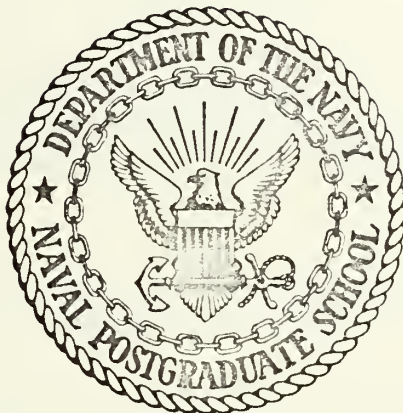


ON-LINE DATA ACQUISITION AND
INSTRUMENTATION IMPROVEMENTS FOR THE
TRANSONIC TURBINE TEST RIG

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NAVAL POSTGRADUATE SCHOOL

Monterey, California



THESIS

On-Line Data Acquisition
and
Instrumentation Improvements
for the
Transonic Turbine Test Rig

by

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March 1972

Approved for public release; distribution unlimited.

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and
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Transonic Turbine Test Rig

by

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1

ABSTRACT

The Transonic Turbine Test Rig located in the Turbo-Propulsion Laboratory of the Naval Postgraduate School is used to analyze axial turbine stage performance. The Test Rig is designed to separately measure stator and rotor losses without the use of velocity or pressure surveys. Various stator and rotor blade types can be investigated over wide ranges of axial and radial blade clearances in addition to variations in normal operating parameters.

This paper describes the development of on-line data acquisition and analysis for the Turbo-Propulsion Laboratory in conjunction with the Turbine Test Rig. It also describes various improvements to the Turbine Test Rig itself.

TABLE OF CONTENTS

I.	NATURE OF THE PROBLEM -----	7
II.	EQUIPMENT -----	9
	A. TRANSONIC TURBINE TEST RIG -----	9
	B. TURBINE MODIFICATIONS -----	9
	C. DATA ACQUISITION SYSTEM -----	12
III.	GENERAL ACQUISITION AND REDUCTION PLANNING -----	15
IV.	RESULTS AND RECOMMENDATIONS -----	19
	A. RESULTS -----	19
	B. RECOMMENDATIONS -----	22
APPENDIX A	FORTRAN SYMBOLS -----	48
APPENDIX B	TTR OPERATING PROCEDURES -----	51
APPENDIX C	SAMPLE TTR ON-LINE REDUCTION RUN -----	62
APPENDIX D	ANALYTIC DETERMINATION OF CLOSURE PLATE TORQUE -----	66
APPENDIX E	REDUCTION THEORY AND COMPUTER PROGRAMS -----	68
	1. Flow nozzle calibration program -----	72
	2. Labyrinth leak rate calibration program -----	81
	3. On-Line data reduction program -----	89
	4. Output plot program -----	108
LIST OF REFERENCES	-----	111
INITIAL DISTRIBUTION LIST	-----	112
FORM DD 1473	-----	113

LIST OF TABLES

I.	TTR Sample Reduction Results-----	37
B-I.	TTR Instrumentation, Calibration and Units -----	54
E-I.	Flow Nozzle Calibration Results -----	77
E-II.	Labyrinth Leak Calibration Results -----	84

LIST OF ILLUSTRATIONS

1.	Piping Installation, Transonic Turbine Test Rig -----	24
2.	Floating Stator Assembly -----	25
3.	Transonic Turbine Test Rig -----	26
4.	Flow Straightener and Plenum Baffle Installation -----	27
5.	Turbine Blading Arrangement -----	28
6.	Stator Support Collar -----	29
7.	Stator Support Collar Installation -----	30
8.	Data Acquisition Equipment -----	31
9.	Referred Stator Torque vs. Referred RPM -----	32
10.	State Efficiencies vs. Isentropic Head Coefficient -----	33
11.	Stage Efficiencies vs. Referred RPM -----	34
12.	Stage Efficiencies vs. Stator Pressure Ratio -----	35
13.	Turbine and Shroud Details -----	36
E-1.	Flow Nozzle Calibration Plot -----	78
E-2.	Labyrinth Leak Calibration Plots (2) -----	85
E-3.	TTR On-Line Data Reduction Flow Chart -----	88

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I. NATURE OF THE PROBLEM

The Transonic Turbine Test Rig is a single stage axial flow machine. The turbine uses air from a remote compressor as a working fluid to analyze various stator and rotor designs and configurations. It may be operated over wide ranges of velocities to include transonic rotor inlet velocities.

The test rig was designed by Dr. M.H. Vavra of the Department of Aeronautics, Naval Postgraduate School, Monterey, California. The great value of the Transonic Turbine Test Rig, or TTTR, is that it permits one to analyze the performance of a turbine stage including the separate determination of stator and rotor efficiencies without the need for flow surveys.

Unfortunately, a great deal of data must be reduced in using the turbine. A normal TTTR run consists of roughly ten points. Each point contains 30 temperatures, pressures, forces or frequencies. The reduction of this data by desk calculator requires a minimum of two man-hours per point. (Initial runs by the author and other students required closer to ten man-hours per point.) Manual data recording for use with a regular FORTRAN program was not only slow but entailed key punching the data to cards for a data deck.

Manual data acquisition for the TTTR frequently resulted in an entire run being useless due to undetected instrumentation problems. Not only was one run wasted but the machine could not be rerigged for the next run until the preceding data proved valid. Since each TTTR run requires two technicians and a data recorder the loss of time and manpower associated with manual data acquisition is clearly unacceptable.

Thus, it was decided that the TTTR should be provided with digital on-line data acquisition and reduction.

Although initial use of the on-line data system involves only the TTTR, the system is a general pressure, temperature, force and frequency acquisition system with broad potential use for all the test equipment in the Turbo-Propulsion Laboratory.

In addition to the above, the Transonic Turbine Test Rig has occasionally produced inconsistent data. In an effort to solve this problem modifications to the TTTR have been continually implemented since its construction, the latest being those of Esdaile [Ref. 1]. As of July 1971 the primary instrumentation problems remaining appeared to center around the measurement of the stator torque. Two of the most probable causes of the torque inaccuracy were thought to be:

1. Temperature gradients in the working fluid which, through uneven thermal expansion of the stator support and stator torque flexures, induced a torque moment on the stator.
2. Tangential velocities introduced into the stator from the plenum causing an induced torque from the tangential change of momentum as the flow entered the stator blades.

II. EQUIPMENT

A. TRANSONIC TURBINE TEST RIG

The turbine receives air from a remotely located Allis-Chalmer VA-312 industrial compressor. In the TTTR test cell the air may be divided. Part of the flow is through the turbine and part through a hood exhauster jet (Figure 1). The exhauster is used to evacuate a sealed hood over the turbine in order to achieve high stage pressure ratios. Stator inlet to rotor exhaust pressure ratios up to six to one are obtainable in the hooded configuration. Pressure ratios of three to one are available with the turbine exhausting to the atmosphere.

Within the turbine, air flow enters the stator plenum radially and exits axially through the stator (Figures 2 and 3). The free floating stator assembly is centered in labyrinth seals by bearings fore and aft which transmit axial and tangential forces to the respective force measuring devices.

The rotor drives a commercially built air brake dynamometer. Rotor axial clearance is adjusted by sliding the rotor shaft in its bearing support. Radial rotor tip clearance is changed by use of tip shroud inserts which fit into the stator assembly.

Detailed turbine installation is described by Eckert [Ref. 2] and amplified by Lenzini [Ref. 3] and Esdaile [Ref. 1].

B. TURBINE MODIFICATIONS

The possibility of a stator inlet flow swirl is described by Esdaile [Ref. 1]. Stator plenum and stator inlet surveys by the author show that a swirl did exist at very high volumetric flow rates. A honeycomb flow straightener substituted for the stator blades produced a small but

consistent stator torque. However, during normal runs with the stator installed the pressure ratio will be much greater than that obtainable with the honeycomb. This will reduce the volumetric flow rate leading to a decrease of one-half to one-third in the velocities within the stator casing. Although this reduction in velocities will decrease any induced stator moments the following changes were made (see Figure 3):

1. A stator plenum inlet flow straightener was installed. The flow straightener was composed of close packed 1/2" thin wall tube extending slightly more than eight pipe diameters upstream of the inlet. The upstream side of the flow straightener was covered with fine copper screen (mesh #60) to reduce inlet pressure gradients radially and help prevent turbine damage from foreign objects.
2. Flow baffles were installed inside the stator plenum casing and are arranged axially at the two, six and ten o'clock positions (Figure 4). The purpose of the baffles is to reduce tangential swirl velocities within the plenum.
3. In the center portion of the turbine plenum the large drilled sleeve was entirely removed and replaced by thin rods covered with three layers of fine copper screen (mesh #60). This was done to introduce a pressure drop so that the plenum would be at a more constant higher pressure (Figure 3). Hopefully, this would result in a more even radial flow into the floating stator assembly.
4. On the inner or floating stator inlet sleeve the inlet holes were increased from one inch to one and one quarter inches in diameter to help maintain the now equalized flow.

The problem of thermal expansion and stator torque is described by Esdaile [Ref. 1]. Basically, the warmer air inside the stator caused the horizontal flexures and stator to expand more or less than the support frame. This differential expansion produced a moment which was measured with the stator torque.

In order to eliminate the thermal expansion problem a new stator support assembly was installed (Figures 5,6, and 7).

The stator support must center the stator in the labyrinth seals and be completely free to stator rotational moments. This was accomplished using a large diameter, thin line ball bearing and a radial expansion collar supported on rigid horizontal brackets (Figure 6). The bearing rides between the inner ring attached to the stator and middle or expansion ring. The expansion ring is centered and supported by four radial steel pins connecting the outer ring. The pins are ream fitted to provide radial centering, allow radial thermal expansion and transmit axial forces to the stator cradle frame through the support brackets.

In order to determine the stator labyrinth seal leak rate, pressure must be measured on each side of the seal. The stator plenum pressure had previously been used for the inside pressure. Because of the expected pressure drop across the stator plenum screens new static pressure taps were drilled through the labyrinth castings. The labyrinth leak rate was then calibrated as a function of the new pressures.

During disassembly of the stator, particle accumulations were noted on the inner walls of the stator case. These buildups followed the support struts for the stator closure assembly indicating probable flow wakes. These wakes were verified by later circumferential velocity surveys. The stator inlet total pressure and temperature probes, which were originally located downstream of these struts, have been relocated. The present

arrangement consists of three Kiel type total pressure probes and two semi-hooded total temperature, iron-constantan thermocouples. The pressure probes are located at the twelve, four and eight o'clock positions looking downstream. All three probes are located radially near the mean blade radius. A radial total pressure survey was conducted in the twelve o'clock probe position. The survey probe was then set to read a mean pressure (very near the mean radius) and the stator inlet probes adjusted to correspond with the survey probe readings.

The two stator inlet total temperature thermocouples are of the semi-hooded type and have a probe shaft of 1/16 inch diameter. These thermocouples should produce negligible wakes and are calculated to be accurate to .09 degrees Fahrenheit under expected operative conditions. The thermocouples are located at the two and ten o'clock positions and extend to the mean stator blade radius.

C. DATA ACQUISITION SYSTEM

Data acquisition in the Turbo-Propulsion Laboratory is arranged to utilize a commercially produced, B & F Model SY133, Pressure Data Acquisition System (Figure 8). The laboratory is instrumented so that the B & F data system may be easily and rapidly coupled to either the Allis-Chalmers compressor, the TTTR test cell, the Transonic Compressor test cell or the model test room. Each of these test cells has available 48 pressure lines, 12 thermocouple leads, 10 individually conditioned (each channel has its own balancing bridge and power supply) transducer/strain gage type leads and 10 frequency leads.

The pressure lines connect to mercury manometer banks in the control room and parallel into a pressure selector valve. This valve controls which cell inputs to the B & F system. The thermocouple, transducer/strain

gage and frequency leads enter the control room and are routed to rotary switches which connect the desired input cell to the B & F acquisition system.

In addition each cell has provisions for 12 bearing temperature monitors and 12 vibration pickups. These are read out in the control room as a safety monitor only and are not linked to the data acquisition system.

Detailed information for the B & F system is contained in the instruction manual [Ref. 4]. The B & F data equipment is designed as a general pressure, thermocouple, transducer, strain gage and frequency acquisition system. Two individually calibrated pressure scanning valves are used to read 48 pressures (24 each). Twenty thermocouple channels are available for millivolt outputs (although each cell has only 12 leads). A thermocouple reference is maintained at 32°F using a Pace Engineering Company Electronic Reference Junction. Ten individually conditioned bridge channels with their own excitation power are available for either pressure transducer or strain gage information. Ten channels are available for frequency acquisition. In addition a row of ten thumb wheels is used to record desired run constants.

The B & F system will scan the data inputs and display each channel in its scan turn. Each channel value is then converted to a digital signal. The digital signal is coded using the American Standard Code for Information Interchange (ASCII) eight level code for transmission to the teletype. The teletype prints and tape-punches the channel numbers and their corresponding values.

The teletype is a Teletype Corp. Model 33 with a minor modification to allow computer control of the tape reader [Ref. 5]. The teletype terminal uses a regular telephone and a Livermore Data Systems, Inc.,

acoustically coupled data set to gain on-line access to the IBM 360/67 computer on the main campus of the Naval Postgraduate School [Ref. 6].

