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DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

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MELBOURNE, VICTORIA

Flight Mechanics Technical Memorandum 426

A FORTRAN PROGRAM FOR PROCESSING LOW SPEED WIND TUNNEL TEST DATA FOR THE JINDIVIK AUXILIARY INTAKE

by

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A FORTRAN PROGRAM FOR PROCESSING LOW SPEED WIND TUNNEL TEST DATA FOR THE JINDIVIK AUXILIARY INTAKE

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SUMMARY

A FORTRAN computer program was written for post processing low speed wind tunnel pressure data acquired from the Jindivik auxiliary intake model. The scanivalve pressure measurement system was used with the standard data acquisition system to read the pressures from 59 pressure tappings. The program analysed raw data and produced numerical and graphical output. These consisted of static pressure graphs, mass flow graphs and total pressure contour plots.

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Contents

Notation

ALPHA	-	see α
AXPS	-	intake duct static pressures (kPa)
B	-	atmospheric pressure (mba)
BETA	-	see β
DC60	-	see DC_{60}
DC_{60}	-	distortion factor
DP	-	see ΔP
EPS	-	see ϵ
GDPTP0	-	array containing the total pressure ratios at the engine face in grid format as shown in figure 11
JPRESS(i)	-	array containing 59 scanivalve pressure readings
$\dot{m}$	-	mass flow (lb/sec)
m	-	number of grid points in radial direction
MDOT	-	see $\dot{m}$
n	-	number of grid points in circumferential direction
P_a	-	atmospheric pressure (kPa)
P_m	-	true equivalent pressure from scanivalve (kPa)
P_s	-	static pressure (kPa)
P_t	-	engine face total pressure (kPa)
P_v	-	engine face dynamic pressure (kPa)
P_0	-	tunnel freestream total pressure (kPa) (static + dynamic)
P_1	-	pressure before venturi throat $(In.H_2O)$
P(ij)	-	PTM(i,j) in 1-D format
PMAX	-	maximum engine face total pressure ratio
PMIN	-	minimum engine face total pressure ratio
P0	-	differential tunnel total pressure (kPa)
PS	-	differential engine face static pressure (kPa)
PSAV	-	average of six static pressure ratios around engine face
PSP0	-	P_s/P_0
PT	-	differential engine face total pressure (kPa)
PTAV	-	average of thirty P_t/P_0 values at engine face
PTM(i,j)	-	interpolated and measured engine face total pressure ratios
PTMIN(I,J)	-	PTP0(i) in 2-D format
PTP0	-	see PTAV
PTP0(i)	-	thirty engine face total pressure ratios
Ptu	-	tunnel freestream total pressure (kPa) (static + dynamic)
PT60	-	minimum of [average P_t/P_0 over 60° sectors at 5° intervals]
PT60PS	-	sector in which PT60 occurs
PVAV	-	average of thirty P_v/P_0 values at engine face
P1	-	see P_1
R	-	current value of annulus number
RO	-	see ρ_{ten}

SECAVG	–	sector average total pressure ratios
T_a	–	atmospheric temperature (K)
T_1	-	temperature in the venturi (°C)
TA	–	see T_a
TH	–	current value of circumferential position
T1	–	see T_1
VEL	–	tunnel freestream velocity measured by scanivalves (m/s)
X_s	–	scanivalve pressure reading
XMDOT	–	mass flow parameter $\dot{m}\sqrt{T_a}/P_a$
α	–	pitch angle (deg) - nose up positive
β	–	yaw angle (deg) - nose to port positive
ΔP	–	pressure difference from P_1 position to the venturi throat $(In.H_2O)$
ϵ	–	expansibility factor
λ	–	venturi pressure ratio
ρ_{ven}	–	venturi air density (lb/ft^3)

Subscripts

$_{avg}$	–	average

List of Figures and Tables

1 Introduction

A test program was carried out in the ARL low speed wind tunnel on a model of the Jindivik (Figs 1,2), to evaluate the incorporation of an auxiliary intake designed to improve performance at low speeds. A FORTRAN program CALJIN was written on the DEC[1] PDP 11/44 to process the data and output the results.

A pressure rake containing thirty total pressure probes, five radial positions at six circumferential locations (Fig. 3), was located at the engine face. Pressure measurements were obtained via two scanivalves connected to the pressure rake.

The pressures were measured using the wind tunnel scanivalve system, and the output data was acquired using the standard wind tunnel data acquisition program DATAIN (Ref. 1). Due to the size of the available memory it was not possible to install CALJIN as a subtask of DATAIN, therefore the raw data were output to a file for processing by CALJIN independently. Although this method is slightly cumbersome, many of the raw data files needed adjusting because of faults in the automatic data acquisition process. These faults usually involved the loss of one character in a data line and it had to be inserted manually.

The results were expressed as pressure ratios and they were output in graphical and numerical format. The test results were presented on 3 different types of plots as follows.

1. A graph of the ratio of intake static pressure to tunnel freestream total pressure (static + dynamic) vs axial location along the duct away from the engine face towards the intake lip. (Fig 4)
2. A graph of the average ratio of total pressure at the engine face to tunnel freestream total pressure $(P_t/P_0)_{avg}$ vs. mass flow parameter $m\sqrt{T_o}/P_o$ was plotted from data for a range of mass flows. (Fig. 5)
3. A cross sectional total pressure ratio contour plot at the engine face, as shown in figure 6.

In order to obtain more data points, (i.e. more than the 30 readings taken), needed to plot contour levels, it was necessary to interpolate values between the measured pressure points. Initially, linear interpolation methods were used, but the contour plots were not very smooth and the results were not accurate enough. A more accurate cubic spline interpolation scheme was therefore used to produce the interpolated pressures needed for the contour plots.

In addition the numerical data were presented in tabular form (Table 1). The plots were output on the HP[2] 7220T plotter. Although the plotter was slow the quality

[1] DEC is a registered trademark of Digital Equipment Corporation
[2] HP is a registered trademark of Hewlett-Packard

TEST NUMBER: 293

MODEL DESCRIPTION: 36.9*130 APERTURE WITH PROFILED LIP

VELOCITY = 32.87
ALPHA = 0.00
BETA = 0.00

ANNULUS NO. : 1			ANNULUS NO. : 2		
PROBE	PT/PO	PV/PO	PROBE	PT/PO	PV/PO
1	0.8785	0.0477	7	0.8943	0.0635
2	0.9039	0.0732	8	0.9322	0.1014
3	0.9380	0.1072	9	0.9718	0.1410
4	0.9222	0.0914	10	0.9425	0.1117
5	0.9322	0.1014	11	0.9783	0.1475
6	0.9029	0.0721	12	0.9311	0.1004
AVG	0.9130	0.0822	AVG	0.9417	0.1109

ANNULUS NO. : 3			ANNULUS NO. : 4		
PROBE	PT/PO	PV/PO	PROBE	PT/PO	PV/PO
13	0.8891	0.0584	19	0.8953	0.0646
14	0.9642	0.1334	20	0.9766	0.1458
15	0.9897	0.1589	21	0.9928	0.1620
16	0.9594	0.1286	22	0.9835	0.1527
17	0.9886	0.1579	23	0.9917	0.1610
18	0.9676	0.1369	24	0.9835	0.1527
AVG	0.9598	0.1290	AVG	0.9706	0.1398

ANNULUS NO. : 5			Pstatic - ENGINE FACE	
PROBE	PT/PO	PV/PO	PROBE	PS/PO
25	0.9493	0.1183	31	0.8299
26	0.9917	0.1610	32	0.8306
27	0.9966	0.1658	33	0.8323
28	0.9955	0.1647	34	0.8372
29	0.9935	0.1627	35	0.8306
30	0.9928	0.1620	36	0.8341
AVG	0.9865	0.1557		

AX POS	1	2	3	4	5	6	7	8
PS/PO	0.831	0.826	0.795	0.737	0.716	0.736	0.743	0.742

AX POS	9	10	11	12	13	14	15	16
PS/PO	0.731	0.550	0.945	0.943	0.936	0.926	0.975	0.899

PT60 = 0.90918 DC60 = 0.36528 PT60PS = 67
PTAV = 0.95430 PVAV = 0.12352 PSAV = 0.83078
PO = 0.06799 EPS = 0.98152 MDOT = 2.74472
B(mba) = 1025.700 TA = 286.40 DP = 11.42
P1 = 50.50 T1 = 14.00 Ptu(kPa) = 103.031
XMDOT = 3.12235

TABLE 1 TABULATED NUMERICAL OUTPUT FROM CALJIN and clarity of the plots produced was good, as shown in the examples reproduced in figures 4, 5, and 6.

2 Program Structure

The program structure is illustrated in figure 7 in the form of a tree diagram, showing the major tasks (programs) and subroutines. The source code for these files can be found in the directory DU0:[200,10] of the PDP 11/44 (see Appendix A). The only exception being HPPLT, which represents the HP plotting library routines, which are located in DU0:[1,1]HPPLTLIB.

The program JINDIV, which is essentially a menu-driver to invoke each separate task, is divided into four main sections:

- CALJIN - the calculation and processing of the measured data
- PLTPS - the static pressure graph.
- PLTPT - the mass flow graph.
- PLTCNT - the contour pressure plot.

