAT "DATE:",F3.0,[illegible]
890 PEN
900 PLOT 0.1*X1,1.05*Y2-0.05[illegible]
910 LABEL (920,1.1,1.5,0,4)[illegible]
920 FORMAT "RPM:",F7.0
921 DISP "<CONT-70> FOR ANOTHER PLOT"
922 STOP
930 GET "TRNS:1",13,10
940 END
```

Calibration Test BASIC Program "STATIC"

```
10 REM---------"STATIC"---------- [illegible]
20 REM---A [illegible] AND STORES STATIC CALIBRATION [illegible]
30 REM---A D CONVERTER. ACTUAL PRESSURES, REFERENCE PRESSURE
40 REM---AND TEMP ARE INPUT MANUALLY.
50 FILES STAT
60 DIM S[10],A[20,2]
70 DISP "INPUT # DATA PTS.";
80 INPUT Z
90 MAT A=ZER
100 MAT S=ZER
110 FOR K=1 TO Z
120 S1=0
130 ENTER (1,140) [illegible]
140 FORMAT 5F2.0,F1.0,F7.4
150 ENTER (1,160)I5
160 FORMAT F1.0
170 FOR I=1 TO 10
180 ENTER (1,*)S[I]
190 S1=S1+S[I]
200 NEXT I
210 A[K,1]=S1/10
220 NEXT K
230 FOR I=1 TO Z
240 DISP "INPUT [illegible] FOR PT: "I;
250 INPUT A[I,2]
260 NEXT I
270 REM--INPUT DATE--
280 A[16,1]=I3
290 A[17,1]=I4
300 A[18,1]=I5
310 DISP "INPUT P-REF";
320 INPUT A[19,1]
330 DISP "INPUT TEMP";
340 INPUT A[20,1]
350 PRINT LIN2
360 WRITE (15,370)A[19,1],A[20,1]
370 FORMAT [illegible]
380 PRINT
390 FOR I=1 TO Z
400 FOR J=1 TO 2
410 WRITE (15,420)A[I,J];
420 FORMAT F10.3
430 NEXT J
440 PRINT
450 NEXT I
460 DISP "[illegible]";
470 INPUT [illegible]
480 READ [illegible]
490 MAT PRINT [illegible]
500 PRINT
510 WRITE (15,520)[illegible]
520 FORMAT [illegible] "DATE" [illegible]
530 WRITE (15,540)[illegible]
540 FORMAT [illegible]
550 PRINT LIN2
```

```
10 REM----***S [illegible]
20 REM----PROGRAM TO REDUCE AND PLOT [illegible]
30 REM----CALIBRATION DATA FROM THE [illegible]
40 DEG
50 FILES [illegible]
60 DIM D[20,2],A[4,4],B[4],X[4]
70 DISP "INPUT RECORD #";
80 INPUT N0
90 READ #1,N0
100 MAT READ #1;D
110 REM----POLYNOMIAL REGRESSION----
120 DISP "INPUT DEGREE OF FIT";
130 INPUT N1
140 REDIM A[N1+1,N1+1],B[N1+1],X[N1+1]
150 DISP "INPUT # OF DATA PTS";
160 INPUT N2
170 MAT A=ZER
180 FOR I=1 TO N1+1
190 FOR J=1 TO N1+1
200 FOR K=1 TO N2
210 A[I,J]=A[I,J]+D[K,1]^(I+J-2)
220 NEXT K
230 NEXT J
240 NEXT I
250 MAT B=ZER
260 FOR I=1 TO N1+1
270 FOR K=1 TO N2
280 B[I]=B[I]+D[K,2]*D[K,1]^(I-1)
290 NEXT K
300 NEXT I
310 MAT A=INV(A)
320 MAT X=ZER
330 MAT X=A*B
340 PRINT "COEFFICIENTS"
350 PRINT
360 FOR I=1 TO N1+1
370 PRINT [illegible]
380 FORMAT [illegible]
390 NEXT I
400 DISP [illegible]
410 STOP
420 GOTO 450
430 GOTO 120
440 REM----PLOTTING [illegible]
450 DISP "INPUT [illegible]";
460 INPUT X1
470 DISP "INPUT [illegible]";
480 INPUT Y1
490 SCALE -0.1 [illegible]
500 XAXIS [illegible]
510 YAXIS [illegible]
520 XAXIS [illegible]
530 YAXIS [illegible]
540 PEN
550 [illegible]
```

```
560 FOR J=0 TO X1 STEP [illegible]
570 PLOT [illegible]
580 CPLOT [illegible]
590 LABEL [illegible]
600 NEXT J
610 [illegible]=0.065[illegible]
620 FOR J=0 TO Y1 STEP [illegible]
630 PLOT [illegible],J,0
640 CPLOT 0,-0.5
650 LABEL (*,0.9,0.9,0,[illegible]) J
660 NEXT J
670 PEN
680 PLOT [illegible],0.45[illegible],0
690 LABEL (*,1.5,1.7,90,0.6) [illegible]
700 PEN
710 PLOT 0.45[illegible],-0.07[illegible],0
720 LABEL (*,1,0.9,0,0.8) "VOLTS"
730 PEN
740 FOR I=1 TO N2
750 PLOT D[I,1],D[I,2],-2
760 PEN
770 CPLOT -0.3,-0.2
780 LABEL (*,0.9,0.9,0,0.[illegible]) [illegible]
790 PEN
800 NEXT I
810 FOR I=0.001[illegible] TO X1 STEP [illegible]
820 PLOT I,FNP(I)
830 IF FNA(I)[illegible] THEN 850
840 NEXT I
850 PEN
860 GOTO 930
870 DEF FNP(T)
880 [illegible]=0
890 FOR [illegible]=0 TO [illegible]
900 [illegible]
910 NEXT [illegible]
920 RETURN [illegible]
930 PLOT [illegible]
940 LABEL (950,1.[illegible],0.9,0,[illegible])
950 FORMAT "[illegible] PRESSURE [illegible]"
960 PEN
970 PLOT [illegible],1.15,[illegible]
980 LABEL [illegible]
990 PEN
1000 PLOT [illegible]
1010 LABEL [illegible]
1020 PEN
1030 PLOT [illegible]
1040 LABEL [illegible]
1050 PEN
1060 DISP [illegible]
1070 STOP
1080 LETTER
1090 END
```

A.3 Operating Procedures

A.3.1 Operation of the 21MX Computer

Detailed information regarding operation of the 21MX Computer and its I/O devices is contained in Ref. 9 and Ref. 14. The following paragraphs summarize the procedures most often used and provide a guide around difficulties and pitfalls that have been encountered in the use of this equipment.

A.3.1.1 Essential Concepts

The operating procedures for the 21MX are more easily assimilated if several basic features of the system are appreciated first. The following is a list of essential fundamental concepts:

(a) POWER ON (p. 5, Ref. 9) When power is applied to the computer it is simply a block of empty memory and can only be addressed from the front panel.

(b) IBL (p. 6, Ref. 9) By pressing the IBL switch on the front panel an internal Read-Only-Memory (ROM) is loaded into the memory of the 21MX which enables paper tape to be read from the photoreader. This feature is referred to as the "Basic Binary Loader" in the 21MX literature. The Photoreader is the only I/O device which can be addressed at this point.

(c) "ABSOLUTE" AND "RELOCATABLE" PROGRAMS Computer Software converts Fortran or Assembly Language programs into machine language in the form of a "relocatable" program tape during the compiling (or assembly) process. In this form the program does not contain the necessary library subroutines and other instructions which are necessary for execution. These must be loaded along with the basic program each time it is run. When a relocatable program and its required subroutines are loaded, the Basic Control System is capable of producing a completely self contained, machine language tape which can be loaded and executed by itself. This tape is referred to as an "Absolute Binary" tape.

(d) BASIC CONTROL SYSTEM (Procedure for generating this program is given in Ref. 14). This is an "Absolute Binary" program which contains the I/O subroutines (drivers) and which can read several "relocatable" programs and connect them with the required library subroutines. It is capable of running the main program or punching an "absolute" version of the program as mentioned above.

(e) FRONT PANEL The 21MX uses six accessible storage registers. The operator is almost solely concerned with the 'P' and 'S' (switch) registers. The 'P' register stores the next address to be accessed by the memory. Therefore when a starting address is called for in the procedure it is entered in the 'P' register. Each register is filled by entering the required octal code into the 16-BIT 'Display' register (1)*. The 'Display' register BITs are numbered 15 through Ø beginning at the left end and the three BITs corresponding to each octal digit are indicated. In order to transfer the contents of the 'display' register into the storage register selected, the "STORE" switch (8) is momentarily depressed. All switches on the face of the 21MX are dual function 'rocker' switches and care should be taken to insure that the switch is depressed in the proper direction.

A.3.1.2 Fortran Programs The following is a step-by-step procedure for generating and compiling Fortran programs. More detailed information is given in Ref. 14. The steps are summarized in Table A2.

1. On the Teletype, punch a Fortran 'source tape'

    (a) Normal Fortran programming rules apply, with the following exceptions:

        (i) A control statement starting in column one should be the first statement (Ref. 14).

---

* Numbers in parentheses refer to Figure A4.

(ii) The second statement should be the program name starting in column seven. (e.g.: PROGRAM TEST).

(iii) It is possible to compile up to five programs at a time. Following the END statement of the last program, there should be an END$ statement.

(b) In punching tapes on the Teletype always be sure to punch sufficient leader and trailer to facilitate threading into the photoreader. Four cycles of the 'HERE IS' command is sufficient.

(c) CR-LF must follow every statement that is punched or it will not be read by the computer.

2. Load the configured FORTRAN COMPILER, PASS 1 Tape. (see Ref. 14 for configuration of this tape).

(a) Place this tape into the photoreader.

(i) Press LOAD

(ii) Thread the tape with the sprocket holes toward the machine.

(iii) Press READ

(b) Set 'S' register BITs 9 and 7 on. This code is an octal 12 (12_8) which corresponds to the Unit Reference number of the photoreader.

(c) Press PRESET (3)

(d) Press IBL (3)

(e) Press RUN (2)

(i) The PASS 1 tape will be read.

