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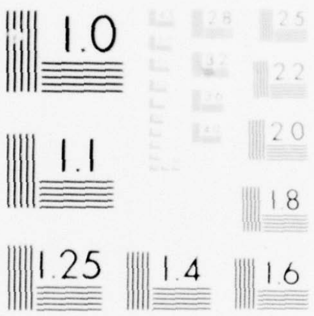
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NAVAL POSTGRADUATE SCHOOL
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DATA ACQUISITION AND ANALYSIS TECHNIQUES FOR MEASUREMENT OF UNSTEADY WALL PRESSURES IN A TRANSONIC COMPRESSOR

J. M. Simmons and R. P. Shreeve

July 1977

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Real-time data acquisition and analysis techniques have been developed for the measurement of unsteady wall pressures in a transonic compressor. The report contains listing and explanatory notes for the computer codes and is intended as a guide to users of the system. Preliminary results are presented in the form of casing wall pressure contours. They demonstrate the effectiveness and versatility of the system in its ability to synchronize sampling of rapidly fluctuating signals with the rotation of the rotor.

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1. INTRODUCTION

The work reported here is part of a continuing program aimed at determining the unsteady flow in a transonic compressor stage. The stage is installed in the Turbopropulsion Laboratories of the Department of Aeronautics, Naval Postgraduate School.

This report has been compiled to facilitate use of the data acquisition and analysis programs which have been developed primarily for the study of unsteady fluctuating pressures on the casing inner wall. The equipment and instrumentation are discussed briefly in section 2. The data acquisition system and programs are outlined in section 3 and described in detail in the appendices. The post-real time data analysis programs are outlined with sample results in section 4 and are described in detail in the appendices. Section 5 contains conclusions and recommendations for further work.

2. EQUIPMENT AND INSTRUMENTATION

2.1 The Transonic Compressor

The transonic compressor test rig comprises an air turbine drive unit and an induction section which contains a filter, throttle, settling chamber and flow measuring nozzle. 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 the tip Mach number, the flow angle is 65° and the pressure ratio is 1.6 at a referred flow rate of 19 lbm/sec. The laboratory facilities and the test rig are described in detail by VAVRA and SHREEVE (1972) and VAVRA (1973).

2.2 Pressure Measurement

Eight Kulite CQL-080-25 pressure transducers with natural frequency about 125 kHz are mounted with their diaphragms flush with the inner case wall of the compressor. Further details are reported by PAIGE (1976). Table 1 in Appendix A gives the axial and circumferential location of the transducers relative to transducer number K6 which is the furthest upstream. The transducers are used in conjunction with Datel Model 201C instrumentation amplifiers which have a flat frequency response to 100 kHz.

Each Kulite pressure transducer is matched by a pneumatic static pressure tap at the same axial location in the case wall (except in one case - see Table 1 in Appendix A) but displaced circumferentially. Other pneumatic static and total pressure taps are available upstream. A data recording system (VAVRA and SHREEVE, 1972) is used to record both the steady pressures from the pneumatic taps and the temperature data. The paper tape output from this system is processed using a Hewlett Packard Model HP9830A programmable calculator to provide input data for the measurement of fluctuating pressures and to establish the compressor operating point.

2.3 The Timing Disk

To enable synchronization of the sampling of the pressure transducer outputs with the rotation of the rotor, an instrumented timing disk is fitted to the rotor shaft. The disk contains holes at intervals of one per rotor blade and one per rotor revolution. Light sensitive diodes and wave shaper circuits provide pulse trains to control sampling of the pressure transducers. This system is described in detail by WEST (1976).

3. DATA ACQUISITION

3.1 The System Hardware

Figure 1 is a schematic of the data acquisition hardware with arrows indicating the flow of data and control signals. The system is under the control of the HP 21MX computer which operates either directly or through the device called "Pacer" to control the analog-to-digital (A/D) converter (model HP5610A) and which transfers data to the HP9867B mass memory unit via the HP9830A calculator.

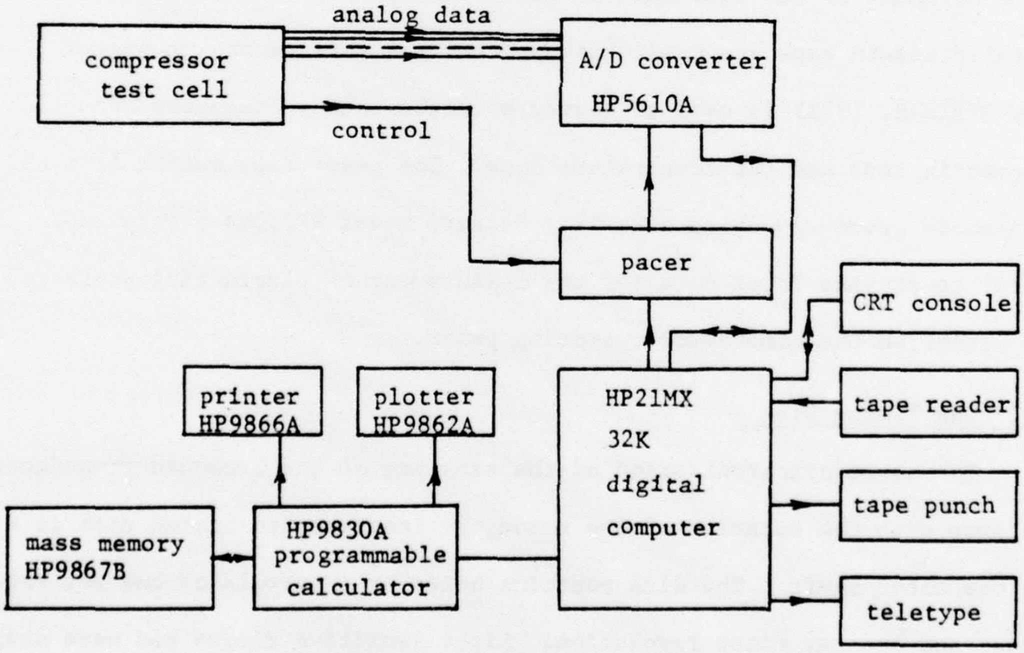

Figure 1. Schematic of the data acquisition system hardware

The peripheral device called the "pacer" is described in detail by WEST (1976) who originally called it RPACE. The pacer can trigger data acquisition from a stationary transducer at any fixed point in the rotating rotor frame, independent of the rotor speed. In effect, it divides the circumference of the rotor into 9 intervals, each with a circumferential length equal to that of the arc (measured at the wall) across two adjacent blade passages. Each of the 9 intervals are subdivided into 256 equal sub-intervals.

The pacer receives one per revolution and one per blade input signals from the timing disk and performs two functions; it controls the timing for data acquisition and determines the speed of the rotor.

3.2 The Program KULITE

KULITE is the data acquisition program (in BASIC language) for the HP 21MX computer. A flow diagram, listing, variable assignment and notes are presented in Appendix B. KULITE can be operated in three modes, viz. free-run, calibration and pacer.

In free-run mode the A/D converter operates in mode 4 (see Reference No. 5). Up to 1616 samples of one A/D converter channel are taken with a frequency of 10^5 samples per second. The sampling process is not synchronized with the rotor rotation.

In calibration mode the A/D converter operates in mode 4 (see Reference No. 5). It scans through A/D converter channel numbers 1 to 12, taking 1616 samples on each channel. The average of the 1616 samples is computed before the next channel is sampled. The scan is performed four times, with four different calibration pressures applied to the reference side of each Kulite transducer.

In pacer mode the A/D converter operates in mode 0 (see Reference No. 5). Sampling of a Kulite transducer output is synchronized with rotor rotation by means of two pulse trains generated from light beams chopped by the timing disk on the compressor shaft. One pulse train has a frequency of one per rotor revolution and the other has a frequency of 18 per rotor revolution; each pulse in the latter train corresponding to the passing of a blade past a fixed point. A full description is given by WEST (1976).

In this mode a pressure transducer is sampled on successive revolutions at a fixed point in the rotating rotor frame. Currently, the sample interval is several revolutions of the rotor. Changes in program RPACE would allow samples to be taken at intervals of one revolution. If the flow can be regarded as steady in the rotating rotor frame this technique enables measurement of the wall pressure distribution "carried around" by the rotor. Flow unsteadiness in the rotating frame can be averaged or the frequency content of the unsteadiness in successive samples can be examined. In this report only averaged data from 10 samples taken at each of 128 points across two rotor blade passages, is presented.

In all three modes of operation the program KULITE transfers data from the HP21MX to the HP9830A.

3.3 The Program TRAN4

TRAN4 is the data acquisition program (in BASIC language) for the HP9830A programmable calculator. It receives data from the HP21MX computer, processes it and stores data on a disk of the HP9867B mass memory. A flow diagram, listing, variable assignment and notes are presented in Appendix C.

3.4 The Program RESET1

RESET1 initializes a record number on the storage disk so that at the start of a run data can be stored in file DATAY1 beginning at the first record. The program is listed in Appendix D.

4. DATA ANALYSIS

4.1 The Program

Off line data analysis is at present performed on the HP9830A with the BASIC language programs MAP1, MAP2, CONT, CONT1, PLOTSA, PLOTSB and TITIPK. These programs are described in detail, with listings, flow diagrams and notes, in Appendices E through J.

MAP1 is used to determine the sensitivity of the Kulite pressure transducers from data acquired with KULITE in the calibration mode. In addition, MAP1 is used to convert the voltages sampled at the pressure transducer outputs to pressure coefficients.

MAP2 is used to convert the 8 x 128 array of measured pressure coefficients to a 29 x 128 array through quadratic interpolation in the axial direction. The program was written to reduce the effects of the course transducer spacing in the axial direction. However, care must be exercised when it is used to interpolated across discontinuities such as shock waves and rotor blades. Linear interpolation is available through use of the program CONT or CONT1 to plot contours of casing wall pressures.

CONT is used to plot contours of constant casing wall pressure (in the frame of the rotor) from an array of pressure coefficients. (i.e. it produces a wall pressure "map"). The program will accept any general rectangular array provided that the spacing in each direction is uniform. This latter requirement restricts it's use in this application to arrays obtained from MAP2.

CONT1 is used to plot contours of constant casing wall pressure when the array of measured pressure coefficients contains nonuniform spacing in the axial direction. Nonuniform spacing results in this application from the axial location of the Kulite pressure transducers.

PLOTSA is used to plot (on the HP9862A plotter) the uncalibrated pressure distribution (in volts) across a blade pair for a given Kulite transducer. The input data is that originating from pacer mode of operation. The program is also used to plot the output of the one per blade signal from the timing disk.

PLOTSB is used to plot (on the HP9862A plotter) the uncalibrated free-run data (in volts) from a given transducer against circumferential distance.

TITIPK is used to superimpose the blade tip profiles on the wall pressure maps.

4.2 Sample Results

The results presented here are intended only to illustrate the capabilities of the programs. Comprehensive results will be given in a subsequent report.

Figure 2 is a plot versus circumferential distance of the average pressure in the frame of the rotor across an arc of the casing wall equivalent to two blade passages. The pressure coefficient is defined in Appendix E. The plot was made with PLOTSA using data acquired in the pacer mode of operation. The precise location of each distribution relative to the rotor blades is not defined here. The locations are known approximately from the blade pair number specified in the acquisition program. They are located precisely from

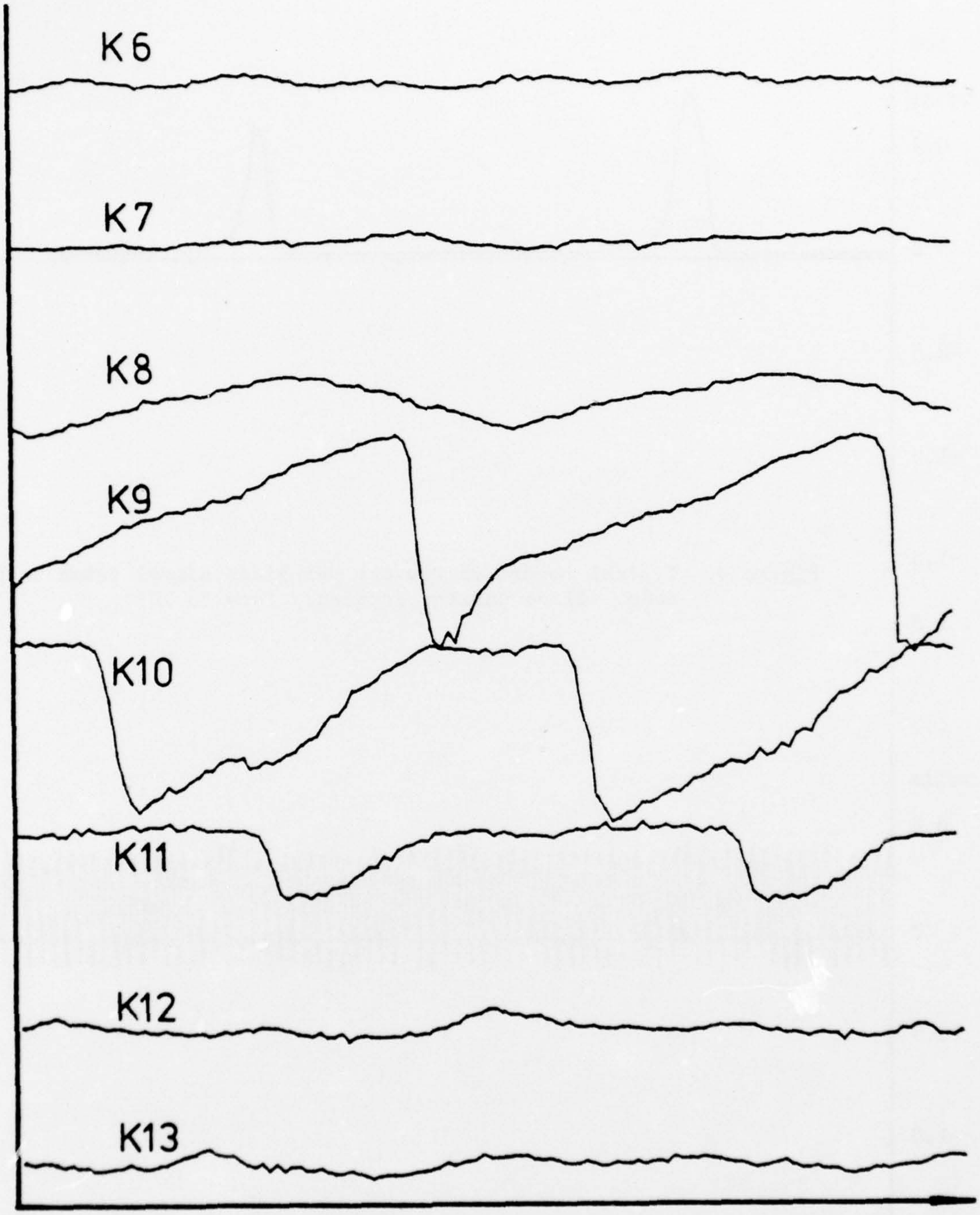

Figure 2. Waveshapes of unsteady pressure distributions across two blade passages (uncalibrated and with arbitrary offsets) for the Kulite transducers. Data taken in pacer mode. 50% design speed; throttled to near surge. 8.7 lbm/sec referred flow rate. Pressure ratio = 1.155:1. Blade pair #2.