III. GENERAL ACQUISITION AND REDUCTION PLANNING

Most Turbo-Propulsion Laboratory data consists of pressures, temperatures, forces and frequencies. The experimental procedure will generally be:

1. Set up experimental equipment and calibrate instrumentation.
2. Acquire and store raw data.
3. Reduce data.
4. Record detailed output and present the results of primary importance.

The final results will normally be expressible using tables or graphs.

Through use of pressure transducers, thermocouples, strain gages, force capsules, etc., all of the physical data may be acquired as either digital voltages or frequencies on the B & F data acquisition system. Data may be stored using teletype punch tape, computer magnetic tape or computer generated punch cards.

The manipulation, presentation and storage of the final results may be as flexible and varied as the experimenter desires. Primary guidelines are best obtained from the computer center User's Manual [Ref. 7] and the computer center consultants. The present system utilizes the time sharing CP/CMS program in conjunction with the IBM 360 (see Appendix B).

The TTTR on-line data reduction program makes use of the following options:

1. On line return of certain key results to check input data and help in readjusting equipment following each data point.

2. Complete result output for each run (this is the normal FORTRAN program output).
3. Punch card output to be used in conjunction with later operations. e.g., These cards are used as data in a normal FORTRAN program which plots the results using the CALCOMP plotters coupled to the IBM 360 computer. (This is necessary at present since the CP/CMS system is not linked to the plotters.)

In addition it is recommended that the following on-line, CP/CMS options be considered:

1. Program Editing

Editing of the reduction program using CP/CMS time sharing is considerable faster than punch card editing. A card deck may be entered on the CP/CMS tape and then edited or a complete program developed using time sharing [Ref. 7]. Editing may also be used to change parameters, constants, etc., during or between actual data runs.

2. Program Debugging

The CP/CMS system is designed to help in program debugging [Ref. 7]. The debugging procedure includes the ability to stop the program and examine numerical values anywhere during execution.

3. Error Analysis

The on-line system may be used to check the sensitivity of results to variations or errors in any of the input values. This is easily done by changing each data bit, one at a time, a certain percentage and checking the output results against a known or standard result.

For planning on-line data acquisition and reduction the following general organization is recommended:

1. Insure desired experiment is amenable to digital analysis with the physical data available.
2. Determine best instrumentation compatible with the experimental machine and the B & F data acquisition system. Consideration should be given to such things as:
 - a. Pressure Transducers
 - (1) Absolute Pressure vs. Gage Pressure
 - (2) Calibration and Units
 - b. Thermocouples; Millivolt to Degree Conversion
 - c. Forces; Strain Gage vs. Inductance Force CapsuleConsideration must be given to calibration and verification of instrumentation and the conversion of raw data to engineering units in the computer program. Remember that manual data may be entered by the experimenter if required.
3. Write reduction programs using either card punch, CP/CMS time sharing or both.
 - a. Use standard FORTRAN programming procedures.
 - b. Generous use of subroutines with a small, simple main program will make debugging, editing and use by others easier.
 - c. Polynomial approximations to correction factors, conversions or calibration functions may be easily generated using tabulated or experimental data and a standard polynomial curve fit subroutine from the computer library.
4. Determine the best method of storing information and presenting results. Again these functions are easily accomplished using subroutines. Storage and presentation may include the IBM remote terminals, magnetic tape with the CP/CMS system, punch cards printed output and CALCOMP plotter output.

For an example of how such a system would be set up, see the appendices which show the various flow charts, programs and detailed procedures applied to the TTTR. Detailed computer operations will be further covered in the User's Manual [Ref. 7] and the operator's manuals for the teletype [Ref. 5] and data acquisition system [Ref. 4].

IV. RESULTS AND RECOMMENDATIONS

A. RESULTS

Two runs were made using an ASME standard orifice to verify the nozzle flow coefficient. The flow coefficient agrees within 0.1% of that of Esdaile [Ref. 1] (see Appendix E).

Five runs were conducted to recalculate the labyrinth leak rate polynomial. Of these two developed unwanted leaks and one was discovered to have the stator misaligned in the labyrinth. Run number four was used to curve fit the referred leak rate and on run number five the temperature was varied to check the temperature correction. Excellent agreement was achieved between the analytic expression and the actual points (see Figure E-2).

Three runs were made to check the stator torque and perform stator plenum and stator inlet surveys with a honeycomb flow straightener installed in place of the stator blades. Two of these runs were prior to installation of the flow baffles and one after the baffle installation. These runs were conducted with the torque calibration weights attached to approximate the expected stator torque of a data run. Due to the low pressure ratio across the honeycomb flow straightener a high volumetric flow rate existed during these surveys. The results indicate that at high volumetric flow rates a small swirl did exist but was significantly reduced by the plenum baffles. A small but consistent torque increase was evident as the mass flow rate increased from 1.0 to 3.0 lbm/sec. This torque was reduced with installation of the flow baffles to roughly 0.8% of the expected stator torque during normal operation.

It is felt that with the greatly reduced volumetric flow rates of normal operation this torque will further decrease to a negligible magnitude. Also during these runs the stator torque was tare loaded to mid-range and its sensitivity checked using a 0.1 lb. increment deadweight. In all three runs the torque was stable, linear and sensitive to within 0.1 in-lbf (a normal run would measure roughly 15.0 ft-lbf of stator torque). Flow temperatures were also varied and no thermal effects were noted on the stator torque.

In December 1971 final instrumentation and calibration were effected and the first of eight operating runs conducted. Of the eight runs, two were conducted using manual data, one was conducted using manual and punch tape data and five using punch tape entirely. Due to instrumentation problems only one manual run and two punch tape runs were considered valid.

From the valid runs the following turbine results are noted:

1. Stator torque, stator axial force and dynamometer torque readings all returned to their zero's (to 0.5% of their operating values) upon shut down. During operation all three force capsules were responsive and stable to within 1.0%.
2. The stator torque plotted against the referred RPM was linear indicating good torque measurement (See Figure 9).
3. The closure plate axial force readings from the flexure strain gages did not return to zero upon shut down. A residual reading of roughly 10.0% of the operating force remained. Furthermore, the strain gage force did not agree with the force calculated using the closure plate and hub pressures. This observation appears to differ with the findings of Esdaile [Ref. 1] who reported close agreement between the two methods of determining the closure plate axial force.

4. The total-static and total-total stage efficiencies were within the expected range and repeated well for all runs when plotted against the isentropic head coefficient, referred RPM and pressure ratio (see Figures 10, 11, and 12).
5. There appeared to be errors in the stator and rotor efficiencies. In determining these efficiencies it is necessary to know the stator exit velocity. The stator exit velocity is determined using, among other things, the axial force on the stator. To determine the stator axial force one must know accurately the stator exit tip and hub pressures, the rotor shroud pressures and the closure plate axial force (see Figure 13).

The on-line data system worked quite well and the flexibility of the CP/CMS system far exceeded the author's expectations. Maintenance of the B & F Data Acquisition System created some problems due to a lack of experienced electronics technicians within the Department of Aeronautics.

Some delays were experienced in the reduction phase due to the flow of the reduction program (see Figure E-3). The program requires that all data points of a run be read prior to the detailed reduction. If one of these points contained an error (possibly from misreading the punch tape or from a bad manually punched value) the program would generally detect the error (i.e., square root of a negative argument) and stop execution. The operator would then be required to correct the error and re-enter the entire run data tape. This is a minor problem and by using care in manual data entry and a relatively small number of data points per run should not cause serious delays.

In conclusion:

1. The on-line data acquisition and reduction system is operational and in conjunction with the CP/CMS system greatly enhances the utility of the Turbo-Propulsion Laboratory.
2. The TTTR stator torque problem has been corrected.
3. The determination of the TTTR stator axial force needs to be improved. This problem appears to stem from the inability to accurately measure one or more of the rotor shroud pressures, the stator exit tip and hub pressures or, most importantly, the closure plate axial force. (See Table I for a detailed output from a representative run.)

B. RECOMMENDATIONS

It is recommended that use of the on-line data system be continued within the Turbo-Propulsion Laboratory. Continued use of this system by persons with reasonable computer ability will increase its flexibility greatly.

It is recommended that a careful inspection of the TTTR closure plate axial force strain gages and pressure ports be conducted. Since the closure plate torque is no longer required a redesign of the closure plate flexures might be considered if further difficulty is encountered in measuring the closure plate axial force. The readings and positions of the stator exit hub and tip pressures and the rotor shroud pressures should be verified. Multiple pressure ports for each pressure measurement should be used whenever possible and checked against each other to detect errors or leaks. Although good total stage analysis is presently available, a recalibration of the axial force flexures on the closure plate

and a verification of the various axial forces should be conducted prior to attempting further separation of losses between the stator and rotor.

Finally, consideration should be given to development of a FORTRAN subroutine to be used as a reduction program standard data input subroutine. Such a subroutine could be used to read the B & F generated tape and store the data in arrays using the channel numbers for an index. The user could then call these data by channel number. Such a standard subroutine would be available to use in any data reduction program and would further standardize the B & F data acquisition procedure (the present TTR input subroutine is admittedly somewhat awkward and restrictive). This standard input subroutine would save time in writing reduction programs for new test equipment and increase the flexibility of the on-line data reduction system.