3. Load the Fortran Source Tape

(a) Place the tape into the photoreader (step 2a)

(b) Prepare the Teletype

(i) Switch to 'local'

(ii) Punch a leader

(iii) Turn punch off

(iv) Switch to 'line'

(v) Turn punch on

(c) Set 'P' register to 100_8

(d) Press PRESET

(e) Press RUN

(i) The program is compiled and any syntax errors are typed out.

(ii) Error codes appear starting in column 1 preceded by an "E-" (ref. 14, p. EM-

10) Any errors will require restarting at step 1.

(iii) The Intermediate Binary Tape is punched at this time.

4. Load the FORTRAN COMPILER, PASS 2 Tape

   (a) This step is identical to step 2

5. Load the Intermediate Binary Tape

   (a) Place the tape in the Photoreader (step 2a)

   (b) Set the 'P' register to 100_8

   (c) Press PRESET

   (d) Press RUN

      (i) The tape will halt after reading the control statement with 102007_8 in the display register.

   (e) Press RUN

      (i) The Final Binary Object Tape is punched. This is a relocatable binary program tape capable of running with the Basic Control System.

A.3.1.3 <u>Running Programs with the Basic Control System (BSC)</u>

After the Final Binary Object Tape has been punched, the Basic Control System and Fortran Library Subroutine tapes must be loaded to enable the program to run. The following is the procedure for doing this:

1. Load the Configured BCS tape (See Ref. 14 for configuration of this tape)

   (a) This step is identical to step 2 of section A3.1.2.

2. Set the 'P' register to a starting address of 2_8.

3. Set the 'S' register as desired (See Ref. 14). BIT 15 on will give the shortest loading time but gives no printout of program storage locations which can be useful in debugging.

4. Load the Final Binary Object Tape

5. Press PRESET

6. Press RUN

   (a) Upon completion of reading the Final Binary Object Tape, the subroutine required by the program will be listed.

   (b) *LOAD will be printed.

7. Set the 'S' register BIT 2 on

8. Load the FORTRAN IV Library tape

9. Press RUN

   (a) Upon completion 6a and 6b are repeated

10. Load the L5610 Library tape if required (if not, go to step 12)

11. Press RUN

    (a) Steps 6a and 6b are repeated

12. Load the Fortran EAU Library tape

13. Press RUN

    (a) Upon Completion *LST is printed

14. If a memory allocation listing is desired, clear the 'S' register (if not, set BIT 2 off and BIT 15 on)

15. Press RUN

    (a) On completion of the listing *RUN is printed

16. Press RUN to execute the program.

Table A2 summarizes the steps and source references for these procedures.

A.3.1.4 <u>Error Codes</u> Error and Halt codes can appear in two places. They are either typed on the teletype or they appear in the display register of the 21MX. See Ref. 14, p. BCS-15 for those error codes that appear on the teletype. Table A2 is a list of the most common display register halt codes.

TABLE A2: 21MX Display Register Halt Codes

Octal Code	Meaning	Action
102007	Control Statement Read	Press RUN
102055	Turn Punch Off, Press RUN	As Stated
102056	Turn Punch On, Press RUN	As Stated
102077	Standard Stop Code, Successful Termination	None

In general an error code or non-standard halt code accompanying a program halt will require restarting the operation (compiling or reunning) from step 1. To date code 102007 is the only halt code which has been recoverable by pressing RUN.

TABLE A3: Procedures for Generating and Running Fortran Programs on the HP 21MX Computer

STEP		DESCRIPTION	REFERENCE
1.	Punch Source Tape	Operator types and punches Fortran statements at the teletype	HP Fortram Programmers Manual
2.	Compile Program	Use Fortran Compiler Pass 1 & Pass 2 programs to generate a relocatable binary tape.*	Procedure: 3 p. SSO-9 Operating Proc. Manual
3.	Run Program (or punch absolute binary tape)	Load and Run under Basic Control System**	Procedure: 3 p. BCS-11 Operating Proc. Manual

* Fortran Pass 1 tape must be configured for the system (Procedure 1; p. SIO-5; Operating Procedures Manual)

** Basic Control System (BCS) must be generated for the system (Procedure 1; p. BCS-2; Operating Procedures Manual)

NOTE: For assembly Language Programs, the Procedure for Step 1 is given in the HP Assembly Programmers Manual. Step 2 is given in Procedure 1; p. SSO-3; Operating Procedures Manual. Step 3 is unaffected by the choice of source language.

A.3.2 <u>Data Acquisition using Program "KATE"</u> Program "KATE" is the data acquisition program written for the 21MX computer. The source program was written in HP Fortran. Section A.2 contains a complete statement listing, a list of variable assignments and a flowchart for the program. The following is a step-by-step procedure for the acquisition of data using this program and the associated software for transfer of data to the HP 9830A. Reference is made to the views of the equipment given in Fig. A3 and A4.

1. Power ON
   - (a) Turn on main power switch (1)*
   - (b) Turn on A/D power (2)*
   - (c) Turn on photoreader power (3)*
   - (d) Turn 21MX RESET/PWR switch (5)* counter-clockwise to RESET then clockwise to ON
2. Turn on the HP 9830A calculator and peripherals
3. If using an Absolute Binary Tape go to step 3a, if using a Relocatable Tape go to step 3b.

3a Load "KATE" (Absolute)
   - (a) Set the 'S' Register BIT 9 and BIT 7 on
   - (b) Press PRESET
   - (c) Press IBL
   - (d) Press RUN - The Absolute Binary Tape will be Read at this time.

---

* Numbers in parentheses refer to Figure A3

(e) When the Teletype prints *RUN, Press RUN to execute the program.

3b Load "KATE" (relocatable)

(a) See section A3.1.3 for instructions on loading programs under the BCS.

(b) When Teletype prints *RUN, Press RUN to execute the program.

4. Teletype messages and responses

(a) INPUT DATE...DAY MONTH YEAR: input six numerical values for the date in the order requested. Do not leave spaces or commas between the numbers.

(b) INPUT TEST # & RUN #: Input the Test and Run numbers separated by commas.

(c) ENTER MODE AND # OF SCANS/CHAN: Enter the desired mode of operation for the A/D converter followed by a comma. Then enter the number of scans desired <u>per channel</u>. Limits on the number of scans are:

Mode 4 (Random Mode): Ø - 16ØØ
Mode 5 (Sequential Mode): Ø - 1ØØ

(d) INPUT CHANNEL # (Random Mode Only): Enter the channel to be scanned by the A/D converter.

(e) ENTER CONTINUE SIGNAL: The program will branch according to the value entered here.

0 - Program returns to step 4a
1 - Data acquisition begins
2 - Last data acquired is printed on the Teletype

If data is to be acquired, first go to step 5.

5. HP 9830A Data Transfer Program: "TRANS"

   (a) See Ref. 11 for HP 9830A power on procedures.

   (b) Insure that disk # PL-004 "Transonic Compressor" is installed in the Mass Memory unit.

   (c) Enter UNIT Ø

   (d) Enter GET "TRANS"

   (e) Enter "RUN"

      i) The Mass Memory will 'click' and the display will remain blank. The program is awaiting data transfer.

6. When the desired operating point has been established on the Transonic Compressor, Enter Continue Signal "1".

   (a) After approximately 15 seconds (for 1000 scans) the teletype will print ENTER CONTINUE SIGNAL. This is an indication that the A/D has completed scanning. However due to its slower rate of operation another 15 to 30 seconds will be required for the HP 9830A to complete transfer.

   (b) Data transfer is completed when the HP 9830A prints an information 'header' (Fig. A-6).

   (c) The HP 9830A transfer program will automatically 'restart' and await another data run. Additional runs can be made by simply entering "1" each time a "CONTINUE" signal is requested.

7. Terminating Acquisition

(a) If further data acquisition is required, a Continue Signal "Ø" should be entered, which will restart program "KATE" from the beginning. The program will await a keyboard response indefinitely and will not interfere with data reduction on the HP 9830A.

(b) HP 9830A program "TRANS" can be terminated by entering STOP.

8. Further Notes

(a) If, after any run, a TTY printout of raw data is desired, enter Continue Signal "2". This printout is quite slow for any sizable number of scans and should therefore be limited to a few tests.

(b) Continue signal "Ø" entered at any time will restart the program from "INPUT DATE...". This allows any of the parameters to be changed.

(c) The Run # is automatically incremented by one each time a new run is initiated.

(d) After data transfer, raw data can be printed on the HP 9830A by entering "STOP" and then "CONT 520". After the printout is complete, the program will automatically recycle to await further data transfer.