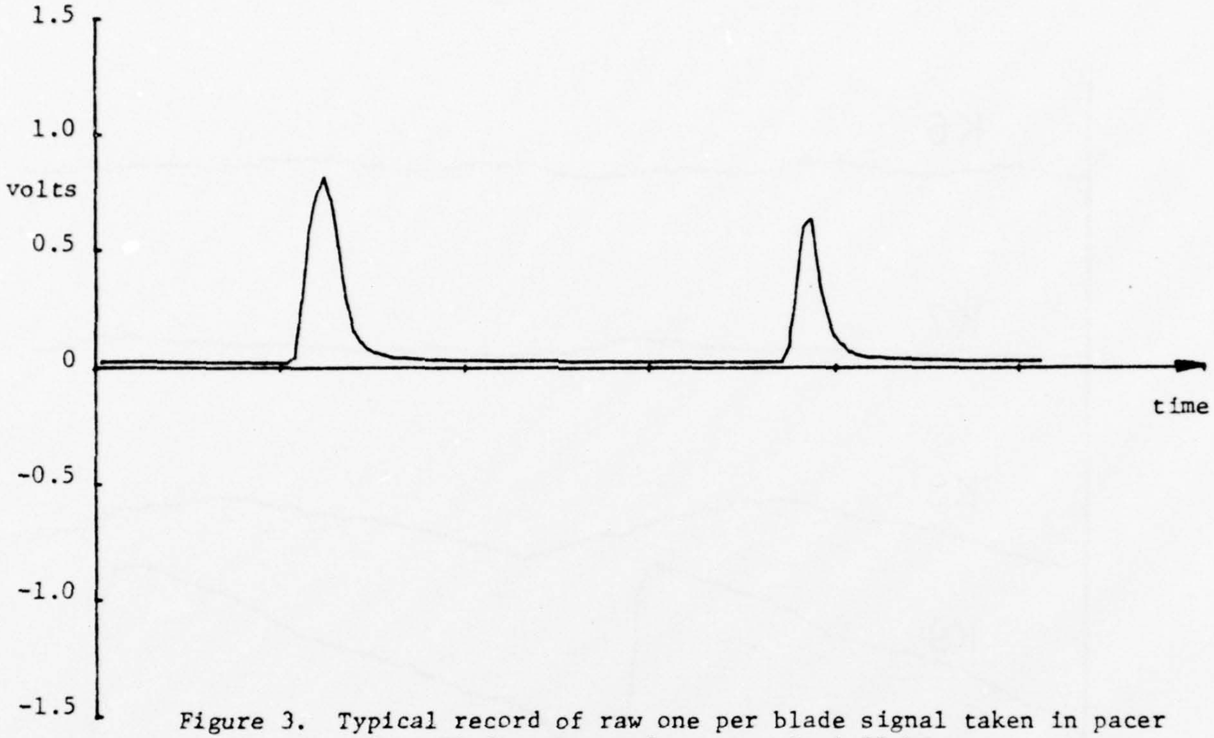

Figure 3. Typical record of raw one per blade signal taken in pacer mode. Blade passage frequency is 4.55 kHz.

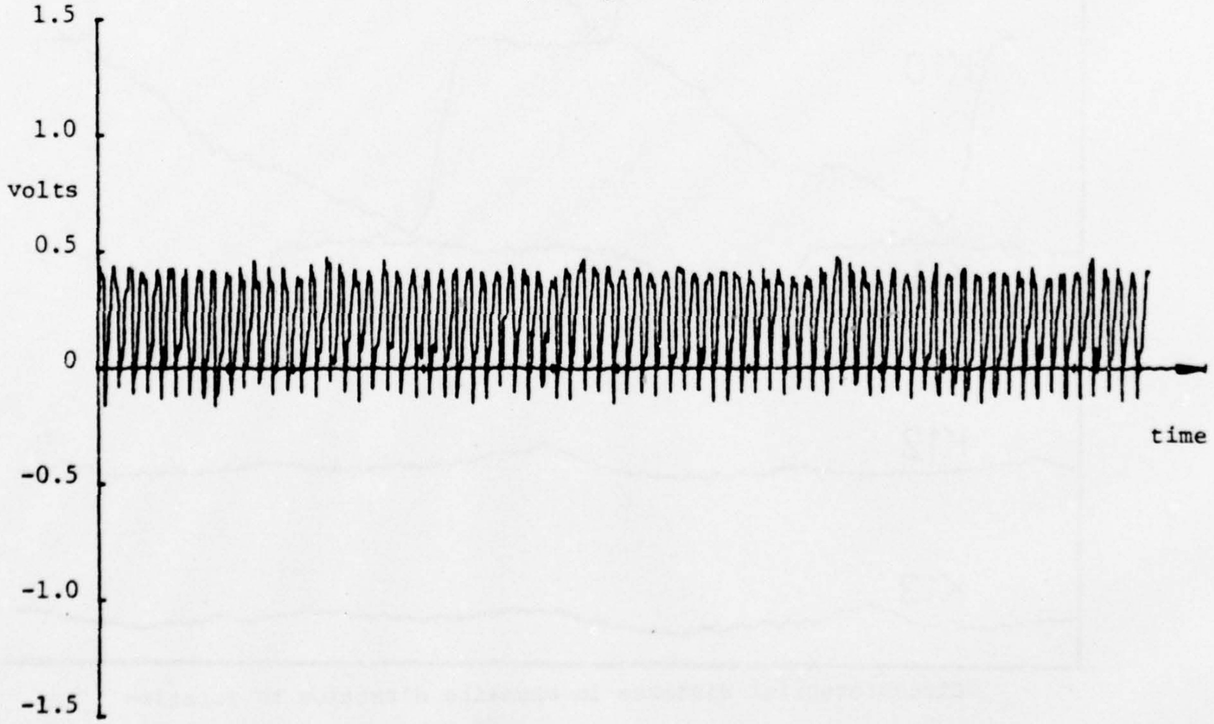

Figure 4. Typical record of data taken in free-run mode from Kulite number K10. The record is comprised of 1616 samples taken at a frequency of 100 kHz. Each cycle is due to a blade passage with a blade passing frequency of 4.55 kHz. Compressor operating conditions as in figure 2.

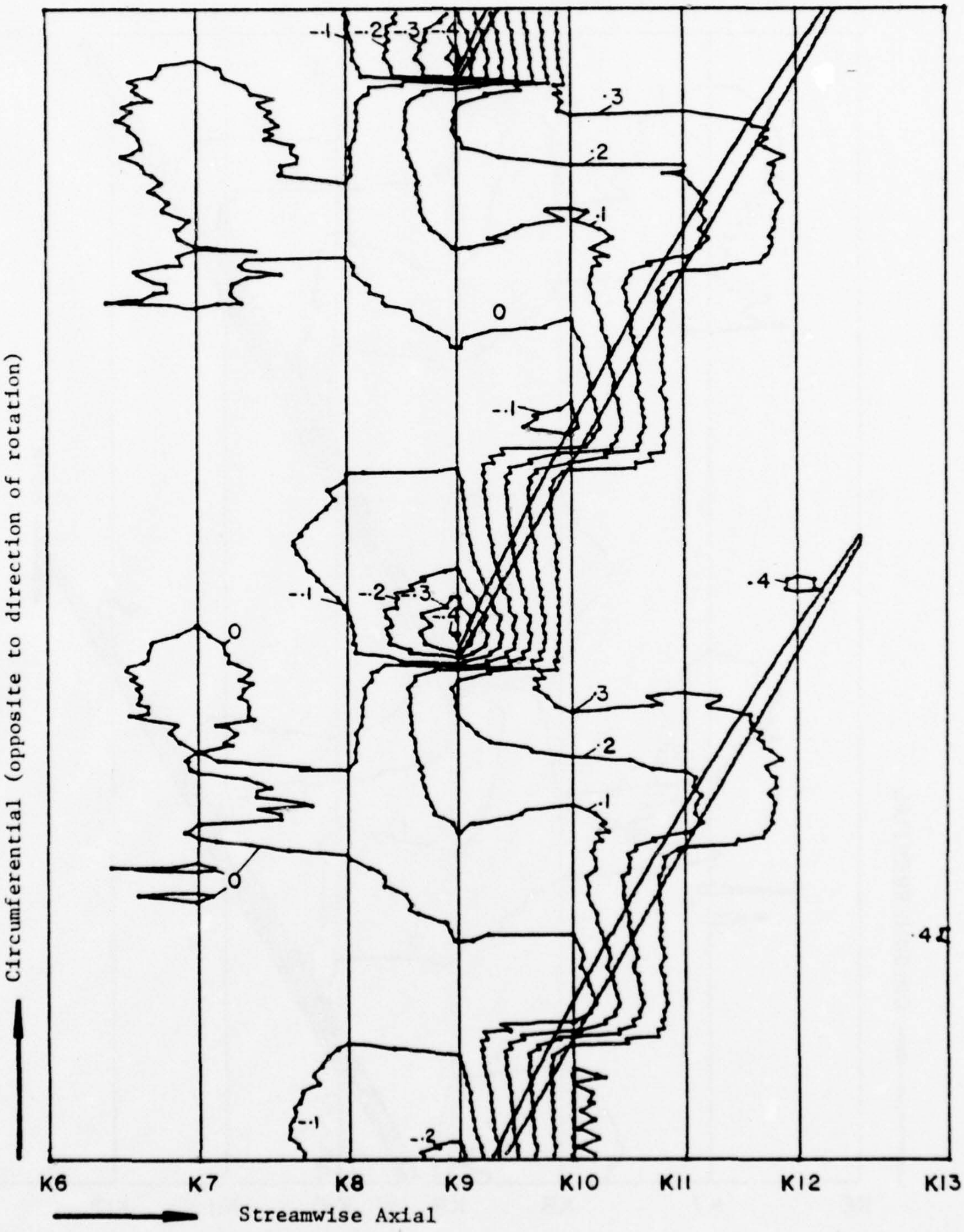

Figure 5. Contours of constant pressure coefficient ΔC_p plotted by CONT1. (See Appendix E for definition of ΔC_p). Blade pair number 2. Compressor operating conditions as in figure 2.

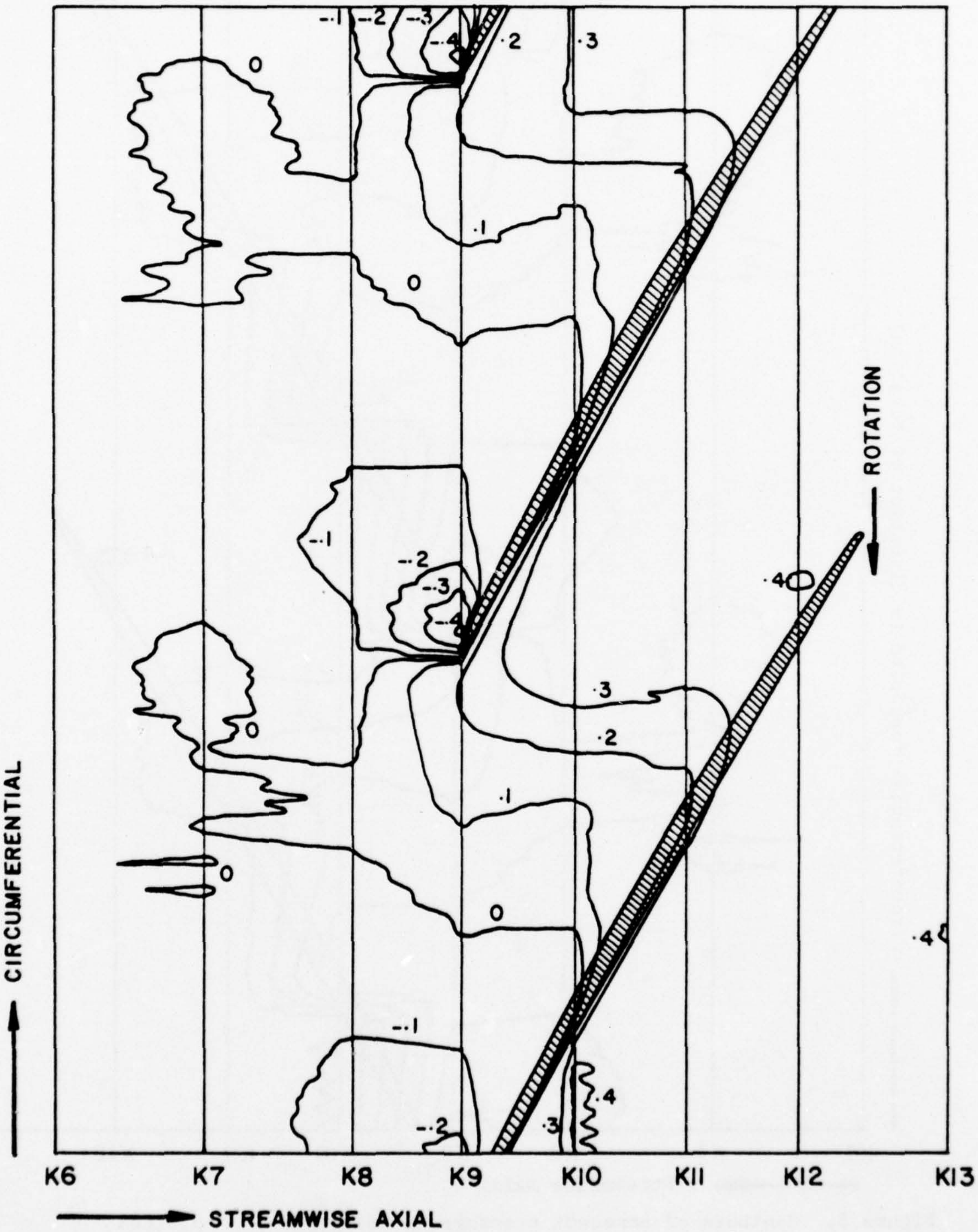

Figure 6. Smoothed contours of constant pressure coefficient obtained from Figure 5.

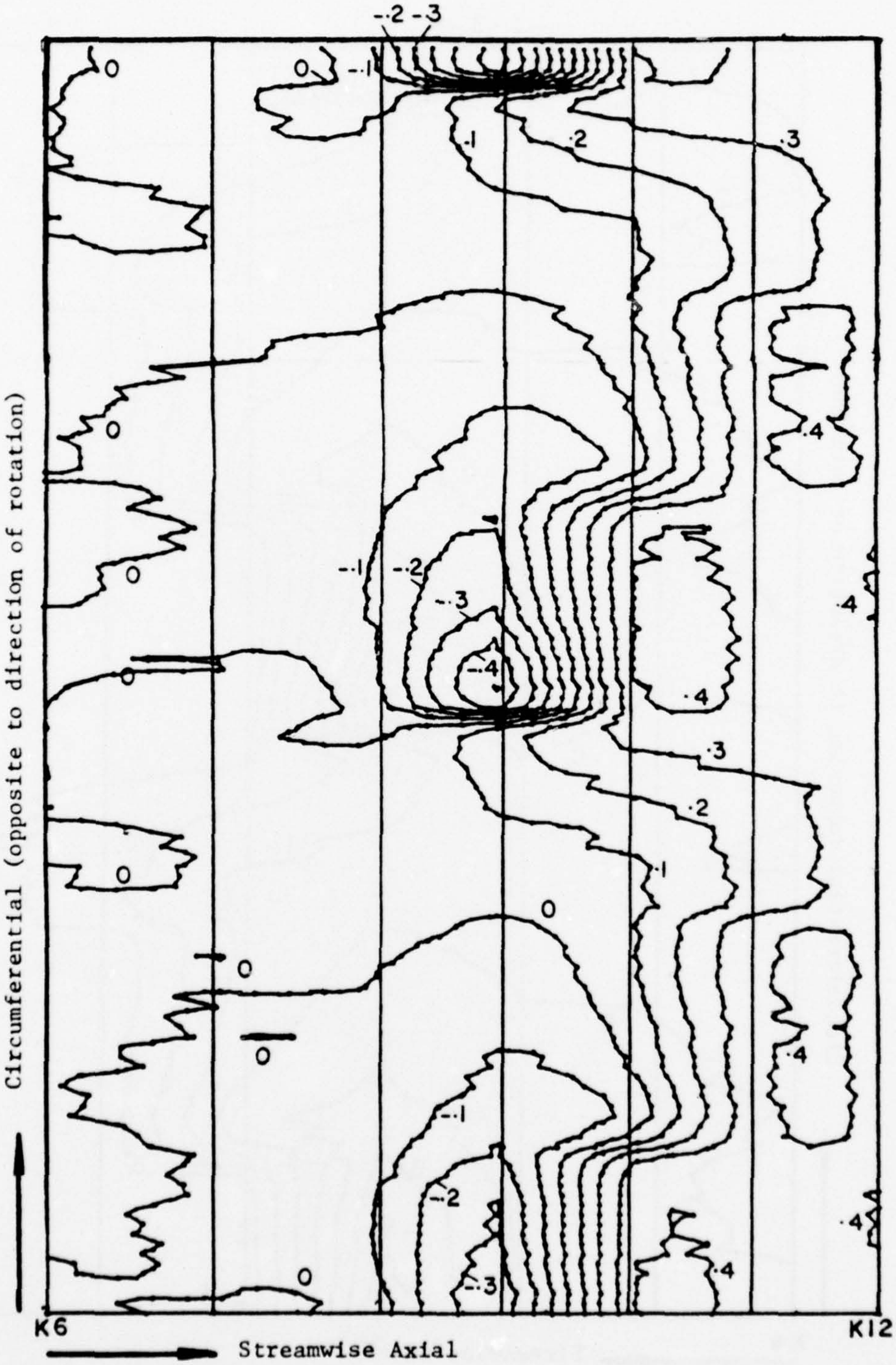

Figure 7. Contours of constant pressure coefficient plotted by CONT with 25x255 array. Blade pair number 2. Compressor operating conditions as in Figure 2.

