WL-TR-91-2003

AD-A242 760

KPLOT - A COMPUTER PROGRAM FOR CONTOUR PLOTTING HIGH FREQUENCY STATIC PRESSURE EXPERIMENTAL DATA

Steven L. Puterbaugh

Technology Branch
Turbine Engine Division

July 1990

91-16120

INTERIM REPORT FOR PERIOD 1 NOV 1988 - 1 MAY 1990

Approved for Public Release; Distribution Unlimited

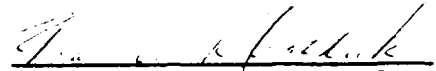## NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.
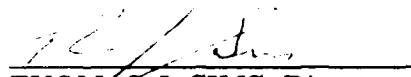
This report is relasale to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

MARVIN A. STIBICH, TAM
Compressor Research Group
Technology Branch

FRANCIS R. OSTDIEK, Chief
Technology Branch
Turbine Engine Division

FOR THE COMMANDER

THOMAS J. SIMS, Director
Turbine Engine Division
Aero Propulsion and Power Directorate

If your mailing address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify WRDC/POTX, Wright-Patterson AFB, OH 45433-6563 to help maintain a current mailing list.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for Public Release; Distribution Unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	

4. PERFORMING ORGANIZATION REPORT NUMBER(S) WL-TR-91-2003	5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION Aero Propulsion and Power Directorate	6b. OFFICE SYMBOL (If applicable) WL/POTX	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) WPAFB, OH, 45433-6563		7b. ADDRESS (City, State, and ZIP Code)

8a. NAME OF FUNDING/SPONSORING ORGANIZATION	8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO	WORK UNIT ACCESSION NO.
61102F	2307	S1	27

11. TITLE (Include Security Classification)
KPLOT - A Computer Program for Contour Plotting High Frequency Static Pressure Experimental Data

12. PERSONAL AUTHOR(S)
S.L. Puterbaugh

13a. TYPE OF REPORT Interim	13b. TIME COVERED FROM 1 Nov 88 TO 1 May 90	14. DATE OF REPORT (Year, Month, Day) 1990 June	15. PAGE COUNT 25

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Axial Compressor
	01	01	Gas Turbine
	01	03	Aircraft Turbine Engine

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A description of and a user's manual for a computer program which will contour plot the output of high frequency response pressure transducers is presented.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Steven L. Puterbaugh	22b. TELEPHONE (Include Area Code) (513) 255-4738	22c. OFFICE SYMBOL WL/POTX
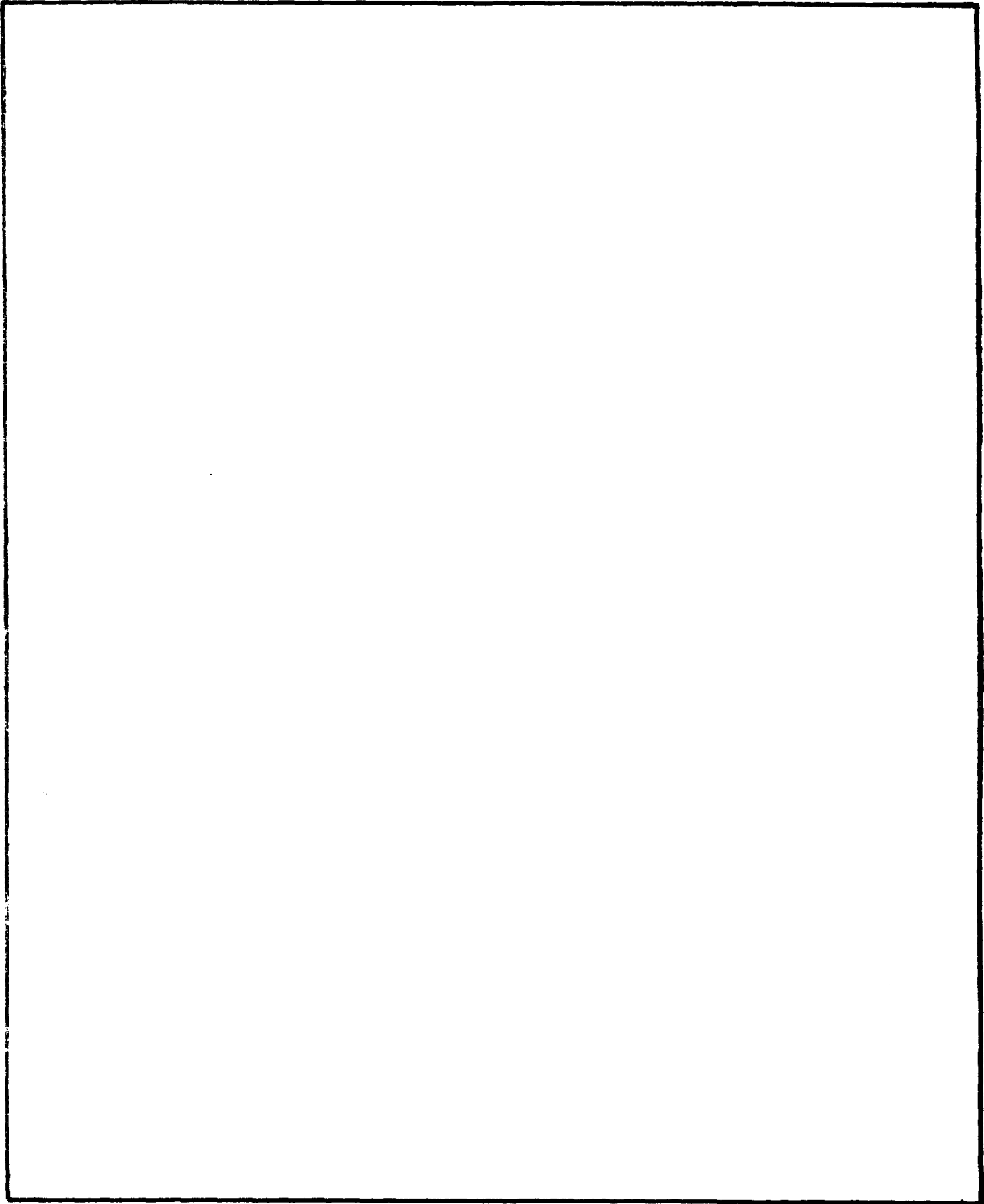
DD Form 1473, JUN 86　　　Previous editions are obsolete.