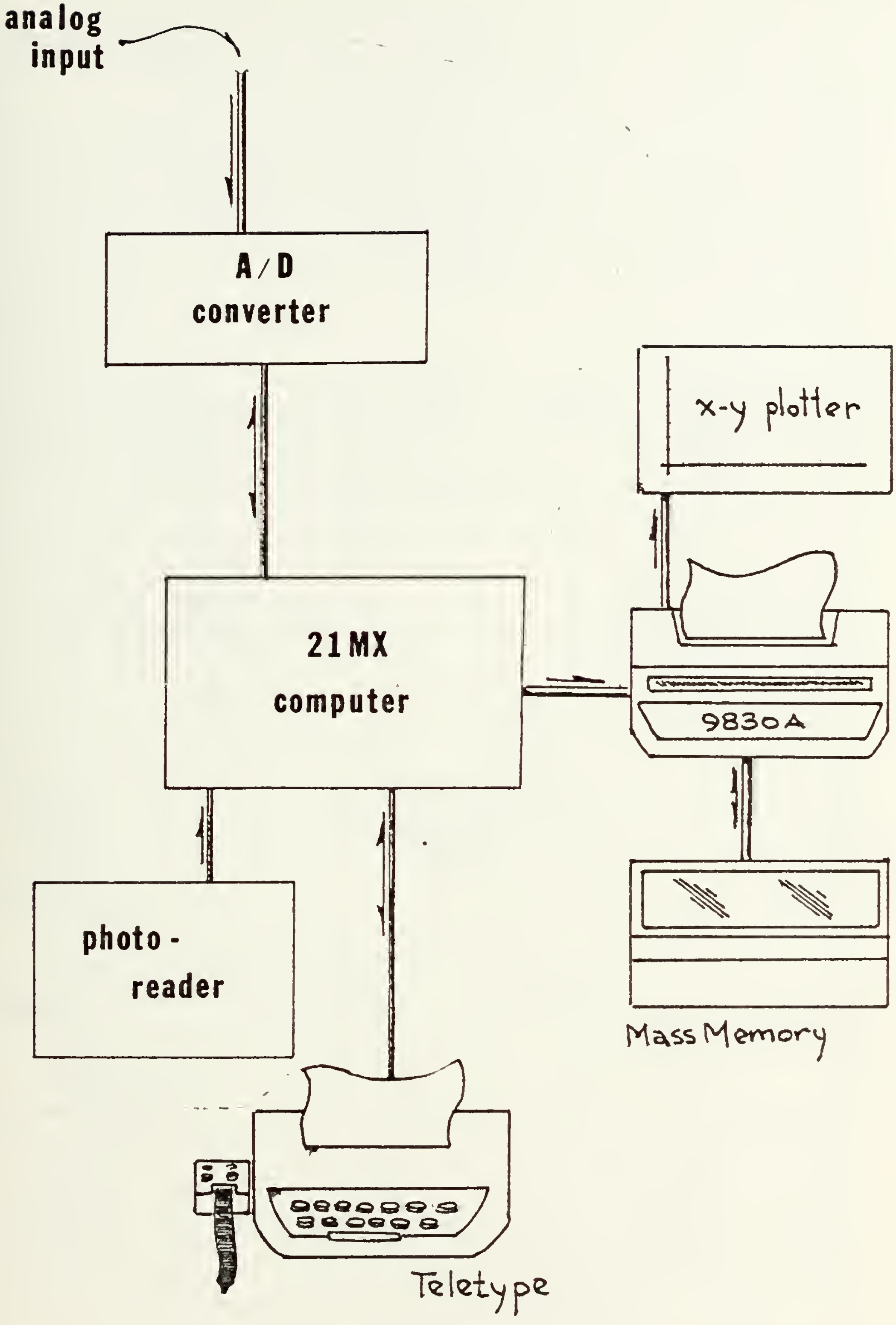

Figure A1. Components of the Real-time Data System

Program: KATE

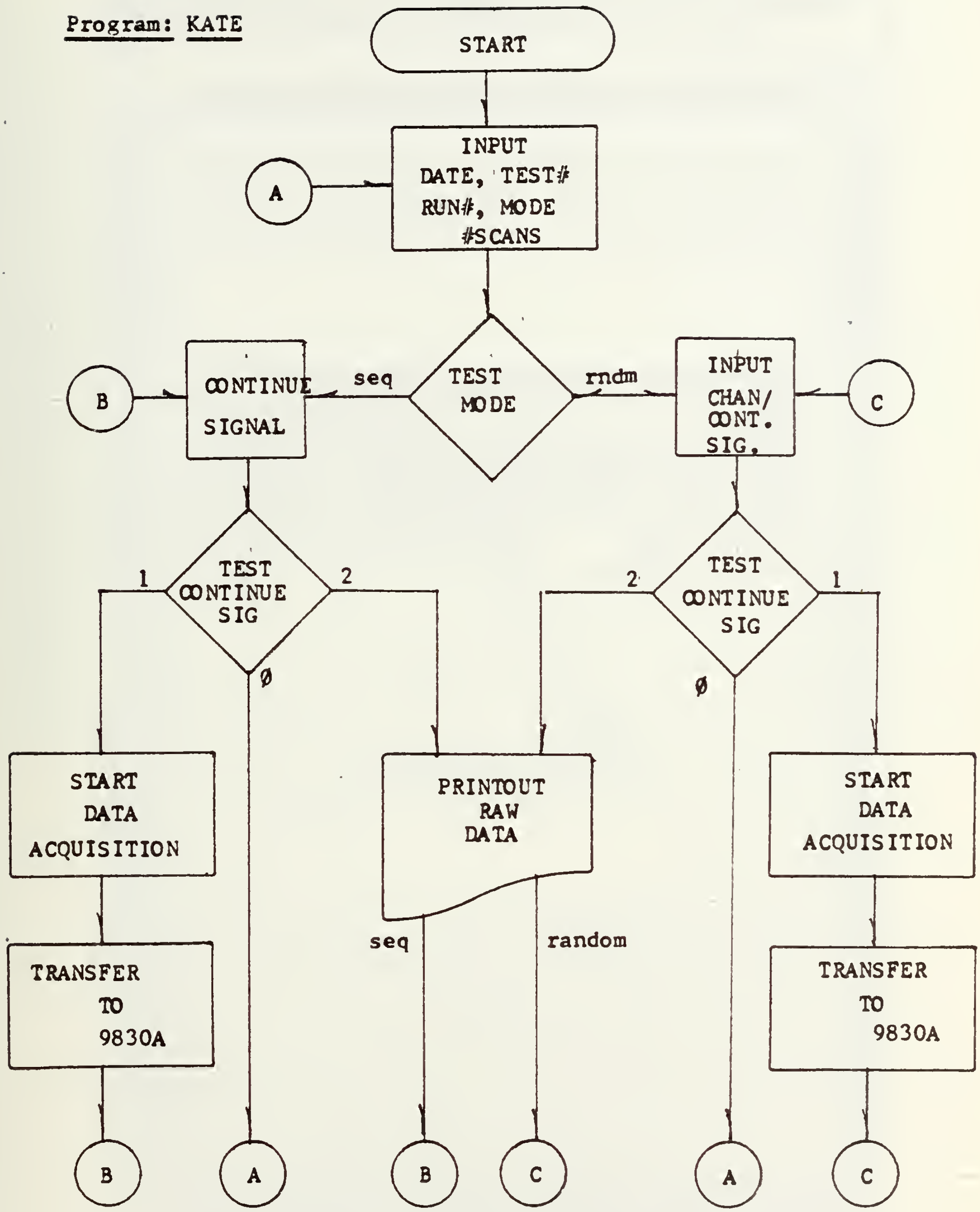

Figure A2. Flowchart for Program: KATE

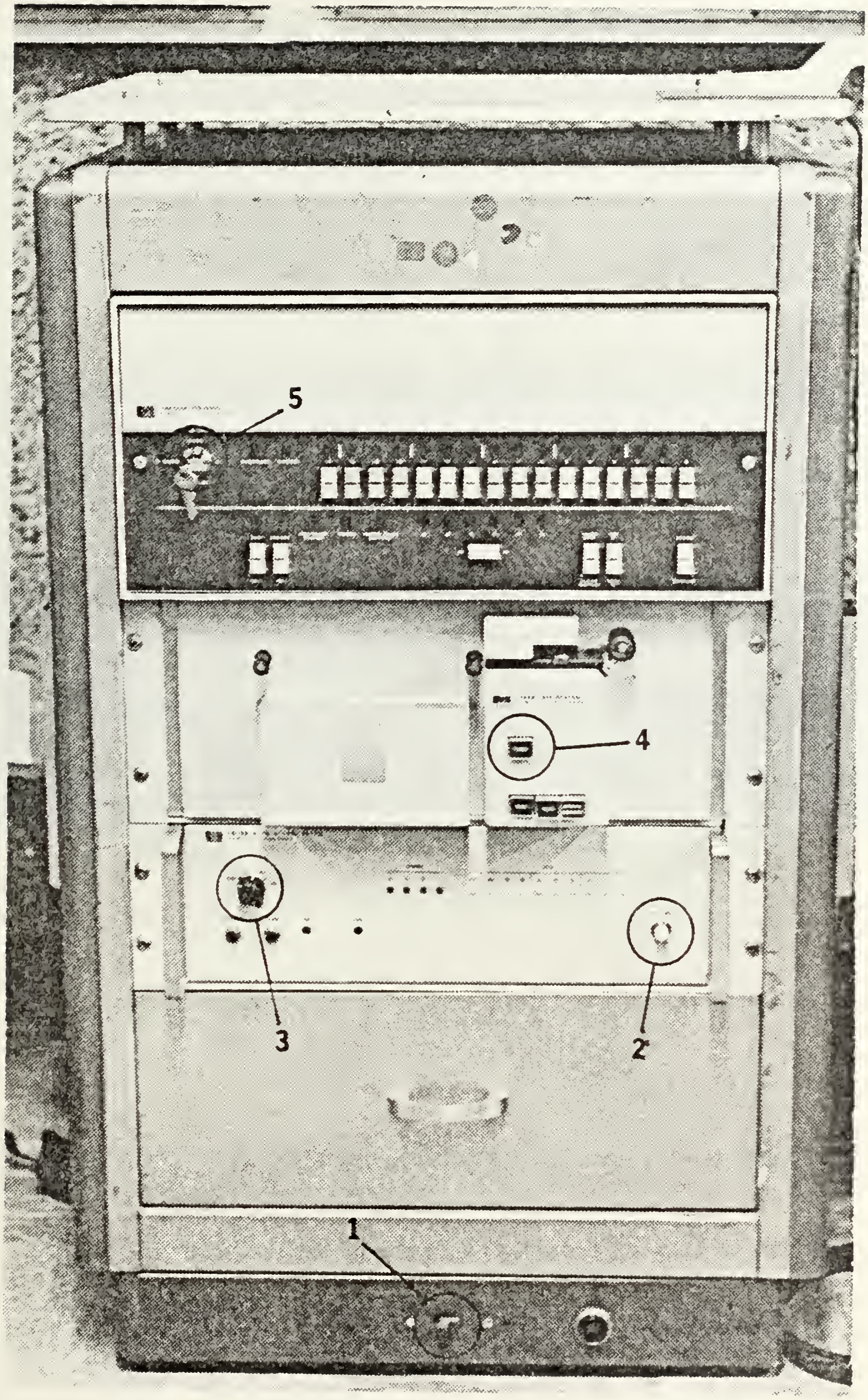

Figure A3. Hewlett-Packard 21MX, Photo-reader and A/D Converter (top to bottom)

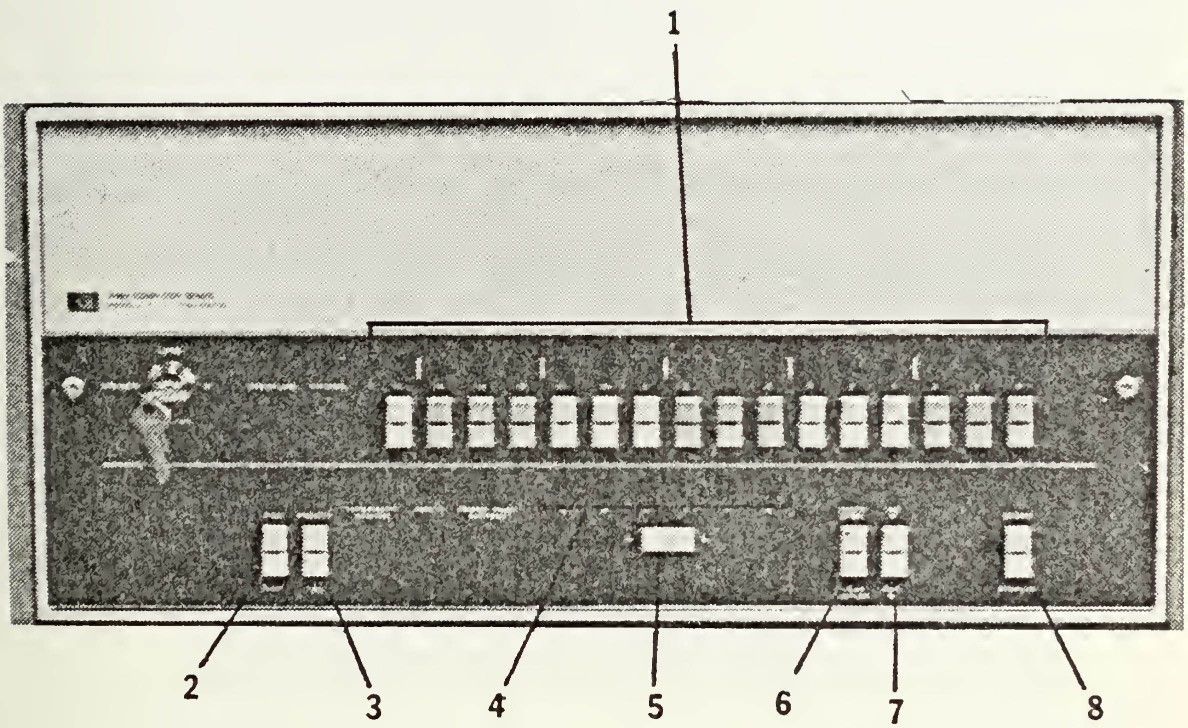

Figure A4. Hewlett-Packard 21MX Computer Front Panel

```
KEYBOARD INPUTS REQ'D:
  MODE: 4=SINGLE CHANNEL
        5=SEQUENTIAL

#SCANS/CHAN SHOULD BE MULTIPLE OF 5

REPEAT CODE:
  0....REPEAT FROM MODE INPUT
  1....REPEAT WITH SAME MODE
  2....REPEAT WITH SAME MODE & NEW CHAN (RANDOM ONLY)

CONTINUE SIGNAL: ANY POS INTEGER..CR-LF
```

```
INPUT DATE...DAY MONTH YEAR
020676
INPUT TEST # & RUN #
49,1
ENTER MODE AND # OF SCANS/CHAN
4,999
ENTER CONTINUE SIGNAL
1
INPUT CHANNEL #
0
ENTER CONTINUE SIGNAL
1
ENTER 0 TO SUPRESS PRINTOUT
```

Figure A5. Sample Messages and Responses for Program "KATE"

Figure A6. Sample Information 'Header' for Program "TRANS"

Appendix B: System Calibration

B.1 Static Calibration

Two types of static calibration were performed on a Kulite transducer mounted in a brass tube (O.D. = 0.125") with the sensitive face flush with the end. First, a regulated pressure source and a Mercury manometer were used to verify the linearity of the transducer and to examine the repeatability of the output. Figure B1 shows the results of three such tests. Second, a controlled temperature oil bath was used to investigate the temperature sensitivity of the Kulite. Figure B2 shows the variation in transducer output which was obtained as a function of temperature for a differential pressure ranging from ± 6 inches of mercury. Figure B3 shows this same data plotted as differential pressure vs. transducer output voltage for varying temperatures. It can be seen that the transducer output for temperatures ranging from 0 to 50° C fell within a voltage band representing approximately 2.4% of full scale output for an unamplified signal. This compares favorably with the factory supplied specifications (Table II). The linear least squares fit to the data in Fig. B3 is given by:

$$p - p_{ref} = 5.995\,e + 0.34855$$

The calibration was not used directly in the reduction of the dynamic data but as a baseline with which to compare the "on-line" calibration coefficients.

B.2 Verification of Sampling Interval and Recording Accuracy

In order to obtain the time scale for the data recorded by the real-time system it was necessary to verify the sampling interval and to determine whether or not it was constant. This was done by sampling a sine wave input at a known frequency and determining the number of full waves sampled in a given number of samples. Repititions of this procedure determined the steadiness of the rate. The sampling interval was determined by the 10 μ sec with a possible variation of less than 0.25%. The possible variation was the result only of the inability to specify the input wave with greater accuracy. The sample rate was therefore taken to be constant at 10 μ sec in all reduction programs. The fidelity of the data transfer and reproduction was tested by plotting the input sine function superimposed on the sampled data. Figure B4 shows the results of this test.

B.3 Periodic Flow Generator

In order to evaluate instrumentation and procedures for the program of real-time measurements on the compressor, a method was devised to generate periodic pressures at amplitudes and frequencies typical of those in the compressor. Several techniques including those in Ref. 1, were considered but no wholly satisfactory method was evident. For simplicity, speed and ease of manufacturer the apparatus shown in Fig. B5 and Fig. B6 was constructed. It consists of a notched disk rotating over a small free jet (Fig. B7). A Thermo-Systems model 1125 Calibrated Free Jet was mounted on its own control box and a notched disk turned by an electric motor capable of 10,000 RPM was mounted to intersect the jet (Fig. B8). Sixty notches were cut in the periphery of the disk so that the RPM was numerically equal to the jet chopping frequency in Hertz. This allowed frequencies up to ten kiloHertz to be generated which exceeded the range of blade-passing frequencies expected in the TRANSX compressor.