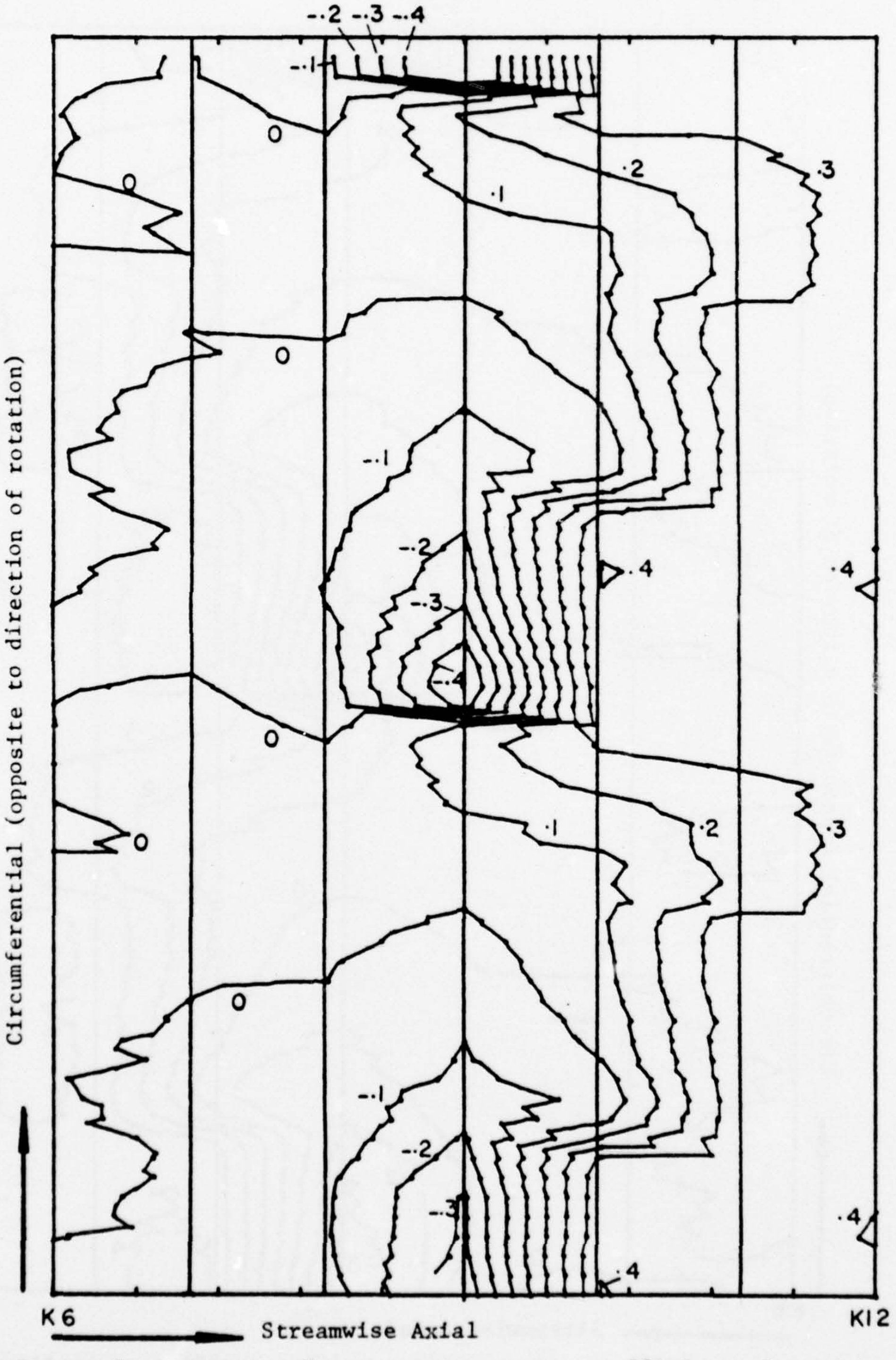

Figure 8. Contours of constant pressure coefficient plotted by CONT with 7x64 array as subset of array used for Figure 7.

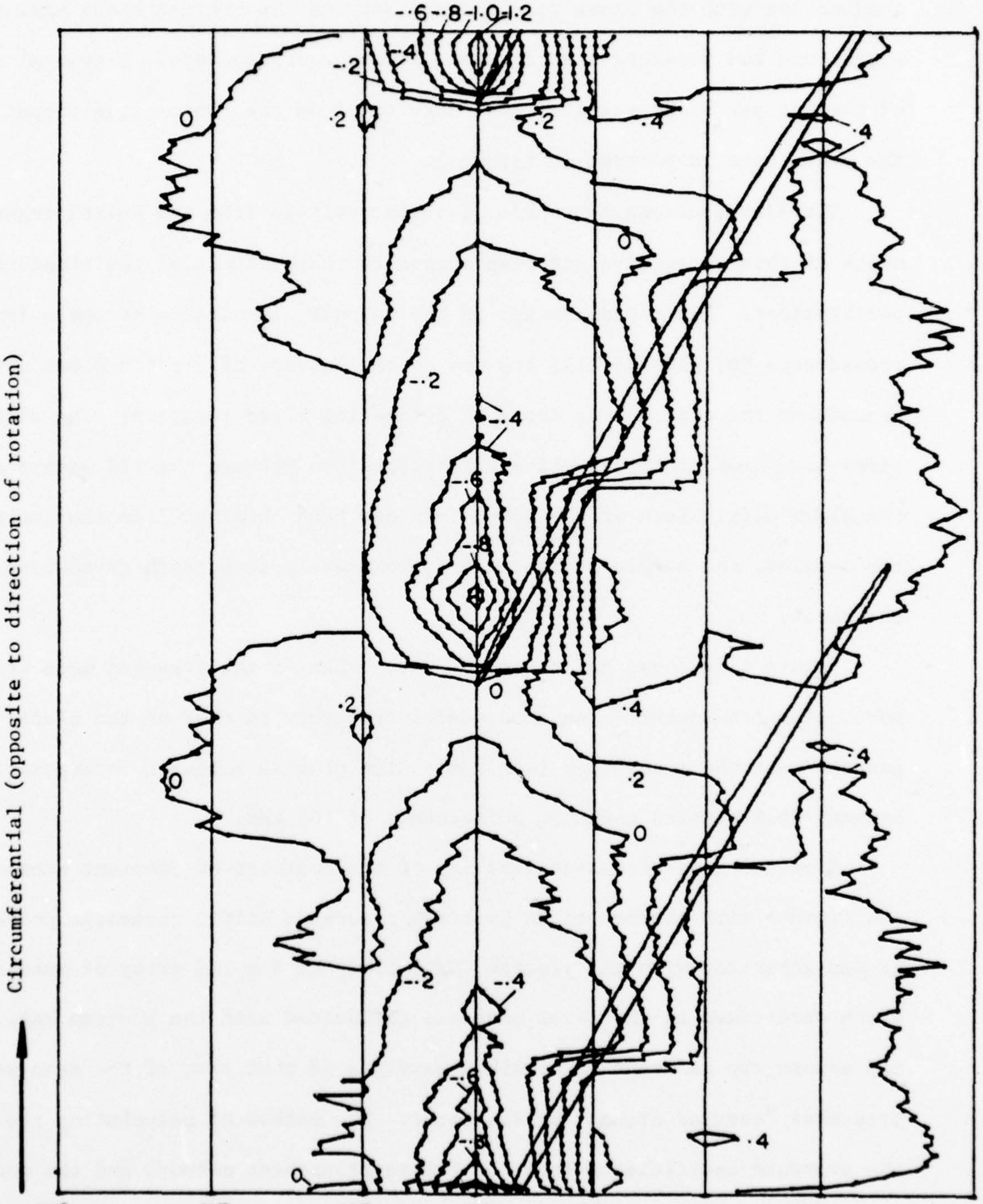

Figure 9. Contours of constant pressure coefficient plotted by CONT with 8x128 array. Note there is a small error in blade location. Blade pair number 2. Sixty percent design speed. Throttled to near surge.

a knowledge of the orientation of the timing disk relative to the rotor in conjunction with the phase relationship between the one per blade timing signal and the pressure distributions from the transducers. A typical record of the one per blade signal, taken directly from the photo-diode output in the pacer mode is plotted in figure 3.

The distributions shown are of output voltage from the Kulite transducers which at this stage have not been scaled to take account of the tranducer calibrations. The rapid changes in the signals, in particular those from transducers K9, K10 and K11, are due to the passage of a rotor blade across a transducer and provide one means of estimating blade location. The distributions have been plotted by linear interpolation between the 128 points across the blade pair. Each of the 128 points has been obtained from the average of ten samples, one sample being taken approximately each tenth revolution of the rotor.

Figure 4 is a typical record of data taken in the free-run mode from a particular transducer. The fundamental frequency is that of the blade passage past the transducer (4.55kHz). The plot is a linear interpolation between 1616 samples taken at a frequency of 100 kHz.

Figure 5 is a representative map of the contours of constant pressure coefficient with respect to an upstream reference static pneumatic pressure. It was generated with the program CONT1 from the 8 x 128 array of measurements which were taken in the pacer mode and calibrated with the program MAP1. The map across two adjacent rotor blade passages is thus that of the mean wall pressures "carried around" by the rotor. The method of calculating the the pressure coefficients from the Kulite transducer outputs and the measurements from the pneumatic taps is given in Appendix E.

The location of the blade tip in figure 5 was determined from the circumferential location of the rapid change in pressure distribution associated with transducer K9 (figure 2). The transducer K9 has an axial location such that it is crossed by the leading edge of rotor blades. A more precise location of blades can be obtained from measurement of the circumferential location of the one per blade raw signal (figure 3) relative to the pressure distributions (figure 2) and from knowledge of the location of the one per blade holes in the timing disk relative to the rotor.

Smoothing of the Wall Pressure Maps

It is clear in figure 5 that linear interpolation between pressure coefficients in the axial direction across a blade gives incorrect contours along the blade between the transducer locations. This difficulty can only be overcome satisfactorily by using more Kulite transducers to provide a finer mesh than the rather coarse one provided by eight transducers. In this study the contours in the vicinity of the blades have been smoothed graphically by connecting with smooth curves those points in the map at which the pressure coefficient is the same and which lie on the lines scanned by the transducers. At operating conditions which give rise to shock waves it is possible that a similar smoothing procedure will be required. In the long run there is a need for a numerical interpolation technique which avoids interpolation across blades.

Figure 7 is a wall pressure map produced by CONT for similar operating conditions to those used to obtain figure 5. However, pressures were measured at 255 points in the circumferential direction and MAP2 was used to generate pressure coefficients at 25 equally spaced stations in the axial direction between transducers K6 and K12. It is clear that quadratic interpolation does not avoid the problems of contour distortion by interpolation across a blade. In view of the very slow execution of CONT with a 25 x 255 array of pressure coefficients, it is recommended that an 8 x 128 array be used with CONT1.

Figure 8 is a wall pressure map of the same data as in figure 7 except that only every fourth circumferential point (of the original 255) was used in the reduction with CONT1 (i.e. axial interpolation is linear through use of CONT1 but MAP2 is not used). The resulting 7 x 64 array of pressure coefficients gives rise to very similar contours to those shown in figure 7 for the finer mesh. In fact, the appearance of contours with $C_p = 0.4$ near the blades in figure 7 might be an erroneous result of quadratic interpolation across blades. Note that the grid lines in figure 8 which indicate transducer locations are incorrectly plotted to have equal spacing, but this does not affect the above comments.

Figure 9 is a plot of contours for a higher compressor rotational speed. The data reduction techniques were identical to those used to obtain figure 5. Note that the blade location shown was that calculated for the data of figure 5. The location is slightly in error due to a difference in the tuning of the phase-lock loop circuit in the pacer for the second test. This problem has been solved recently by using the near-discontinuity in the pressure distribution measured by the transducer at the leading edge to position the blade tip.

Again it is stressed that the results presented are prelinimary and are intended merely to demonstrate the methods used and the capabilities of the system.

5. CONCLUSIONS AND RECOMMENDATIONS

Programs for the acquisition and reduction of fluctuating casing wall pressures in a transonic compressor stage have been developed and run successfully with the compressor at this time operating at up to 60 percent of the design speed. Evaluation of the data acquisition system on a mechanical simulator indicates that it can operate over the full speed range of the compressor. In fact, at higher speeds the signal to noise ratio in the Kulite transducer outputs will improve significantly because of the higher pressures that will be encountered.

The pacer mode of synchronized sampling has made it possible to determine in a versatile manner the wall pressure maps in the rotating frame of the rotor. The pacer system can also be used to obtain measurements of flow properties away from the wall, e.g. flow velocity measurements with a dynamic probe. Wall pressure maps have been presented solely to demonstrate the capabilities of the pacer technique and of the data acquisition and analysis. Comprehensive data will be presented and interpreted in a subsequent report.

There are some aspects of the programs which can be refined or which need further evaluation and the following recommendations are made.

1. The subroutine RPACE in KULITE causes a sample to be taken in pacer mode about every tenth revolution of the rotor at 60 percent of design speed. This causes a delay in data acquisition which could be reduced by modifying subroutine RPACE.
2. The degree of steadiness of pressure distributions in the frame of the rotor needs further investigation. This should begin with an examination of the standard deviations already computed in pacer mode. In separate

tests, a larger number of samples (at least 500) should be taken for each of several steps between blade pairs and the variations at each step examined for frequency content. The measurements should then be repeated with the case wall rotated peripherally by at least 90°.

3. The technique of calibration of the Kulite pressure transducers under operating conditions effectively takes account of change in transducer sensitivity with temperature. Change in transducer offset (d.c. level) with temperature is presently handled by equating the time-average transducer output voltage with the steady pressure obtained from a pneumatic static tap at the same axial location. The relationship between the steady pressure indicated by the pneumatic tap and the time time-averaged pressure at the tap needs further investigation.
4. Because transducer K10 and pneumatic tap S10 are not coincident axially it is necessary to interpolate between readings at S10 and S11. The interpolation in MAP1 is at present linear but its adequacy has not been fully evaluated.
5. The large pressure gradients in the axial direction across rotor blades are not resolved well because of the limited number of transducers. Two additional transducers, located midway between K9 and K10 and K10 and K11, would greatly alleviate this difficulty. Linear axial interpolation across blades, as in CONT1, is misleading and hand smoothing of contours near blades is presently necessary. Quadratic interpolation, as in MAP2, does not solve the problem. Extrapolation of data up to but not across a blade surface should be investigated.

6. Shock waves have not been encountered at the low operating speeds at which the present data was obtained. The accuracy of resolution of shock waves should be studied in the light of the above discussion regarding large pressure gradients across blades.

7. The blades have been located on the wall pressure maps in this report from knowledge of the point in the circumferential pressure distribution (indicated by transducer K9 at the blade leading edge) at which the circumferential pressure gradient is steepest. This technique is subject to an, as yet, undetermined uncertainty due to irregularities in the geometry from blade to blade. The alternative procedure, whereby blades are located by use of the phase relationship between the one per blade signal and the circumferential pressure distributions, also needs further evaluation.

8. In its present form the data acquisition system requires frequent keyboard entries by the operator. In principle the system can be fully automated by pre-entering all necessary data with DATA statements and by replacing INPUT statements by READ statements. Some WAIT statements in KULITE would be needed to allow TRAN4 to catch up to KULITE.

9. The format of graphical outputs can be improved by using the plotter to add alphameric information.

10. Two-way data transfer beteen the HP21MX and the HP9830A is feasible. This capability should be developed to enable use of the faster HP21MX for repetitious data reduction.

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APPENDIX A

Table 1 contains the axial and circumferential location of the Kulite pressure transducers and the axial location of the pneumatic static pressure taps.

Kulite transducer number	Pneumatic static tap number	Axial distance downstream of K6 (inches)	Circumferential location relative to K6 in direction of rotation
K6	—	0	0°
K7	—	0.50	+ 10°
K8	—	1.00	0°
K9	—	1.37	+ 10°
K10	—	1.75	0°
K11	—	2.12	+ 10°
K12	—	2.50	0°
K13	—	3.00	+ 10°
	S6	0	—
	S7	0.50	—
	S8	1.00	—
	S9	1.37	—
	S10	1.55	—
	S11	2.12	—
	S12	2.50	—
	S13	3.00	—

Table 1 Location of Kulite pressure transducers and pneumatic static pressure taps.

APPENDIX B

DETAILS OF KULITE

KULITE is the data acquisition program for the HP21MX computer. Its three modes of operation are indicated in section 3.2. Figure 10 is a flow diagram of the program and a listing is given in Table 2.

Variable Assignment for KULITE

I1 - Run #. Same as Run # in Log Book assigned to each start-up of the compressor

I2 - Test #. Refers to a particular operating condition within a run.

I3 - Day

I4 - Month

I5 - Year

I6 - A/D converter mode #.

I7 - Samples/channel in free-run mode.

I8 - Not used.