The division of the program into these sections allowed each task to be developed and debugged individually without any connection to the other tasks. PLTPS was incorporated as a subtask of CALJIN after the completion of the programming, resulting in three distinct tasks, CALJIN, PLTCNT, and PLTPT.

Initially, it was assumed that the entire data processing and output routines would be invoked as a subtask of the standard data acquisition program DATAIN. However, due to the memory limitations of the PDP 11/44 this was not possible, and it was necessary for the programs to be written as separate modules.

The existing program NORMALSPM (a subtask running under DATAIN) was modified and renamed NORMALJIN to output the fixed data and scanivalve measurements to a file DL1:JINXXX.JCS[1], which could be read by CALJIN. During the tests, faults occurred in acquiring a preset data value (Preset 6) from the data serializer, therefore this was manually input by the operator at runtime.

2.1 Program JINDIV

The program JINDIV, which is a separate major task on the PDP 11/44, sets up the main menu for the processing of pressure data, and output of graphs and plots.

[1]All files are in directory [100,7],unless otherwise stated, and this will not be included in the file description.

Three separate tasks CALJIN, PLTCNT, PLTPT, are invoked through this program, with event flags 52, 53 and 54 respectively. At the completion of a selected task the program returns to the main menu.

2.2 Task CALJIN

The program CALJIN is the main component of the computer software written for the Jindivik test program. All of the data processing is carried out in CALJIN and its related subroutines, and the processed data is output to files for printing or further analysis.

2.2.1 Input

Input to CALJIN consists of two items of information.

- First, the user must indicate if the test configuration to be processed includes one of the range of auxiliary air intakes tested. If an auxiliary intake configuration is present static pressure hole number 10 does not have a measured reading (Fig. 8), and this must be taken into account to avoid it being plotted incorrectly as a data point. A set value of $P_s/P_0 = 0.55$, which is well outside the test range is assigned to hole number 10 when an auxiliary air intake is included in the tests.
- The second input is the name of the data file to be processed.

  The standard data acquisition program DATAIN asks for a data file name. The user selects a file name in the form JINXXX where XXX is the sequential test number. The subroutine NORMALJIN (modified from NORMALSPM) outputs the pressures and other data to a file DL1:JINXXX.JCS which is then input to CALJIN. The user only needs to type JINXXX without the necessary extensions.

The format of the file DL1:JINXXX.JCS (Table 2) is as follows:

1. The first 6 lines contain the 59 scanivalve readings (two 48 port scanivalves were used) in integer free format, followed by a blank line.
2. The next 2 lines of data are the 7 Preset values read in from the data serializer in real free format.
3. The next 5 lines are test description lines in character format.

```
   -3      0    592    592     -6     -6     13     13   -340   -266   -167
 -213   -184   -269   -294   -184    -69   -154    -50   -187   -309    -91
  -17   -105    -20    -81   -291    -55     -8    -35    -11    -35   -135
  -11      3      0     -6     -8   -481   -479   -474   -489   -479   -469
 -491   -582   -752   -875   -830   -813   -735   -840     -8   -147   -154
 -172   -203   -262   -281

0.0000000      0.0000000      14.00000      50.50000      11.42000
   102.5700       286.4000

36.9*130 APERTURE WITH PROFILED LIP


JINDIVIK AUXILIARY AIR INTAKE
PROPULSION BRANCH
1
DL1:JIN293.DAT
04-JUN-90
DL1:CONFJIN5.DAT
   1
```

TABLE 2 INPUT FILE FOR CALJIN

4. The following 7 lines contain the title, customer name, test point number, data file name (DL1:JINXXX.DAT[1]), date of file creation, configuration file name and configuration value[2].

2.2.2 Scanivalve Pressure Calibrations and Pressure Readings

Pressure tubes from the Jindivik model were connected to two SCANCO 48D type scanivalves located under the working section of the wind tunnel. STATHAM ±5 psi differential pressure transducers were used in the scanivalves. The transducers were not linear over the entire pressure range.

Calibration of the transducers revealed a linear relationship over the range $-24kPa \leq P_m \leq +24kPa$, however a definite increase in slope is evident outside this range (Figs 9,10). Linear equations for each of these regions relating the scanivalve pressure reading X_s, and the true equivalent pressure P_m, in kiloPascals, were derived leading to four equations, two for each of the transducers.

The calibration equations for Scanivalve D with Transducer 54820 are:

$$P_m = 0.045113X_s + 10.692 \quad \text{for} \quad X_s \leq -769 \tag{1}$$

$$P_m = 0.045113X_s - 10.692 \quad \text{for} \quad X_s \geq 769 \tag{2}$$

The calibration equations for Scanivalve E with Transducer 57045 are:

$$P_m = 0.040956X_s + 5.835 \quad \text{for} \quad X_s \leq -730 \tag{3}$$

$$P_m = 0.040956X_s - 5.835 \quad \text{for} \quad X_s \geq 730 \tag{4}$$

A known pressure of $21.0kPa$ was applied to a port on each of the scanivalves during the tests. A calibration factor for each of the scanivalves can then be calculated for the range of values $-769 \leq X_s \leq +769$ (scanivalve D), and $-730 \leq X_s \leq +730$ (scanivalve E), and used to determine pressures within these ranges.

Scanivalve pressure readings are read into variable JPRESS, an integer array with 59 values. Pressures are grouped in JPRESS(i) as shown in Table 3.

Table 3: Variable JPRESS(i)

i	Description
1,2	Atmospheric Pressure
3,4	Calibration Pressure of $21.0kPa$
5,6	Tunnel freestream Static Pressure
7,8	Tunnel freestream Total Pressure
9,...,38	Engine face Total Pressure
39,...,44	Engine face Static Pressure
45,...,59	Intake duct Static Pressure

[1] This is the raw data file created by DATAIN

[2] These values are not all required by CALJIN even though they are written to the data file

The pressures are output as ratios to the tunnel freestream total pressure, i.e. P_t/P_0 and P_s/P_0. The differential pressure transducers measured the difference between the pressure on a given model pressure tapping and atmospheric pressure P_a which are:

$$PT = P_t - P_a$$

$$PS = P_s - P_a$$

$$P0 = P_0 - P_a$$

To calculate the correct pressure ratios, P_a must be added to both the numerator and the denominator, so that the total pressure ratio is:

$$\frac{P_t}{P_0} = \frac{PT + P_a}{P0 + P_a} \tag{5}$$

and the static pressure ratio is:[6]

$$\frac{P_s}{P_0} = \frac{PS + P_a}{P0 + P_a} \tag{6}$$

The six measured static pressures around the engine face are averaged to give $(P_s/P_0)_{avg}$. The dynamic pressure ratios can then be calculated using equation 7.

$$\left(\frac{P_v}{P_0}\right)_i = \left(\frac{P_t}{P_0}\right)_i - \left(\frac{P_s}{P_0}\right)_{avg} \qquad i = 1, \ldots, 30 \tag{7}$$

2.2.3 Cubic Spline Interpolation for P_t/P_0

Total pressure measurements were recorded at thirty positions at the engine face, over five annuli, each annulus containing six pressure probes (Fig. 3). To carry out the necessary calculations, and to produce a reasonable pressure contour plot, intermediate interpolated pressure values at 5° intervals around each annulus are required. A linear interpolation method was originally implemented, however the resulting contour plots were not very smooth and the correlation with sample data from the static tests was not satisfactory. A cubic spline interpolation was used which produced more accurate results.

The cubic spline routines are found in DU0:[200,10]CUBSPL.FTN, and are called by both CALJIN and CNTJIN. The two subroutines SPLINE and SPLINT contained in CUBSPL appear in their original C format given in Reference 2, along with a detailed explanation of the algorithms.

Interpolated and measured pressure ratios at the engine face are stored in a two dimensional array GDPTP0(R,TH) where R = 1,...5, TH = 1,...,72 (Fig. 11). A polar grid was chosen because it allowed the results for each annulus, or for a given sector, to be manipulated easily, as described in the following section.

[6] In CALJIN the static pressure variables are PS and AXPS.

2.2.4 Engine Face and Duct Calculations

Processing of the measured data and the calculation of parameters such as the distortion factor DC_{60}, mass flow rate $\dot{m}$ are found in the following section of CALJIN.

Distortion Factor

The distortion factor is a measurement of the variation of total pressure across the engine face, and is defined by equation 8.

$$DC_{60} = \frac{\left(\frac{P_t}{P_0}\right)_{avg} - \left(\frac{P_t}{P_0}\right)_{60}}{\left(\frac{P_t}{P_0}\right)_{avg}} \quad (8)$$

where:

$\left(\frac{P_t}{P_0}\right)_{avg}$ is the average of the thirty total pressure values at the engine face;
$\left(\frac{P_t}{P_0}\right)_{60}$ is the minimum of [average (P_t/P_0) over 60° sectors at 5° intervals];
$\left(\frac{P_t}{P_0}\right)_{avg}$ is the average of the thirty dynamic pressure values at the engine face.