The transducer used in the calibration tests described above was mounted as shown in Fig. B8, so that, ignoring transient flow deflections in the unsteady process, it would measure the flow impact pressure. In the potential core of the free jet, the transducer would be expected to register a pressure equal to the supply pressure.

B.3.1 Results from the Periodic Flow Generator Tests

The periodic Flow Generator produced a wave form approximating a square wave through a useful frequency range. Figure B9 is an example of the signal generated by the Periodic Flow Generator as measured by the transducer and photographed on an oscilloscope. Figure B10 is the same signal recorded by the real-time data system and subsequently plotted using the programs described in Appendix A. The resolution of the transducer and real-time system was found to be such that the pneumatic noise was reproduced in the output data. The electrical noise level was, in comparison, negligible.

B.4 On-Line Calibration Technique

Due to the impossibility of measuring the temperature on the face of each transducer during operation and in view of the sensitivity of the calibration to temperature, a method of calibration was adopted which could be used while the compressor was running. E.C. Armentrout in Ref. 7 discusses a method of varying the reference pressure on the transducer in order to determine the pressure sensitivity during operation. A similar procedure was followed here.

B.4.1 Theory

The output of the transducer (e) under the influence of a time varying pressure (p) can be described by:

$$e = k_0 + k_1 (p - p_{ref}) + k_2 (p - p_{ref})^2 + \cdots$$

where p_r is the steady reference pressure and k_0, k_1 and k_2 are coefficients which can depend on temperature. Based on the investigations discussed in section B1, linearity with pressure was assumed so that:

$$e = k_0 + k_1 (p - p_{ref})$$

By describing the instantaneous pressure as the sum of the time average pressure ($\bar{p}$) and a fluctuating component (p') and by taking the time integral of voltage, there results:

$$\mathcal{E} = \frac{1}{t}\int_0^t e\,dt = k_0 + k_1 (\bar{p} - p_{ref})$$

Thus the time average of a voltage sampled over time with a known reference pressure is a function of three unknown parameters: k_0, k_1 and $\bar{p}$. However, these parameters are not separable and, in fact, the two independent parameters in this relation are k_1 and $k_2 = k_0 + k_1 \bar{p}$. It is therefore impossible to solve for k_1 and k_2 by applying two different reference pressures and calculating the time average of the voltage signals. In order to obtain k_0, the intercept of the transducer calibration, from the value of k_2 the time average pressure must be determined separately. In the TRNSX compressor measurements, the wall static pressure was measured at the same axial location as the transducer using a standard straight tap with a diameter of 0.040". Weyer, in Ref. 1, discusses the departure of static pressure measurements from the true time average. The error depends upon the amplitude and the wave shape of the pressure fluctuation. Using Weyer's results the error in assuming the wall static pressure to be the true time average is 1% to 2% at the compressor speeds for which measurements have so far been made. Therefore in reducing the data from the compressor measurements, the wall static tap (S9) pressure measurement recorded by the steady state data system was taken to be the time average pressure without correction.