I9 - Experiment #. Refers to either
(i) One time series of free-run data,
(ii) A complete set of calibration readings (averaged) for all transducers, or
(iii) Averaged pressures across one blade pair in Pacer mode.

A1 - Channel #. Refers to A/D converter.

T1 - Transducer #.

N1 - Samples/point in Pacer mode.

N2 - Blade pair #.

M - Mean of pressure samples at a point in Pacer mode.

S - Standard deviation of pressure samples at a point in Pacer mode.

R - Mean of one/blade signal at a point in Pacer mode.

L - Row number in K matrix of calibrations.

A3,A4,A5,A6 - Associated with subroutine RPACE and defined by WEST (1976)

A[101, 16] - Consecutive free-run samples stored row by row.

B[101, 16] - Buffer in subroutine R5610

C[10], D[10] - Buffers in subroutine R5610

$$E[4, 255] \quad - \begin{bmatrix} M_1 & M_3 & \text{- - - - step 2 - - -} & M_{255} \\ S_1 & S_3 & \text{- - - - - - - - - - - -} & S_{255} \\ A4_1 & A4_3 & \text{- - - - - - - - - - -} & A4_{255} \\ R_1 & R_3 & \text{- - - - - - - - - - - -} & R_{255} \end{bmatrix}$$

This is the matrix of averaged data taken in RPACE across two blade passages. Note that 128 points are taken across two blade passages. This number can be changed to 255 by changing Line 195.

K[5, 12] - Matrix of calibrations. Rows 1, 2, 3, each contain averaged calibration voltages for the twelve transducers. Each of rows 1, 2, 3 corresponds to a different calibration level. Row 5 contains I1, I2, I3, I4, I5, I9 and the three reference pressures (which are keyed in on request) in K[5,7], K[5,8], K[5,9]. Row 4 is treated as another calibration level and is used to scan the offsets if needed. In that case any value can be input to K[5,10] for P Ref.

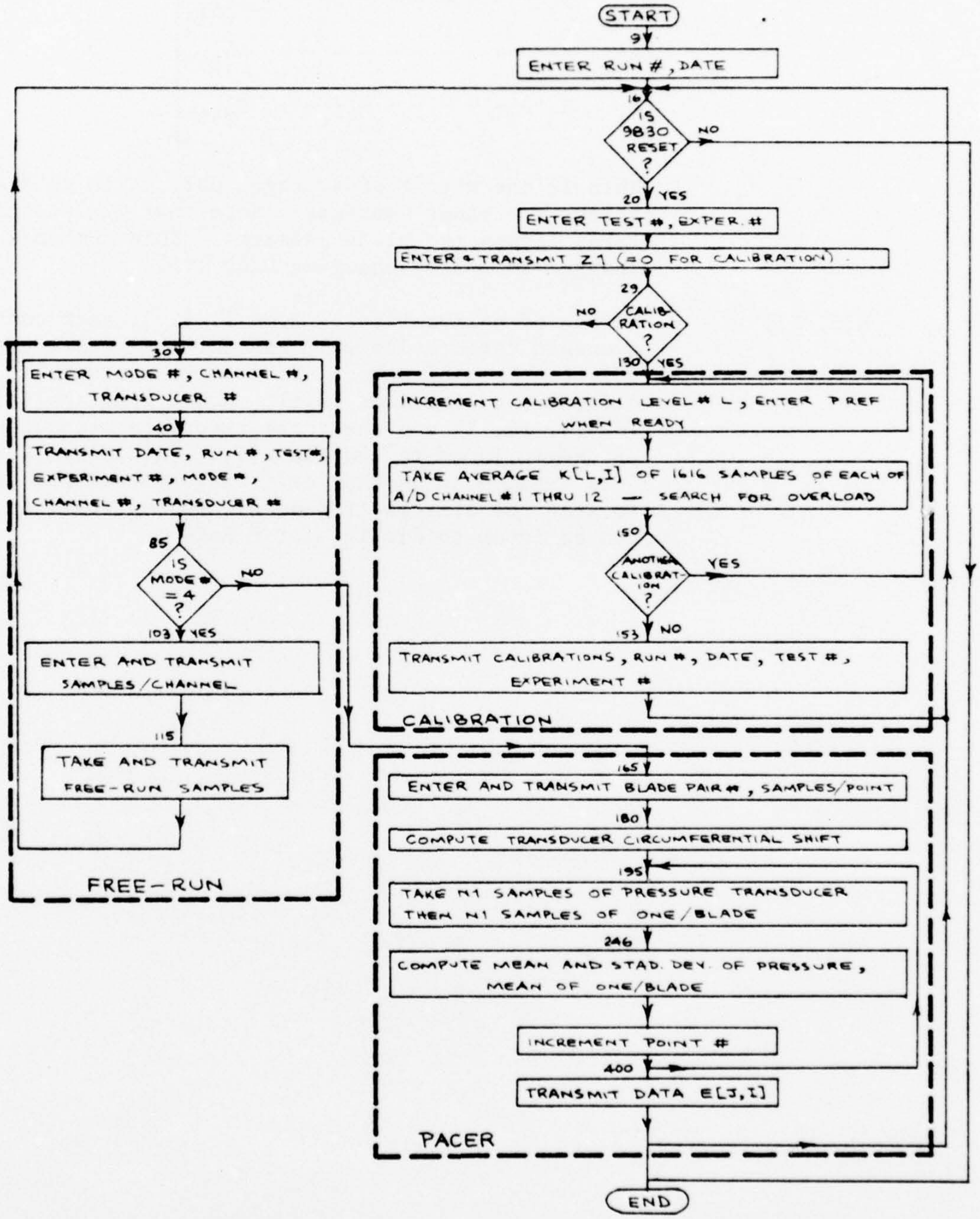


Figure 10. Flow diagram for KULITE

Table 2. Listing of KULITE

```
1  REM "KULITE" DATA LOGGING PROGRAM--SIMMONS--11 APRIL, 1977
5  DIM A[101,16],B[101,16],C[10],D[10],E[4,255],K[5,12]
9  PRINT "ENTER---RUN#,MONTH,DAY,YEAR"
10  FOR I=1 TO 5
11  FOR J=1 TO 12
12  LET K[I,J]=0
13  NEXT J
14  NEXT I
15  INPUT I1,I4,I3,I5
16  PRINT "ENTER 0 IF 9830 IS RESET----1 FOR END"
17  INPUT R8
18  IF R8>.5 THEN 470
20  PRINT "ENTER---TEST#, EXPERIMENT#"
25  INPUT I2,I9
26  PRINT "0 FOR CALIBRATION---OTHERWISE 1"
27  INPUT Z1
28  PRINT# 8;Z1
29  IF Z1<.5 THEN 129
30  PRINT "ENTER---MODE#, CHANNEL#, TRANSDUCER#"
35  INPUT I6,A1,T1
40  PRINT# 8;I1
45  PRINT# 8;I2
50  PRINT# 8;I3
55  PRINT# 8;I4
60  PRINT# 8;I5
65  PRINT# 8;I6
70  PRINT# 8;I9
75  PRINT# 8;T1
80  PRINT# 8;A1
85  IF I6=0 THEN 165
90  IF I6=4 THEN 103
95  PRINT "WRONG MODE#"
98  GOTO 30
103  PRINT "ENTER  SAMPLES / CHANNEL (NOT > 1616)"
105  INPUT I7
110  PRINT# 8;I7
115  R5610(7,A[1,1],I7,A1,I6,B[1,1])
116  PRINT "DATA TAKEN"
120  FOR J=1 TO 101
124  FOR I=1 TO 16
125  PRINT# 8;A[J,I]
126  NEXT I
127  NEXT J
128  GOTO 16
129  LET L=0
130  LET L=L+1
131  PRINT "ENTER P REF(IN. H2O REL ATMOS) IF READY FOR CALIBRATION"
132  INPUT K[5,6+L]
```

Table 2. Cont.

```
133  FOR J1=1 TO 12
134  PRINT "STARTING CALIBRATION OF A/D CHANNEL # "J1
135  LET A1=J1
136  R5610(7,A[1,1],1616,A1,4,B[1,1])
137  LET K[L,J1]=0
138  FOR J=1 TO 101
139  FOR I=1 TO 15 STEP 2
140  IF ABS(A[J,I])<.98 THEN 145
141  PRINT "*****************************"
142  PRINT "******OVERLOAD ON "J1"*******"
143  PRINT "*****************************"
144  GOTO 131
145  LET K[L,J1]=K[L,J1]+A[J,I]
146  NEXT I
147  NEXT J
148  LET K[L,J1]=K[L,J1]/1616
149  NEXT J1
150  PRINT "0 FOR ANOTHER CALIBRATION--OTHERWISE 1"
151  INPUT Z2
152  IF Z2<.5 THEN 130
153  LET K[5,1]=I1
154  LET K[5,2]=I2
155  LET K[5,3]=I3
156  LET K[5,4]=I4
157  LET K[5,5]=I5
158  LET K[5,6]=I9
159  FOR I=1 TO 5
160  FOR J=1 TO 12
161  PRINT# 8;K[I,J]
162  NEXT J
163  NEXT I
164  GOTO 16
165  PRINT "ENTER BLADE PAIR #, SAMPLES/POINT"
166  INPUT N2,N1
167  PRINT# 8;N1
168  PRINT# 8;N2
170  LET A3=0
180  IF T1>INT(T1/2)*2+.1 THEN 190
181  LET A6=32768+N2*256-64
182  GOTO 195
190  LET A6=32768+N2*256
```

Table 2. Cont.

```
195  FOR I=1 TO 255 STEP 2
200  LET A3=A6+I
215  LET R=0
225  RPACE(A3,A4,A5)
230  R5610(7,C[1],N1,A1,0,D[1])
240  FOR J=1 TO N1
241  LET B[J,1]=C[J]
242  NEXT J
243  LET A3=32768+N2*256+I
244  RPACE(A3,A4,A5)
245  R5610(7,C[1],N1,0,0,D[1])
246  FOR J=1 TO N1
247  LET R=R+C[J]
250  NEXT J
255  LET R=R/N1
260  LET S=0
270  LET M=0
280  FOR J=1 TO N1
290  LET M=M+B[J,1]
300  NEXT J
310  LET M=M/N1
320  FOR J=1 TO N1
330  LET S=S+((B[J,1]-M)*(B[J,1]-M))
340  NEXT J
350  LET S=SQR(S/(N1-1))
360  LET E[1,I]=M
370  LET E[2,I]=S
380  LET E[3,I]=A4
385  LET E[4,I]=R
390  NEXT I
400  FOR J=1 TO 4
410  FOR I=1 TO 255 STEP 2
420  PRINT# 8;E[J,I]
430  NEXT I
440  NEXT J
450  GOTO 16
470  END
```

Notes on KULITE

1. A/D converter channels. It is essential that the "raw" one per blade signal be input to channel 1 of the A/D converter. Allocation of the other channels is not unique but the allocation in Table 3 is recommended. Channels 11 and 12 are scanned but at present are not used in subsequent analysis.

A/D Converter Channel Number	Signal
0	one per blade raw signal
1	K6
2	K7
3	K8
4	K9
5	K10
6	K11
7	K12
8	K13
9	$P_{ref} - P_{atmos}$*
10	$S2 - P_{ref}$
11	Unused
12	Unused

Table 3. Allocation of signals to A/D converter channels.
*P_{ref} is pressure applied to reference side of Kulite transducers.

2. Subroutine R5610 is described by WEST (1976, p. 17).

3. In calibration mode the scan through the twelve channels must be made four times. The first scan must be with the pressure tapping S2 applied simultaneously to the reference side of Kulite transducers. The second

and third scans must be made with other steady pressures applied to the reference side of the Kulites. The fourth scan must be made to satisfy the program but at this stage the data taken is not used in subsequent analysis. This scan is included to enable logging of the offsets on the Kulite amplifiers should they be of interest.

4. The program searches for overloads (i.e. greater than 0.98 volts or less than - 0.98 volts in the calibration signals). If it detects an overload among alternate samples in the 1616 samples taken from any transducer the offending A/D converter channel number is displayed, the scan is aborted and the program is reset to repeat the scan. The limit of 0.98 volts can be changed in line 140.

5. The one per revolution signal from the timing wheel indicates the origin for circumferential measurements around the rotor. The pacer then uses the one per blade signal to divide the rotor circumference into 9 equal intervals, the first interval beginning at the origin. These intervals are designated by blade pair numbers, although the start of an interval need not coincide with a blade tip. Each interval represents a circumferential length, in the rotor frame, equal to that of the arc (measured at the wall) across two adjacent blade passages. Each of the nine intervals is divided into 256 sub-intervals. In pacer mode the scan across an interval begins after the first sub-interval and ends after the 255th sub-interval. With stepping sequentially across the sub-intervals in pairs, a total of 128 points are sampled. It is convenient to take 10 samples at each point (one sample approximately each ten revolutions) to compute the mean and standard deviation.

6. Even numbered transducers (e.g. K6, K8 etc.) are located on one axial line and odd numbered transducers are on another axial line which is displaced around the casing wall by 10 degrees in the direction opposite that of rotation of the rotor. The parity of the transducer number is evaluated in line 180.

   The variable A3 determines the time (in terms of degrees of rotation of the rotor) after the one per revolution pulse when a sample is taken at point I. For example, in line 190, A6 = 32768 + N2 * 256 for odd transducer numbers, and A3 = A6 + I. This defines the sampling time (approximately each tenth revolution) for point I in blade pair N2. (I = 1 to 255, N2 = 1 to 9). Point I can be sampled 10 degrees earlier for even numbered transducers by setting

   A6 = 32768 + N2 * 256 - 64

   and A3 = A6 + I

   The subroutine RPACE is described in more detail by WEST (1976).

7. During each scan of a transducer across a blade pair the raw one per blade is also sampled. This is used later in TRAN4 to determine the location of the measured pressure distribution relative to the rotor.

APPENDIX C

DETAILS OF TRAN4

TRAN4 is the data acquisition program for the HP 9830A programmable calculator. Figure 11 is a flow diagram and a listing is in Table 4.

Variable Assignment for TRAN4

N1 - RECORD #. i.e. Number of first available record in DATAY1

Z1 - IDENTIFIER (= 0 FOR CALIBRATION - OTHERWISE 1)

A3 - BLADE PAIR #

A2 - SAMPLES/POINT in Pacer mode.

T1 - LOCATION (between 1 and 255) of point in blade pair where 1/blade signal is 0.5 volts and increasing.

T2 - Location of point in blade pair where 1/blade signal is 0.5 volts and decreasing.

A[5,128] -

$$\left[\begin{array}{llll} M_1 & M_3 & \text{- - - - - step 2 - - - - - - - - - - - - - -} & M_{255} \\ S_1 & S_3 & \text{- -} & S_{255} \\ A_{4_1} & A_{4_3} & \text{- -} & A4_{255} \\ R_1 & R_2 & \text{- -} & R_{255} \\ \multicolumn{4}{l}{I1,\ I2,\ I3,\ I4,\ I5,\ I6,\ I7,\ T1,\ A1,\ A2,\ A3,\ 0,\ 0,\ \text{- - - -}\ 0} \end{array}\right]$$

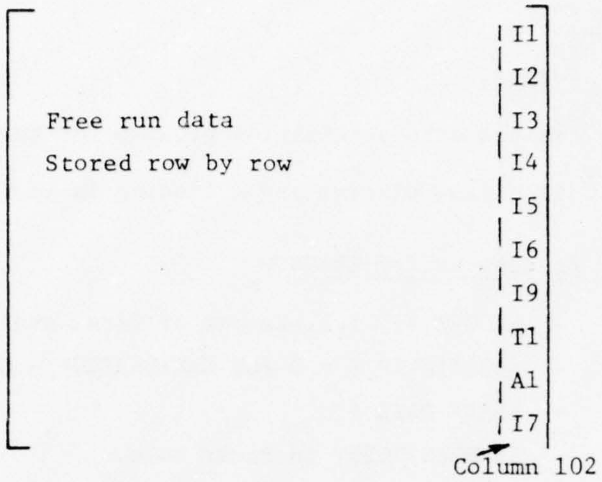
NOTE that variable names in this array are those used in 21MX program. They should not be confused with variables used in TRAN4. This is the matrix of averaged data taken in RPACE across two blade passages. Note that 128 points can be changed by changing dimension statement and the FOR loop.

B[9] - Buffer for identification data

$[I1, I2, I3, I4, I5, I6, I9, T1, A1]^T$

NOTE that the variable names in this array are those used in 21MX program.

D[16, 102] —



NOTE that variable names in column 102 are those used in 21MX program.

K[5, 12] - Same as K[5, 12] in 21MX program.

DATA FILES

RECY #	This file contains 1 record. It contains N1 which is the number of the 1st available record in file DATAY1
DATAY1	Data file for calibration, free run and Pacer data. i.e. for K, D and A arrays respectively. It contains 300 records.