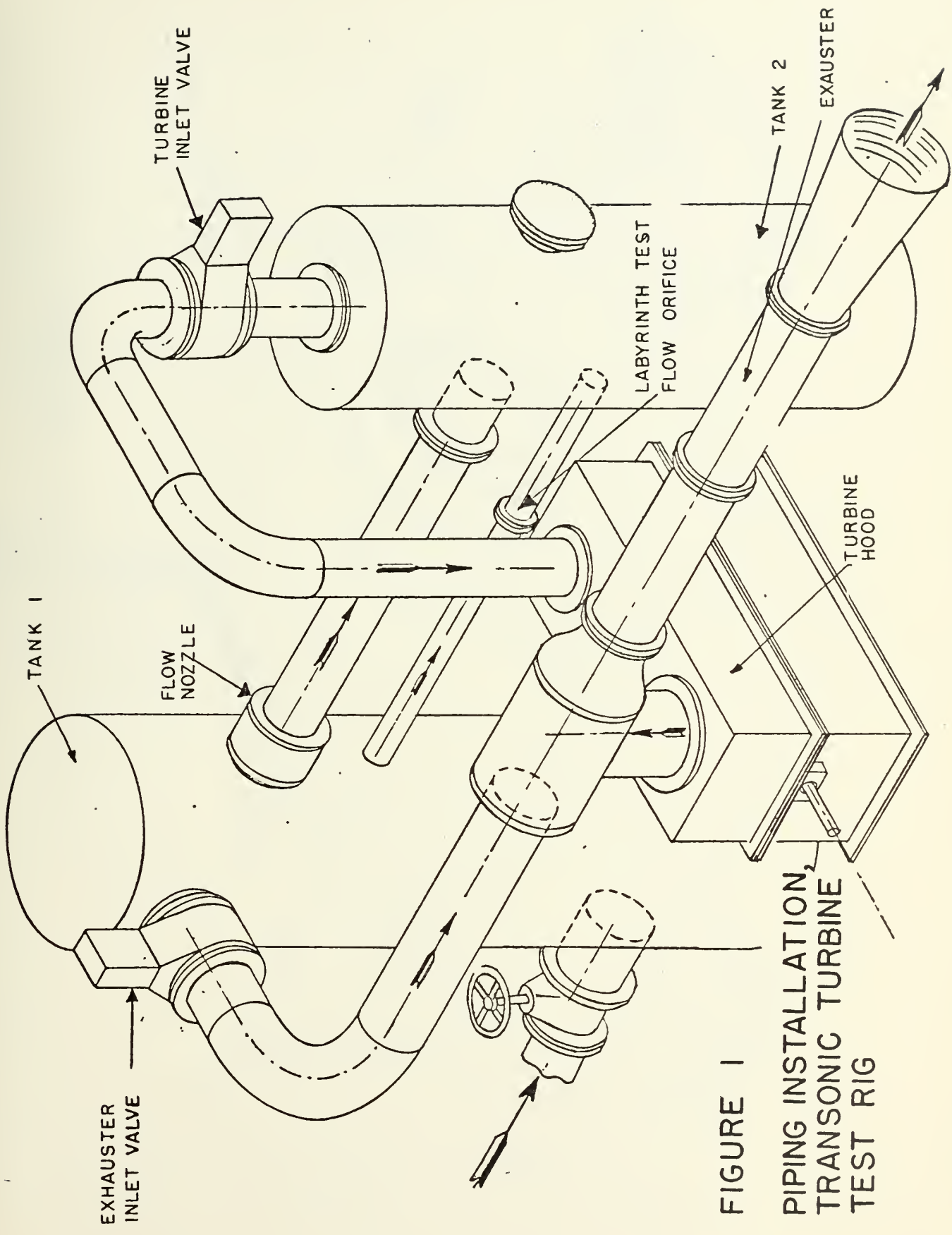


FIGURE 1
 PIPING INSTALLATION,
 TRANSONIC TURBINE
 TEST RIG

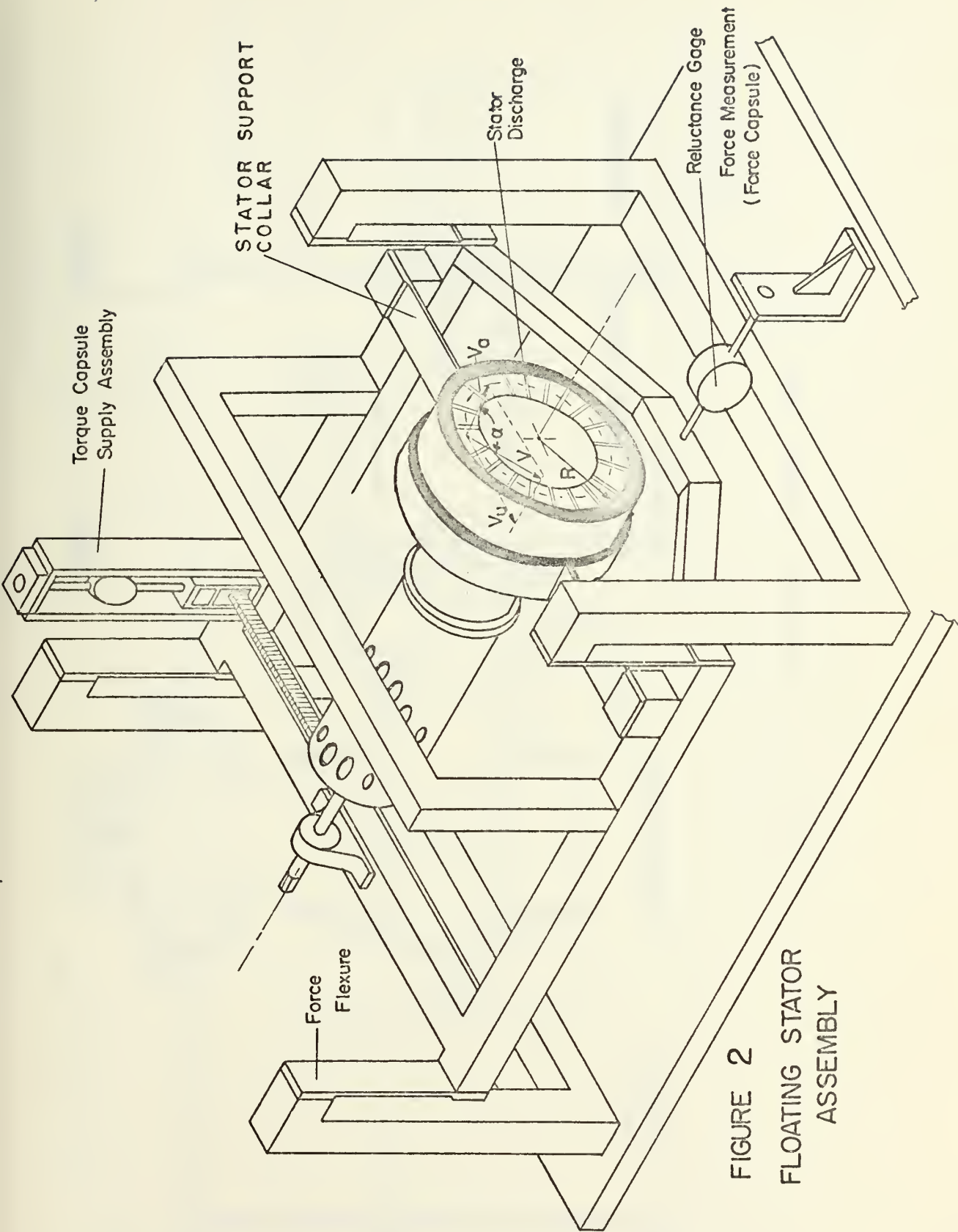


FIGURE 2
 FLOATING STATOR
 ASSEMBLY

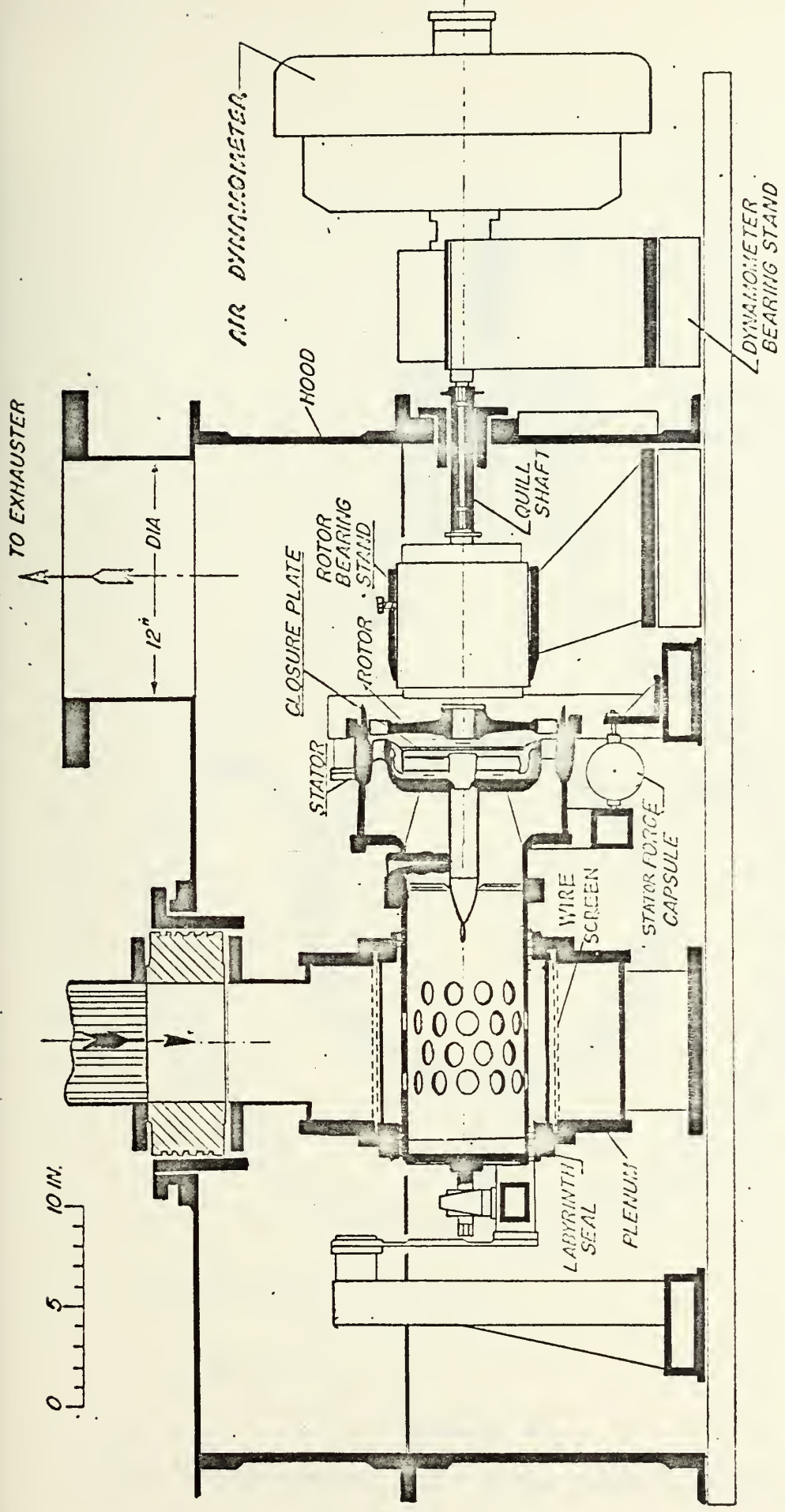
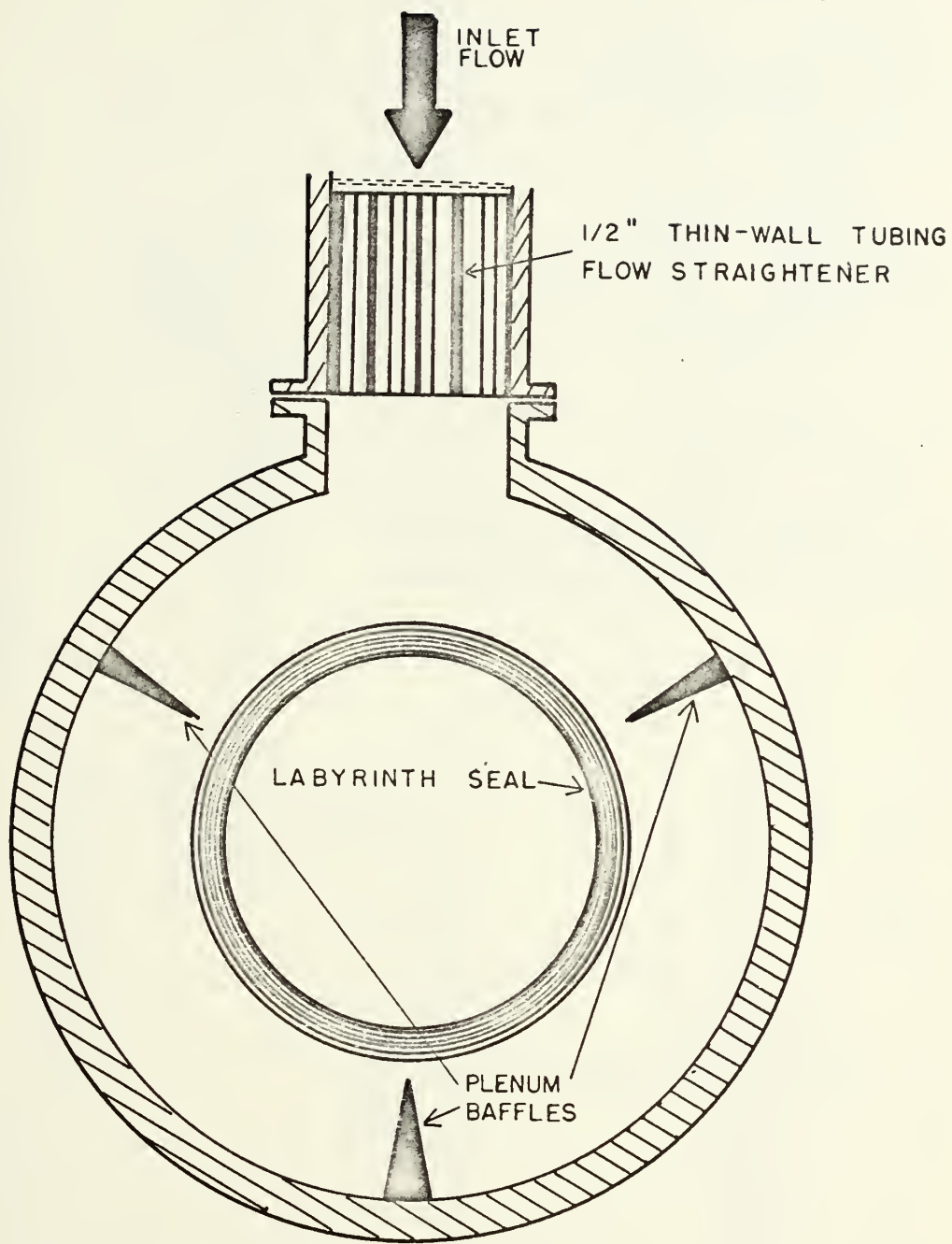