In order to calculate $(P_t/P_0)_{60}$, 60° sectors are chosen by taking the GDPTP0(R,TH) values for R=1,...,5, TH=1 (Lower limit),...,TH=13 (Upper limit) (Fig. 11), calculating the average of these total pressure ratios and storing the solution in the variable SECAVG(1). The lower limit and upper limit of TH are incremented by 1 and the average pressure ratio found again (SECAVG(2)). This process is repeated until all 72 values of the sector averages are calculated. The only tricky section of this algorithm is to remember when wrap around of the sectors occur, i.e. when the upper limit of TH equals 73, values of TH equal to 1 must be used, and so on.

The minimum of the 72 sector average values is chosen and this is assigned to the variable PT60 ($(P_t/P_0)_{60}$), allowing the distortion factor DC_{60} to be calculated according to equation 8.

Mass Flow Rate

Air mass flow through the engine is calculated from the venturi readings of:

P_1	-	pressure before the throat $(In.H_2O)$;
ΔP	-	pressure difference from P_1 position to the throat $(In.H_2O)$;
T_1	-	temperature in the venturi (°C).

The following equations, derived from equations found in Reference 3, are used to calculate the mass flow $\dot{m}$ and the mass flow parameter $\dot{m}\sqrt{T_a}/P_a$.

Venturi air density (lb/ft^3):

$$\rho_{ven} = 0.7329 \left(\frac{0.0296\ B - 0.0737\ P_1}{273.15 + T_1}\right) \quad (9)$$

Expansibility factor:

$$\epsilon = \left(3.5\,\lambda^{1.4286}\frac{0.9517}{1-0.0483\,\lambda^{1.4286}}\,\frac{1-\lambda^{0.2857}}{1-\lambda}\right)^{\frac{1}{2}} \tag{10}$$

where the venturi pressure ratio is defined as:

$$\lambda = 1 - \frac{\Delta P}{P_a - P_t} \tag{11}$$

Mass flow rate (lb/sec):

$$\dot{m} = 3.1735\,\epsilon\,\sqrt{\rho_{v,a}\,\Delta P} \tag{12}$$

Therefore the mass flow parameter[7].

$$\frac{\dot{m}\sqrt{T_a}}{P_a} = \frac{\dot{m}\,\sqrt{273.15+T_t}}{B\,\frac{14.696}{101.325}} \tag{13}$$

The values of $(P_t/P_0)_{avg}$ and $\dot{m}\sqrt{T_a}/P_a$ for each test (i.e. one mass flow setting) are appended to a file DU0:XMDYPT.DAT. This file is accessed by the task PLTPT when a series of tests have been completed, and a summary of the results is plotted.

2.2.5 Subtask PLTPS

PLTPS is invoked from within CALJIN and produces the Static Pressure ratio (P_s/P_0) vs. Axial Location (from engine face) graph. The static pressures are passed from CALJIN via the file DU0:PSTAT.DAT containing the test number, the sixteen values of P_s/P_0 from the engine face to the intake lip, and the test description.

Standard HP plotting library routines DU0:[1,1]HPPLTLIB to control the HP 7220T plotter are used to produce the plot file DU0:PSGXXX.PLT, which is immediately queued to the plotter.

2.2.6 Total Pressure Ratio Contour Plotting

The grid numbering system for the engine face, used for the manipulation of the pressure ratios for contouring is different to the numbering system previously explained in section 2.2.4. A diagram illustrating the variation in the grid orientation is shown in figure 11. The pressure ratios are converted from their original one dimensional array variable PTP0(i) i = 1, ..., 30, to the corresponding two dimensional array format PTMIN(I,J) I = 1, ..., 7, J = 1, ..., 7. Pressure data is then in the correct format for input to the subroutine DU0:[200,10]CNTJIN.

[7] The units of P_a in this formula are psi not kPa

In the radial direction five pressure measurements are taken. The contour program requires values at both boundaries (i.e. the inner and outer circles), and these are calculated using linear extrapolation.

Two subroutines are contained within CNTJIN, one called CNTJIN and the other INTERP. INTERP performs the cubic spline interpolation on the pressure data by calling CUBSPL, and the results are stored in the format necessary for input to the contour routines.

After the interpolation is carried out on the measured total pressure ratios, the complete total pressure data is then transformed from the two dimensional coordinate format PTM(i,j) $i = 1,\ldots,7$, $j = 1,\ldots,73$, (Fig. 11) to a one dimensional array P(ij) according to equation 14.

$$ij = i + (j-1) \times m \qquad i = 1,\ldots,7 \;\; j = 1,\ldots,73 \tag{14}$$

where m = number of grid points in the i direction.

In order to plot contours it is necessary to choose a range of contour values for which the pressure ratios will be plotted. As the total pressure ratios for all tests always lie within the range $0.84 \leq P_t/P_0 \leq 0.99$, the method chosen was to find the minimum and maximum pressure ratios (PMIN and PMAX), and to divide this range into increments of 0.01.

A file, DU0:PINXXX.DAT (Table 4), is created to store the interpolated pressure data and the required constants. The format of this file is as follows:

1. First line contains α, β, tunnel velocity (m/s), $\dot{m}\sqrt{T_a}/P_a$, $(P_t/P_0)_{avg}$, $(P_t/P_0)_{60}$, and DC_{60}.
2. Second line, m – number of radial grid points, n – number of circumferential grid points, and the number of contour levels.
3. Third line, the actual contour level values.
4. Remainder of the file contains a table of pressure ratios, one line for each circumferential position.