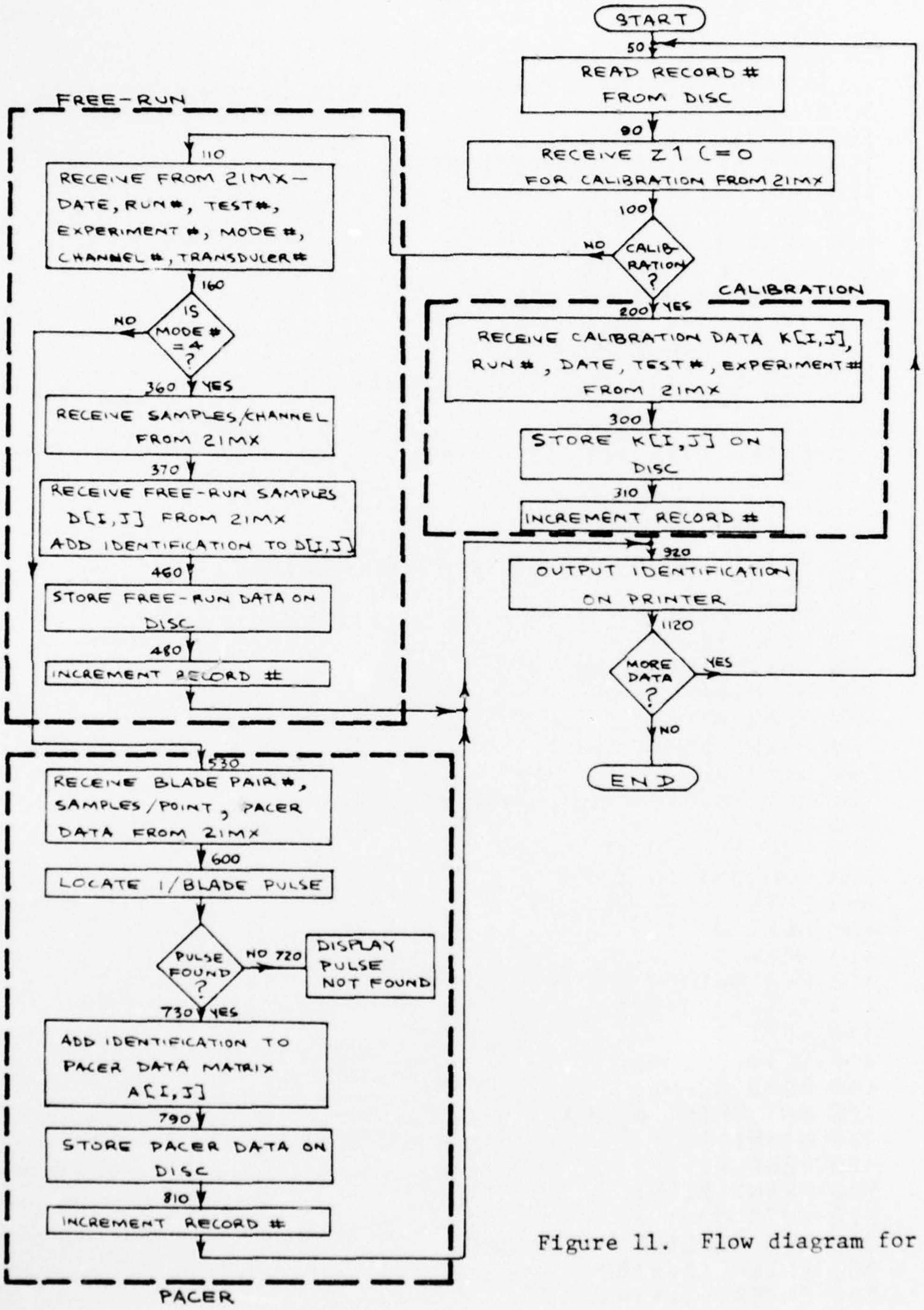


Figure 11. Flow diagram for TRAN4

Table 4. Listing of TRAN4

```
10 REM --- TRAN4 ---SIMMONS---12 APRIL, 1977
20 UNIT 0
30 FILES RECVA,DATAV1
40 DIM D5[16,102],A5[5,128],B[9],K[5,12]
50 READ #1;N1
60 MAT D=ZER
70 MAT A=ZER
80 REM TEST IF NEXT DATA FROM 21MX IS A CALIBRATION
90 ENTER (1,*)Z1
100 IF Z1<0.5 THEN 200
110 REM RECEIVE IDENTIFICATION DATA
120 FOR I=1 TO 9
130 ENTER (1,*)B[I]
140 NEXT I
150 REM TEST MODE#
160 IF B[6]=0 THEN 530
170 IF B[6]=4 THEN 360
180 DISP "WRONG MODE #";
190 REM RECEIVE AND STORE CALIBRATION DATA
200 FOR I=1 TO 5
210 FOR J=1 TO 12
220 ENTER (1,*)K[I,J]
230 NEXT J
240 NEXT I
250 PRINT
260 PRINT "ARRAY OF CALIBRATION VOLTAGES"
270 PRINT
280 MAT PRINT K
290 READ #2,N1
300 MAT PRINT # 2;K
310 N1=N1+1
320 READ #1,1
330 PRINT #1;N1
340 GOTO 920
350 REM RECEIVE AND STORE FREE-RUN DATA
360 ENTER (1,*)I7
370 FOR I=1 TO 16
380 FOR J=1 TO 101
390 ENTER (1,*)D[I,J]
400 NEXT J
410 NEXT I
420 FOR I=1 TO 9
430 D[I,102]=B[I]
440 NEXT I
450 D[10,102]=I7
460 READ #2,N1
470 MAT PRINT # 2;D
480 N1=N1+13
490 READ #1,1
500 PRINT #1;N1
510 GOTO 850
520 REM RECEIVE PACER DATA
530 ENTER (1,*)A2
540 ENTER (1,*)A3
550 FOR J=1 TO 4
560 FOR I=1 TO 128
570 ENTER (1,*)A[J,I]
580 NEXT I
590 NEXT J
600 REM FIND POSITION OF REFERENCE PULSE--1/ BLADE
```

Table 4. Cont.

```
610 I=0
620 I=I+1
630 IF I>128 THEN 720
640 IF A[4,I]>0.5 THEN 660
650 GOTO 620
660 T1=I
670 I=I+1
680 IF A[4,I]<0.5 THEN 700
690 GOTO 670
700 T2=I
710 GOTO 730
720 DISP "REFERENCE PULSE NOT FOUND";
730 FOR I=1 TO 9
740 A[5,I]=B[I]
750 NEXT I
760 A[5,10]=A2
770 A[5,11]=A3
780 REM STORE PACER DATA
790 READ #2,N1
800 MAT PRINT # 2;A
810 N1=N1+5
820 READ #1,1
830 PRINT #1;N1
840 REM PRINT EXPERIMENT IDENTIFACTION
850 PRINT
860 PRINT
870 WRITE (15,880)B[1],B[2],B[4],B[3],B[5]
880 FORMAT 5X,"RUN#",F5.0,5X,"TEST#",F5.0,10X,F3.0,"/",F3.0,"/",F5.0
890 PRINT "MODE #"B[6],"      EXPERIMENT #"B[7]
900 IF B[6]=0 THEN 1050
910 IF Z1>0.5 THEN 990
920 PRINT
930 PRINT
940 WRITE (15,880)K[5,1],K[5,2],K[5,4],K[5,3],K[5,5]
950 PRINT "EXPERIMENT#"K[5,6]
960 PRINT "CALIBRATION----P REF="K[5,7]
970 PRINT "                                        REC#"N1-1
980 GOTO 1010
990 PRINT "TRANSDUCER #"B[8],"      CHANNEL #"B[9]
1000 PRINT "SAMPLES/CHANNEL"I7,"      REC #"N1-13
1010 PRINT
1020 PRINT
1030 PRINT "*****************************************************
1040 GOTO 1120
1050 PRINT "TRANSDUCER #"B[8],"      CHANNEL #"B[9]
1060 WRITE (15,1080)A3,A2,N1-5
1070 PRINT "REFERENCE PULSE AT POINT#"(T1+T2)/2
1080 FORMAT "BLADE PAIR #",F4.0,5X,"SAMPLES/POINT",F4.0,5X,"REC #",F5.0
1090 PRINT
1100 PRINT
1110 PRINT "*****************************************************
1120 DISP "ENTER 1 FOR MORE DATA";
1130 INPUT Q
1140 IF Q=1 THEN 30
1150 PRINT
1160 PRINT
1170 PRINT
1180 END
```

Notes on TRAN4

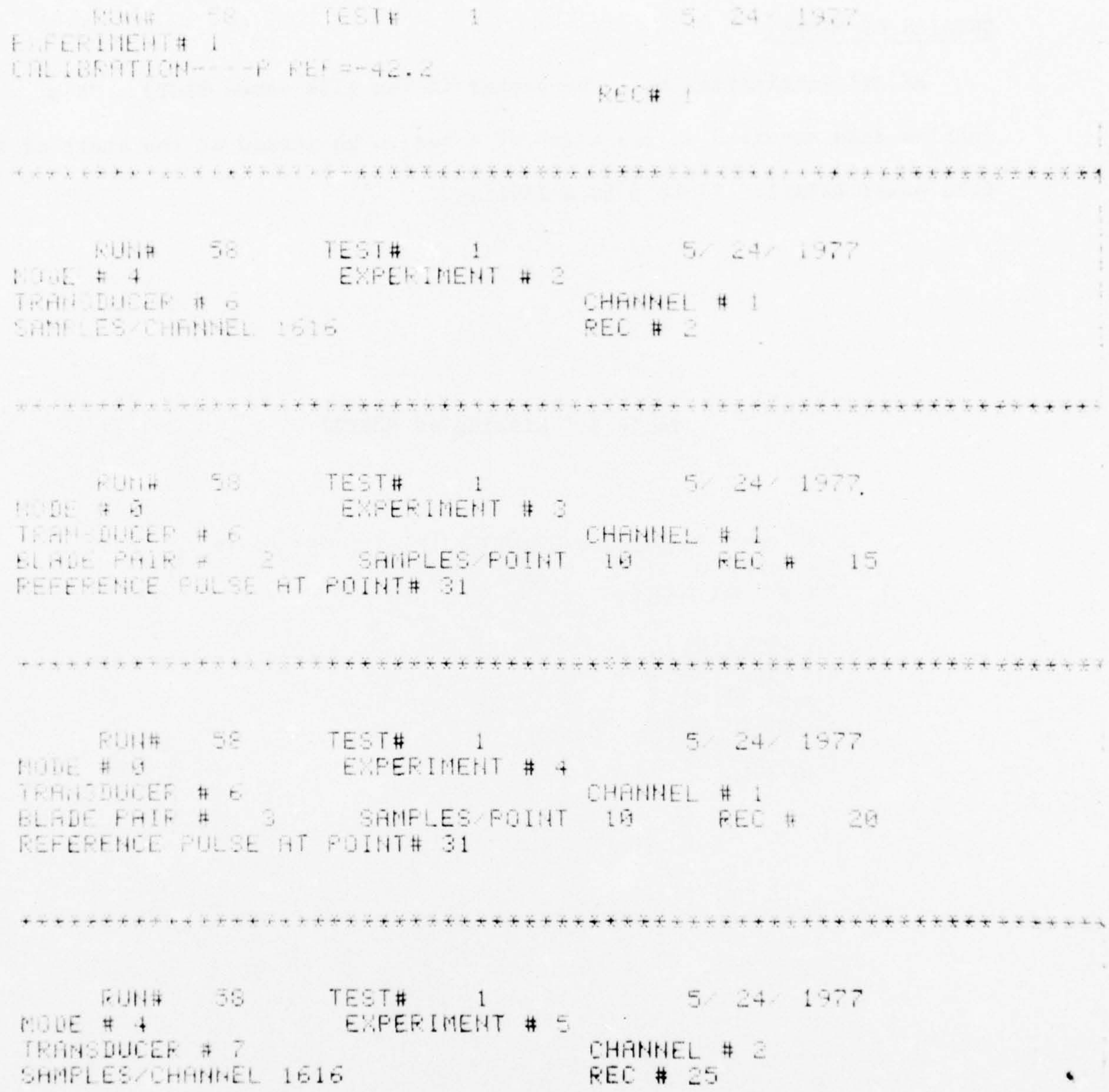
1. (line 30) DATAY1 is a file on a removable disk for temporary storage. At the end of Run number n (n is a two digit integer) a file CKRWn must be opened on the fixed disk and data must be copied into it from DAYA1 for long term storage. The number of records in CKRWn must equal the sum of record number printed out with identification of the last experiment and a number k where

   k = 1 if last experiment was a calibration
   = 5 if last experiment was in pacer mode
   = 13 if last experiment was in free-run mode

   Figure 12 contains sample print-out from TRAN4 for the three modes.

2. (Line 600) The position of the centre of the raw one per blade pulse is found relative to the pressure distribution across a blade pair by searching through the 128 averaged samples at each point to find the sample which first exceeds 0.5 volts and the first subsequent sample which is less than 0.5 volts. The corresponding point numbers are averaged. If the pulse is not found (due to inadequate signal level), the program displays an ERROR. After the correct one per blade signal has been re-established both KULITE and TRAN4 must be rerun.

Figure 12. Sample print-out from TRAN4 for calibration, mode 0 (pacer) and mode 4 (free-run) operation.



```
     RUN#   58      TEST#    1            5/ 24/ 1977
EXPERIMENT# 1
CALIBRATION----P REF=-42.2
                                    REC# 1


*******************************************************************


     RUN#   58      TEST#    1            5/ 24/ 1977
MODE # 4            EXPERIMENT # 2
TRANSDUCER # 6                     CHANNEL # 1
SAMPLES/CHANNEL 1616               REC # 2


*******************************************************************


     RUN#   58      TEST#    1            5/ 24/ 1977
MODE # 0            EXPERIMENT # 3
TRANSDUCER # 6                     CHANNEL # 1
BLADE PAIR #   2     SAMPLES/POINT  10     REC #    15
REFERENCE PULSE AT POINT# 31


*******************************************************************


     RUN#   58      TEST#    1            5/ 24/ 1977
MODE # 0            EXPERIMENT # 4
TRANSDUCER # 6                     CHANNEL # 1
BLADE PAIR #   3     SAMPLES/POINT  10     REC #    20
REFERENCE PULSE AT POINT# 31


*******************************************************************


     RUN#   58      TEST#    1            5/ 24/ 1977
MODE # 4            EXPERIMENT # 5
TRANSDUCER # 7                     CHANNEL # 2
SAMPLES/CHANNEL 1616               REC # 25
```

APPENDIX D

DETAILS OF RESET1

RESET1 initializes to 1 the number in the file named RECY#. This enables data acquired at the start of a run to be stored at the start of the file named DATAY1. Table 5 is a listing.

Table 5. Listing of RESET1

```
10 REM  "RESET1"-SIMMONS  SETS RECY# TO 1
20 UNIT 0
30 FILES RECY#
40 A=1
50 READ #1,1
60 PRINT #1;A
70 READ #1,1
80 READ #1;A
90 PRINT A
100 END
```

APPENDIX E

DETAILS OF MAP1

MAP1 is used to compute the sensitivities of the Kulite pressure transducers and to convert voltages sampled at the pressure transducer outputs to pressure coefficients. Figure 13 is a flow diagram and a listing is in Table 6.

Variable Assignment for MAP1

N - compressor RPM

T - total temperature (called T_{TOT} elsewhere) measured at axial location of S2 (entered in degrees F).

P1 - Static pressure (P_{STAT}) measured at S2 (entered in inches of water absolute).

P2 - Total pressure (P_{TOT}) measured at axial location of S2 (entered in inches of water absolute).

M - square of Mach number at axial location of S2.

U1 - square of rotor tip speed in ft^2/sec^2.

A1 - square of speed of sound at axial location of S2 in ft/sec.

Q - Reference pressure for computing pressure coefficients.

C1, C2, C3 - First, second and third calibration pressures applied to reference side of Kulite transducers (inches of water relative to atmospheric).

R0 - Record number for calibration data on disk.

T0 - Kulite transducer number.

A - Kulite transducer sensitivity in inches of water per volt.

P0 - Pressure from pneumatic wall static tap corresponding in axial location to a Kulite transducer. (inches of water relative to pressure at S2).