FIGURE 3 TRANSONIC TURBINE TEST RIG



VIEW LOOKING UPSTREAM

FIGURE 4
FLOW STRAIGHTENER AND PLENUM BAFFLE INSTALLATION

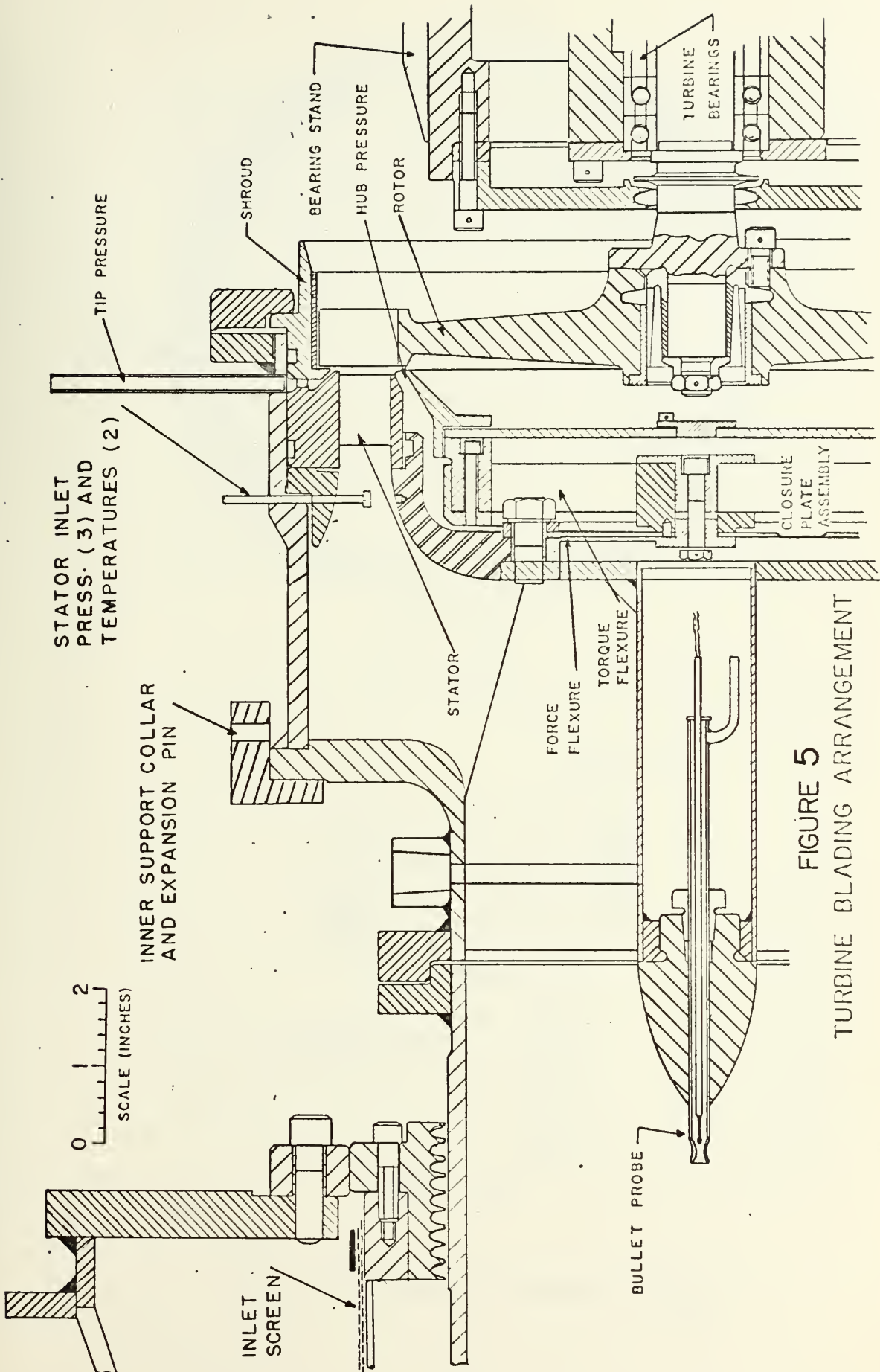
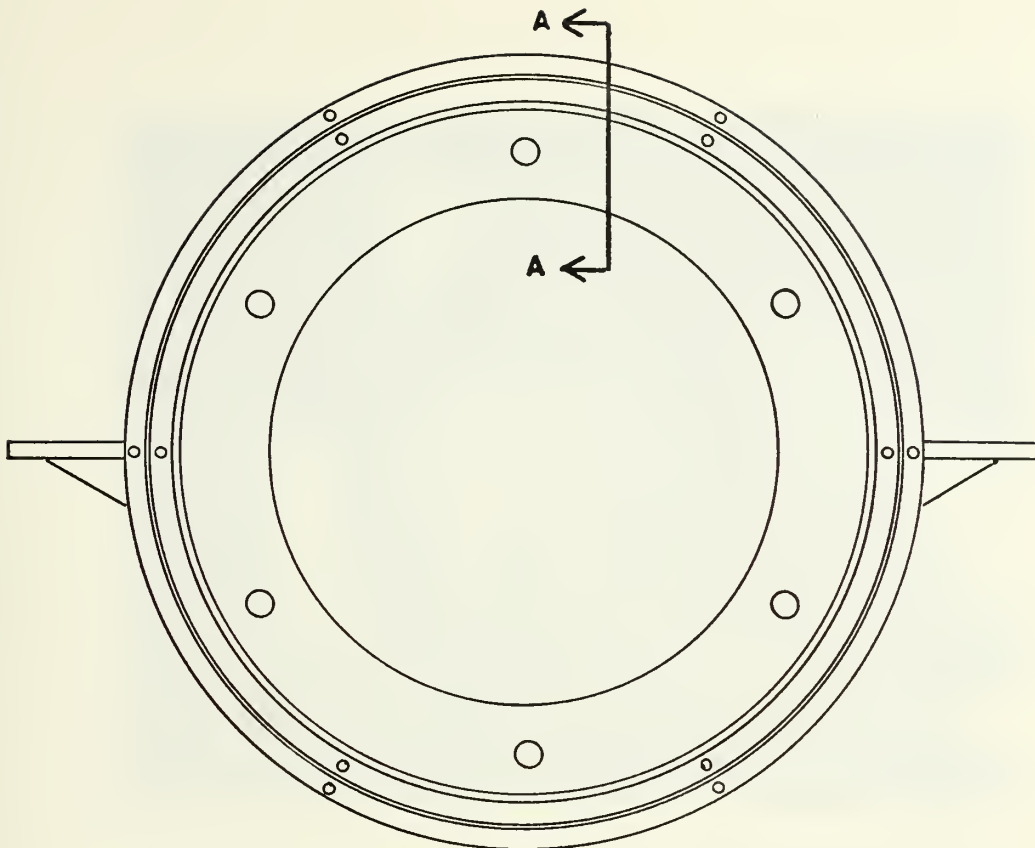
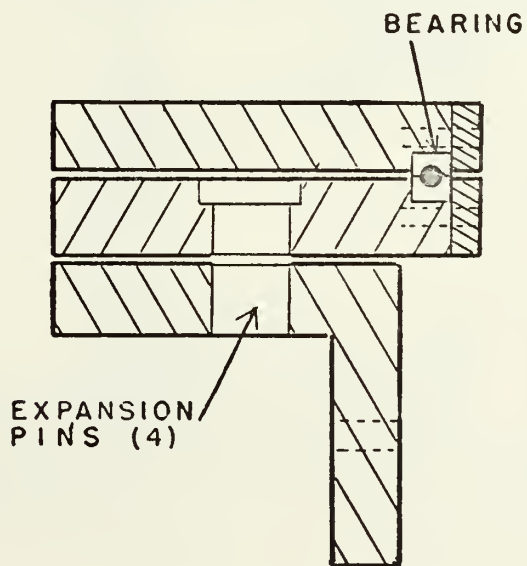


FIGURE 5
TURBINE BLADING ARRANGEMENT



FRONT VIEW



VIEW A-A

FIGURE 6 STATOR SUPPORT COLLAR

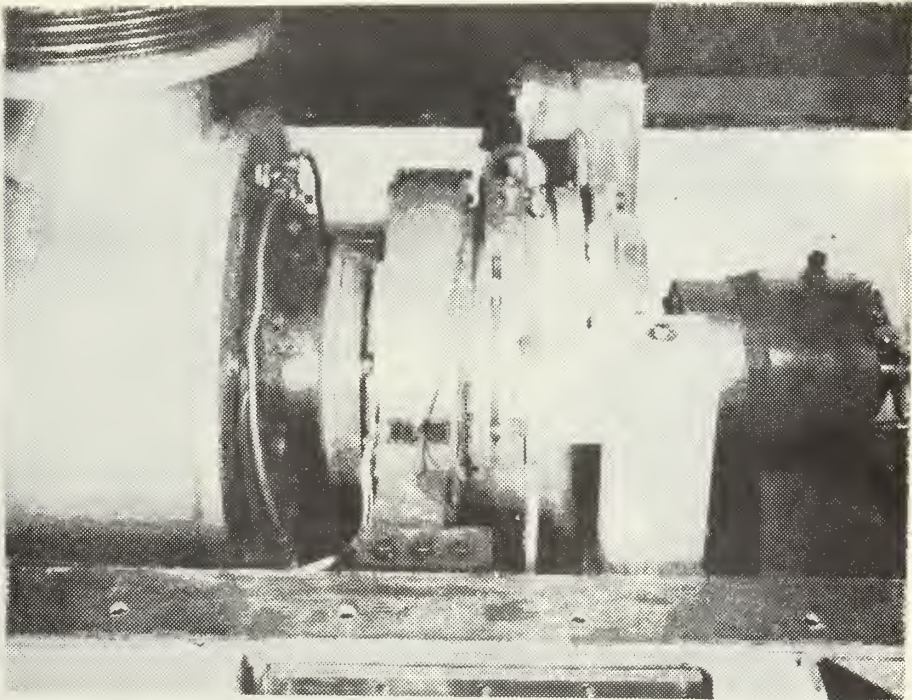
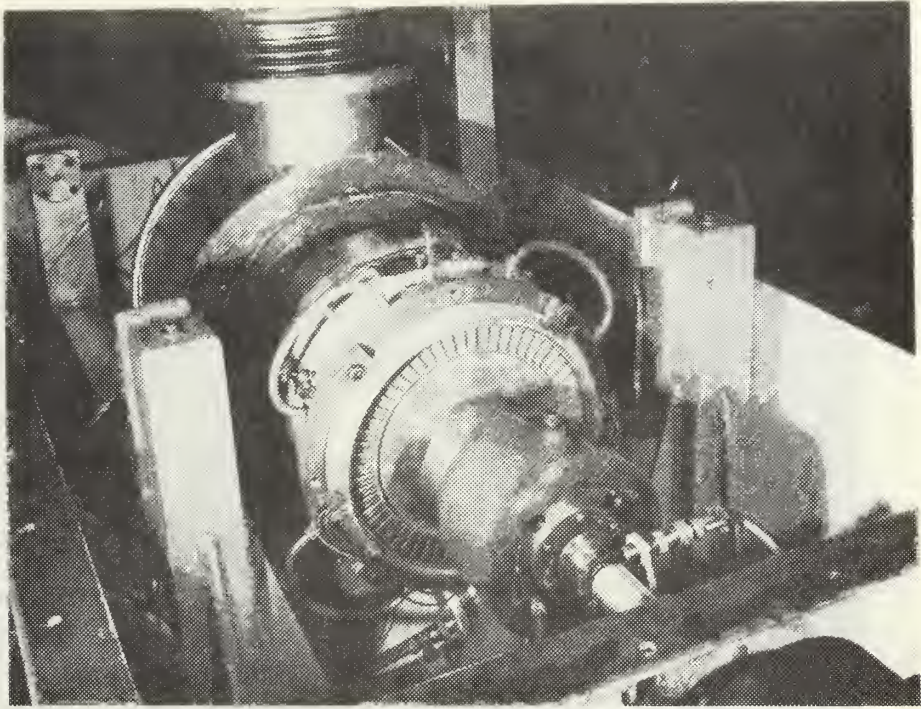


Figure 7. Stator Support Collar Installation.

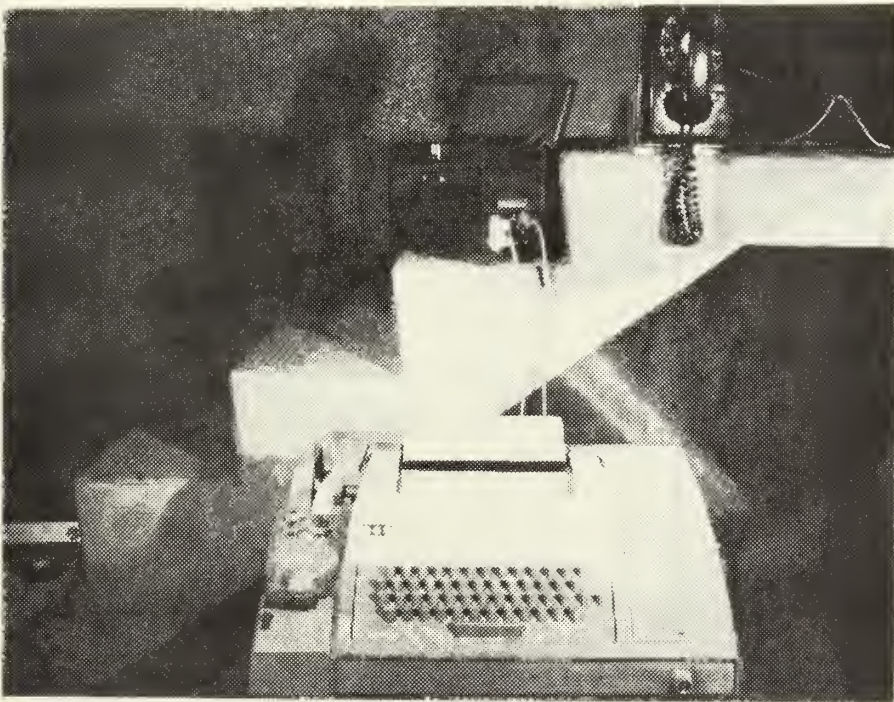
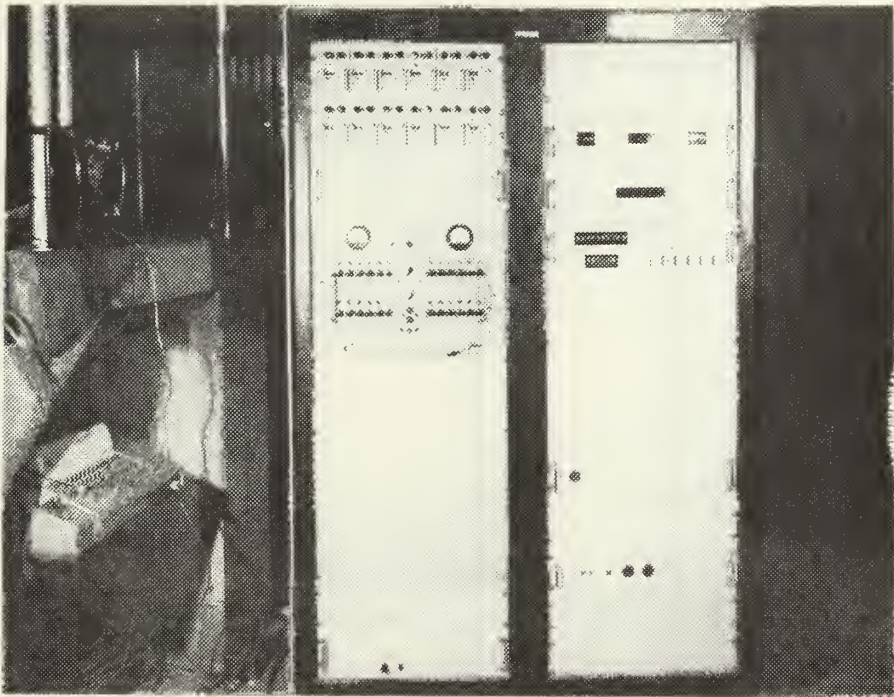


Figure 8. Data Acquisition Equipment.