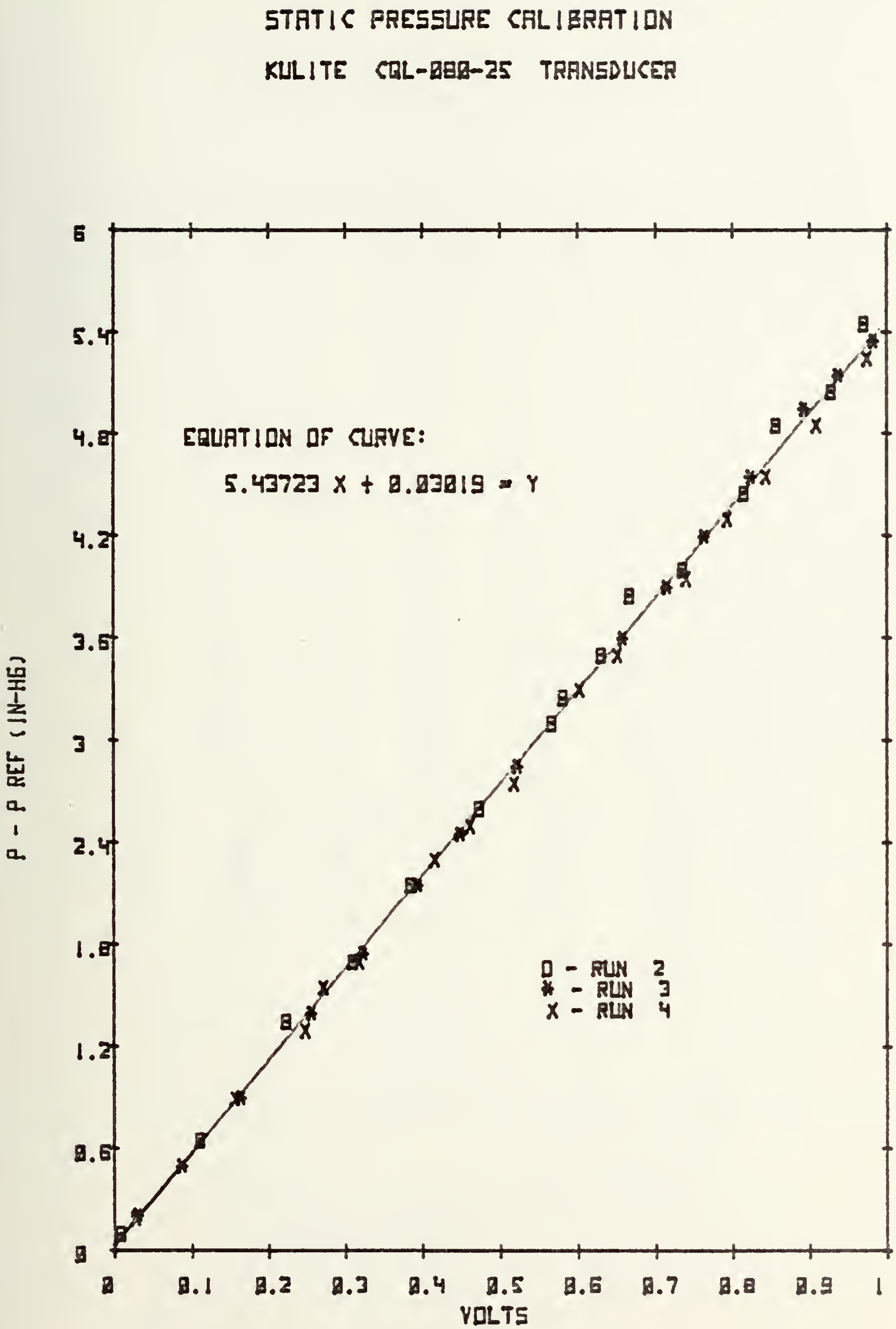
STATIC PRESSURE CALIBRATION
KULITE CQL-080-25 TRANSDUCER
EQUATION OF CURVE:
5.43723 X + 0.03019 = Y
O - RUN 2
* - RUN 3
X - RUN 4
P - P REF (IN-HG)
VOLTS
0
0.6
1.2
1.8
2.4
3
3.6
4.2
4.8
5.4
6
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Figure B1.

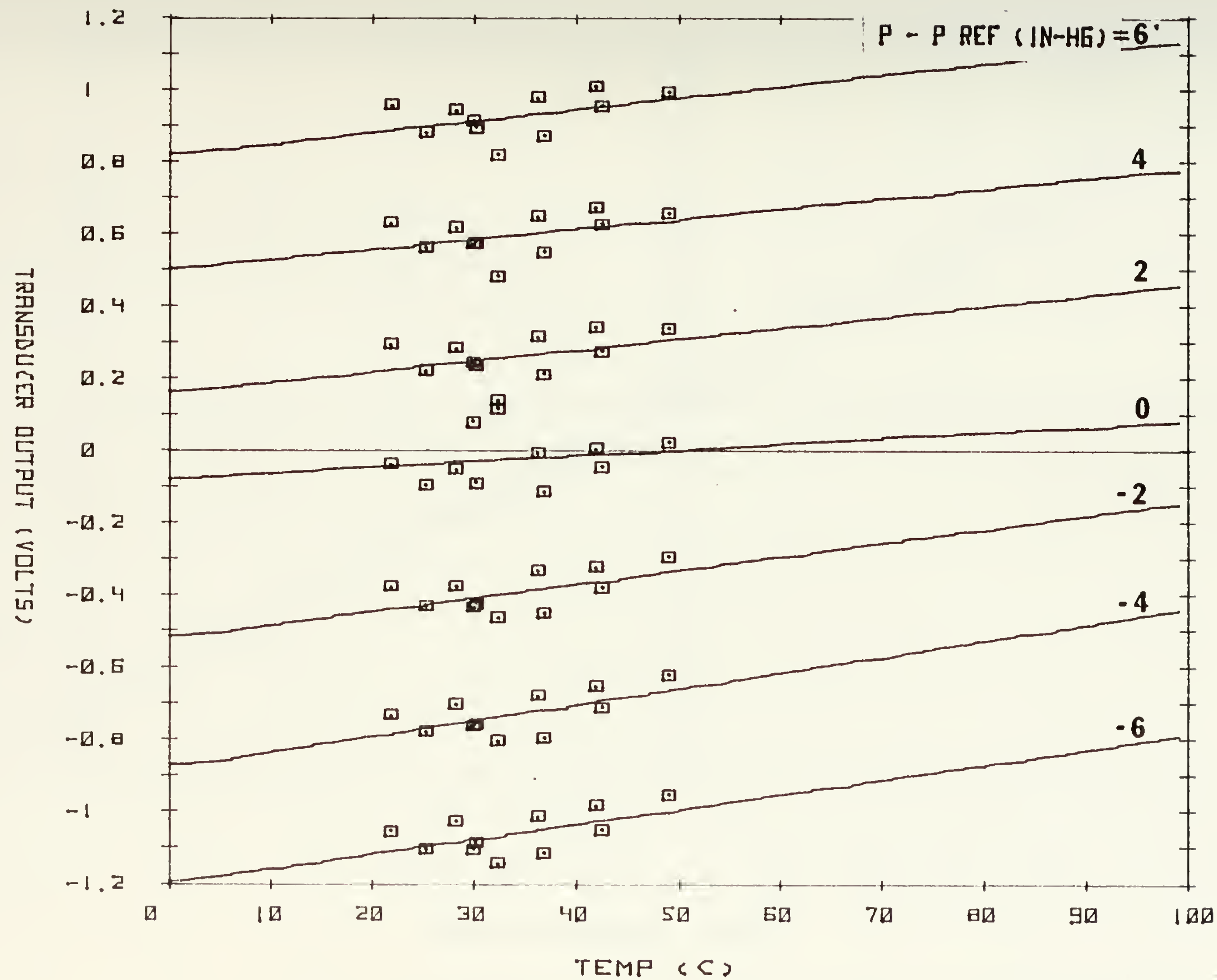

Figure B2. Transducer Output vs. Temperature (Varying Pressure)

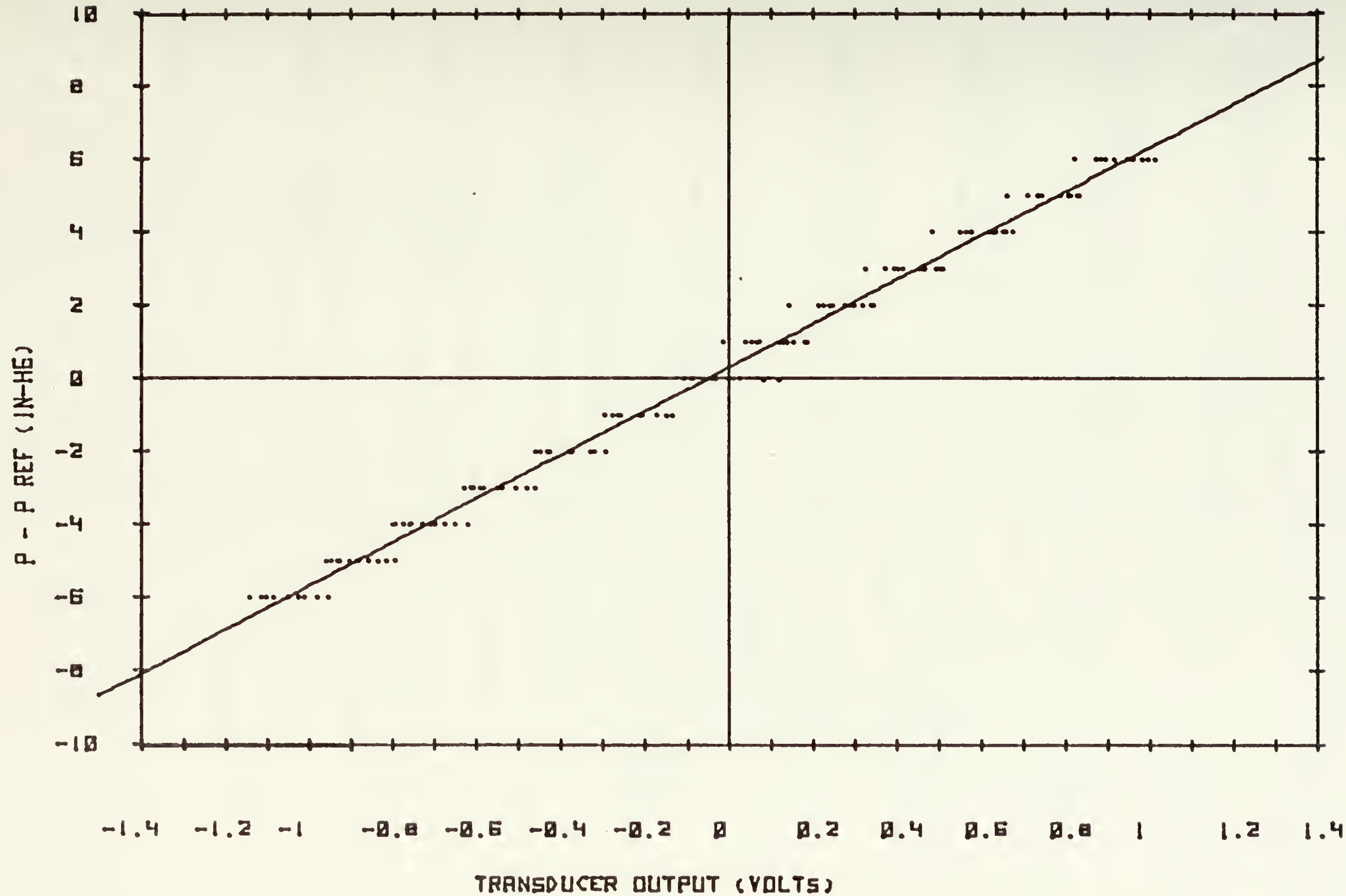