PREFACE

This interim report was prepared by Steven L. Puterbaugh of the Technology Branch, Turbine Engine Division, Aero Propulsion and Power Directorate, Wright Laboratory, Wright-Patterson AFB, Ohio. The work was accomplished between 1 November 1988 and 1 May 1990.

The report represents results from a portion of the effort of the Compressor Research Group, supervised by Dr. Arthur J. Wennerstrom, and was conducted under Work Unit 27, Task S1, of Project 2307, "Turbomachinery Fluid Mechanics."

This report describes a FORTRAN computer program developed to create a contour plot of experimentally determined static pressure distributions existing over the blade tips of a transonic compressor rotor. The input data used by the program was the digitized, ensemble averaged output of casing mounted high frequency response pressure transducers. The resulting plots give the compressor designer important information regarding shock position and strength and wave pattern.

iii

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

SECTION I

INTRODUCTION

This report describes a FORTRAN program, 'KPLOT,' which takes experimentally determined static pressure distributions existing over transonic compressor rotor blade tips as input and creates one of several plots as output. The plot options include static pressure versus time (single channel or multiple channel) or a contour plot. The measurements are made by high frequency response pressure transducers mounted in the case at several axial locations over the rotor tip. The transducers are manufactured by Kulite Corporation and therefore will be called simply 'kulites.'

The source code was written in FORTRAN 77 and developed on a DEC MicroVAX III. The program was also run on a Zenith Z-248 (AT compatible) personal computer with minor modifications. An in-house developed graphics routine library, 'Cgraph' (Reference 1), was used to create the graphics output. Cgraph supports several different output devices, but KPLOT has only been demonstrated using a DEC LN03/PLUS laser printer.

SECTION II

BACKGROUND

.

Since the invention of the gas turbine engine, it has been the objective of the designer to increase the thrust of the engine relative to its weight. One of the avenues toward this end was to increase the pressure rise capability of compressor stages by increasing the rotor tip speed. Rotors were soon designed with sufficiently high tip speed such that the speed of the blade tip relative to the incoming air flow was supersonic. A shock therefore exists in the flow and its position and strength significantly affect the performance of the compressor stage.

A method of experimentally determining this information (at the tip only) is to mount kulites in the casing over the rotor tip at various axial locations, record their output, and process and plot the results. Figure 1 illustrates a typical kulite installation ('unwrapped' tip section, looking inward). The resulting contour plot of static pressure, superimposed over the blade tips, indicates the upstream wave pattern and the position and strength of the passage shock. An example of such a plot is shown in Figure 2.

The instrumentation used for tip mounted static pressure data acquisition by the Compressor Research Group includes Kulite high frequency response pressure transducers, Neff Model 124A wide band signal amplifiers, a Bell & Howell Model VR3400A analog tape deck, a Datachron Model 3470 tape search unit, a Datachron Model 3070 translator/generator, and a custom pulse generator box. In addition to the above hardware, a Honeywell Model SAI-48 signal averager and correlator is used for data processing. The data acquisition and processing steps are controlled by a MODCOMP Classic II/15 16 bit

microcomputer. A block diagram of the kulite data system is shown in Figure 3.

The kulite transducer output is recorded simultaneously with a data point which includes typical pressure and temperature data. The test data can then be used to define the operating point and provide required transducer calibration information. Sixty seconds of kulite data is recorded.