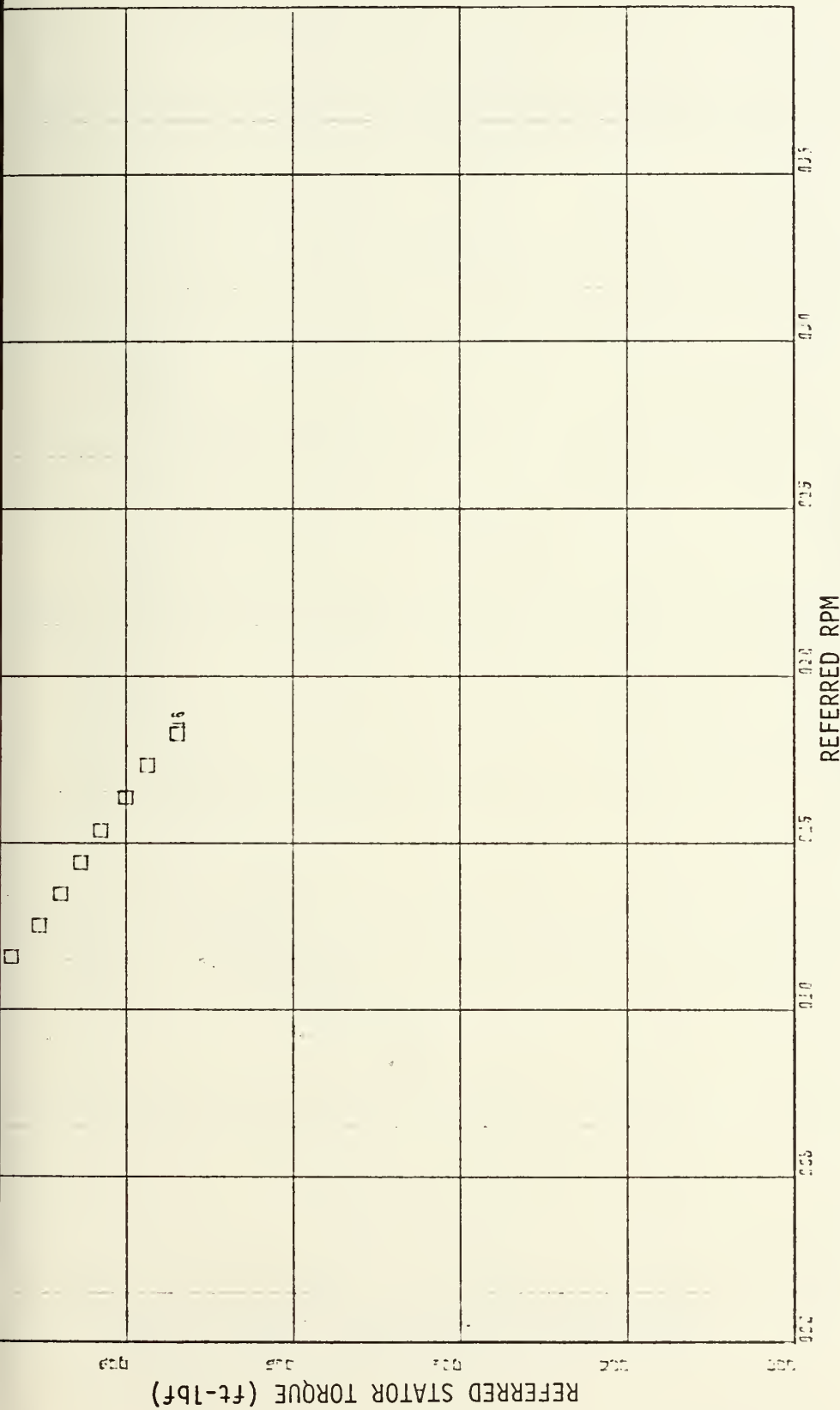


Figure 9. Referred Stator Torque vs. Referred RPM

X-SCALE: 5.00E+03 UNITS INCH.
 Y-SCALE: 2.00E+00 UNITS INCH.

DETHOMAS TTTR RUN #16 DAY 11 MO. 02 YEAR 72
 REFERRED STATOR TORQUE VS. REFERRED RPM

EFFICIENCIES (TOTAL-STATIC, ROTOR, STATOR)

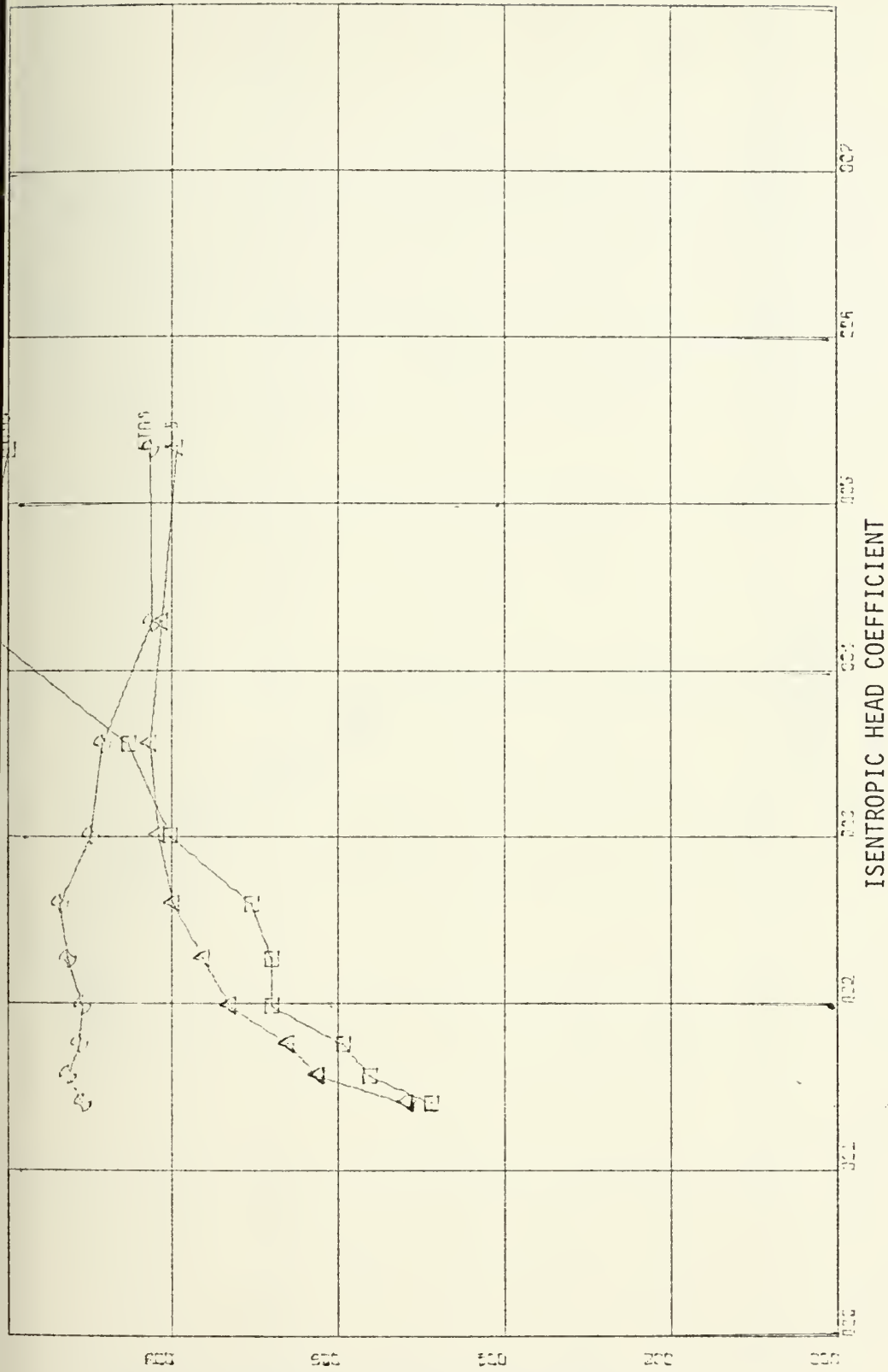


Figure 10. Stage Efficiencies vs. Isentropic Head Coefficient

1.000-1.000-00 UNITS INCH.

2.000-2.000-01 UNITS INCH.

DETHOMAS TEST RIN #16 DAY 11 MO. 02 YEAR 72
 EFFICIENCIES ST-R. ROTOR&STATOR VS IS. HEAD COEFF.

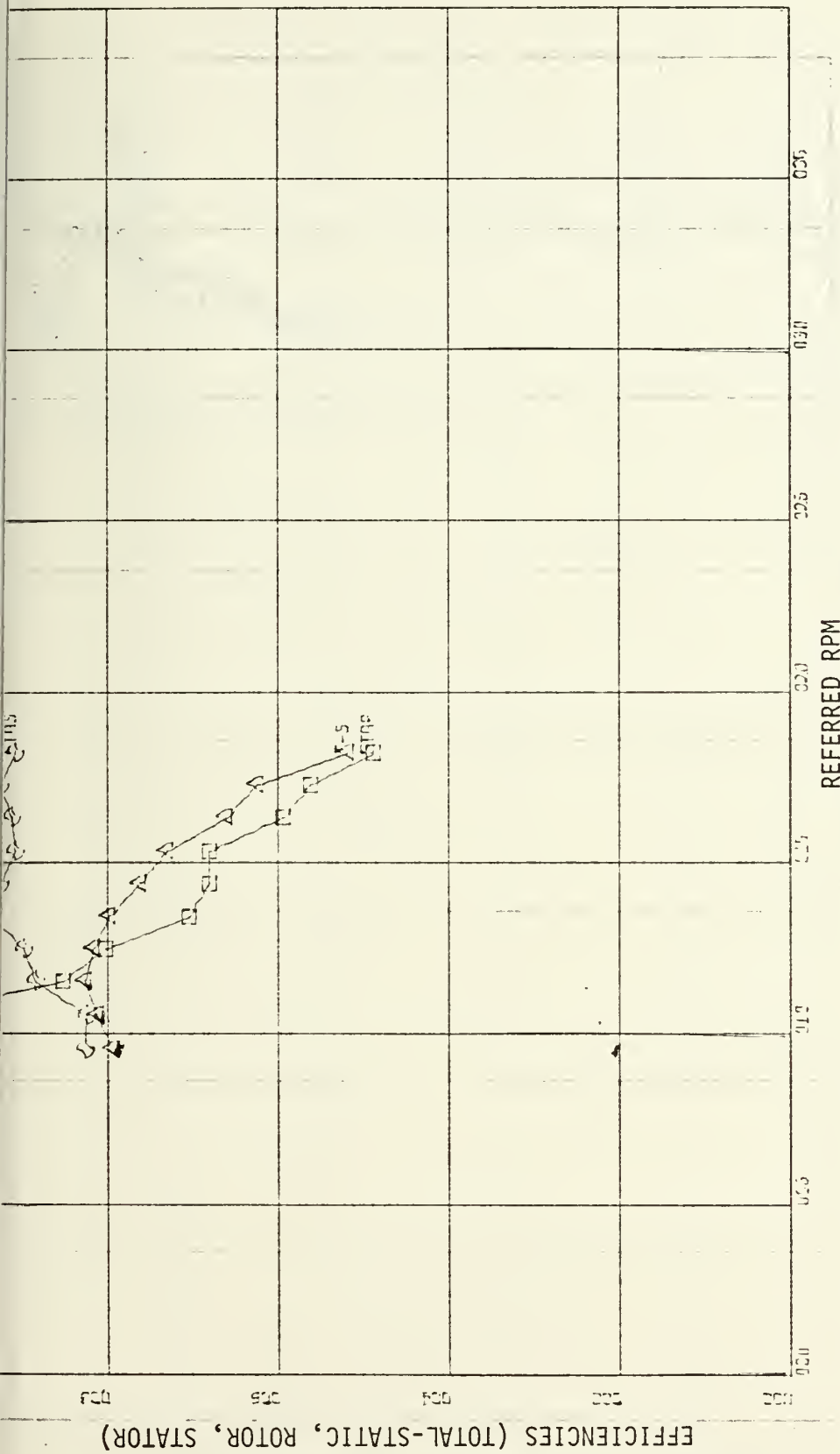


Figure 11. Stage Efficiencies vs. Referred RPM

X-SCALE: 5.00E+03 UNITS INCH.
 Y-SCALE: 2.00E+01 UNITS INCH.