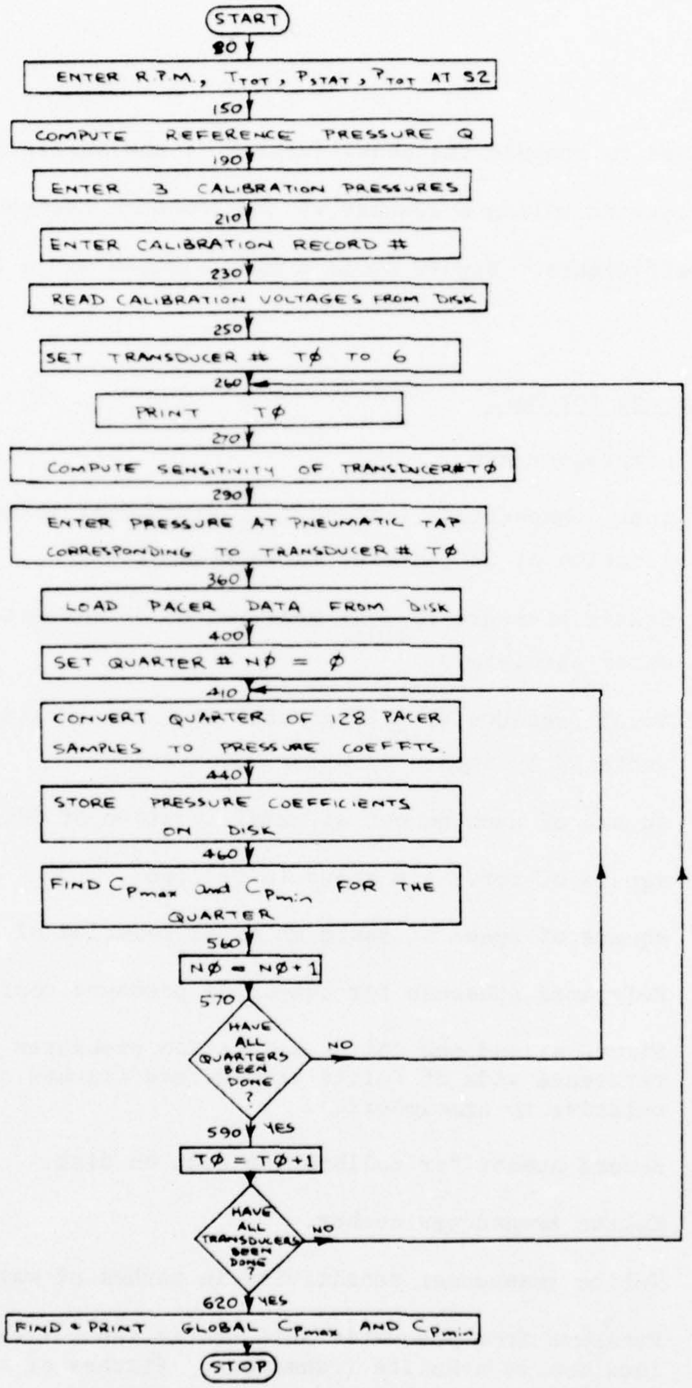


Figure 13. Flow diagram for MAP 1

Table 6. Listing of MAP1

```
10 REM "MAP1" [illegible] ------- 19 AUG. 1977
20 UNIT 0
30 FILES *,PR[illegible]
40 DIM A[5,128],C[5,12],P[32],U[8,4],L[8,4],B$[6]
50 DISP "ENTER NAME OF DATA FILE (CFRW??)";
60 INPUT B$
70 ASSIGN B$,1,B9
80 DISP "ENTER RPM";
90 INPUT N
100 DISP "ENTER T IN DEG. F";
110 INPUT T
120 T=T+460
130 DISP "ENTER PSTAT,PTOT(IN.H2O ABS)";
140 INPUT P1,P2
150 M=((P2/P1)↑(0.4/1.4)-1)*2/0.4
160 U1=(PI*N*5.5/30)/12
170 A1=1.4*53.34*T/(1+0.2*M)*32.2
180 Q=0.7*P1*(M+U1/A1)
190 DISP "ENTER 3 CAL PRESSURES -IN.H2O REL ATMOS";
200 INPUT C1,C2,C3
210 DISP "ENTER CAL REC#";
220 INPUT R0
230 READ #1,R0
240 MAT READ # 1;C
250 T0=6
260 PRINT "TRANS. NO.= "T0
270 GOSUB 790
280 PRINT "SENS. OF T"T0"="A"IN. H2O/VOLT"
290 DISP "ENTER PWALL FOR T"T0"IN.H2O REL S2";
300 INPUT P0
310 REM IF T0=10 INTERPOLATION IS NEEDED BECAUSE K10 AND S10 ARE OFFSET
320 IF ABS(T0-10)>0.5 THEN 360
330 DISP "ALSO ENTER PWALL FOR T11";
340 INPUT P9
350 P0=P0+(P9-P0)*0.2/0.57
360 DISP "ENTER PACER PRESS REC# FOR T"T0;
370 INPUT R1
380 READ #1,R1
390 MAT READ # 1;A
400 N0=0
410 FOR I=1 TO 32
420 P[I]=((A[1,N0*32+I]-C[1,T0-5])*A+P0)/Q
430 NEXT I
440 READ #2,(T0-6)*4+N0+1
450 MAT PRINT # 2;P
460 L[T0-5,N0+1]=P[1]
470 FOR I=2 TO 32
480 IF P[I]>L[T0-5,N0+1] THEN 500
490 L[T0-5,N0+1]=P[I]
500 NEXT I
510 U[T0-5,N0+1]=P[1]
520 FOR I=2 TO 32
530 IF P[I]<U[T0-5,N0+1] THEN 550
540 U[T0-5,N0+1]=P[I]
550 NEXT I
560 N0=N0+1
570 IF N0>3.5 THEN 590
580 GOTO 410
590 T0=T0+1
600 IF T0>13.5 THEN 620
```

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Table 6. Cont.

```
610 GOTO 260
620 U=-1E+50
630 FOR I=1 TO 6
640 FOR J=1 TO 4
650 IF U[I,J]<U THEN 670
660 U=U[I,J]
670 NEXT J
680 NEXT I
690 PRINT "CP MAX="U
700 L=1E+50
710 FOR I=1 TO 6
720 FOR J=1 TO 4
730 IF L[I,J]>L THEN 750
740 L=L[I,J]
750 NEXT J
760 NEXT I
770 PRINT "CP MIN="L
780 STOP
790 REM SUBROUTINE TO CALCULATE TRANSDUCER SENSITIVITY A IN IN.H20/VOL
800 A=3*(C1*C[1,T0-5]+C2*C[2,T0-5]+C3*C[3,T0-5])
810 A=A-(C1+C2+C3)*(C[1,T0-5]+C[2,T0-5]+C[3,T0-5])
820 A=A/(3*(C1↑2+C2↑2+C3↑2)-(C1+C2+C3)↑2)
830 A=-1/A
840 RETURN
850 END
```

R1 - Record number for pacer data.

N0 - N0 + 1 is pacer data quarter number. The 128 samples are divided into 4 sets of 32.

U - Maximum pressure coefficient in set across two blade passages.

L - Minimum pressure coefficient in set across two blade passages.

AS[5, 128] - Same as A[5, 128] in TRAN4.

C[5, 12] - Same as K[5, 12] in TRAN4.

P[32] - Array of pressure coefficients for one transducer and in one quarter of pressure distribution across two blade passages.

U[8, 4] - U[I, J] is local maximum pressure coefficient for transducer number I and quarter J.

L[8, 4] - L[I, J] is local minimum pressure coefficient for transducer number I and quarter J.

DATAY1 - Same data file as in TRAN4.

PRESS - contains pressure coefficients. The 32 records contain in order quarters 1, 2, 3, 4 for transducer 6, quarters 1, 2, 3, 4 for transducer 7, etc.

Notes on MAP1

1. The correct CKRWn file name for the run under consideration must be entered.
2. Storage of pressure coefficients. The 128 pressure coefficients associated with each transducer have been grouped into 4 sets (quarters) with each set being stored in a separate record. This has been done to facilitate use of interpolation programs such as MAP2. Interpolation expands the size of the data array so that pressure coefficients must be recalled from the mass memory in subsets in order to meet the storage limitations of the HP9830A.

3. Sensitivities of the Kulite transducers are computed as follows:

C1, C2, C3 are the three steady pressures applied to the reference side of the Kulite transducers. They correspond to mean output voltages C[1, TO - 5], C[2, TO - 5], C[3, TO - 5] from Kulite transducer number TO. The sensitivity of a transducer (i.e. the slope of its calibration curve at a particular mean operating temperature and pressure) is obtained from a least squares fit of a straight line through the three points.

4. Calculation of pressure coefficients.

The Kulite transducer output voltages E are converted to pressure coefficients C_p as follows:

$$C_p = ((E - \bar{E}) * A + P0)/Q$$

where $\bar{E}$ = transducer mean output voltage obtained during calibration with S2 on reference side of diaphragm.

A = sensitivity of transducer in inches of water per volt.

P0 = mean wall pressure (at same axial location as Kulite transducer) measured with pneumatic tap. (inches of water relative to S2).

Q = reference dynamic pressure (inches of water absolute) computed as follows:

The reference dynamic pressure is expressed in terms of the upstream density ρ and the upstream flow velocity measured in the rotating frame of the rotor. Hence

$$Q = \frac{1}{2} \rho \, (V^2 + U^2)$$

where V = flow velocity at station S2 (ft/sec).

U = rotor tip speed

$$= \frac{\pi N}{30} \times \frac{5.5}{12} \text{ ft.sec.} \qquad (1)$$

N = rotor RPM

It follows (noting that variable names are not necessarily the same as in the listing of MAP1) that

$$Q = \frac{1}{2}\,\gamma P\,(M^2 + U^2/a^2) \tag{2}$$

where P, a, M are static pressure, speed of sound and Mach number at station S2.

But $$a^2 = \gamma R T_T \left[\left(1 + \frac{\gamma-1}{2} M^2\right)^{-1}\right] \tag{3}$$

and $$M^2 = \frac{2}{\gamma-1}\left[\left(\frac{P_T}{P}\right)^{\frac{\gamma-1}{\gamma}} - 1\right] \tag{4}$$

where T_T *and* P_T *are total temperature* and pressure at S2.

By introducing (1), (3) and (4) into (2), Q can be calculated in terms of P, P_T and T_T .

5. Note that S10 and K10 are not at the same axial location. For purposes of computing pressure coefficients an effective mean wall pressure at K10 is obtained by linear interpolation using values at S10 and S11.
6. The maximum and minimum pressure coefficients are computed to aid in the choice of contours when using the programs CONT or CONT1.

APPENDIX F

DETAILS OF MAP2

MAP2 is used to convert the 8 x 128 array of measured pressure coefficients to a 29 x 128 array through quadratic interpolation in the axial direction. A listing is in Table 7.

Variable Assignment for MAP2

B[32] - temporary storage of pressure coefficients

C[29,32] - array of interpolated pressure coefficients across one quarter of a blade pair.

P[8, 32] - Array of pressure coefficients at Kulite transducer locations across one quarter of blade pair.

X[8] - Axial location of Kulite transducers downstream of transducer K6. (inches).

Q - quarter number.

PRESS - Same data file as in MAP1.

INTER - File for storage of interpolated pressure coefficients across one quarter of blade pair (15 records).

Notes on MAP2

1. Lagrangian interpolation is used, i.e. if P_1, P_2, and P_3 are known at x_1, x_2, x_3 then

$$P(x) = \frac{(x-x_2)\ (x-x_3)}{(x_1-x_2)(x_1-x_3)} P_1 + \frac{(x-x_1)\ (x-x_3)}{(x_2-x_1)(x_2-x_3)} P_2 + \frac{(x-x_1)\ (x-x_2)}{(x_3-x_1)(x_3-x_2)} P_3$$

Table 7. Listing of MAP2

```
10 REM "MAP 2"---SIMMONS-------19 MAY, 1977
20 UNIT 0
30 FILES PRESS,INTER
40 DIM B[32],P[8,32],C[29,32]
50 REM KULITE AXIAL LOCATIONS (INCHES) FOLLOW
60 X[1]=0
70 X[2]=0.5
80 X[3]=1
90 X[4]=1.37
100 X[5]=1.75
110 X[6]=2.12
120 X[7]=2.5
130 X[8]=3
140 REM MEASURED PRESSURE COEFFICIENTS ARE LOADED FROM DISK
150 DISP "ENTER QUARTER #";
160 INPUT Q
170 FOR I=1 TO 8
180 READ #1,4*I-3+Q-1
190 MAT READ # 1:B
200 FOR J=1 TO 32
210 C[I,J]=B[J]
220 NEXT J
230 NEXT I
240 REM INTERPOLATE BETWEEN X(1) AND X(3)
250 L=INT(0.5/Q+28)
260 X1=Q/28
270 FOR J=1 TO 32
280 C[1,J]=P[1,J]
290 NEXT J
300 FOR J=1 TO 32
310 FOR I=1 TO L
320 C[I+1,J]=(I*X1-X[2])*(I*X1-X[3])/((X[1]-X[2])*(X[1]-X[3]))*P[1,J]
330 C[I+1,J]=(I*X1-X[1])*(I*X1-X[3])/((X[2]-X[1])*(X[2]-X[3]))*P[2,J]+C[I+1,J]
340 C[I+1,J]=(I*X1-X[1])*(I*X1-X[2])/((X[3]-X[1])*(X[3]-X[2]))*P[3,J]+C[I+1,J]
350 NEXT I
360 NEXT J
```

Table 7. Cont.

```
370 REM INTERPOLATE BETWEEN X(7) AND X(8)
380 L=INT(2.5/3*28)
390 FOR J=1 TO 32
400 FOR I=L+1 TO 28
410 C[I+1,J]=(I*X1-X[7])*(I*X1-X[8])/(X[6]-X[7])/(X[6]-X[8])*P[6,J]
420 C[I+1,J]=(I*X1-X[6])*(I*X1-X[8])/(X[7]-X[6])/(X[7]-X[8])*P[7,J]+C[I+1,J]
430 C[I+1,J]=(I*X1-X[6])*(I*X1-X[7])/(X[8]-X[6])/(X[8]-X[7])*P[8,J]+C[I+1,J]
440 NEXT I
450 NEXT J
460 REM INTERPOLATE BETWEEN X(2) AND X(7)
470 FOR K=2 TO 6
480 PRINT K
490 FOR J=1 TO 32
500 FOR M=INT(X[K]/3*28)+2 TO INT(X[K+1]/3*28)+1
510 I=M-1
520 C[M,J]=(I*X1-X[K])*(I*X1-X[K+1])/(X[K-1]-X[K])/(X[K-1]-X[K+1])*P[K-1,J]
530 C[M,J]=(I*X1-X[K-1])*(I*X1-X[K+1])/(X[K]-X[K-1])/(X[K]-X[K+1])*P[K,J]+C[M,J]
540 C=C[M,J]
550 C[M,J]=(I*X1-X[K-1])*(I*X1-X[K])/(X[K+1]-X[K-1])/(X[K+1]-X[K])*P[K+1,J]+C
560 C[M,J]=(I*X1-X[K+1])*(I*X1-X[K+2])/(X[K]-X[K+1])/(X[K]-X[K+2])*P[K,J]+C[M,J]
570 D=C[M,J]
580 C[M,J]=(I*X1-X[K])*(I*X1-X[K+2])/(X[K+1]-X[K])/(X[K+1]-X[K+2])*P[K+1,J]+D
590 E=C[M,J]
600 C[M,J]=(I*X1-X[K])*(I*X1-X[K+1])/(X[K+2]-X[K])/(X[K+2]-X[K+1])*P[K+2,J]+E
610 C[M,J]=C[M,J]/2
620 NEXT M
630 NEXT J
640 NEXT K
650 REM STORE INTERPOLATED PRESSURE COEFFICIENTS ON DISK
660 READ #2,1
670 MAT PRINT # 2;C
680 DISP "END"
690 END
```

2. As a result of the equispaced interpolation, the transducer axial locations will in general not coincide with axial stations in the interpolated array.
3. Three interpolations are made in the axial direction between transducer measurements.
4. The program must be run for each quarter of the array of measured pressure coefficients. After each running of the program the contours must be plotted with CONT prior to running MAP2 for another quarter.
5. Interpolation between X[1] and X[2] is made with a quadratic through pressure coefficients at X[1], X[2] and X[3]. Interpolation between X[7] and X[8] is made with a quadratic through X[6], X[7] and X[8]. Interpolation between X[I] and X[I + 1] (for I > 1 and < 6) is made by averaging the quadratic through X[I - 1], X[I] and X[I + 1] and the quadratic through X[I], X[I + 1] and X[I + 2].

APPENDIX G

DETAILS OF CONT1

CONT1 is used to plot contours of constant casing wall pressure from an array of measured pressure coefficients. The program handles the non-uniform axial spacing of the Kulite transducers but requires uniform circumferential spacing in the array. CONT1 is written to accept the array generated by MAP1. Figure 14 is a flow diagram and a listing is in Table 8.