2.2.7 Output of Results

Numerical results are output to both the screen and a file DU0:OUTXXX.DAT in the tabulated format shown in Table 1. Two copies of this file are placed in the line printer queue. The only difference between the screen and file output, is that the file output contains a title page, detailing the test description, name of customer, configuration and data file names, and the creation date of the data file.

```
0.0000000       0.0000000       32.67256        3.122348        0.9543005
0.9091607       0.3652825
    7      73      12
0.8500000       0.8900000       0.9000000       0.9100000       0.9200000
0.9300000       0.9400000       0.9500000       0.9600000       0.9700000
0.9800000       0.9900000
0.9695966  0.9490445  0.8953347  0.8891374  0.8943018  0.8784643  0.8708969
0.9700013  0.9496810  0.8965770  0.8901640  0.8946157  0.8786944  0.8710870
0.9711357  0.9514695  0.9000746  0.8930687  0.8955361  0.8793627  0.8716348
0.9728805  0.9542284  0.9054838  0.8975890  0.8970315  0.8804364  0.8725071
0.9751160  0.9577761  0.9124610  0.9034622  0.8990702  0.8815825  0.8736700
0.9777226  0.9619310  0.9206622  0.9104255  0.9016204  0.8836681  0.8750902
0.9805810  0.9665118  0.9297439  0.9182166  0.9046509  0.8857604  0.8767342
0.9835718  0.9713367  0.9393622  0.9265727  0.9081296  0.8881263  0.8785684
0.9865753  0.9762244  0.9491737  0.9352312  0.9120251  0.8907329  0.8805593
0.9894720  0.9809930  0.9588342  0.9439294  0.9163056  0.8935475  0.8826733
0.9921426  0.9854611  0.9680002  0.9524047  0.9209395  0.8965369  0.8848771
0.9944673  0.9894473  0.9763281  0.9603946  0.9258953  0.8996655  0.8871370
0.9963269  0.9927698  0.9834739  0.9676363  0.9311413  0.9029092  0.8894195
0.9976338  0.9952928  0.9891750  0.9739184  0.9366301  0.9062225  0.8916934
0.9984253  0.9970621  0.9934921  0.9792326  0.9422525  0.9095578  0.8939358
0.9987828  0.9981697  0.9965671  0.9836125  0.9478833  0.9128607  0.8961263
0.9987697  0.9987066  0.9985417  0.9871309  0.9533976  0.9160769  0.8982447
0.9984615  0.9987648  0.9995575  0.9898009  0.9586701  0.9191522  0.9002701
0.9979303  0.9984358  0.9997566  0.9916757  0.9635761  0.9220324  0.9021823
0.9972465  0.9978111  0.9992806  0.9927983  0.9679902  0.9246630  0.9039608
0.9964891  0.9969824  0.9982715  0.9932120  0.9717878  0.9269900  0.9055851
0.9957238  0.9960412  0.9968707  0.9929597  0.9748434  0.9289588  0.9070346
0.9950250  0.9950790  0.9952201  0.9920846  0.9770322  0.9305152  0.9082888
0.9944654  0.9941876  0.9934616  0.9906298  0.9782293  0.9316052  0.9093276
0.9941171  0.9934554  0.9917369  0.9886383  0.9783095  0.9321741  0.9101301
0.9940338  0.9929627  0.9901636  0.9861653  0.9772032  0.9321932  0.9106869
0.9941933  0.9926903  0.9887624  0.9833142  0.9750627  0.9317340  0.9110311
0.9945548  0.9926106  0.9875301  0.9802002  0.9720961  0.9308938  0.9112068
0.9950771  0.9926931  0.9864631  0.9769386  0.9685109  0.9297695  0.9112583
0.9957194  0.9929072  0.9855580  0.9736448  0.9645151  0.9284579  0.9112294
0.9964407  0.9932224  0.9848117  0.9704341  0.9603165  0.9270564  0.9111644
0.9972001  0.9936060  0.9842204  0.9674218  0.9561228  0.9256619  0.9111072
0.9979568  0.9940336  0.9837812  0.9647233  0.9521420  0.9243714  0.9111023
0.9986694  0.9944686  0.9834902  0.9624539  0.9485817  0.9232818  0.9111933
0.9992974  0.9948823  0.9833442  0.9607288  0.9456500  0.9224904  0.9114244
0.9997997  0.9952445  0.9833400  0.9596636  0.9435545  0.9220940  0.9118399
1.0001382  0.9955242  0.9834739  0.9593733  0.9425029  0.9221897  0.9124837
1.0002757  0.9956999  0.9837416  0.9599338  0.9426367  0.9228404  0.9133814
1.0002432  0.9957850  0.9841343  0.9612615  0.9438301  0.9239722  0.9144838
1.0000721  0.9958019  0.9846423  0.9632335  0.9458911  0.9254775  0.9157236
0.9997972  0.9957728  0.9852555  0.9657268  0.9486275  0.9272484  0.9170331
0.9994529  0.9957199  0.9859640  0.9686182  0.9518469  0.9291767  0.9183445
0.9990739  0.9956656  0.9867583  0.9717848  0.9553574  0.9311548  0.9195905
0.9986947  0.9956321  0.9876253  0.9751034  0.9589666  0.9330748  0.9207034
0.9983500  0.9956417  0.9885642  0.9784512  0.9624824  0.9348289  0.9216156
0.9980741  0.9957168  0.9895562  0.9817048  0.9657126  0.9363089  0.9222594
0.9979018  0.9958795  0.9905943  0.9847414  0.9684650  0.9374072  0.9225674
0.9978676  0.9961522  0.9916658  0.9874379  0.9705476  0.9380159  0.9224719
0.9980062  0.9965571  0.9927698  0.9896712  0.9717679  0.9380271  0.9219053
0.9983357  0.9971003  0.9938714  0.9913349  0.9719819  0.9373628  0.9208212
0.9988092  0.9977227  0.9948829  0.9923587  0.9712375  0.9360645  0.9192584
0.9993634  0.9983490  0.9956980  0 9926091  0.9696306  0.9342038  0.9172764
0.9999350  0.9989039  0.9962096  0.9925725  0.9672570  0.9318522  0.9149353
1.0004605  0.9993122  0.9963114  0.9916552  0.9642126  0.9290610  0.9122947
1.0008767  0.9994954  0.9958966  0.9900337  0.9605933  0.9259619  0.9094146
1.0011202  0.9993873  0.9948586  0.9876542  0.9564949  0.9225662  0.9063547
1.0011281  0.9989038  0.9930908  0.9845835  0.9520136  0.9189656  0.9031749
1.0008366  0.9979721  0.9904864  0.9807076  0.9472448  0.9152313  0.8999348
1.0001825  0.9965173  0.9869390  0.9760330  0.9422848  0.9114350  0.8966946
0.9991027  0.9944541  0.9823417  0.9705362  0.9372292  0.9076481  0.8935138
0.9975336  0.9917369  0.9765860  0.9641934  0.9321741  0.9039420  0.8904523
0.9954423  0.9883011  0.9696389  0.9570249  0.9272083  0.9003806  0.8875620
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0.9700062  0.9496486  0.8964471  0.8900968  0.8946633  0.8786874  0.8710539
0.9695966  0.9490445  0.8953347  0.8891374  0.8943018  0.8784643  0.8708969
```

TABLE 4 INPUT FILE FOR PLTCNT

2.3 Task PLTCNT

This task, which produces the total pressure contour plot, is invoked by choosing the second option in the main menu of JINDIV. In order for a contour plot (Fig. 6) to be created, the raw data for that test must be processed first, i.e. the first option (task CALJIN) of JINDIV must be carried out before the second option (task PLTCNT).

2.3.1 Input

PLTCNT requests the test number and a one line test description of the test for which the user wants to produce a contour plot. The file DU0:PINXXX.DAT containing the pressure ratio data and constants is read into the appropriate variables. The format of the file PINXXX.DAT is described in section 2.2.6.

2.3.2 Contour Program

A standard contour plotting package DU0:[200,10]CONTOUR.FTN is used to create the pressure contours using the interpolated pressure data from PINXXX.DAT. Unfortunately this contour package does not label the contour levels and they must be labelled manually as shown in figure 6. To make this process easier, the program CONTOUR was modified to alternate the line type of the contour when a change in contour level occurs.

The plot commands are written to a file DU0:CNTXXX.PLT as they are calculated. After the program CONTOUR has been completed, the title and test information is appended to the plot file, followed by the plot commands to draw the inner and outer circles. In addition to the constant pressure contours, dashed lines are placed at 60° intervals to show the positions of the probe rakes around the engine face.

2.3.3 Contour Plot Output

The file containing the HP plot commands, CNTXXX.PLT, is then placed in the queue for the HP 7220T plotter. Contour plotting is the most time consuming part of the processing procedure, as some of the plots may include up to fourteen contour levels. The speed of the plotting could be increased by using a faster plotter or a laser printer/plotter.

2.4 Task PLTPT

This task is invoked by choosing the third option in the main menu of JINDIV. PLTPT produces a plot of $(P_t/P_0)_{avg}$ vs. $\dot{m}\sqrt{T_o}/P_o$ for a range of mass flows (Fig. 5). After a series of tests are completed PLTPT is run ' summarise the output of the tests. Any discontinuity in this graph most likely indicates the presence of erroneous data points, and it was found that this was the easiest method to determine if incorrect data was input.

2.4.1 Input

The test number and test description are required as input to PLTPT. The test number chosen is the corresponding test number of the last test in that series of tests. The values of $(P_t/P_0)_{avg}$ and $\dot{m}\sqrt{T_a}/P_a$ from file DU0:XMDYPT.DAT (which is updated through CALJIN), are read into two arrays for plotting.

2.4.2 Plot Description

In addition to the graph of $(P_t/P_0)_{avg}$ vs. $\dot{m}\sqrt{T_a}/P_a$ being plotted from the two arrays, constant RPM lines representing the 12,000 and 13,800 RPM engine settings are plotted.

The equations of these two lines are given by equations 15 and 16 respectively.

$$\frac{\dot{m}\sqrt{T_a}}{P_a} = 2.706\left(\frac{P_t}{P_0}\right)_{avg} \tag{15}$$

$$\frac{\dot{m}\sqrt{T_a}}{P_a} = 3.181\left(\frac{P_t}{P_0}\right)_{avg} \tag{16}$$

2.4.3 Plot Output

The HP plot commands are written to a file DU0:PTGXXX.PLT, and this is placed in the queue for the HP 7220T plotter. A copy of the file DU0:XMDYPT.DAT is made, and the new file name is DU0:PTGXXX.DAT.

It is very important to note that after a series of tests are completed and the plot file PTGXXX.PLT is output correctly, the file contents of XMDYPT.DAT must be cleared manually, prior to processing additional tests. This can be achieved by editting the file, deleting the two columns of data, and saving a new version of XMDYPT.DAT. If this is not performed, data points will be appended to the end of the file, and future plots will include more than one series of tests.

2.5 Subroutines

Two additional subroutines are not covered by the previous sections of this document, these are CATJIN and INFILE.

CATJIN is called by each of the tasks in order to set up the name of the data file and plot file based on the test number. Depending on which task calls this subroutine the file name returned is a concatenation of the required characters and test number. If CATJIN is called by PLTPS with parameters flag = 3 and test number = 23, CATJIN will return the file name PSG023.PLT.

INFILE (a subroutine of DATAIN), called by CALJIN, reads in the file name (JINXXX) and returns the full file name description (DL1:JINXXX.JCS).

3 Software Installation

The task DU0:[200,10]COMJIN.TSK must be installed in order for DATAIN to recognise the task name JIN. COMJIN, a subtask of DATAIN, performs the acquisition of the scanivalve pressure measurements and outputs the values in the format described in section 2.2.1. The only differences between COMJIN and COMSPM (the original subtask for scanivalve pressure measurement) are the modifications made to the subroutine NORMALJIN.

The programs JINDIV, CALJIN, PLTPS, PLTCNT and PLTPT must be installed from directory DU0:[200,10]. A command file DU0:[200,10]JININS.CMD, which includes the commands to compile, link and install the tasks, can be run to carry out the correct installation of these programs and subroutines.

3.1 Procedure to Install and Run Software

The following DCL[8] commands for the DEC PDP 11/44 will install and run the program. Bold faced text must be input via the keyboard.