Data processing centers around the Honeywell signal averager. The averager samples the input signal, representing it digitally as 400 discrete values, after receiving an external trigger pulse. The time resolution used (time step occupied by each of the 400 values) is typically 1 micro second. This provides data sufficient to plot the pressure over a little more than 2 blade passages for tip speeds in the 1250 to 1500 ft/sec range. The trigger pulse is a one-per-blade pulse synchronized with a one-per-rev signal. The kulite signal is typically averaged over 4096 samples to give the final waveform. Since kulites are usually installed in a 'staggered' configuration in the rotor case, the timing of the trigger pulse is modified to effectively 'move' the kulites into a single axial row to obtain the proper interrelationship. This is done by delaying the trigger pulse for a specific length of time, the hardware has a maximum 1 microsecond resolution, as determined by kulite position and test article speed, by a special circuit before being sent to the averager. This procedure is automated through in-house developed software and is executed once for each kulite channel.

The output of the above procedure is an ASCII data file containing the discrete values for each of the 400 time steps for each channel. The format of this file is described in Section V. The program described in this report then uses these data along with geometry information to create static pressure versus time plots (Figure 4) and/or static pressure contour plots (Figure 2).

SECTION III

METHOD

KPLOT is designed to be flexible and easy to use. The user interactively selects plots to be output through a menu driven interface. Three different plots are available, a single trace plot, a multi-trace plot, and a contour plot.

The input files are structured to minimize the amount of preparation required for each data point by using a modular approach. Four different input files are required. They are a plot definition file, a blade data file, a file containing kulite digitized data, and a file containing static pressure data. The plot definition file provides plot parameters, instrumentation configuration information, and other miscellaneous information. The blade data file contains the coordinates of the tip streamsurface section of the blade. The kulite data file contains the output of the data reduction procedure described in Section II, this is the digitized transducer output. The static pressure data file contains the pressure value measured at the static ports associated with each kulite transducer (located in the same axial plane, Figure 1). These data are used to calibrate the signal. For a given test program, only the kulite and static pressure data will change from point to point, therefore only these files need to be updated. The format of each file is described in Section V.

One of the main functions of KPLOT is to calibrate the kulite signal. This is required when the transducer's reference side is exposed to a pressure other than local 'averaged,' or steady state, pressure (as is often the case). Simply stated, the procedure occurs in two steps. During step 1, the raw signal is 'scaled' to the proper amplitude and then 'offset' to the proper level in the second. A detailed description of the calibration process is now given.

4

The first step is to convert the electrical signal to a psi value about some 'zero psi' value which corresponds to zero volts. This is done by multiplying each discrete value of a given channel's output by its associated calibration factor (psi/volt). This value is determined experimentally during transducer installation and represents the sensitivity of the entire channel (transducer, signal conditioner, amplifier) to pressure. The calibration is completed by integrating the resulting waveform over one period and finding the diffc ance between the integration result and the associated 'steady-state' static pressure. This delta is then added to each discrete value of the waveform to give the final calibrated signal. The calibration process is illustrated in Figure 5. This procedure has been developed based on the assumption that the mathematically integrated (or averaged) static pressure is equivalent to the 'pneumatically averaged' value read by the steady-state instrumentation.

The contour plot is created in a 2-dimensional space domain, the y axis coincident with the axial direction of the rotor and the x axis coincident with the 'unwrapped' circumferential direction. Since the kulite signals are recorded in time, they must be transformed from the time domain to space domain using tip radius and tip speed.

KPLOT assumes that the casing radius is unchanging in the axial extent enclosed by the first and last kulites, i.e., the area of interest. This is typical for test articles designed by the Compressor Research Group. This assumption simplifies 'unwrapping' the tip section into 2-d space since it is simply a cylinder. A similar procedure for a casing whose radius varies with axial coordinate would require a transformation which would inevitably result in a distorted contour plot. Thi enhancement is left to the interested party.

An in-house developed graphics library, 'Cgraph' (Ref 1), was used to create KPLOT. The contour plotting routines are internal to Cgraph, having been adapted from procedure CONTOUR2 by B.R. Heap, et al. (Ref 2).

SECTION IV

PROGRAM AND SUBROUTINE DESCRIPTION

A modular software design approach was used to write KPLOT. Ten routines including the main routine were written each dedicated to a particular function as much as practical. Figure 6 illustrates the subroutine structure. The following paragraphs described each routine beginning with the main routine, KPLOT.

PROGRAM KPLOT: This routine controls the execution of the overall program. All computations, user I/O, and file system I/O occur in other routines. Execution begins by calling the routine which handles data input, DATAIO. Next the blade shapes are scaled as required for plotting purposes by BLSCAL and the signals are calibrated by CAL. Finally interaction with the user and plot creation occurs in USERIO before execution is terminated.

SUBROUTINE BLADES: This routine plots several consecutive blades, blanking out the portion(s) of the blades which extend outside of the subplot area.

The blade tip sensor indicates blade position and, therefore, implicitly indicates the blade-to-blade passage position. It is assumed that the data has been synchronized by the data reduction process such that the blade passage, as indicated by the tip sensor, is centered within the time window (the period of time analyzed during data reduction). If the blade tip sensor was installed over the rotor approximately centered between leading and trailing edges, then a blade passage will be centered on the plot. This configuration usually provides the most informative and appealing format.

The tip blade surface is represented by a set of coordinates specified relative to its stacking axis. Consecutive blades are plotted by computing their coordinates as an offset

6

relative to the original, or 'master' blade.