Figure B3. Pressure vs. Transducer Output (Varying Temperature)

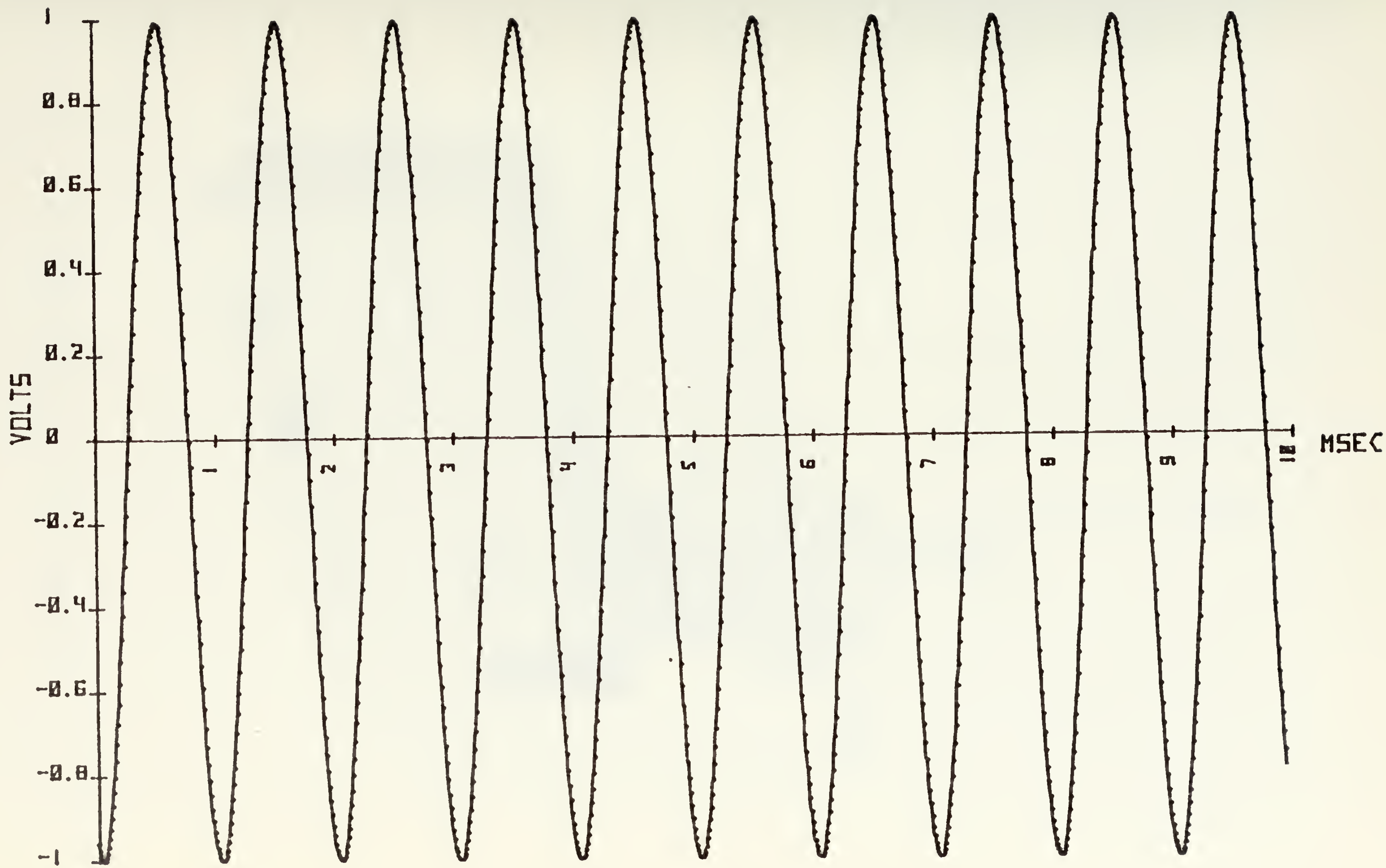

Figure B4. Reproduce Sine Wave Signal (···) With Functional Sine Plot Superimposed (—)

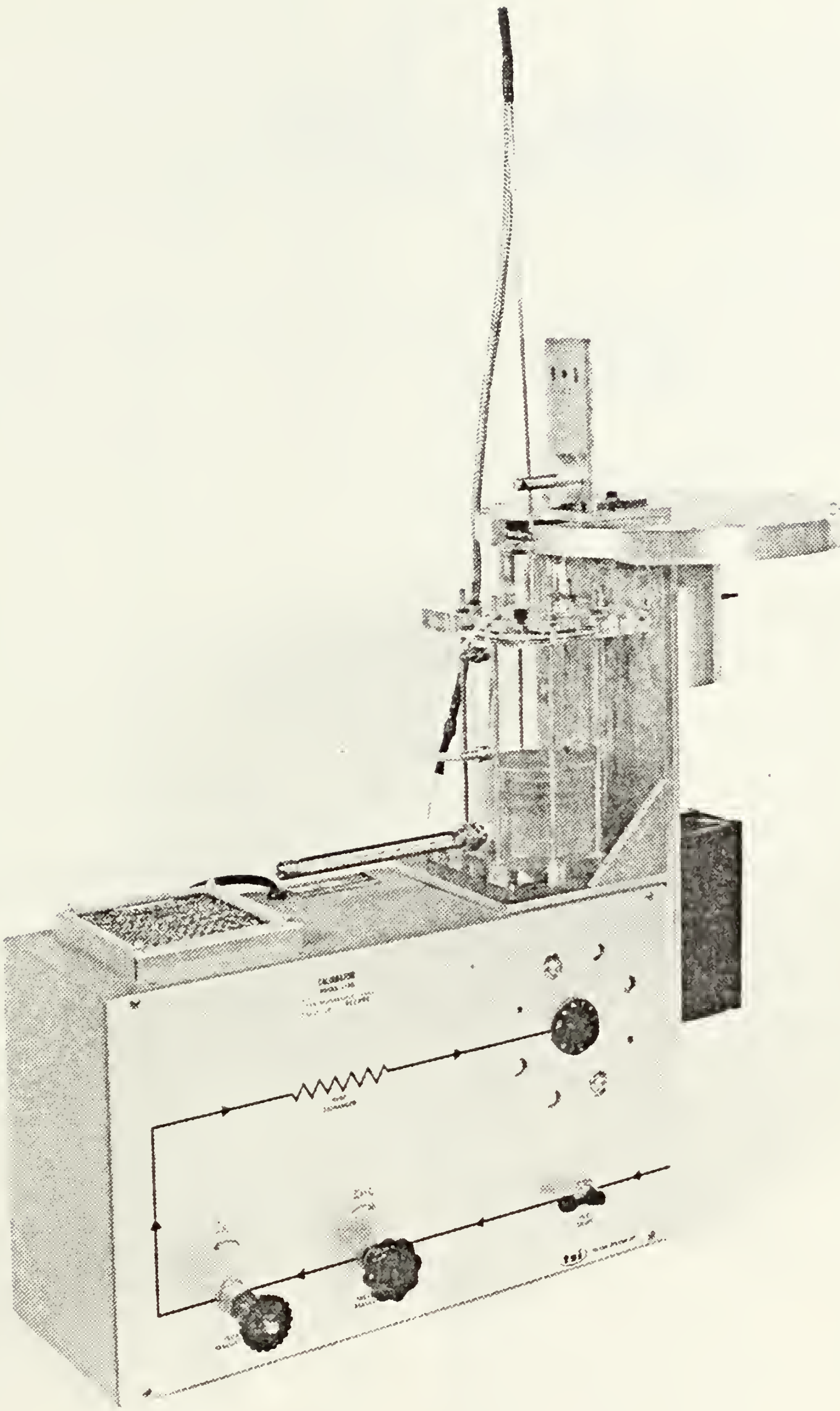

Figure B5. The Periodic Flow Generator

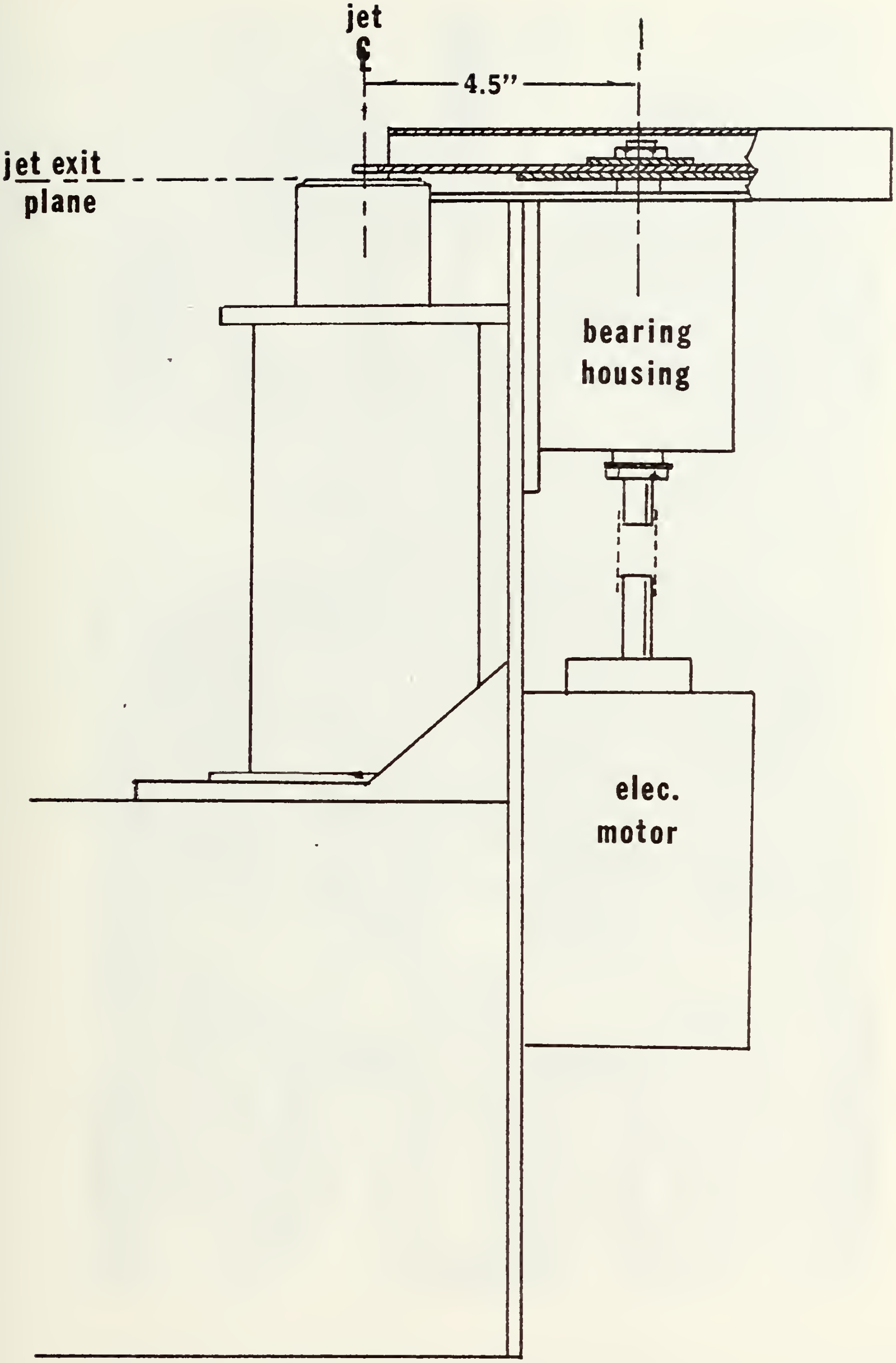

Figure B6. The Periodic Flow Generator. Showing arrangement of the jet nozzle and the notched disk.