>SET DEF DU0:[200,10]	set directory as DU0:[200,10]
>@COMJIN	if changes have been made to NORMALJIN
>INS COMJIN	install task COMJIN
>@JININS	install tasks JINDIV,CALJIN,PLTPS,PLTCNT,PLTPT
>SET DEF DU0:[100,7]	or login to directory DU0:[100,7]

****Ready to run DATAIN****

>R DATAIN
1: Job name: **JIN**

[8]Digital Command Language

2: Data file name: JINXXX
3: Configuration file name: CONFJINx — x - configuration no.
4: Acquire pressure measurements if online
5: Enter Patm: P_a — Preset(6) not functional
6: Output printed: N

****Exit DATAIN****

Set up the HP 7220T plotter

****Ready to run JINDIV****

>R JINDIV
1: Option: 1 — process raw data
2: Hit <return> until main menu is displayed
3: Option: 2 — output contour plot
4: Repeat 1 → 3 until a series of tests are processed
5: Option: 3 — output mass flow graph
6: Option: Q — Quit task

After quitting from the program JINDIV and ascertaining that the data is correct, clear the contents of the file DU0:XMDYPT.DAT before running JINDIV again.

4 Conclusion

Computer software developed for the low speed wind tunnel PDP 11/44 computer and described in this document made the post processing of data from the Jindivik tests both quick and easy to perform. A range of mass flows were set and the data acquired, and within twenty minutes (depending on the data being 'error-free') the complete results including pressure contour plots, graphs and tabulated data for a series of tests were ready to be analysed.

The scanivalves are now being phased out and a new PSI pressure scanning system is being installed which will enable the pressures to be acquired at a much faster rate, and 'error-free' on the first acquisition. This factor and the possible replacement of the HP 7220T plotter for a faster plotter, will lead to a considerable reduction in the processing time of wind tunnel test results.

Acknowledgements

The author would like to acknowledge A. M. Abdel-Fattah from the Propulsion Branch who requested the wind tunnel tests for which this program was developed. In addition the author would like to thank S. Lam for his continual support in the development of the computer software, and K. O'Dwyer, P. Malone and M. Fisher for their suggestions and assistance during the test program.

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[1] B. D. Fairlie. *A Real Time Data Acquisition System for a Low Speed Wind Tunnel.* A.R.L. Aerodynamics Report 163. 1985.

[2] Press, Flannery, Teukolsky, Vetterling. *Numerical Recipes in C - the art of scientific computing.* Cambridge University Press, Cambridge. 1988.

[3] British Standards Institution. *Methods for the Measurement of Fluid Flow in Pipes. Part 1: Orifice Plates, Nozzles, and Venturi Tubes.* British Standard 1042: Part 1: 1964.

Appendix — Location of Files

Source files in directory DU0:[200,10]:

JINDIV.FTN
CALJIN.FTN
PLTPS.FTN
PLTCNT.FTN
PLTPT.FTN
CNTJIN.FTN
CUBSPL.FTN
CATJIN.FTN
CONTOUR.FTN
NORMALJIN.FTN

Data files and plot files in directory DU0:[100,7] during testing:

OUTXXX.DAT
PINXXX.DAT
XMDYPT.DAT
PTGXXX.DAT
PSGXXX.PLT
CNTXXX.PLT
PTGXXX.PLT

Data files in directory DL1:[100,7]:

JINXXX.DAT	-	raw data file from DATAIN
JINXXX.JCS	-	output file from NORMALJIN

Copy of data files and plot files in directory DL0:[100,7]:

OUTXXX.DAT
PTGXXX.DAT
PSGXXX.PLT
CNTXXX.PLT
PTGXXX.PLT

FIG. 1 JINDIVIK MODEL IN LOW SPEED WIND TUNNEL

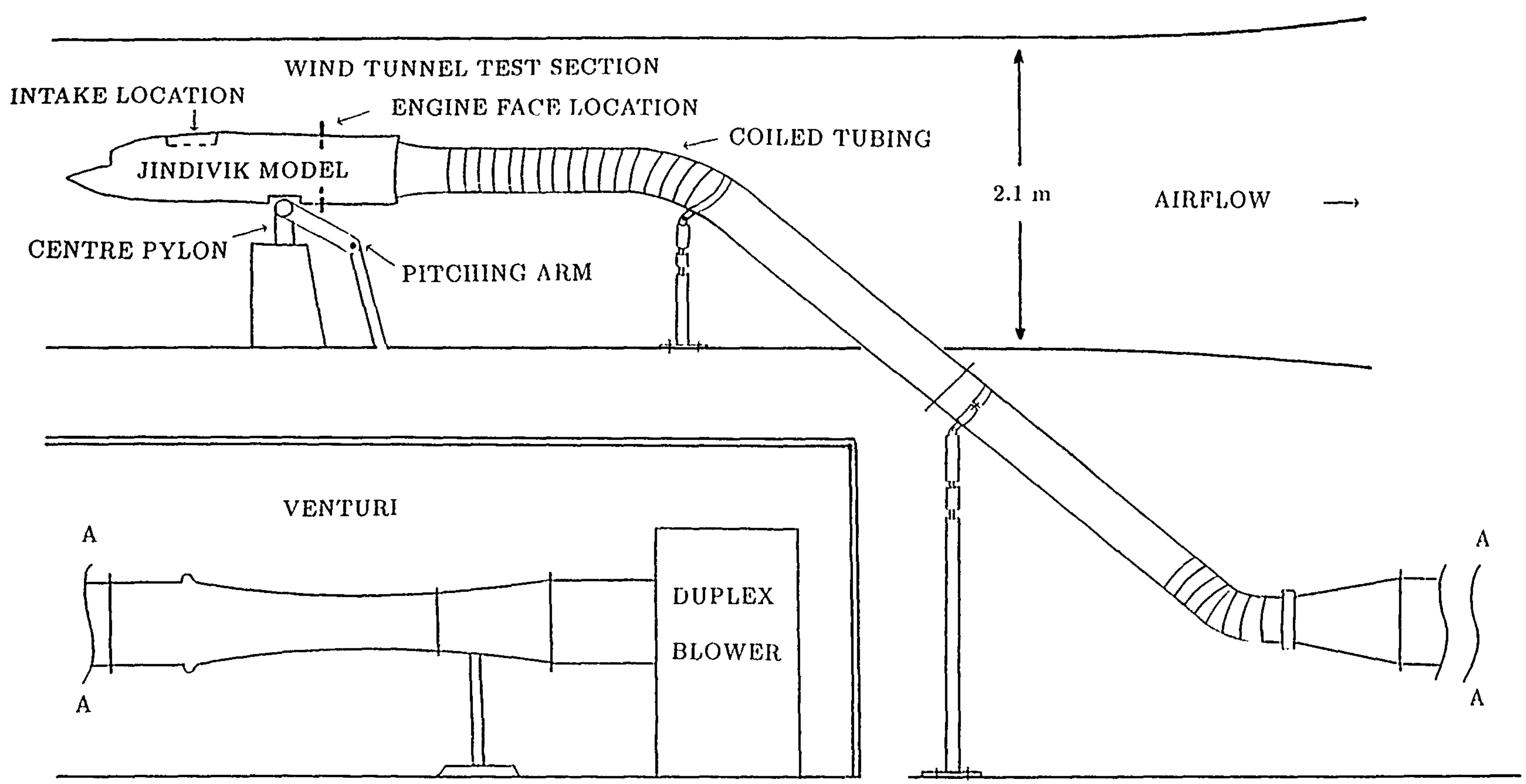


FIG. 2 EXPERIMENTAL SETUP OF JINDIVIK MODEL

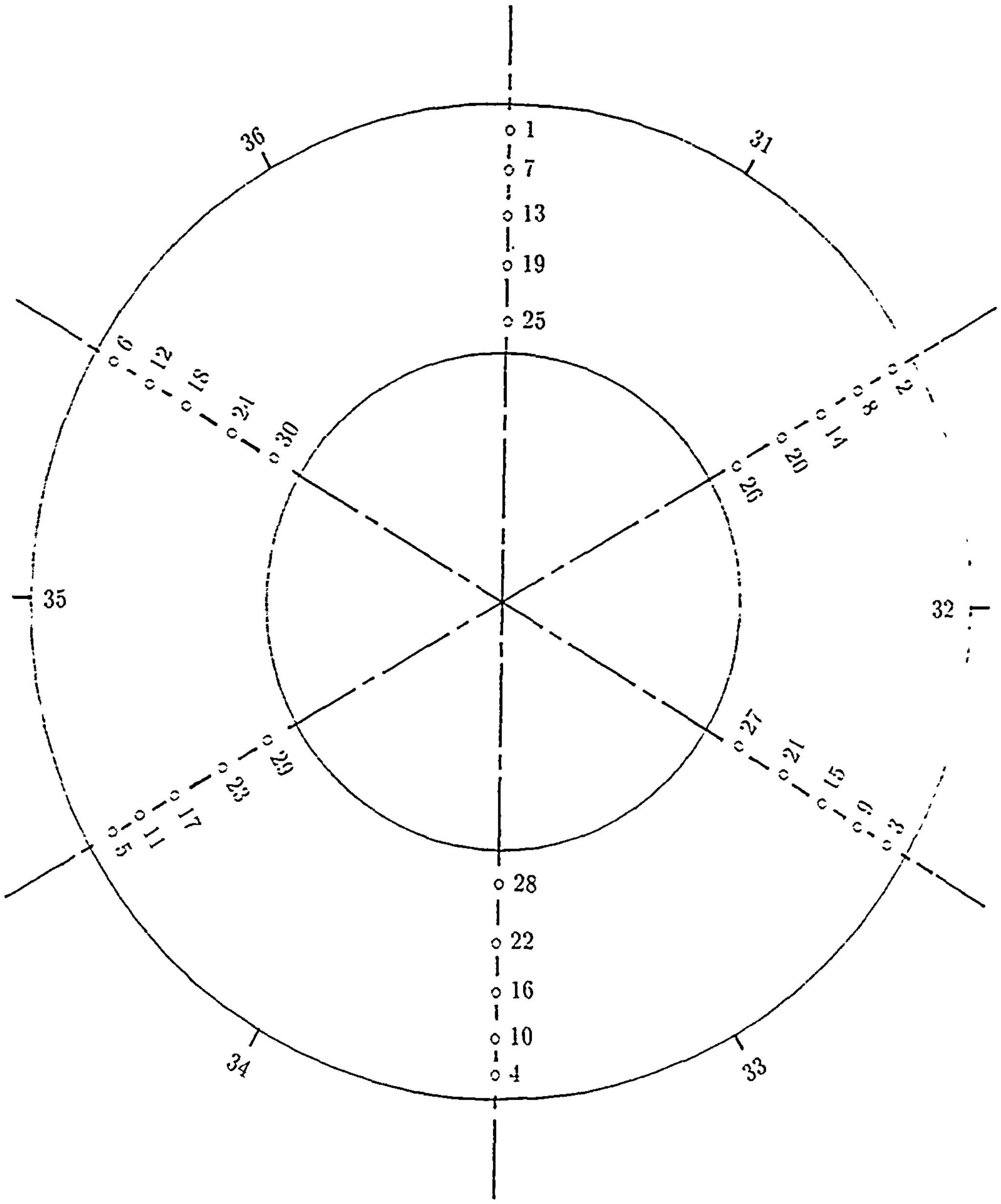


FIG. 3 PRESSURE PROBE POSITIONS AROUND ENGINE FACE