The first step for BLADES is to determine the coordinate on the blade surface which passes under the tip sensor. The master blade is then offset so that the center of the blade-to-blade position as indicated by the tip sensor will lie at the center of the plot.

BLADES then begins to plot 10 consecutive blades, from left to right. Logic has been developed so that only the portions of the blades which lie on the subplot area are plotted. The process begins by computing the x coordinate of the offset blade. Each coordinate is then checked to see if it lies within the subplot area or the vector connecting it with the previous coordinate has just crossed the subplot boundary. If the coordinate or vector lies within the boundary, then plotting occurs.

SUBROUTINE BLSCAL:

This routine scales the blade and references the blade surface coordinates and kulite axial coordinates to the same coordinate system. Execution begins by computing the scale factor whose application causes the blade to extend from kulite 'kle' to 'kte' (see Figure 1). Each blade surface coordinate is then multiplied by the scale factor. Finally, the axial blade surface coordinates and axial kulite positions are translated so that the origin lies at the blade trailing edge.

SUBROUTINE CAL:

This routine converts the digitized wave form from raw units (volts) to engineering units (psia). The program currently allows the input of only one value of sensitivity (PSI/volt) for all channels, which results from the way the Compressor Research Group has historically calibrated kulites. Clearly, the program could be easily modified to accept values for each channel or even separate values for above and below reference pressure for a single transducer.

7

Execution begins by multiplying each raw value by the gain value to convert from voltage to a 'quasi' psi value where zero psi corresponds to zero volts. The next step is to compute the 'offset' required to add to the values which will move the wave form to the proper 'DC level.' The number of time bins which constitute a period are first computed. Then the psi-time function is numerically integrated over the period by summing each value. The average 'quasi' pressure is then found by dividing the integrated value by the number of time bins. Since the actual average static pressure is known, the difference between the actual and 'quasi' average values is the offset required. The offset is then added to each of the 400 values to finally produce the calibrated wave form.

SUBROUTINE CPLOT:

This routine controls the contour plotting function. A contour plot of static pressure is superimposed over several consecutive rotor blade tip sections. Execution begins by initializing plotting by calling PLINIT. Next the one-dimensional array (ff) is repacked with the two-dimensional array (vcal) such that only every 8th point in the circumferential direction will be plotted. This improves the speed and appearance of the plot. The function max and min is then determined and used to autoscale the contour levels. Finally, the contour is plotted by calling subroutine CONTUR (contained in the Cgraph graphics package).

SUBROUTINE DATAIO:

This routine controls the data input step. The data file names are all specified by the user. All input data are loaded into common memory for use by other routines. Four different files are accessed, a plot definition file, a blade data file, a kulite data file, and a static pressure data file. In each case the user is prompted for the file name, the specified

8

file is then opened, the data are read, and then the file is closed. After the files have been read, DATAIO computes the tip radius (the tip is assumed cylindrical), the rotor tip speed, and the 'circumferential coordinates' associated with each time bin.

SUBROUTINE MTRACE:

This routine controls the creation of the multi-trace plot. This plot shows each kulite channel's signal centered relative to its axial location, superimposed upon the rotor tip blade sections. Execution begins by initializing the plot by calling PLINIT. Next a scale factor is determined so that the largest peak-to-peak variation will be maximized yet lie within the allowable plotting envelope. This is done by first determining the global maximum peak-to-peak variation. Next each kulite position is checked for the smallest plotting envelope. The scale factor is then computed by dividing the minimum plotting envelope size by the maximum peak-to-peak variation and multiplying this value by 2.0. Next each channel's signal is converted to this 'plotting domain' by computing a new zero and amplitude. This converted signal is then plotted by calling subroutine CURVE (Cgraph graphics package).

SUBROUTINE PLINIT:

This routine initializes the plotting function for each of the 3 types of plots. The argument (iplot) indicates which plot initialization is required, a 1 indicates a single trace plot, a 2 indicates a multiple trace plot, and a 3 indicates a contour plot. If (iplot) is 1, then the argument (nk) indicates which kulite channel is to be plotted. All subroutine calls from within this routine are made to Cgraph graphics package subroutines.

Execution begins by calling PLTRDY to initialize the output plotting device. Control then branches to the required plot initialization sequence.

If single trace initialization is requested, then the subplot area is set to 70% page size in the x direction and 57.1% page size in the y direction. The page sizes were previously

9

defined by an input file. Subroutine PAGE is then called to set page geometry. Next the y axis limits and scale factors are determined. The y values are searched for max's and min's to be used in AUTOSC. The scale factors are then set by SCALE and the y axis is drawn by YLABL. Finally, the channel header is printed at the lower left hand corner of the plot.

If multiple trace or contour initialization is requested, then the x axis and y axis limits and scale factors are computed. The subplot area is then determined as a function of the ratio of the axial kulite location extent and the circumferential time extent. If a contour plot is requested, then a title containing header information is printed. Subroutine BLADES is then called to create the rotor blade tips and dashed line parameters are set for subsequent contour plotting.

Finally, if contour plotting was not requested, the data point identification number is plotted in the lower right hand corner of the page.