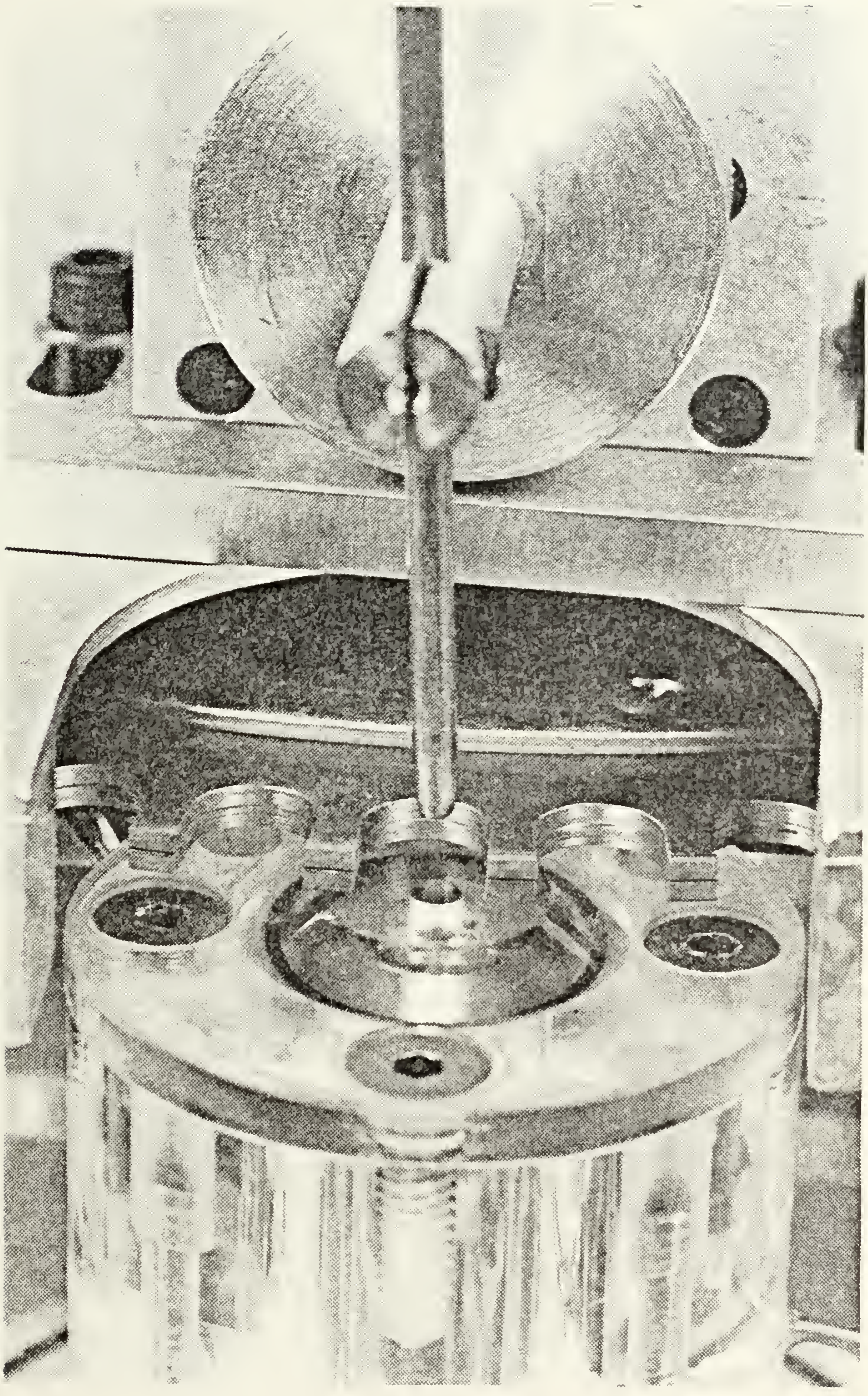

Figure B7. Closeup of the Periodic Flow Generator, showing the jet nozzle, notched disk and tube containing the transducer.

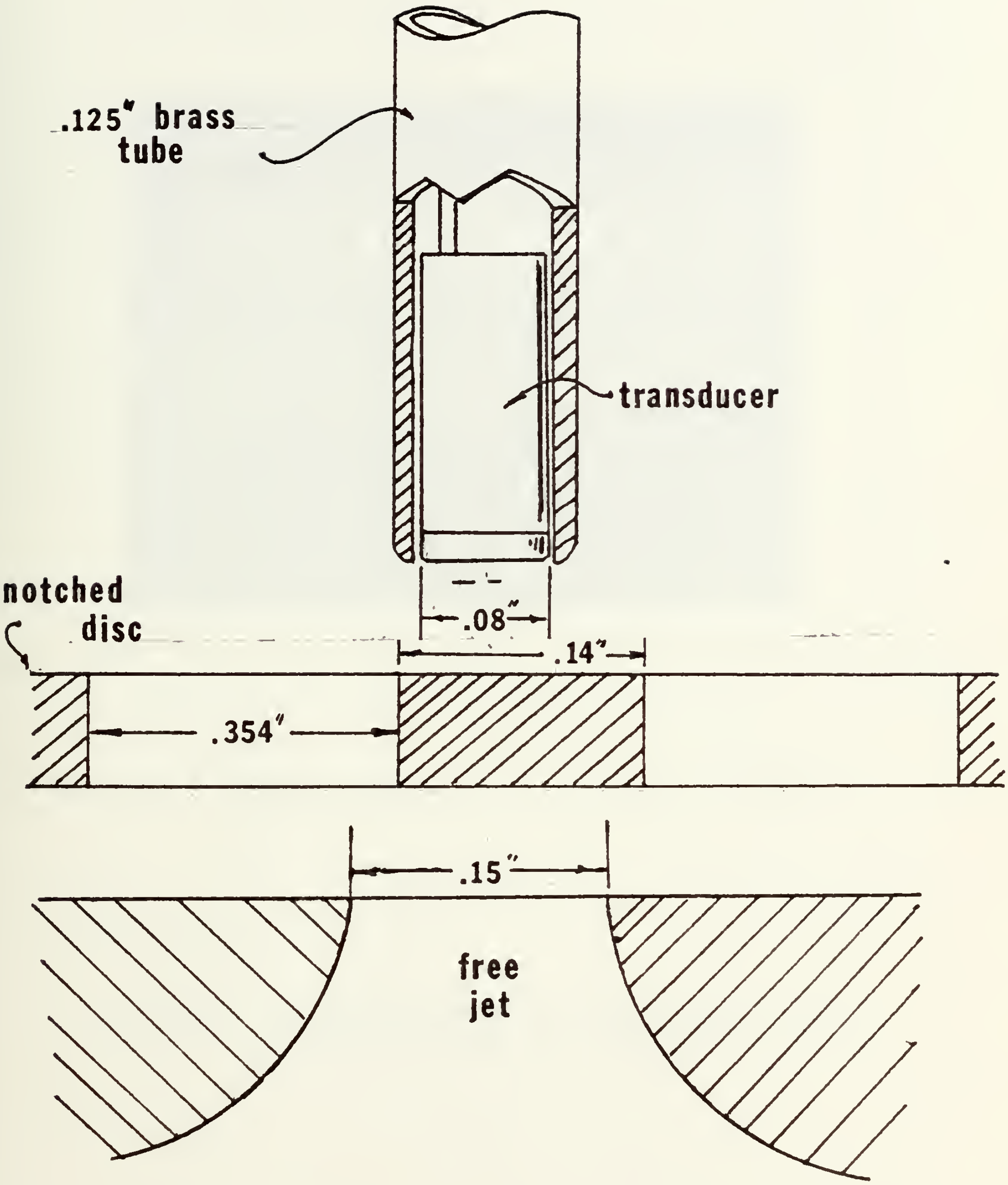

Figure B8. Dimensions of the Jet, Notched Disk and Transducer

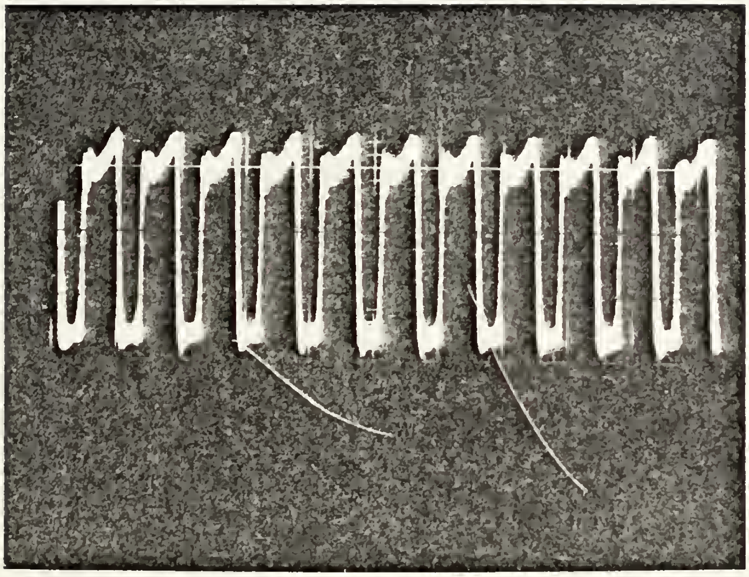

Figure B9. Transducer Signal From the Periodic Flow Generator at 1000 Hz. (Oscilloscope Trace)

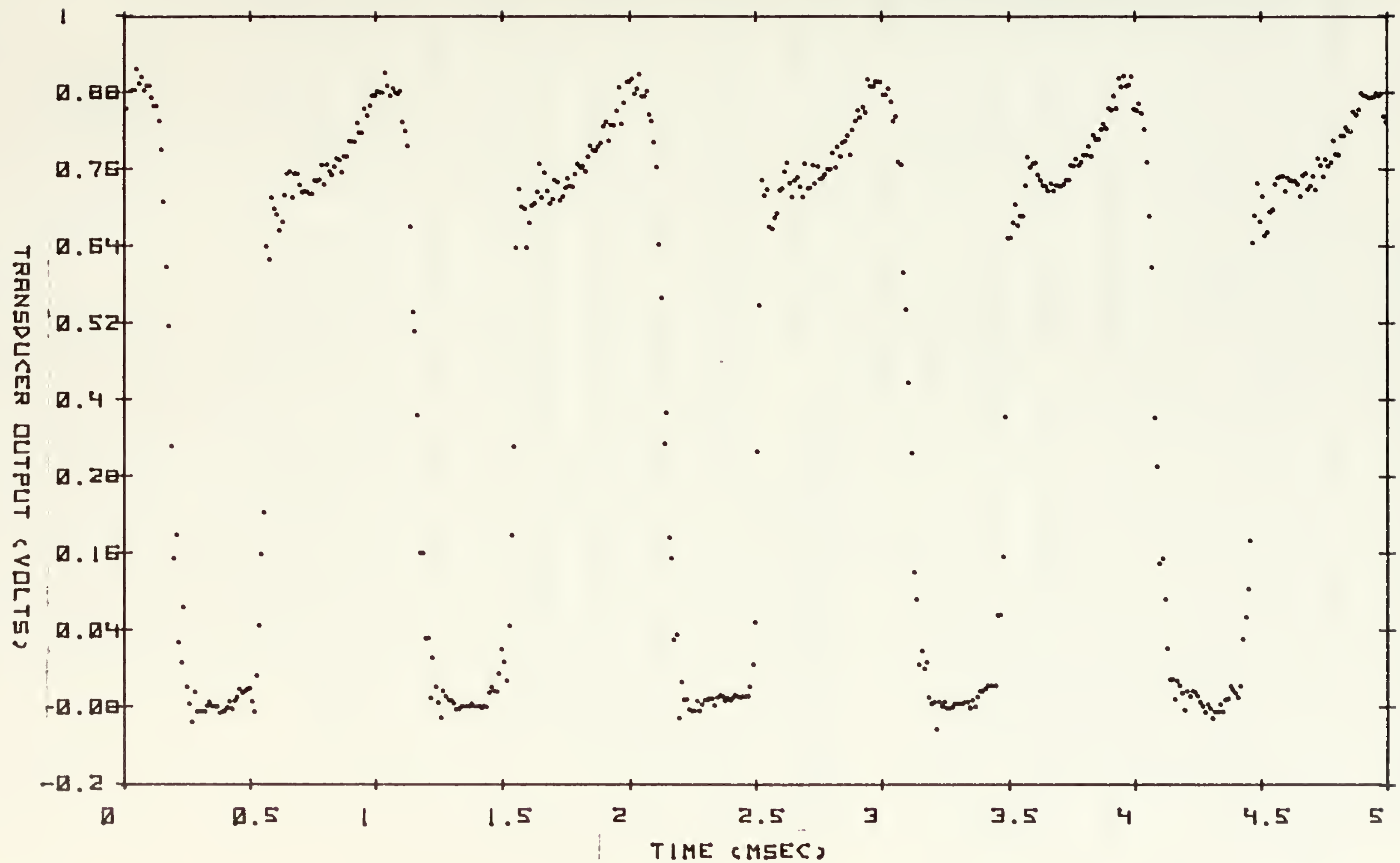

Figure B10. Digital Reproduction of Periodic Flow Generator Signal at 1000 Hz

Appendix C: Reduction of Data to Pressure Distributions

Unsteady pressure data obtained from measurements on the compressor were plotted as a differential pressure distribution across a single blade space by program "BLADE". To do this, the program searches sequentially through the data and locates the first maximum value. This sample is taken on the pressure side of the blade immediately before the blade passes the transducer. From the compressor RPM which is input at the keyboard, the blade passing period is calculated. Since the sample rate is known and is constant, the pressure data are then known as a function of normalized elapsed time, where

$$\text{Normalized Elapsed Time} = \frac{\text{elapsed time from first sample}}{\text{blade passing period}}$$

Graphically this corresponds to the relative position of the sample in a particular blade space. The data points are plotted beginning with the point immediately following the initial peak and proceding sequentially until the elapsed time from the first sample equals or exceeds the blade passing period. When this occurs, the next sample is plotted in the same relative position that it would have occupied in the following blade space and the data for the next cycle are plotted with this as a starting point. The process is repeated until the data from eighteen cycles, or one revolution, have been plotted.

Appendix D: Calculation of the Peak Pressure Amplitude on the Blading in Subsonic Conditions

Reference 5 discusses the determination of the pressure distribution on subsonic blading and defines a pressure coefficient as follows:

$$S = \frac{P - P_2}{\frac{1}{2}\rho_2 W_2^2} \approx \frac{P - P_a}{\frac{1}{2}\rho_2 W_2^2} = \frac{P - P_a}{q_2}$$

Based on the information in Ref. 5, the geometry of the TRANSX compressor blading and the design turning angle at the blade tip, S was expected to be greater than -1. Using the analysis given in Ref. 6, an approximation of q_2 in terms of the flow function and nondimensional velocity can be obtained. Using the notation of Ref. 6, q_2 is approximated by

$$q_2 = \frac{1}{2}\rho_2 W_2^2 = \Phi_o X_o \frac{1}{2}\left[\frac{\rho_t V_t^2}{\cos^2 \beta_2}\right]$$

where

$$\Phi_o = \frac{\dot{W}_m}{\rho_t V_t \left(\frac{\pi r_o^2}{144}\right)} , \quad \frac{1}{k_{B1}\,\xi}$$