DETHOMAS TTRB RUN #16 DAY 11 MO. 02 YEAR 72
 EFFICIENCIES TEST--S. ROTOR & STATOR VS. REFERRED RPM

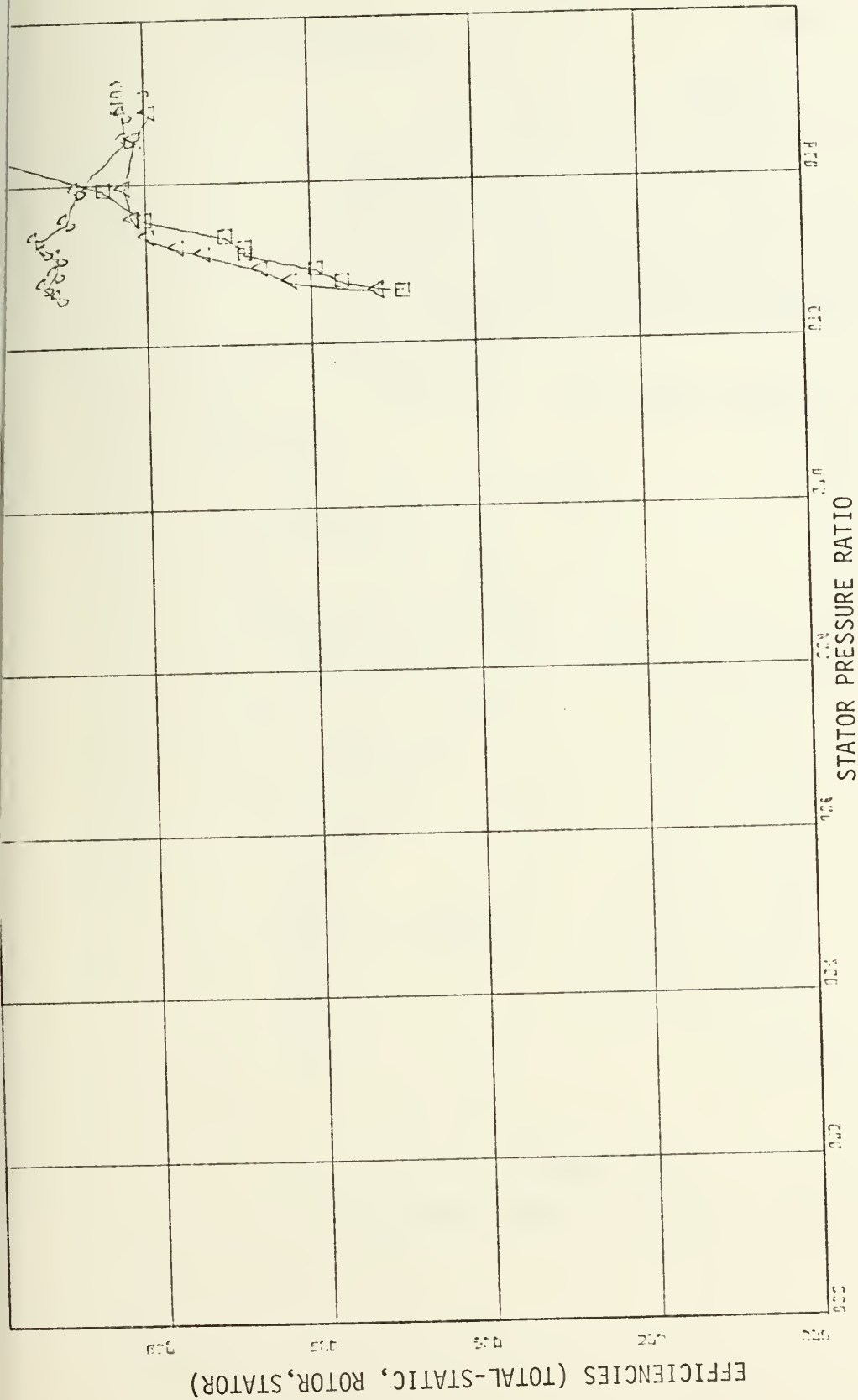


Figure 12. Stage Efficiencies vs. Stator Pressure Ratio

X-SCALE=2.00E-01 UNITS INCH.

Y-SCALE=2.00E+01 UNITS INCH.

DETHOMAS TTR RUN #16 DAY 11 MO. 02 YEAR 72
 EFFICIENCIES(T-S, ROTOR&STATOR) VS. STATOR P.R.

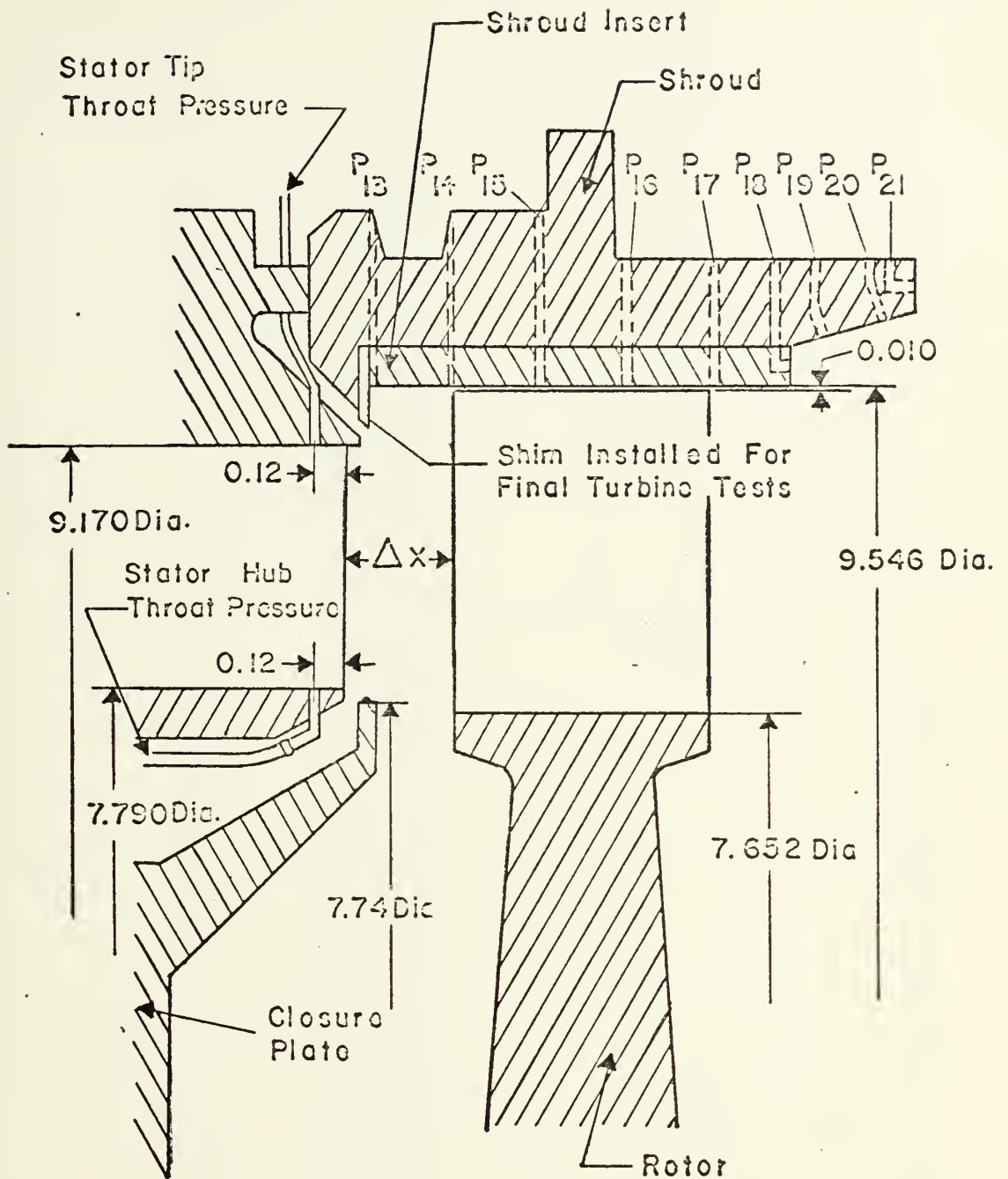


FIGURE 13
 TURBINE AND SHROUD DETAILS

TRANSONIC TURBINE TEST RIG INPUT DATA

NO	BAR	NOZ	PTD	HUR	TIP	P13	P18	P19	P20	P21	MONTH 02			YEAR 72			AKIL	TORQR	DYNAR	CLAXI	
											DAY 11	PHD	DH	TNOZ	TTO	THD					RPM
1	30.05	66.02	44.26	29.25	32.37	32.62	30.22	30.01	29.96	29.96	29.96	29.78	6.21	2.06	1.89	1.03	9910.	-265.	444.	461.	13.
2	30.05	68.46	44.07	29.60	32.77	33.09	30.20	29.97	29.89	29.81	29.90	29.97	5.60	2.11	1.94	1.03	11000.	152.	472.	452.	14.
3	30.05	68.72	44.10	29.84	33.14	33.46	30.21	29.76	29.81	29.69	29.84	30.04	5.70	2.12	1.96	1.20	12000.	120.	472.	452.	14.
4	30.05	68.86	44.04	30.14	33.45	33.77	30.21	29.63	29.69	29.51	30.03	30.06	5.37	2.13	1.96	1.23	12995.	291.	398.	364.	12.
5	30.05	68.89	44.11	30.43	33.85	34.16	30.32	29.63	29.51	30.15	30.05	30.05	5.30	2.13	1.97	1.22	14000.	476.	398.	373.	16.
6	30.05	68.99	44.06	30.70	34.15	34.48	30.37	29.63	29.52	30.22	30.05	30.05	5.25	2.14	1.97	1.21	14980.	631.	376.	369.	17.
7	30.05	69.08	44.13	31.00	34.51	34.85	30.56	29.64	29.55	30.22	30.06	30.06	5.09	2.14	1.98	1.32	16010.	782.	366.	241.	18.
8	30.05	69.65	44.10	31.31	34.86	35.18	30.75	29.67	29.58	30.35	30.07	30.07	4.99	2.14	1.98	1.32	17020.	972.	353.	202.	18.
9	30.05	69.65	44.13	31.67	35.24	35.55	30.96	29.69	29.64	30.50	30.07	30.07	4.99	2.14	1.99	1.32	18005.	1146.	342.	178.	19.
10	30.06	69.09	44.03	31.97	35.58	35.88	31.74	29.71	29.75	30.66	30.06	30.06	4.89	2.14	1.99	1.37	19030.	1322.	325.	137.	20.

Table I. TTTR Sample Reduction Results

STATOR RESULTS

CONFIGURATION- CONVERGING NOZZLES, SHROUD P/N 1050, INSERT P/N 2005-3(STRAIGHT)

PUN NUMBER 16 DAY 11 MONTH 02 YEAR 72

METHOD J= 1

POINT	FAX(+)	CFAX(+)	F0(+)	F1(-)	F2(-)	F3(-)	F4(-)	F5(-)	F6A(-)	FNET	TORQ(+)	CLTORQ(+)	RFAX	RTORO
1	-21.20	27.62	1202.92	276.86	56.89	46.55	57.51	87.80	681.93	0.91	14.80	0.01	-14.39	10.04
2	-4.16	24.32	1202.92	280.41	56.79	46.46	57.47	89.03	690.09	1.93	14.17	0.01	-2.84	9.65
3	9.68	21.56	1209.69	283.33	56.78	46.34	57.49	90.03	695.62	1.93	13.80	0.01	6.59	9.40
4	28.28	18.87	1212.52	288.89	56.66	46.15	57.49	91.94	702.68	1.93	13.27	0.02	15.87	9.05
5	38.08	16.34	1213.32	288.99	57.02	45.91	57.70	91.94	709.44	1.93	12.90	0.02	25.02	8.78
6	55.48	14.27	1212.92	291.56	57.25	45.71	57.79	91.94	715.74	1.93	12.53	0.02	34.40	8.54
7	72.76	12.12	1213.92	294.26	57.38	45.51	57.79	91.94	722.02	1.93	12.16	0.02	43.78	8.30
8	92.68	9.13	1213.73	301.64	57.91	46.05	58.91	91.94	737.92	1.93	11.79	0.03	53.07	8.00
9	105.76	7.67	1213.32	303.70	58.22	46.15	59.45	91.94	745.35	1.93	11.43	0.03	62.38	7.71
10										1.93	10.83	0.03	72.13	7.39

FORCE AND MOMENT BALANCE(LBS AND FT-LBS)

POINT	NOZZLE FLOW	TURBINE FLOW	LABLFAK	RE	PHI	XI
1	1.8459	1.8014	0.0445	593156.	0.5770	0.9006
2	1.8149	1.7715	0.0434	583148.	0.5709	0.9006
3	1.8023	1.7592	0.0421	579094.	0.5666	0.8996
4	1.7926	1.7498	0.0421	575956.	0.5645	0.9031
5	1.7508	1.7080	0.0429	562545.	0.5503	0.8967
6	1.7404	1.6976	0.0429	559206.	0.5477	0.8997
7	1.7331	1.6906	0.0426	556293.	0.5440	0.8914
8	1.6986	1.6712	0.0454	542474.	0.5309	0.8954
9	1.6490	1.6499	0.0420	533337.	0.5227	0.8840
10	1.6600					