SUBROUTINE STRACE:

This routines controls the creation of the single trace plot. Execution begins by requesting which channels are required from the user. The user may select a single plot or plots for each channel. If a single plot was requested, the user is prompted for the channel number. Each plot is then created by first calling PLINIT to initialize the plot and then CURVE (Cgraph graphics package) to plot the data.

SUBROUTINE USERIO:

This routine provides the interface for the user to control which plots are to be created. Three types of plots are available, single trace, multiple trace, or contour plots. Execution begins by creating the selection menu. The selection is then interpreted by a 'computed go to', calling subroutines STRACE, MTRACE, or CPLOT as appropriate.

SECTION V

USER'S MANUAL

1. OVERVIEW

KPLOT is a simple program to use, requiring 4 fairly small input files and a minimal of user interaction. The input file formats are discussed in Subsection 3. The user interaction occurs during program execution and is menu driven.

Three different types of plot are available: a single trace plot, a multiple trace plot, and a contour plot (see Figures 2 and 4). The single trace plot shows a single transducer calibrated output as a function of time. This plot can be used to study a single channel in some detail. The multiple trace output shows all transducer signals on the same plot. Each transducer's output signal is plotted on the page such that the relative amplitude and timing can be examined. The blade tip sections are also plotted. This plot can be used to troubleshoot problems with the synchronizing circuit or data input. The contour plot shows labeled static pressure contours superimposed over blade tip sections.

2. PLOT OPTIONS

The three types of plots described above are selected interactively from a menu during program execution. If a single trace plot is requested, KPLOT then requests which channels are to be plotted (all plots is an option). If one of the other two options is selected the plot is created without further user interaction. The only other plotting related control available to the user is page size specification in the plot definition file (Subsection 3.)

3. INPUT FILE FORMAT

Four different input files are required: a plot definition file, a blade data file, a kulite

data file, and a static pressure data file. Each file's format is discussed below in terms of
FORTRAN formatted I/O convention. Each record within a file is given followed by its
FORTRAN format. At the end of each file's section, the definition of each variable is given.
Note that array values are indicated by FORTRAN array convention with the maximum
value of the array enclosed in parentheses.

PLOT DEFINITION FILE

SAMPLE
FORMAT(F12.6)

XPAGE   YPAGE
FORMAT(2F12.6)

NPT   NBLADS
FORMAT(2I3)

AXBNTL
FORMAT(F12.6)

NKUL   KLE   KTE
FORMAT(3I3)

AXKPOS(NKUL)
FORMAT(6F12.6) (Repeated nkul times)

XMBOFF
FORMAT(F12.6)

SAMPLE:	Sample time increment in seconds. The time between each discrete value representing the waveform. Typically 1 micro second.
XPAGE:	Page size in the x direction in inches.
YPAGE:	Page size in the y direction in inches.
NPT:	Number of coordinates describing each side (pressure and suction) of the rotor tip section.
NBLADS:	Number of blades in the blade row.
AXBNTL:	Axial position of the blade tip sensor in inches. (Same coordinate system as kulite locations).
NKUL:	Number of kulites.
KLE:	Kulite number (ID) located at the rotor leading edge.
KTE:	Kulite number (ID) located at the rotor trailing edge.
AXKPOS:	Axial positions of the kulite transducers.
XMBOFF:	Arbitrary blade position 'adjustment' in inches. Used to compensate for blade position signal lag.

BLADE DATA FILE

ZP(NPT)   XP(NPT)   YP(NPT)   ZS(NPT)   XS(NPT)   YS(NPT)
FORMAT(6F12.6) (Repeated npt times)

ZP: Z coordinate (typically coincident with the stack axis) of a point on the pressure surface of the airfoil.

XP: X coordinate (coincident with the machine axis) of a point on the pressure surface of the airfoil.

YP: Y coordinate (perpendicular to both x and z) of a point on the pressure surface of the airfoil.

ZS: Z coordinate (typically coincident with the stack axis) of a point on the suction surface of the airfoil.

XS: X coordinate (coincident with the machine axis) of a point on the pressure surface of the airfoil.

YS: Y coordinate (perpendicular to both x and z) of a point on the suction surface of the airfoil.

KULITE DATA FILE

HEADER(NKUL)   RPM   XBPASS
FORMAT(A17,25X,F7.1,8X,F6.2)

ID
FORMAT(10X,A18)

VOLT(400,NKUL)
FORMAT(10F8.5) (Repeated 40 times)

Note: the above 42 record set occurs nkul times.

HEADER: Channel number header.
RPM: Rotor rotational speed in rpm.
XBPASS: Number of blade passages covered by the data.
ID: Test point ID.
VOLT: Raw data (volts) representing the digitized waveform.

STATIC PRESSURE FILE

GAIN
FORMAT(F12.6)

PS(NKUL)
FORMAT(F12.6) (Repeated nkul times)

GAIN: Psi/volt conversion factor.
PS: Static pressure (psia) measured at a tap located at an axial plane corresponding to each kulite transducer.