TEST NO. : 293.

36.9*130 APERTURE WITH PROFILED LIP

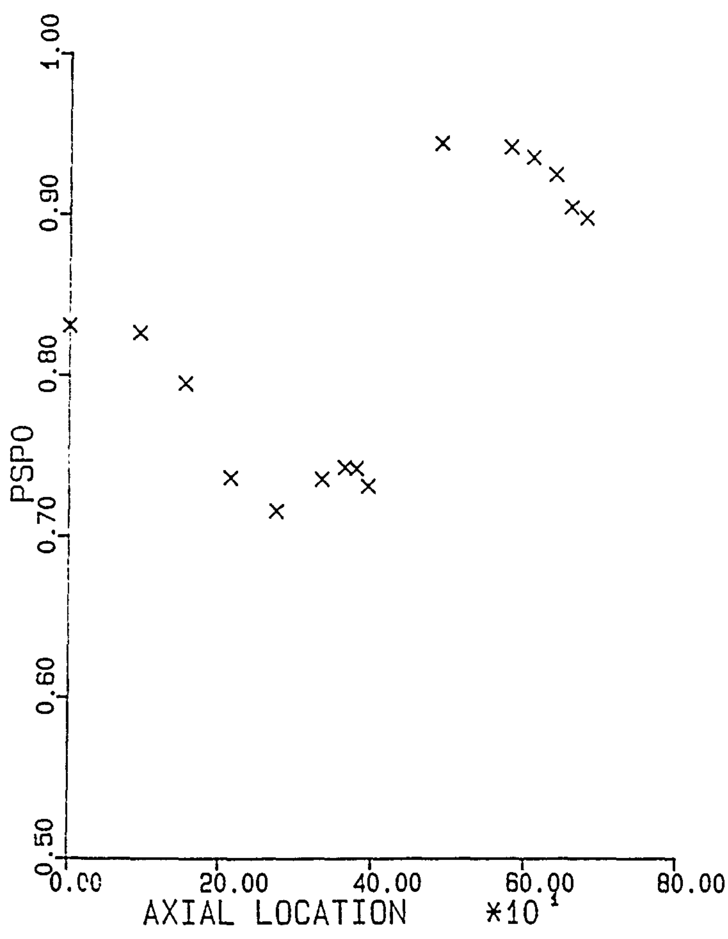


FIG. 4 GRAPH OF P_s/P_0 vs. AXIAL LOCATION (mm)

TEST NO. : 298.

PROFILED LIP - 30M/S ALPHA=0 BETA=0

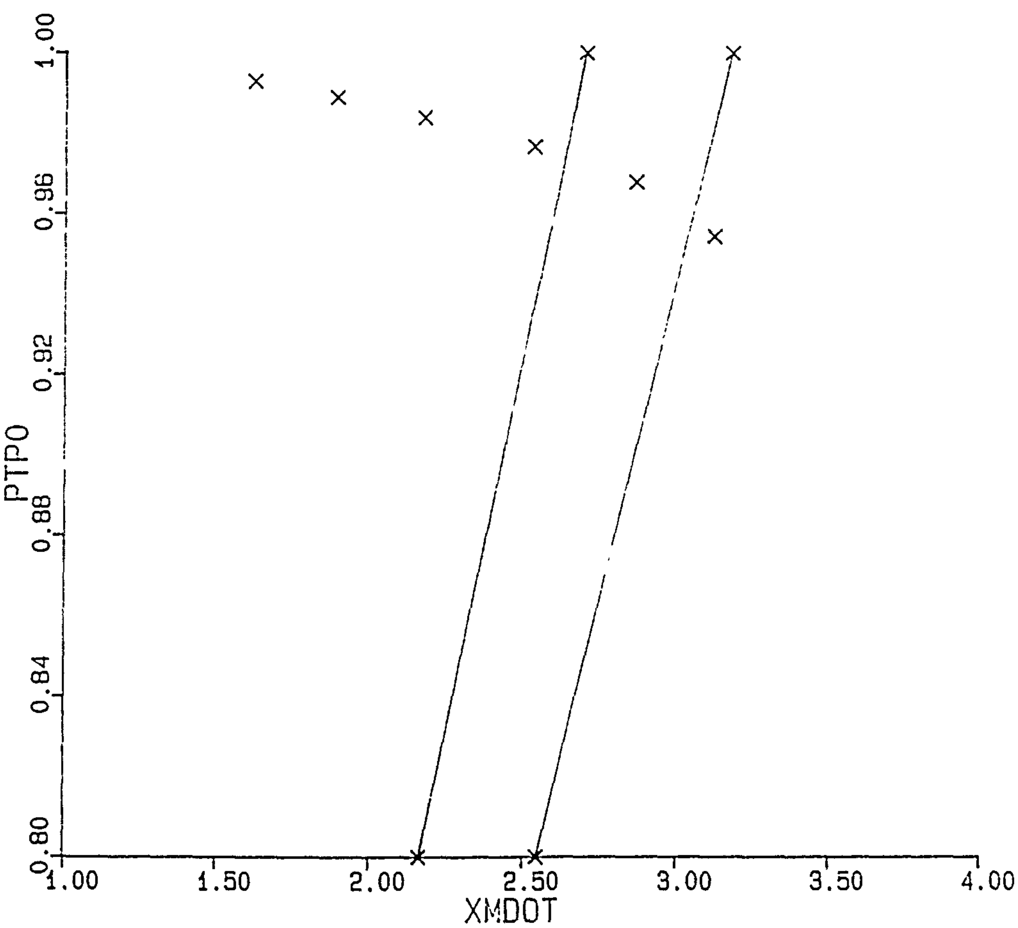
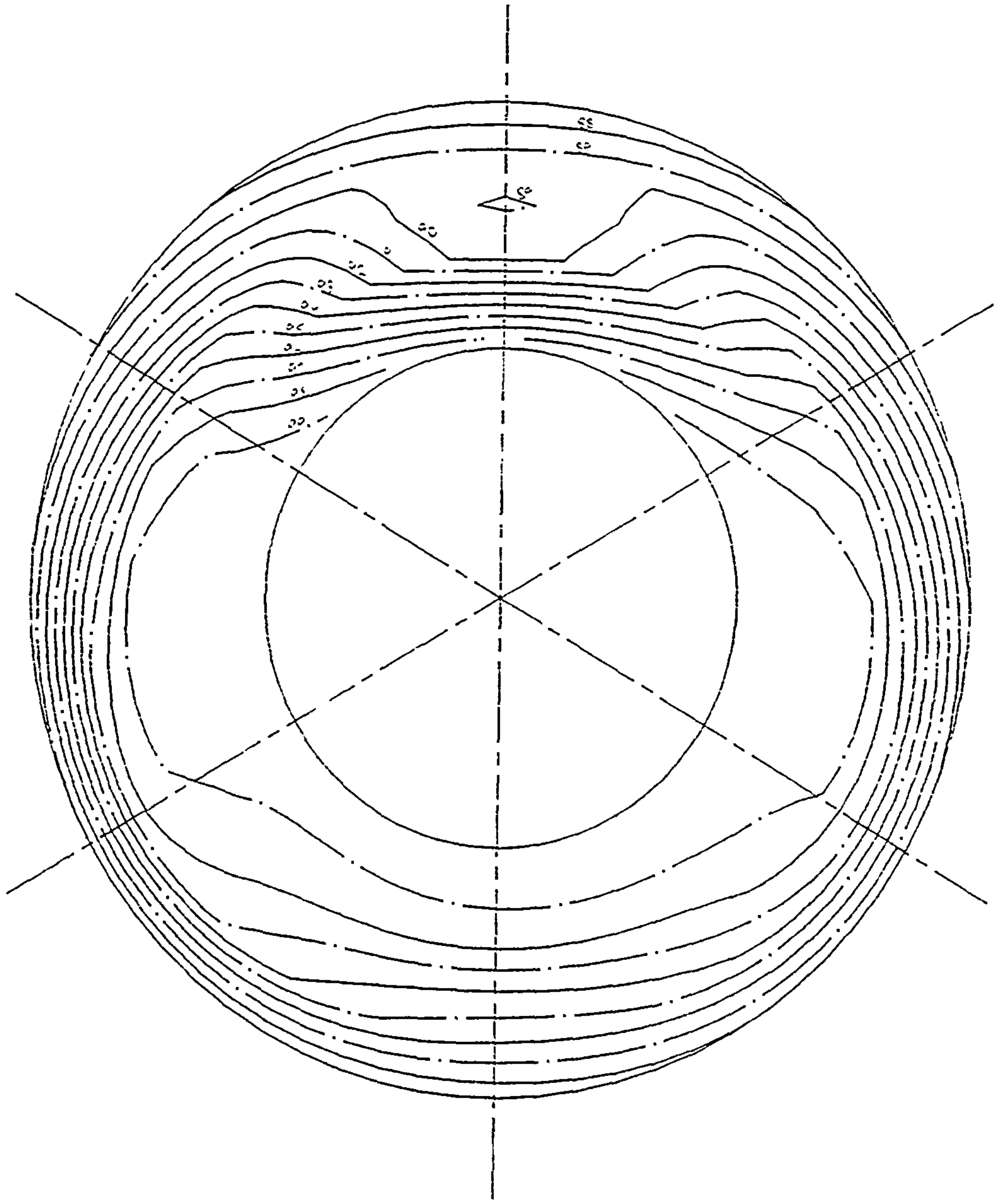