Variable Assignment for CONT1

P[I, J] - array of pressure coefficients

A[3, 3], B[3, 3], Z[3], Q[3], D[2, 2], F[2], G[2, 2], H[2] - defined in note 6 of this appendix.

x[9] - axial location (inches) of Kulite transducers downstream of K6.

I0, J0 - dimensions of P[I, J] in axial and circumferential directions respectively.

C - value of pressure coefficient on a contour.

E - triangular element number.

E1 - number of starting element in a contour plot.

E2 - number of finishing element in a contour plot.

PRESS - Same file as in MAP1.

Notes on CONT1

1. The X (axial) and Y (circumferential) dimensions of P must be entered before program is run. P[8, 128] is nearly the maximum array size that can be stored in the HP9830A.
2. The axes are drawn so that X (axial) runs from K6 to K13 and Y (circumferential) runs from the start to the end of a blade pair. Contours

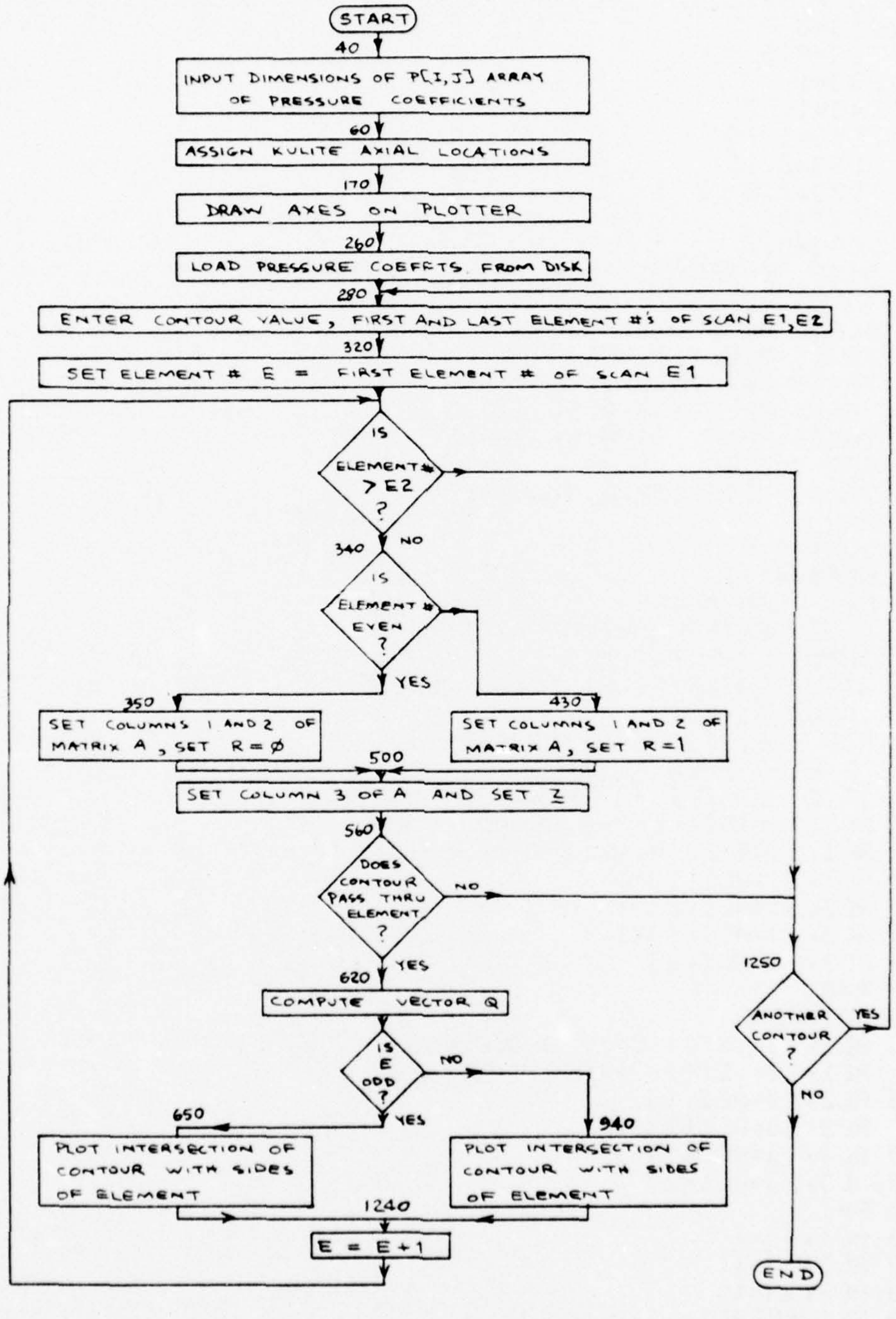

Figure 14. Flow diagram for CONT1

Table 8. Listing of CONT1

```
10 REM WALL PRESSURE MAP PROGRAM "CONT1" -SIMMONS-12 MAY. 197
20 UNIT 0
30 FILES PRESS
40 REM INSERT DIMENSIONS FOR P(I,J)
50 DIM P[8,128],A[3,3],B[3,3],Z[3],O[3],D[2,2],F[2],G[2,2],H[2],X[9]
60 X[1]=0
70 X[2]=0.5
80 X[3]=1
90 X[4]=1.37
100 X[5]=1.75
110 X[6]=2.12
120 X[7]=2.5
130 X[8]=3
140 X[9]=3.5
150 DISP "ENTER X (AXIAL) AND Y DIMENSIONS OF P(I,J)";
160 INPUT I0,J0
170 SCALE 0,X[8],0.5,J0+0.5
180 XAXIS 0.5,4,0,X[8]
190 XAXIS J0+0.5,3,0,X[8]
200 YAXIS X[1],130,0.5,J0+0.5
210 YAXIS X[8],130,0.5,J0+0.5
220 FOR I=2 TO 7
230 YAXIS X[I],130,0.5,J0+0.5
240 PEN
250 NEXT I
260 READ #1,1
270 MAT READ # 1;P
280 DISP "ENTER CONTOUR P=";
290 INPUT C
300 DISP "ENTER FIRST & LAST ELEMENT#",
310 INPUT E1,E2
320 FOR E=E1 TO 2*(I0-1)*(J0-1)
330 IF E>E2 THEN 1250
340 IF E>INT(E/2)*2 THEN 430
350 A[1,1]=INT((E/2-0.00001)/(J0-1))+1
360 A[1,2]=E/2-(A[1,1]-1)*(J0-1)+1
370 A[2,1]=A[1,1]+1
380 A[2,2]=A[1,2]-1
390 A[3,1]=A[1,1]+1
400 A[3,2]=A[1,2]
410 R=0
420 GOTO 500
430 A[1,1]=INT(((E+1)/2-0.00001)/(J0-1))+1
440 A[1,2]=(E+1)/2-(A[1,1]-1)*(J0-1)
450 A[2,1]=A[1,1]
460 A[2,2]=A[1,2]+1
470 A[3,1]=A[1,1]+1
480 A[3,2]=A[1,2]
490 R=1
500 A[1,3]=1
510 A[2,3]=1
520 A[3,3]=1
530 Z[1]=P[A[1,1],A[1,2]]
540 Z[2]=P[A[2,1],A[2,2]]
550 Z[3]=P[A[3,1],A[3,2]]
560 REM CHECK IF C IS IN E
570 IF Z[1] >= C AND C >= Z[2] THEN 620
580 IF Z[2] >= C AND C >= Z[1] THEN 620
590 IF Z[1] >= C AND C >= Z[3] THEN 620
600 IF Z[3] >= C AND C >= Z[1] THEN 620
```

Table 8. Cont.

```
610 GOTO 1230
620 MAT B=INV(A)
630 MAT Q=B*Z
640 IF R<0.5 THEN 940
650 IF Q[1]=0 THEN 720
660 X=(-Q[2]*A[1,2]-Q[3]+C)/Q[1]
670 Y=A[1,2]
680 IF A[1,1] <= X AND A[3,1] >= X THEN 700
690 GOTO 720
700 W=INT(X)
710 PLOT X[W]+(X[W+1]-X[W])*(X-W),Y
720 IF Q[2]=0 THEN 790
730 Y=(-Q[1]*A[1,1]-Q[3]+C)/Q[2]
740 X=A[1,1]
750 IF A[1,2] <= Y AND A[2,2] >= Y THEN 770
760 GOTO 790
770 W=INT(X)
780 PLOT X[W]+(X[W+1]-X[W])*(X-W),Y
790 D[1,1]=1
800 D[1,2]=1
810 D[2,1]=Q[1]
820 D[2,2]=Q[2]
830 F[1]=A[3,1]+A[3,2]
840 F[2]=C-Q[3]
850 M=DET(D)
860 IF M=0 THEN 1230
870 MAT G=INV(D)
880 MAT H=G*F
890 IF H[1] <= A[3,1] AND H[1] >= A[2,1] THEN 910
900 GOTO 1230
910 W=INT(H[1])
920 PLOT X[W]+(X[W+1]-X[W])*(H[1]-W),H[2]
930 GOTO 1230
940 IF Q[1]=0 THEN 1010
950 X=(-Q[2]*A[1,2]-Q[3]+C)/Q[1]
960 Y=A[1,2]
970 IF A[1,1] <= X AND A[3,1] >= X THEN 990
980 GOTO 1010
990 W=INT(X)
1000 PLOT X[W]+(X[W+1]-X[W])*(X-W),Y
1010 IF Q[2]=0 THEN 1080
1020 Y=(-Q[1]*A[2,1]-Q[3]+C)/Q[2]
1030 X=A[2,1]
1040 IF A[2,2] <= Y AND A[3,2] >= Y THEN 1060
1050 GOTO 1080
1060 W=INT(X)
1070 PLOT X[W]+(X[W+1]-X[W])*(X-W),Y
1080 D[1,1]=1
1090 D[1,2]=1
1100 D[2,1]=Q[1]
1110 D[2,2]=Q[2]
1120 F[1]=A[2,1]+A[2,2]
1130 F[2]=C-Q[3]
1140 M=DET(D)
1150 IF M=0 THEN 1230
1160 MAT G=INV(D)
1170 MAT H=G*F
1180 IF H[1] >= A[1,1] AND H[1] <= A[illegible]
1190 GOTO 1230
1200 W=INT(H[1])
```

Table 8. Cont.

```
1210 PLOT X[W]+(X[W+1]-X[W])*(H[1]-W),H[2]
1220 GOTO 1230
1230 PEN
1240 NEXT E
1250 DISP "ANOTHER CONTOUR? 1-YES, 0-NO";
1260 INPUT C8
1270 IF C8>0.5 THEN 280
1280 END
```

will not quite go to these extremities because the pacer system starts sampling at 1/256 th of a blade pair and finishes sampling at 255/256th of a blade pair. Recall that the start of a blade pair need not coincide with a blade because of phase lags in the pacer system and the location of the timing disk relative to the rotor. Grid lines parallel to the Y-axis are the lines scanned by the Kulite transducers.

3. If other transducer locations are used their axial distance downstream of K6 must be entered before the program is run.
4. The variable plotted in the Y-direction is the column number in P. The variable plotted in the X-direction is the axial location of a transducer (downstream of K6) and is derived from the corresponding row number in P. When setting up the X-Y plotter it is advisable to make both the X and Y scales equal to twice full scale. Note that the circumferential distance along the wall across two blade passages is 3.847 inches.
5. Entering of the first and last element numbers enables faster plotting of a contour which is known in advance to cover only a limited part of the field.
6. Triangular element representation of the surface defining the pressure coefficient distribution, C_p (X,Y)

The surface $C_p = C_p$ (X,Y) is approximated by triangular elements as illustrated in figure 15. Element numbers E are as shown. This process represents linear interpolation between measured pressure coefficients. Contours are obtained from the intersection of planes C_p = constant with this approximation to the pressure distribution. Thus the contours are composed of straight line segments. The nodes correspond in the Y-direction (circumferential) to points at which pacer data is available. The node numbering, in the local sense, for typical odd and even numbered elements is shown in figure 15.

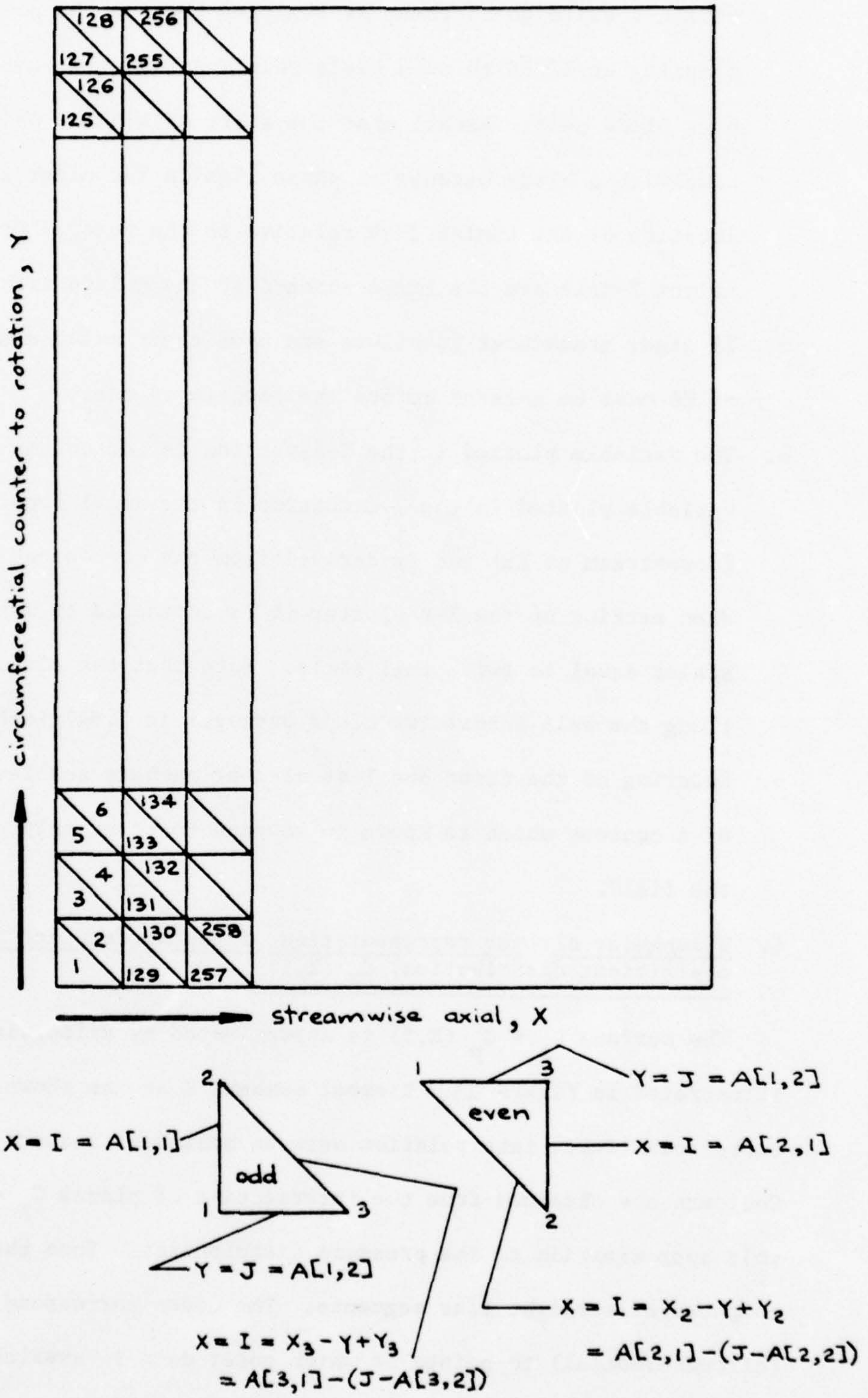

Figure 15 Numbering of triangular elements in CONT and CONT1. Also numbering of nodes (vertices of triangles) for odd and even numbered elements.

If Z = aX + bY + c is the plane containing the three nodes of a triangle then

$$\begin{bmatrix} Z(1) \\ Z(2) \\ Z(3) \end{bmatrix} = \begin{bmatrix} X1 & Y1 & 1 \\ X2 & Y2 & 1 \\ X3 & Y3 & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix}$$

where Z(I) is the pressure coefficient at local node number I (i.e. at XI, YI).

This matrix equation is written as

$$\underset{\sim}{Z} = A\underset{\sim}{a}$$

and hence

$$\underset{\sim}{Q} = A^{-1}\underset{\sim}{Z} = B\underset{\sim}{Z} \quad \text{say.}$$

<u>If E is odd</u>, the node coordinates are related to the element number as follows:

X1 = A[1, 1] = INT (((E + 1)/2 - .00001)/(J0 - 1)) + 1

Y1 = (E + 1)/2 - (A[1, 1] -1) * (J0 -1)

X2 = X1 , Y2 = Y1 + 1

X3 = X1 + 1 , Y3 = Y1

Note that the number .00001 is included to avoid problems associated with round-off error.