13

SECTION VI

CONCLUSIONS

An effective, simple-to-use computer program, KPLOT, has been developed which can create graphical output illustrating static pressure distributions measured over axial compressor rotor tips. Required user input includes 4 input files, one of which is generated in total by a separate hardware/software data reduction system, and minimal interaction. The output is useful to the designer by indicating shock position and strength as it exists in a transonic compressor rotor.
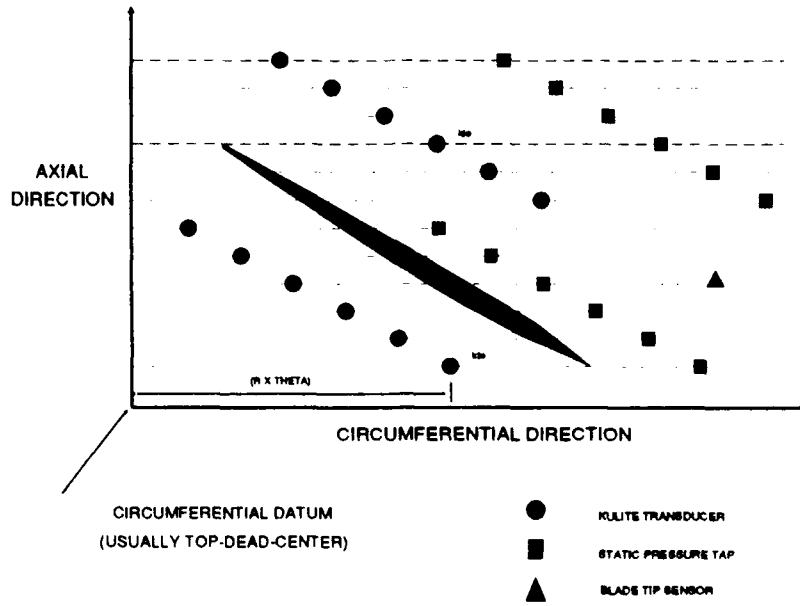
Figure 1. Typical KULITE Installation
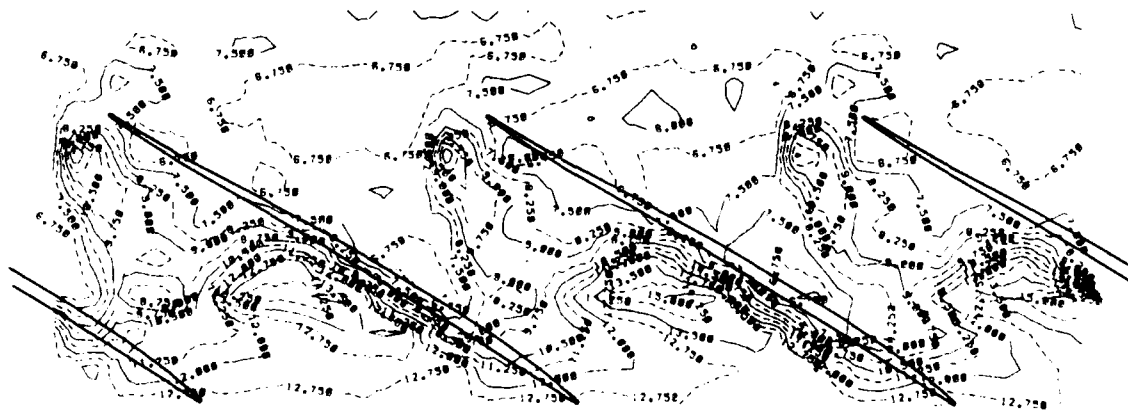
STATIC PRESSURE CONTOURS (PBS890419001000100)
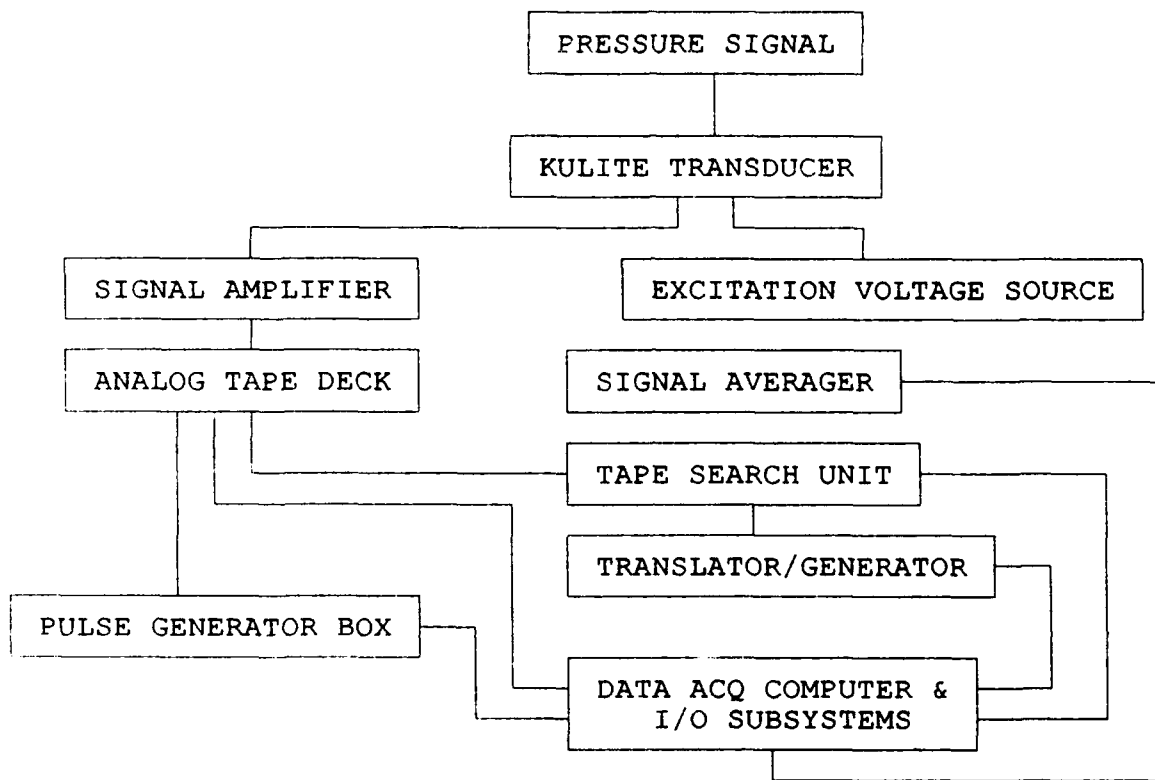