FLOW RATES(LBM/SFC), RE(INOZ), FLOW FNC, AND STATOR BLOCKAGE FACTOR

POINT	NOZZ PNDZ	PTPL	PTD	PIAV	PHD	PLFNUM	PR(PTPL/PHD)	STATOR PR(PTO/PIAV)
1	32.29	21.80	21.65	15.06	14.57	1.4966	1.4374	
2	33.49	21.70	21.56	15.25	14.57	1.4899	1.4131	
3	33.61	21.71	21.57	15.41	14.66	1.4808	1.3997	
4	33.68	21.68	21.54	15.55	14.69	1.4754	1.3952	
5	33.70	21.71	21.58	15.72	14.70	1.4764	1.3725	
6	33.75	21.69	21.55	15.86	14.70	1.4755	1.3599	
7	34.07	21.72	21.57	16.03	14.70	1.4760	1.3316	
8	33.78	21.71	21.59	16.15	14.71	1.4762	1.3201	
9	33.31	21.66	21.54	16.52	14.70	1.4734	1.3036	
10								

PAMB=14.70

POINT	IT0	TI	TIIS	TEMPERATURES(OEG R)
1	557.64	511.53	502.73	
2	559.55	515.41	508.91	
3	559.84	516.95	508.56	
4	560.18	519.38	510.38	
5	560.56	521.78	512.07	
6	560.80	523.30	513.75	
7	561.05	524.47	515.24	
8	561.21	525.00	516.56	
9	561.48	525.49	517.80	
10				

POINT	ABSOLUTE VELOCITIES(FT/SEC), ANGLES(DEG), VEL COEF, AND MACH NOS									
	VAI	VUI	VI	VII	ALPHA 1	VCDEFS	MVI	MVA1	QVA1	RVUI
1	181.01	721.96	744.30	812.23	75.93	0.9164	0.6714	0.1433	0.1564	0.6237
2	174.28	706.30	728.16	782.52	75.93	0.9157	0.6543	0.1591	0.1527	0.6091
3	174.25	696.23	717.78	774.56	75.93	0.9155	0.6440	0.1561	0.1207	0.6003
4	167.22	688.10	709.40	773.51	75.93	0.9171	0.6357	0.1566	0.1202	0.5931
5	165.38	688.00	698.68	763.26	75.93	0.9073	0.6155	0.1473	0.1473	0.5756
6	163.41	681.64	686.06	751.84	75.93	0.9025	0.6070	0.1476	0.1476	0.5683
7	160.39	679.77	671.94	741.92	75.93	0.9026	0.5991	0.1457	0.1457	0.5613
8	156.87	675.69	658.52	729.13	75.93	0.9026	0.5972	0.1428	0.1381	0.5509
9	153.12	671.79	652.05	717.19	75.93	0.8994	0.5987	0.1394	0.1351	0.5388
10		610.72	625.62	701.54	75.93	0.8975	0.5987	0.1359	0.1319	0.5258

POINT	RELATIVE VELOCITIES(FT/SEC), ANGLES(DEG), AND MACH NOS									
	WAI	WUI	WI	WII	RETA 1	MW1	MVA1	QVA1	RVUI	
1	181.01	355.28	398.73	366.68	63.00	0.3596				
2	177.08	299.11	347.60	417.20	59.37	0.3123				
3	174.55	252.27	306.73	446.01	55.31	0.2752				
4	172.52	207.27	269.47	476.01	50.23	0.2417				
5	166.48	148.99	224.82	519.01	41.85	0.2009				
6	163.38	106.37	196.10	554.28	31.37	0.1750				
7	160.39	59.38	173.86	597.39	19.37	0.1550				
8	156.87	-47.57	160.70	629.75	13.56	0.1431				
9	153.12	-93.41	162.32	666.23	8.48	0.1319				
10			179.36	704.13	-31.39	0.1192				

POINT	EFFICIENCIES	
	ZETA STATOR	ETA STATOR(1.-ZETAS)
1	0.1603	0.8397
2	0.1615	0.8385
3	0.1637	0.8363
4	0.1589	0.8411
5	0.1459	0.8541
6	0.1218	0.8782
7	0.1078	0.8922
8	0.1010	0.8990
9	0.1045	0.8955
10		

ROTOR RESULTS

CONFIGURATION- CIRCULAR ARC, SHARP LE ROTOR, P/N 1034-A, AXIAL CLNC 0.250 IN, RADIAL CLNC 0.009 IN

RUN NUMBER 16 DAY 11 MONTH 02 YEAR 72 METHOD J= 1

PRESSURES(P(SIA) AND PRESSURE RATIOS

ΔAMB=14.70

POINT	PTO	PIAV	PT2	P2=PHD	OVERALL PR(PTO/P2)
1	21.56	15.06	14.78	14.57	1.4841
2	21.57	15.25	14.75	14.57	1.4797
3	21.57	15.41	14.85	14.66	1.4716
4	21.54	15.55	14.94	14.69	1.4662
5	21.58	15.72	15.01	14.70	1.4675
6	21.55	15.86	15.13	14.70	1.4663
7	21.59	16.02	15.26	14.70	1.4687
8	21.57	16.18	15.49	14.70	1.4672
9	21.59	16.35	15.60	14.71	1.4678
10	21.54	16.52	15.89	14.70	1.4647

TEMPERATURES(DEG R)

POINT	TT0	TT1	TE	TY2	T2	T21S	TY2H	TY2IS	DELTA TIS	DELTA TH
1	557.64	511.53	525.05	510.23	508.14	506.69	497.96	499.09	58.59	47.41
2	559.82	512.95	525.21	511.50	509.21	508.60	503.39	503.02	58.50	48.30
3	560.18	513.29	525.84	511.83	510.47	509.95	502.17	504.59	58.51	48.35
4	560.56	512.08	525.86	512.12	511.13	511.21	502.37	505.31	58.19	46.43
5	560.80	512.30	526.16	512.42	512.21	511.07	502.70	506.83	58.09	44.38
6	561.05	513.47	526.74	513.38	512.88	510.74	502.99	508.09	58.35	42.67
7	561.21	515.00	528.01	515.75	515.12	510.82	502.99	510.43	58.22	38.46
8	561.31	526.68	529.82	522.92	516.19	510.95	502.99	511.52	58.29	36.39
9	561.48	528.49	532.23	531.36	519.70	511.18	503.47	514.77	58.01	30.13
10										

ABSOLUTE VELOCITIES(FT/SEC) AND ANGLES(DEG)

POINT	WAZ	WU2	W2	W1S	ALPHA 2	MW2	STAGE LOADING FACTOR	STAGE FLOW FACTOR
1	147.98	-54.11	157.56	845.75	-20.09	0.1426	2.02	0.40
2	145.93	-47.97	149.95	833.43	16.17	0.1355	1.72	0.32
3	143.11	94.37	171.98	834.86	33.68	0.1553	1.42	0.29
4	139.81	127.80	149.48	834.09	42.45	0.1710	1.03	0.25
5	139.30	176.40	224.77	835.44	51.70	0.2026	0.86	0.23
6	138.01	216.29	227.05	837.27	57.29	0.2316	0.73	0.22
7	137.87	269.38	302.61	836.34	62.90	0.2720	0.58	0.22
8	136.07	293.79	323.77	836.86	65.15	0.2907	0.49	0.20
9	134.66	343.22	374.28	834.83	68.91	0.3349	0.37	0.19

RELATIVE VELOCITIES(FT/SEC), ANGLES(DEG), AND REL VEL COEFS

POINT	WAZ	WU2	W2	U2	W21S	BETA 2	DRFTA	WCOEFS	MW2
1	147.98	-425.51	450.50	371.39	469.84	-70.82	133.83	0.9588	0.4077
2	145.93	-417.12	441.91	412.43	454.02	-70.72	130.09	0.9733	0.3994
3	144.01	-407.95	432.62	449.72	437.98	-70.55	128.87	0.9892	0.3909
4	142.81	-398.78	426.06	527.01	416.55	-70.93	120.15	0.9059	0.3702
5	139.30	-385.00	408.03	567.20	425.80	-70.11	105.41	0.9615	0.3491
6	138.01	-383.71	408.08	600.04	438.51	-70.10	96.67	0.9306	0.3676
7	137.87	-384.47	393.42	637.85	454.46	-69.49	73.04	0.8657	0.3536
8	136.07	-386.98	404.55	674.77	476.05	-70.34	55.86	0.8498	0.3633
9	134.66	-363.96	388.08	713.18	502.90	-69.70	38.31	0.7717	0.3473

EFFICIENCIES, RPM, WORK OUTPUT(HPI), AND ENTHALPY DROP(BTU/LBM)

POINT	ZETA ROTOR	ETA ROTOR(1-ZETA)	RPM	HP	DELTA HIS	DELTA HW	REHEAT FACTOR	EFF DEGREE OF REACTION
1	0.0836	0.9194	9910	28.99	14.32	11.38	1.0175	0.0681
2	0.0526	0.9474	11005	28.99	14.22	11.56	1.0168	0.1159
3	0.0016	0.9984	12000	28.86	14.04	11.60	1.0165	0.1459
4	0.0282	0.9718	12995	28.12	13.92	11.36	1.0155	0.1590
5	-0.0724	1.0054	14000	28.57	13.96	11.44	1.0179	0.2072
6	0.1346	0.8654	16000	27.49	14.04	10.92	1.0160	0.2198
7	0.2506	0.7494	17020	27.82	13.97	9.23	1.0156	0.2144
8	0.2778	0.7222	18005	26.34	13.99	8.73	1.0158	0.2323
9	0.4045	0.5955	19030	16.55	13.92	7.23	1.0153	0.2104

GENERAL RESULTS

POINT	PRESSURE RATIO	REFERRED SPEED RPM	ISENTROPIC HEAD COEFF	EFFICIENCY TOT-STATIC PERCENT	EFFICIENCY TOT-TOT PERCENT	REFERRED FLOW RATE LB4/SEC	REFERRED MOMENT FT-LB	REFERRED POWER HP	DEGREE OF REACTION THUR	DEGREE OF REACTION (MEAN)	DEGREE OF REACTION (TIP)
1	1.4861	9558.	5.3326	79.45	82.25	1.2674	10.427	18.975	-0.0427	0.0799	0.1982
2	1.4797	10508.	2.2964	81.33	83.79	1.2579	19.427	18.618	0.0426	0.1119	0.1322
3	1.4716	11551.	3.5655	82.61	85.30	1.2445	8.402	18.919	-0.0074	0.1216	0.2297
4	1.4662	12505.	3.0147	81.61	85.17	1.2399	7.950	18.433	0.0082	0.1416	0.2700
5	1.4675	13467.	2.6051	79.80	84.05	1.2088	6.876	17.630	0.0302	0.1666	0.2979
6	1.4663	14407.	2.2719	76.39	82.25	1.2030	6.111	16.763	0.0531	0.1901	0.3221
7	1.4687	15394.	1.9977	73.13	80.61	1.1964	5.466	16.022	0.0770	0.2148	0.3475
8	1.4682	16363.	1.7637	66.06	75.84	1.1837	4.585	14.284	0.1012	0.2399	0.3735
9	1.4678	17308.	1.5779	62.43	73.22	1.1655	4.037	13.304	0.1256	0.2655	0.4002
10	1.4647	18290.	1.4057	51.93	64.75	1.1482	3.115	10.847	0.1541	0.2938	0.4283

* This is the general result output using method J = 1 or continuing and blockage factors to help determine the stator exit velocities.