FIG. 5 GRAPH OF $(P_t/P_0)_{avg}$ vs. $\dot{m}\sqrt{T_a}/P_a$



TEST NO. : 293.
VEL = 32.9 XMDOT = 3.122
ALPHA = 0.0 BETA = 0.0
PTAV = 0.954 PT60 = 0.909 DC60 = 0.365
PROFILED LIP - MASS FLOW 5 - 30 M/S

FIG. 6 P_t/P_0 PRESSURE CONTOUR PLOT AT ENGINE FACE

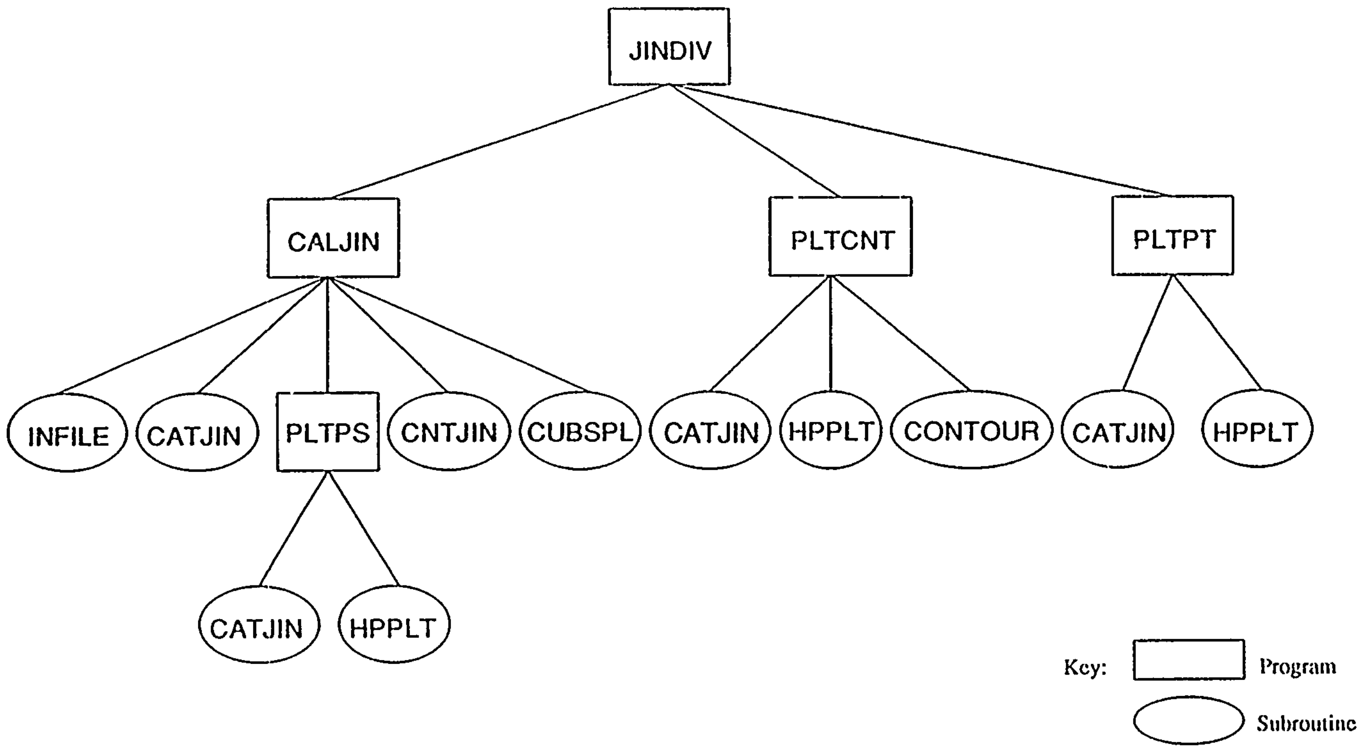


FIG. 7 OVERVIEW OF PROGRAM STRUCTURE

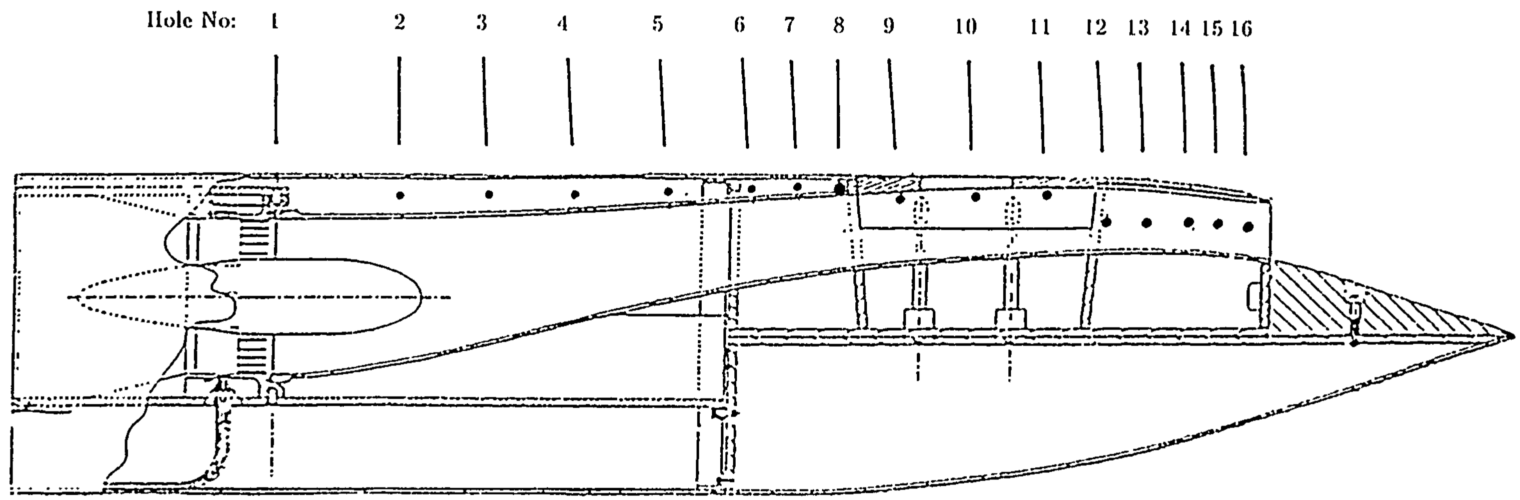


FIG. 8 POSITION OF STATIC HOLES ON JINDIVIK MODEL

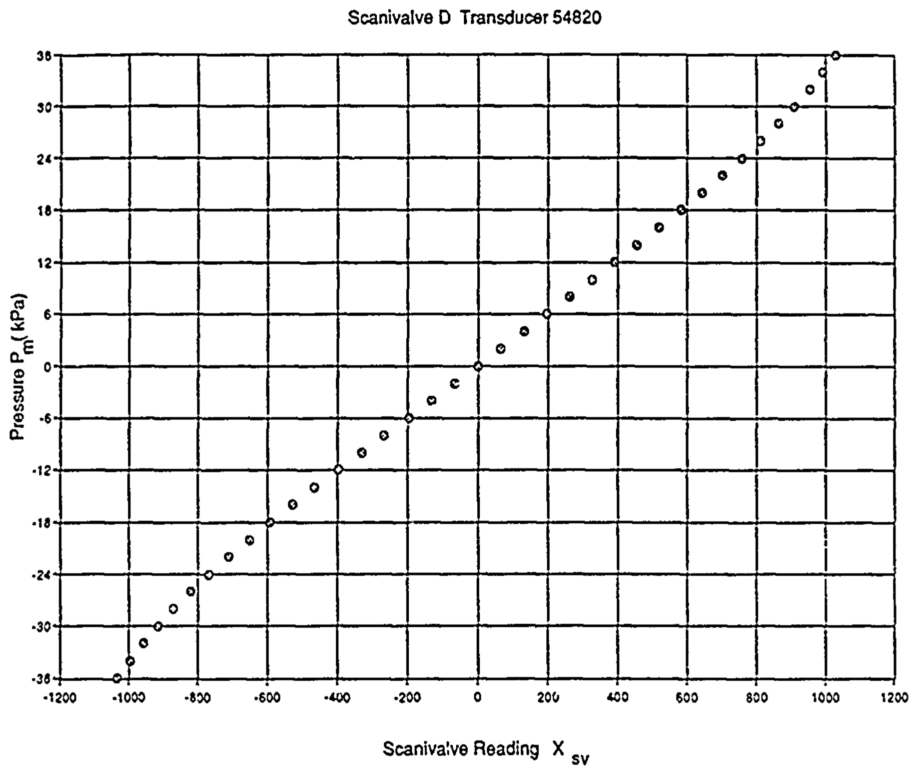


FIG. 9 GRAPH OF SCANIVALVE PRESSURE P_m vs. SCANIVALVE READING X_{sv} FOR SCANIVALVE D WITH TRANSDUCER 54820

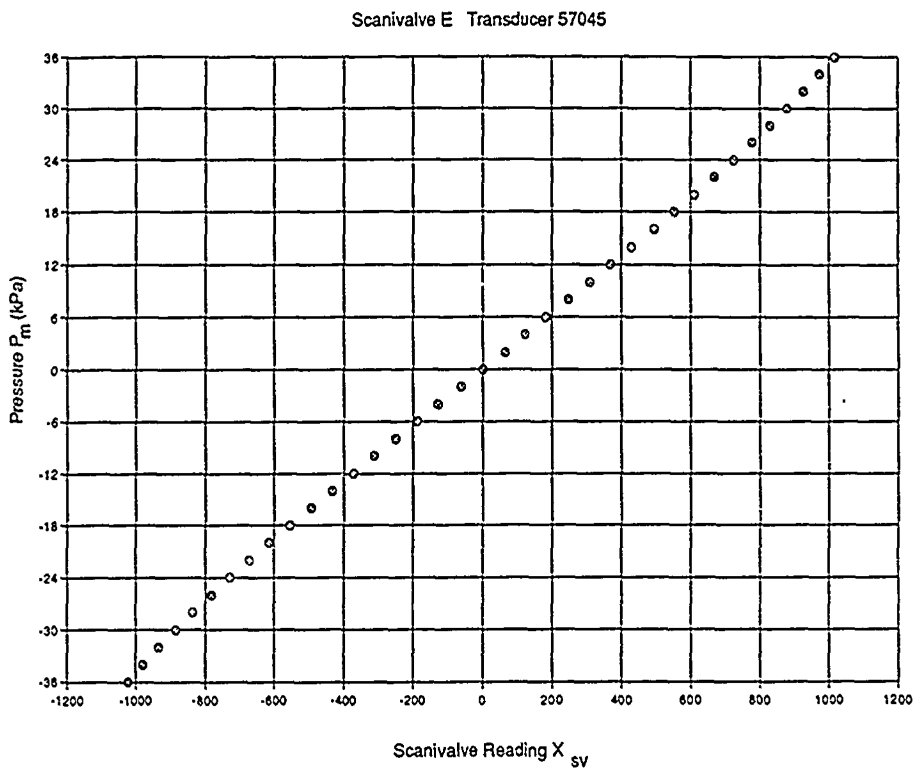


FIG. 10 GRAPH OF SCANIVALVE PRESSURE P_m vs. SCANIVALVE READING X_{sv} FOR SCANIVALVE E WITH TRANSDUCER 57045

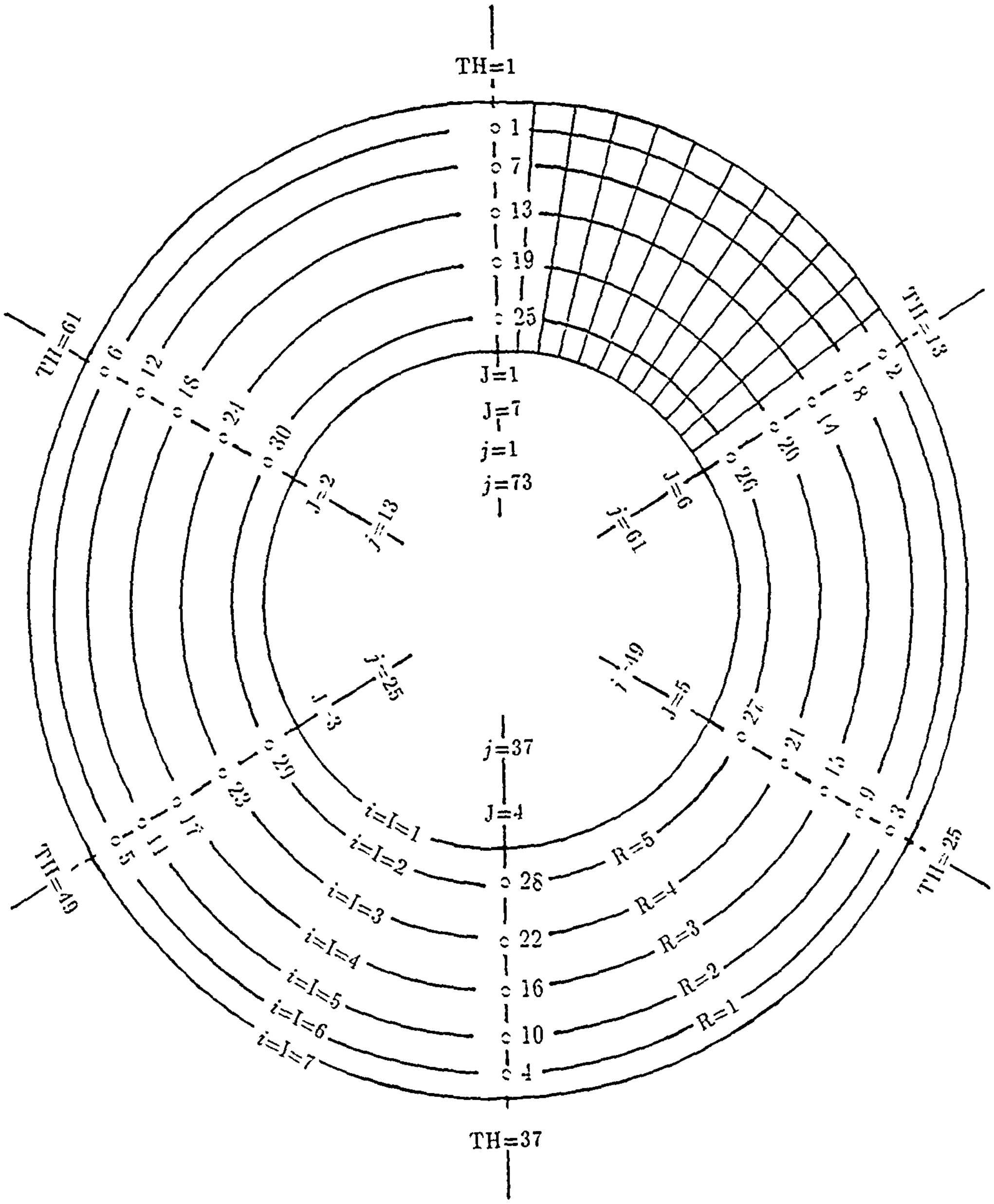


FIG. 11 COMPARISON OF GRIDS FOR VARIABLES GDPTP0(R,TH), PTMIN(I,J), PTM(*i*,*j*)

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16. ABSTRACT

A FORTRAN computer program was written for post processing low speed wind tunnel pressure data acquired from the Jindivik auxiliary intake model. The scanivalve pressure measurement system was used with the standard data acquisition system to read the pressures from 59 pressure tappings. The program analysed raw data and produced numerical and graphical output. These consisted of static pressure graphs, mass flow graphs and total pressure contour plots.

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