Figure 2. Example Contour Plot

15

```
            ┌─────────────────────┐
            │   PRESSURE SIGNAL   │
            └─────────────────────┘
                       │
            ┌─────────────────────┐
            │  KULITE TRANSDUCER  │
            └─────────────────────┘
             │                  │
┌───────────────────┐    ┌────────────────────────────┐
│  SIGNAL AMPLIFIER │    │  EXCITATION VOLTAGE SOURCE │
└───────────────────┘    └────────────────────────────┘
┌───────────────────┐    ┌────────────────────────────┐
│ ANALOG TAPE DECK  │    │     SIGNAL AVERAGER        │
└───────────────────┘    └────────────────────────────┘
                         ┌────────────────────────────┐
                         │     TAPE SEARCH UNIT       │
                         └────────────────────────────┘
                         ┌────────────────────────────┐
                         │   TRANSLATOR/GENERATOR     │
                         └────────────────────────────┘
┌────────────────────────┐  ┌──────────────────────────┐
│  PULSE GENERATOR BOX   │  │   DATA ACQ COMPUTER &    │
└────────────────────────┘  │     I/O SUBSYSTEMS       │
                            └──────────────────────────┘
```
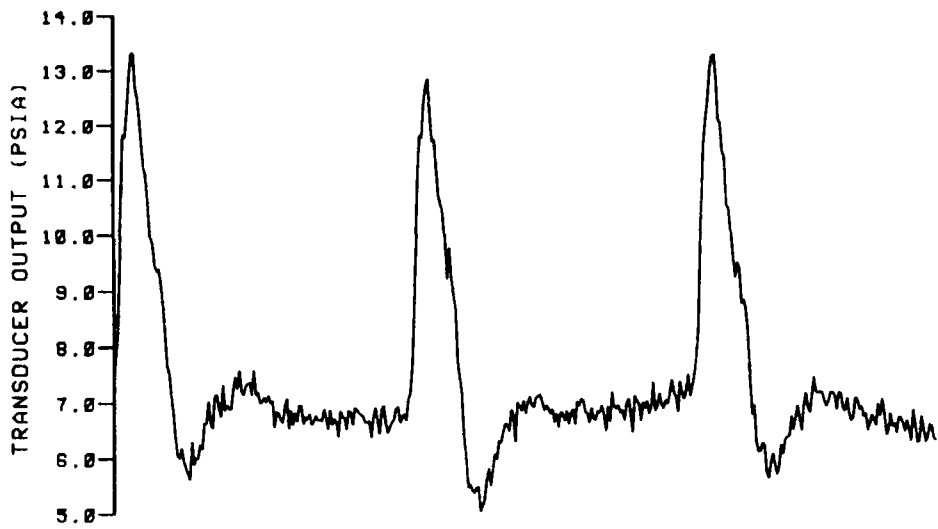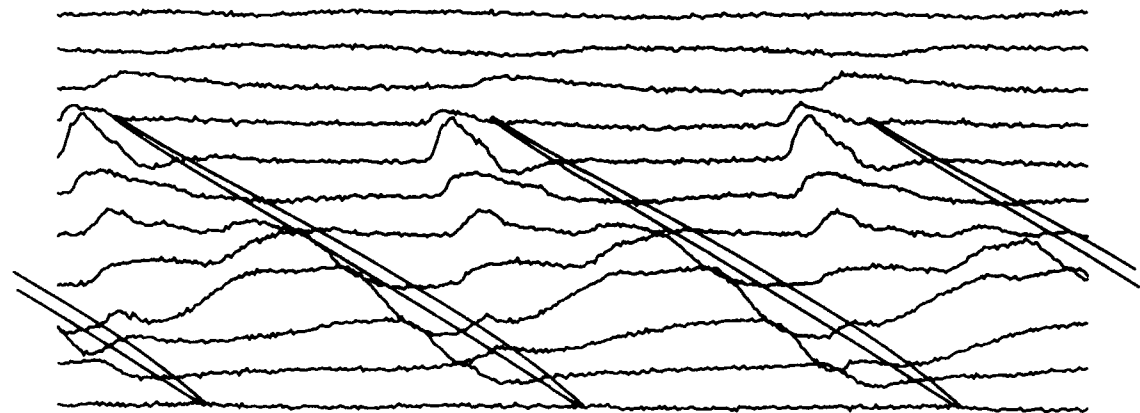
Figure 3. KULITE Instrumentation System Block Diagram