Z = aX + bY + c is plane containing triangle. For Z = c', line of intersection with triangle (i.e. contour) is given by aX + bY + (c -c') = 0.

On the side X = I = A[1, 1], (See Figure 15)

Y = (- aA[1, 1] - (c - c'))/b

= (- Q[1] * A[1, 1] - Q(3) + c')/Q(2)

provided Q(2) ≠ 0

If $Q(2) = 0$, the contour is parallel to the side in question. On the side $Y = J = A[1, 2]$

$$X = (-Q[2] * A[1, 2] - Q(3) + c')/Q(1)$$

$$\text{provided } Q(1) \neq 0$$

On the hypotenuse

$$X + Y = A[3, 1] + A[3, 2]$$

$$aX + bY = c' - c$$

Hence

$$\begin{bmatrix} 1 & 1 \\ a & b \end{bmatrix} \begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} A[3, 1] + A[3, 2] \\ c' - c \end{bmatrix}$$

This matrix equation is written as

$$D\underset{\sim}{H} = \underset{\sim}{F}$$

Hence $\underset{\sim}{H} = G\underset{\sim}{F}$ where $G = D^{-1}$

If E is even, the node coordinates are related to the element number as follows:

$$X1 = A[1, 1] = INT((E/2 - .00001)/(J0 - 1)) + 1$$

$$Y1 = A[1, 2] = E/2 - (A[1, 1] - 1) * (J0 - 1) + 1$$

$$X2 = X1 + 1 \quad , \quad Y2 = Y1 - 1$$

$$X3 = X1 + 1 \quad , \quad Y3 = Y1$$

$Z = aX + bY + c$ is plane containing the triangle. For $Z = c'$, line of intersection (i.e. contour) is given by $aX + bY + (c - c') = 0$.

On the side $X = I = A[2, 1]$,

$$Y = (- Q(1) * A[2, 1] - Q(3) + c')/Q(2)$$

$$\text{provided } Q(2) \neq 0$$

On the side $Y = J = A[1, 2]$

$$X = (- Q(2) * A[1, 2] - Q(3) + c')/Q(1)$$

$$\text{provided } Q(1) \neq 0 .$$

On the hypotenuse

$$X + Y = A[2, 1] + A[2, 2]$$

$$aX + bY = c' - c$$

Hence

$$\begin{bmatrix} 1 & 1 \\ a & b \end{bmatrix} \begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} A[2, 1] + A[2, 2] \\ c' - c \end{bmatrix}$$

This matrix equation is written as

$$\underset{\sim}{D}\underset{\sim}{H} = \underset{\sim}{F}$$

Hence $\underset{\sim}{H} = G\underset{\sim}{F}$ where $G = D^{-1}$

The intersections of the contour with the sides of the triangular elements are computed in the manner outlined above. Tests are performed to identify those points of intersection which lie on side of the triangle as opposed to intersections which lie on extrapolations of the sides.

APPENDIX H

DETAILS OF CONT

CONT is used to plot contours of constant casing wall pressure from an array of pressure coefficients in which both the axial and the circumferential spacings are uniform. It can be used to plot contours for an array output by MAP2. The program differs from CONT1 only in its plotting of x-coordinates of contours. A listing is in Table 9.

Notes on CONT

1. If MAP2 is used for interpolation, the file PRESS must be replaced by file INTER and P must have dimensions P[29, 32] . Contours must be plotted by processing the array of interpolated pressure coefficients in four sections. This requires shifting of origin on the x-y plotter for each quarter.
2. The variables plotted in the x and y directions are respectively the row number and column number of the sub-array of pressure coefficients.

Table 9. Listing of CONT

```
10 REM WALL PRESSURE MAP PROGRAM "CONT"  -SIMMONS-15 DECEMBER, 1976
15 UNIT 0
16 FILES INTER
20 REM #30 DIM P(I0,J0)
30 DIM P[25,32],A[3,3],B[3,3],Z[3],Q[3],D[3,3],F[2],G[2,2],H[2]
40 DISP "ENTER X AND Y DIMENSIONS";
50 INPUT I0,J0
60 SCALE 1,I0,0,J0
70 XAXIS 0,(I0-1)/10,1,I0
80 XAXIS J0,(I0-1)/10,1,I0
90 YAXIS 1,100,0,J0
100 YAXIS I0,100,0,J0
110 READ #1,1
120 MAT READ # 1;P
170 DISP "ENTER CONTOUR P=";
180 INPUT C
185 DISP "ENTER FIRST & LAST ELEMENT#";
186 INPUT E1,E2
190 FOR E=E1 TO 2*(I0-1)*(J0-1)
195 IF E>E2 THEN 1006
200 IF E>INT(E/2)*2 THEN 290
210 A[1,1]=INT((E/2-0.00001)/(J0-1))+1
220 A[1,2]=E/2-(A[1,1]-1)*(J0-1)+1
230 A[2,1]=A[1,1]+1
240 A[2,2]=A[1,2]-1
250 A[3,1]=A[1,1]+1
260 A[3,2]=A[1,2]
270 R=0
280 GOTO 360
290 A[1,1]=INT(((E+1)/2-0.00001)/(J0-1))+1
300 A[1,2]=(E+1)/2-(A[1,1]-1)*(J0-1)
310 A[2,1]=A[1,1]
320 A[2,2]=A[1,2]+1
330 A[3,1]=A[1,1]+1
340 A[3,2]=A[1,2]
350 R=1
360 A[1,3]=1
370 A[2,3]=1
380 A[3,3]=1
400 Z[1]=P[A[1,1],A[1,2]]
410 Z[2]=P[A[2,1],A[2,2]]
420 Z[3]=P[A[3,1],A[3,2]]
421 REM CHECK IF C IS IN E
422 IF Z[1] >= C AND C >= Z[2] THEN 429
423 IF Z[2] >= C AND C >= Z[1] THEN 429
424 IF Z[1] >= C AND C >= Z[3] THEN 429
425 IF Z[3] >= C AND C >= Z[1] THEN 429
428 GOTO 1000
429 MAT B=INV(A)
430 MAT Q=B*Z
440 IF R<0.5 THEN 570
445 IF Q[1]=0 THEN 500
450 X=(-Q[2]*A[1,2]-Q[3]+C)/Q[1]
460 Y=A[1,2]
470 IF A[1,1] <= X AND A[3,1] >= X THEN 490
480 GOTO 500
490 PLOT X,Y-1
500 IF Q[2]=0 THEN 570
```

Table 9. Cont.

```
505 Y=(-Q[1]+A[1,1]-Q[3]+C)/Q[2]
510 X=A[1,1]
520 IF A[1,2] <= Y AND A[2,2] >= Y THEN 540
530 GOTO 570
540 PLOT X,Y-1
570 D[1,1]=1
580 D[1,2]=1
590 D[2,1]=Q[1]
600 D[2,2]=Q[2]
610 F[1]=A[3,1]+A[3,2]
620 F[2]=C-Q[3]
625 M=DET(D)
626 IF M=0 THEN 1000
630 MAT G=INV(D)
640 MAT H=G*F
645 IF H[1] <= A[3,1] AND H[1] >= A[2,1] THEN 650
646 GOTO 1000
650 PLOT H[1],H[2]-1
660 GOTO 1000
670 IF Q[1]=0 THEN 750
690 X=(-Q[2]*A[1,2]-Q[3]+C)/Q[1]
700 Y=A[1,2]
710 IF A[1,1] <= X AND A[3,1] >= X THEN 730
720 GOTO 750
730 PLOT X,Y-1
750 IF Q[2]=0 THEN 830
760 Y=(-Q[1]*A[2,1]-Q[3]+C)/Q[2]
770 X=A[2,1]
780 IF A[2,2] <= Y AND A[3,2] >= Y THEN 800
790 GOTO 830
800 PLOT X,Y-1
830 D[1,1]=1
840 D[1,2]=1
850 D[2,1]=Q[1]
860 D[2,2]=Q[2]
870 F[1]=A[2,1]+A[2,2]
880 F[2]=C-Q[3]
885 M=DET(D)
886 IF M=0 THEN 1000
890 MAT G=INV(D)
900 MAT H=G*F
905 IF H[1] >= A[1,1] AND H[1] <= A[2,1] THEN 910
906 GOTO 1000
910 PLOT H[1],H[2]-1
920 GOTO 1000
1000 PEN
1005 NEXT E
1006 DISP "ANOTHER CONTOUR? 1-YES, 0-NO"
1007 INPUT C8
1008 IF C8>0.5 THEN 170
1010 END
```

APPENDIX I

DETAILS OF PLOTS A AND PLOTS B

PLOTS A and PLOTS B are used to plot pacer raw data and free-run raw data respectively against circumferential distance. The programs are listed in Tables 10 and 11. Note that PLOTS A, with I = 1 in line 110, plots the output of the designated Kulite transducer. If I = 4 the raw one per blade signal on A/D converter channel number 0 is plotted.

Table 10. Listing of PLOTSA

```
10 REM-----*****PLOTSA*****-----R.P.SHREEVE----29/12/76
20 UNIT 0
30 FILES RECY#,DATAY1
40 DIM DS[5,128]
50 DISP "ENTER REC#";
60 INPUT N
70 READ #2,N
80 MAT READ # 2;D
90 SCALE 0,300,-1.5,1.5
100 DISP "DRAW AXES?  1=YES  0=NO";
110 INPUT N0
120 IF N0=0 THEN 150
130 XAXIS 0,50,0,300
140 YAXIS 0,0.5,-1.5,1.5
150 I=1
160 FOR J=1 TO 128
170 PLOT 2*J,D[I,J]
180 NEXT J
190 PEN
200 END
```

Table 11. Listing of PLOTSB

```
5 REM  "PLOTSB"-SIMMONS---28 JANUARY  1977
10 UNIT 0
20 FILES RECY#,DATAY1
30 DIM D[16,102]
40 DISP "ENTER REC#";
50 INPUT N
60 READ #2,N
70 MAT READ # 2;D
80 SCALE 0,1700,-1.5,1.5
81 DISP "DRAW AXES?  1=YES  0=NO";
82 INPUT N0
83 IF N0=0 THEN 110
90 XAXIS 0,100,0,1700
100 YAXIS 0,0.5,-1.5,1.5
110 FOR I=1 TO 16
120 FOR J=1 TO 101
130 PLOT (I-1)*101+J,D[I,J]
140 NEXT J
150 NEXT I
155 PEN
160 END
```

APPENDIX J

DETAILS OF TITIPK

TITIPK is used to superimpose blade tip profiles on wall pressure contours. The program is loaded onto the programmable keys of the HP9830A. The program is listed in Table 12. The blade tip profile is tabulated by PAIGE (1976), figure 2 and table 1). The axial and circumferential units are inches and the program is compatible with a wall pressure map which has dimensions of 3 inches axially by 3.847 inches circumferentially. The "lower left" and "upper right" on the plotter should be set to the corresponding points on the wall pressure map.

The key programs should be "continued" after CONT1 has been run so that the Kulite data is available in main memory. When <CONT> <f_1> is issued, the location (YO) of the blade leading edge from the lower boundary of the wall maps is calculated from the data of transducer K9 and appears in the display. <CONT> <f_0> is then issued and YO is requested as an input. The blade profiles are then drawn and the key program ends. The contour plotting with CONT1 can be continued by issuing <CONT> 1250.

Table 12. Listing of T1T1PK

```
10 REM-----*****T1T1PK*****-----R.P.SHREEVE-----8/6/77
20 REM-----KEY PROGRAM TO PLOT BLADE PROFILE ON WALL PRESSURE MAPS-
30 N1=0
40 SCALE 0,3,0,3.847
50 DATA 2.688,16.23,0.005,59.8264,1.37
60 READ C0,R0,R1,G1,X0
70 DISP "ENTER Y0";
80 INPUT Y9
90 Y0=Y9
100 DEG
110 A1=(C0/2-R1)/(R0-R1)
120 A1=ATN(A1/SQR(1-A1↑2))
130 D1=A1+G1-90
140 X3=0
150 Y3=R1
160 X4=X3+(C0-2*R1)*COSG1
170 Y4=Y3+(C0-2*R1)*SING1
180 X5=X3+(R0-R1)*COSD1
190 Y5=Y3+(R0-R1)*SIND1
200 REM-----PROFILE TIP(AB)-----
210 T2=-G1
220 T3=90-D1
230 T4=(T3-T2)/20
240 FOR T1=T2 TO T3 STEP T4
250 X=X3-R1*SINT1
260 Y=Y3-R1*COST1
270 IF Y+Y0>3.847 THEN 310
280 IF Y+Y0<0 THEN 310
290 PLOT X+X0,Y+Y0
300 GOTO 320
310 PEN
320 NEXT T1
330 REM-----SUCTION SIDE(BC)-----
340 T2=-D1
350 T3=2*A1-D1
360 T4=(T3-T2)/200
370 FOR T1=T2 TO T3 STEP T4
380 X=X5-R0*COST1
390 Y=Y5+R0*SINT1
400 IF Y+Y0>3.847 THEN 440
410 IF Y+Y0<0 THEN 440
420 PLOT X+X0,Y+Y0
430 GOTO 450
440 PEN
450 NEXT T1
460 REM-----PROFILE T.E.(CD)-----
470 T2=-G1+A1
480 T3=180-G1
490 T4=(T3-T2)/20
500 FOR T1=T2 TO T3 STEP T4
510 X=X4+R1*SINT1
520 Y=Y4+R1*COST1
530 IF Y+Y0>3.847 THEN 570
540 IF Y+Y0<0 THEN 570
550 PLOT X+X0,Y+Y0
560 GOTO 580
570 PEN
580 NEXT T1
590 X1=X
600 Y1=Y
```

Table 12. Cont.

```
610 REM-----PRESSURE SIDE(DA)-----
620 X2=X3+R1*SIN(G)
630 Y2=Y3-R1*COS(G)
640 FOR I=1 TO 201
650 X=X1-(I-1)*(X1-X2)/200
660 Y=Y2+(X-X2)*(Y1-Y2)/(X1-X2)
670 IF Y+Y0>3.847 THEN 710
680 IF Y+Y0<0 THEN 710
690 PLOT X+X0,Y+Y0
700 GOTO 720
710 PEN
720 NEXT I
730 PEN
740 IF N1>1.5 THEN 780
750 N1=N1+1
760 Y0=Y9+1.9235*(3-2*N1)
770 GOTO 200
780 END
```

```
10 REM-----ROUTINE TO FIND BLADE LEADING EDGE FOR TITIPK--ON KEY F1
30 W=3.847
40 FOR I=1 TO 128
50 IF P[4,I]<0 THEN 80
60 V1=P[4,I]
70 GOTO 140
80 IF I=1 THEN 140
90 IF V1<0 THEN 140
100 V2=P[4,I]
110 Y0=W*(I-1.5+V1/(V1-V2))/128
120 DISP "Y0=";Y0
130 STOP
140 NEXT I
150 END
```

APPENDIX K

OPERATING PROCEDURE FOR DATA ACQUISITION SYSTEM

1. Load Real Time Executive Basic into HP21MX computer.
2. Load KULITE into HP21MX. Tune pacer.
3. Put disk labeled "Transonic Compressor - Paige" into HP9867B mass memory.
4. At start of a run, get RESET1 from unit 0 and run RESET1 to initialize the number in file RECY# to unity.
5. Scratch RESET1.
6. Get TRAN4 from unit 0.
7. Run TRAN4. The HP9830A display will remain blank while the HP9830A awaits data from the HP21MX.
8. Run KULITE, noting that the two mode switches on the Pacer must be set according to the A/D converter mode to be used (i.e. 0 or 4). In calibration, four scans of the twelve channels must be made. The first scan must be with the pressure at S2 on the reference side of the Kulite transducers. The second and third scans are made with other steady calibration pressures on the reference side. The fourth scans must be made but any signals can be used on the A/D converter provided that they do not cause overloads. In mode 0 the pacer must not be altered during an experiment.
9. On completion of an experiment both the HP9830A and the HP21MX must be reset as instructed by their displays prior to performing another experiment.
10. On completion of a run the data which is stored temporarily in DATAY1 file must be transferred to permanent files CKRWm duplicated on both unit 0 and unit 1. First open CRKWm where m is the run number. The

length of CKRWm must be set at k records where

k = record number for last experiment + g

and g = 1 if last experiment is a calibration

5 if last experiment is a pacer experiment

13 if last experiment is a free-run experiment

11. To abort the HP21MX program, enter AB.

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