and

$$X_o = \frac{\pi r_o}{360\, V_{ref} \operatorname{Tan}\beta_1}$$

Introducing the referred flow rate and referred RPM,

$$q_2 = \frac{W^* N^*}{\operatorname{Tan}\beta_1}\left[\frac{P_t}{P_r}\right]\left[\frac{1}{r_o\, K_{B1}\, \xi\, g_c}\right]\left[\frac{1}{720 \cos^2 \beta_2}\right] \qquad [psia]$$

For a given geometry and operating point, the denominator of the above expression can be evaluated. For the TRANSX Compressor operating at design incidence with rotor exit pressure approximately equal to atmospheric,

$$\frac{p - p_a}{p_{t_1}} = S \frac{q_2}{p_{t_1}} = S\left[\frac{W^*(N^*/1000)}{380 \operatorname{Tan}\beta_1}\right] \equiv S[\Omega]$$

On the suction side of the blade, the minimum value of the pressure coefficient corresponds to minimum pressure so that

$$\frac{p_{min} - p_a}{p_{t_1}} = -\Omega$$

Using typical values of P_t, for the compressor, approximations of the peak pressure amplitude for design and 50% design speed were calculated as follows:

At Design RPM: $W^* = 19.1$bm/sec; $N^*/1000 = 30.46$; $\beta_1 = 65°$

$\Omega = 0.7102$ $\quad p_{min} - p_a = -6.9$ psia

At 50% RPM: $W^* = 11.0$ lbm/sec; $N^*/1000 = 15.5$; $\beta_1 = 65°$

$\Omega = 0.2092$ $\quad p_{min} - p_a = -2.74$ psia

REFERENCES

[1] Weyer, H. B., Advanced Testing Techniques in Turbomachines, paper presented at the Von Karmen Institute for Fluid Dynamics Lecture Series, April 1975.

[2] Gallus, H. E., Unsteady Phenomena, AGARD preprint number 177.

[3] Naval Postgraduate School Report NPS-57VA72091A, A Description of the Turbopropulsion Laboratory in the Aeronautics Department at the Naval Postgraduate School, by M. H. Vavra and R. P. Shreeve, September 1972.

[4] Naval Postgraduate School Report NPS-57VA73071A, Design Report of Hybrid Compressor and Associated Test Rig, by M. H. Vavra, July 1973.

[5] Vavra, M. H., Aero-Thermodynamics and Flow in Turbomachines, p. 353-366, Krieger, 1974.

[6] Naval Postgraduate School Report NPS-57SF74081, Flow into a Transonic Compressor Rotor, by R. P. Shreeve, August 1974.

[7] NASA Technical Memorandum NASA TM X-71599, On-Line Calibration of High Response Pressure Transducers during Jet Engine Testing, by E. C. Armentrout, October 1974.

[8] Hewlett-Packard Operating and Service Manual, Analog to Digital Converter, 5610A.

[9] Hewlett-Packard Operators Manual, HP 21MX Computer Series.

[10] Hewlett-Packard Operating & Service Manual, High Speed Data Acquisition Subsystem 2311A, HP 02311-90001, March 1970.

[11] Hewlett-Packard 9830A Calculator: Operating and Programming.

[12] Hewlett-Packard 9830A Calculator: 9880A/B Mass Memory Operating Manual.

[13] HP Fortran Reference Manual.

[14] HP Software Operating Procedures.

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