16

KULITE CHANNEL 5

Single Transducer Output

Synchronized Multi-Transducer Output w/ Overlayed Blading

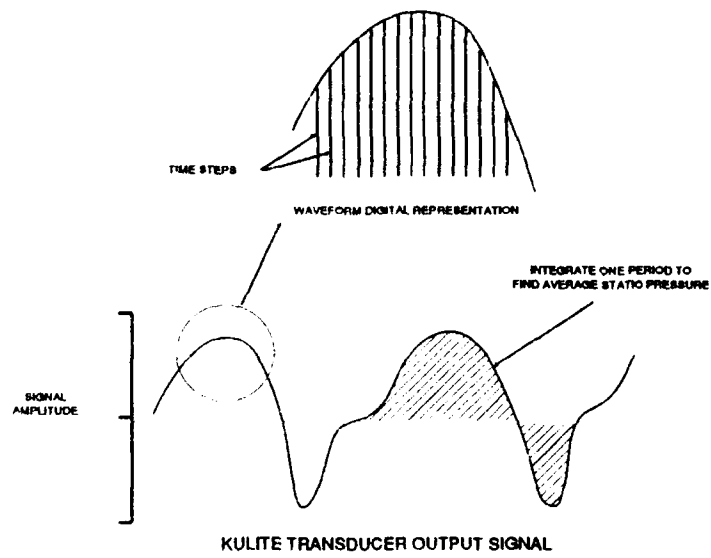Figure 4. Example Static Pressure vs. Time Plots

17

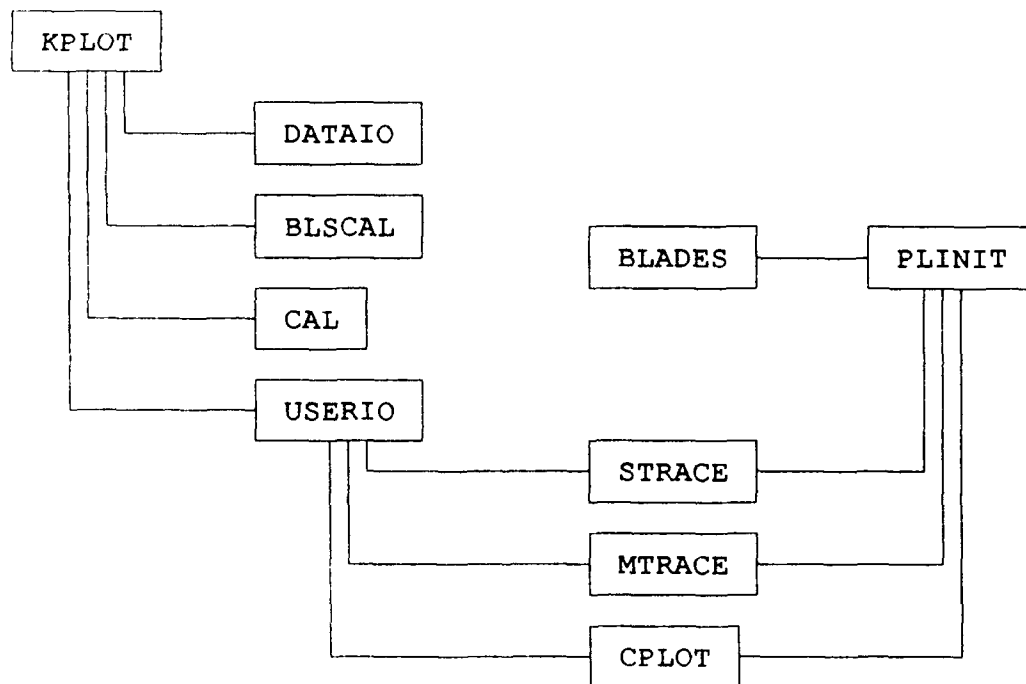Figure 5. Signal Calibration Process

Figure 6. Subroutine Structure

SECTION VII

REFERENCES

1. Puterbaugh, S.L. "Cgraph - A FORTRAN Callable Graphics Library," WL-TR-91-2004, Wright Laboratory, Wright-Patterson AFB, Ohio, May 1990.

2. Heap, B.R., et al., "Three Contouring Algorithms," NPL-DNAM-81, National Physical Laboratories, Teddington, England, December 1969.