STATOR RESULTS

CONFIGURATION- CONVERGING NOZZLES, SHROUD P/N 1050, INSERT P/N 2005-3(STRAIGHT)

RUN NUMBER 16 DAY 11 MONTH 02 YEAR 72

METHOD J= 2

FORCE AND MOMENT BALANCE(LBS AND FT-LBS)

POINT	FAX(+)	CLFAX(+)	F0(+)	F1(+)	F2(-)	F3(-)	F4(-)	F5(-)	F6A(-)	FNET	TORQ(+)	CLTORQ(+)	RFAX	RTORQ
1	-21.20	27.62	1202.02	267.36	56.89	46.55	57.51	87.80	681.93	10.41	14.90	0.01	-14.39	10.04
2	-4.16	24.32	1202.02	272.37	56.79	46.46	57.47	89.03	690.09	9.96	14.17	0.01	-2.84	9.65
3	9.68	21.56	1209.69	284.71	56.78	46.34	57.47	90.03	696.62	9.49	13.80	0.01	6.59	9.40
4	23.28	18.87	1212.52	291.61	56.66	46.15	57.49	90.87	702.68	9.21	13.27	0.02	12.87	8.95
5	38.08	16.37	1212.92	299.72	57.02	45.91	57.70	92.74	715.74	8.63	12.53	0.02	22.40	8.58
6	23.56	13.22	1213.92	303.25	57.58	45.94	58.15	93.76	722.73	8.37	12.20	0.02	42.57	8.30
7	75.76	10.70	1213.32	306.41	57.63	45.99	58.51	94.68	729.96	8.10	11.77	0.02	52.95	8.01
8	91.68	9.13	1213.73	310.77	57.91	46.05	58.91	95.69	737.42	7.78	11.40	0.03	62.38	7.76
10	105.76	7.67	1213.32	313.51	58.22	46.15	59.45	96.60	745.35	7.48	10.83	0.03	72.13	7.39

FLOW RATES(LB/SEC), RE(NOZI), FLOW FNC, AND STATOR BLOCKAGE FACTOR

POINT	NOZZLE FLOW	TURBINE FLOW	LABLEAK	RE	PHI	XI
1	1.8459	1.9014	0.0445	593156.	0.5770	0.8841
2	1.8149	1.7715	0.0434	583148.	0.5709	0.8849
3	1.8023	1.7592	0.0431	579094.	0.5666	0.9016
4	1.7926	1.7498	0.0427	575956.	0.5645	0.9175
5	1.7808	1.7400	0.0429	562545.	0.5503	0.9085
7	1.7494	1.6976	0.0424	528696.	0.5447	0.9121
8	1.7131	1.6712	0.0425	505572.	0.5389	0.9188
9	1.6890	1.6466	0.0425	542671.	0.5306	0.9193
10	1.6600	1.6179	0.0420	533317.	0.5227	0.9191

PRESSURE(P/PSIA) AND PRESSURE RATIOS

PAMB=14.70

POINT	PNOZ	PTPL	PTO	PIAV	PHO	PLENUM	PRIP/PL/PHDI	STATOR	PRIP/TO/PIAVI
1	32.29	21.80	21.65	14.54	14.57	1.4966			1.4884
2	33.61	21.71	21.56	14.82	14.57	1.4899			1.4548
3	33.68	21.68	21.54	15.46	14.66	1.4808			1.3953
4	33.70	21.71	21.58	15.86	14.69	1.4754			1.3580
5	33.73	21.71	21.59	16.16	14.70	1.4764			1.3350
7	33.73	21.59	21.56	16.31	14.70	1.4775			1.3139
8	33.77	21.70	21.57	16.67	14.70	1.4760			1.2942
9	33.78	21.71	21.59	16.91	14.71	1.4762			1.2771
10	33.31	21.66	21.54	17.06	14.70	1.4734			1.2628

TEMPERATURES(DEG R)

POINT	TTO	TI	TIIS
1	557.64	508.12	497.74
2	559.55	512.61	502.72
3	559.84	514.78	509.01
4	560.18	518.03	513.28
5	560.56	518.88	516.14
6	560.80	520.91	517.82
7	561.05	522.87	519.06
8	561.21	524.42	521.34
9	561.38	526.53	524.27
10	561.48	528.53	526.27

ABSOLUTE VELOCITIES(FT/SEC), ANGLES(DEG), VEL COEF, AND MACH NOS

POINT	VAL	VUI	VI	VII	VIII	ALPHA I	VCDEFS	MVI	MVAI	RVAI	RVUI
1	185.89	748.59	771.33	848.33	876.29	76.05	0.9092	0.6766	0.1682	0.1696	0.6467
2	180.98	728.77	750.91	826.29	854.45	76.05	0.9088	0.6615	0.1631	0.1561	0.6285
3	173.56	714.99	735.76	811.45	839.67	76.23	0.9415	0.6374	0.1518	0.1460	0.6165
4	169.39	691.16	711.62	797.59	825.51	76.57	0.9686	0.6188	0.1455	0.1400	0.5934
5	162.50	688.68	707.59	794.51	821.60	76.57	0.9834	0.6188	0.1437	0.1385	0.5801
6	160.80	678.35	692.28	784.28	811.15	76.35	0.9535	0.5988	0.1389	0.1342	0.5510
7	154.27	628.24	641.15	734.05	764.63	76.48	0.9635	0.5781	0.1369	0.1309	0.5251
8	151.96	631.96	643.98	736.93	764.63	76.33	0.9540	0.5584	0.1319	0.1280	0.5442
9	148.69	611.40	624.22	719.58	749.22	76.33	0.9540	0.5584	0.1319	0.1280	0.5264
10	148.69	611.40	624.22	719.58	749.22	76.33	0.9540	0.5584	0.1319	0.1280	0.5264

RELATIVE VELOCITIES(FT/SEC), ANGLES(DEG), AND MACH NOS

POINT	WAI	WUI	WI	WII	WIII	BETA I	MWI
1	185.89	381.91	424.75	366.68	64.05	0.3844	0.3844
2	180.98	321.57	369.00	407.20	60.63	0.3325	0.3325
3	173.56	270.98	321.80	444.01	57.36	0.2893	0.2893
4	169.39	210.34	270.06	480.83	51.15	0.2421	0.2421
5	162.50	170.66	235.65	519.01	46.40	0.2110	0.2110
6	160.80	119.07	200.09	584.28	36.52	0.1788	0.1788
7	159.37	65.93	172.47	582.39	22.47	0.1539	0.1539
8	156.02	18.72	125.53	624.76	4.56	0.1394	0.1394
9	154.99	-92.73	175.24	666.71	-12.95	0.1355	0.1355
10	148.69	-92.73	175.24	704.71	-31.95	0.1555	0.1555

EFFICIENCIES

POINT	ZETA	STATOR	ETA	STATOR(I.-ZETAS)
1	0.1733			0.8267
2	0.1743			0.8257
3	0.1133			0.8867
4	0.1013			0.8987
5	0.0618			0.9382
6	0.0719			0.9281
7	0.0906			0.9094
8	0.0874			0.9126
9	0.0717			0.9283
10	0.0899			0.9101

ROTOR RESULTS

CONFIGURATION- CIRCULAR ARC, SHARP LF ROTOR, P/N 1034-A, AXIAL CLNC 0.250 IN, RADIAL CLNC 0.009 IN

RUN NUMBER 16 DAY 11 MONTH 02 YEAR 72
METHOD J= 2

PRESSURES(P(SIA) AND PRESSURE RATIOS

PAMB=14.70

POINT	PTO	PIAV	PT2	P2=PHD	OVERALL PR(PTO/P2)
1	21.65	14.54	14.76	14.57	1.4861
2	21.56	14.82	14.75	14.57	1.4797
3	21.57	15.46	14.87	14.66	1.4716
4	21.54	15.86	14.95	14.69	1.4662
5	21.58	16.16	15.06	14.70	1.4675
6	21.55	16.31	15.17	14.70	1.4663
7	21.29	16.44	15.28	14.70	1.4657
8	21.59	16.91	15.43	14.71	1.4678
10	21.54	17.06	15.90	14.70	1.4647

TEMPERATURES(DEG R)

POINT	TT0	TT1	TT2	TF	TZ	TZIS	TZTH	TTZIS	DELTA TIS	DELTA TW
1	557.64	508.12	523.43	510.23	508.34	508.35	497.96	499.81	59.68	47.41
2	559.55	512.61	524.30	511.35	509.55	510.13	500.28	502.04	59.27	48.20
3	559.84	514.78	523.82	511.55	509.47	507.01	501.33	503.32	58.51	48.33
4	560.18	518.03	524.60	512.83	510.32	506.82	502.17	504.64	58.01	47.35
5	560.56	518.88	524.90	514.12	510.67	505.04	502.37	505.77	58.19	46.43
6	560.80	520.91	524.90	516.42	511.80	505.70	502.70	507.23	58.09	44.38
7	561.05	522.87	524.10	518.38	512.65	506.39	502.70	508.33	58.35	42.67
8	561.21	524.82	522.72	520.25	512.00	506.35	502.09	510.55	58.22	38.46
10	561.24	528.53	524.52	524.52	518.64	506.93	503.47	511.87	58.01	36.13

ABSOLUTE VELOCITIES(FT/SEC) AND ANGLES(DEG)										
POINT	VAZ	VUZ	VZ	VOIS	ALPHA 2	MV2	STAGE LOADING FACTOR	STAGE FLOW FACTOR	STAGE FLOW FACTOR	
1	148.04	-27.82	150.63	845.75	-10.694	0.1328	2.09	0.45		
2	145.92	60.29	156.08	878.40	22.572	0.1471	1.42	0.32		
3	143.33	98.40	173.67	834.86	34.571	0.1568	1.22	0.29		
4	138.68	148.30	233.73	836.09	46.771	0.1839	1.03	0.27		
5	135.18	189.93	235.47	835.44	53.777	0.2123	0.86	0.25		
6	131.84	222.10	262.48	837.27	58.06	0.2365	0.73	0.23		
7	131.84	272.10	305.02	836.34	63.14	0.2742	0.58	0.20		
8	136.00	299.97	329.36	836.86	65.61	0.2958	0.49	0.20		
9	136.65	349.89	374.90	834.83	68.95	0.3355	0.37	0.19		

RELATIVE VFLOCITIES(FT/SEC), ANGLES(DEG), AND REL VEL COEFS										
POINT	WAZ	WUZ	W2	U2	W21S	BETA 2	DRETA	WCDEFS	MW2	
1	148.04	-399.21	425.77	371.39	425.94	-69.65	133.70	1.0003	0.3882	
2	145.92	-389.42	415.04	449.72	412.71	-69.72	130.35	1.0202	0.3805	
3	143.33	-378.97	411.12	527.07	449.39	-69.71	127.07	0.8239	0.3722	
4	138.68	-370.47	366.69	527.07	478.28	-69.68	117.04	0.8390	0.3694	
5	135.18	-377.25	401.99	601.60	480.27	-69.46	105.98	0.8260	0.3577	
6	131.84	-365.75	390.86	637.85	486.65	-69.79	92.27	0.8260	0.3522	
7	131.84	-374.79	398.70	674.77	506.67	-69.35	74.01	0.7114	0.3514	
8	136.00	-363.29	387.44	713.18	531.26	-70.06	57.36	0.7505	0.3581	
9	136.65				554.11	-69.66	37.71	0.6992	0.3467	

EFFICIENCIES, RPM, WORK OUTPUT(HP), AND ENTHALPY DROPI(BTU/LBM)										
POINT	ZETA ROTOR	ETA ROTOR(1.-ZETA)	RPM	HP	DELTA HIS	DELTA HW	REHEAT FACTOR	EFF DEGREE OF REACTION		
1	-0.0006	1.0006	9910.	28.99	14.32	11.38	1.0209	-0.0044		
2	0.0408	1.0408	11005.	28.99	14.22	11.56	1.0197	0.0613		
3	0.1464	0.8536	12000.	28.86	14.04	11.60	1.0113	0.1093		
4	0.1973	0.8027	12985.	28.12	13.92	11.36	1.0093	0.1549		
5	0.2475	0.7525	14000.	27.57	13.96	10.14	1.0050	0.1858		
6	0.2975	0.6825	14910.	27.49	13.00	10.24	1.0073	0.2081		
7	0.3177	0.6723	16010.	21.82	13.97	9.23	1.0067	0.2126		
8	0.4649	0.5351	17020.	20.34	11.99	8.73	1.0052	0.2258		
9	0.4368	0.5632	18005.	16.55	13.92	7.23	1.0062	0.2121		
10	0.5111	0.4889	19030.							

★
GENERAL RESULTS

POINT	PRESSURE RATIO	REFERRED SPEED RPM	ISENTROPIC HEAD COEFF	EFFICIENCY TOT-STATIC PERCENT	EFFICIENCY TOT-INT PERCENT	REFERRED FLOW LBM/SEC	REFERRED MOMENT FT-LB	REFERRED POWER HP	DEGREE OF REACTION (HUB)	DEGREE OF REACTION (MEAN)	DEGREE OF REACTION (TIP)
1	1.4861	9258.	5.3326	79.45	81.99	1.2674	10.427	18.975	-0.0427	-0.0037	0.1982
2	1.4707	10550.	4.2944	81.33	83.82	1.2539	9.427	19.019	-0.0076	0.0411	0.2339
3	1.4716	10550.	3.0627	82.61	85.54	1.2445	8.402	18.919	-0.0076	0.1312	0.2497
4	1.4662	12675.	2.6051	81.61	85.27	1.2399	7.750	18.453	0.0082	0.1315	0.2700
5	1.4675	13467.	2.2719	79.90	84.81	1.2088	6.811	17.630	0.0302	0.2719	0.2779
6	1.4663	14667.	1.9977	78.13	87.24	1.2070	6.111	16.763	0.0531	0.2602	0.3271
7	1.4687	15394.	1.7637	68.06	86.73	1.1864	5.466	16.022	0.0770	0.2804	0.3471
8	1.4672	16363.	1.5779	62.43	87.12	1.1655	4.895	14.284	0.1012	0.3152	0.3735
9	1.4678	17308.	1.4057	61.93	64.95	1.1482	4.035	13.304	0.1256	0.3501	0.4032
10	1.4647	18290.	1.4057	51.93	64.95	1.1482	3.115	10.847	0.1541	0.3758	0.4283

★ This is the general result output using method J = 2
or continuity and stator forces to determine the
stator exit velocities.

APPENDIX A
FORTRAN SYMBOLS

The following symbols are those input or output symbols of most interest for the TTTR on-line, flow calibration, labyrinth leak calibration and draw programs. Where two units appear, the data enters the program in the first form and is converted to the second for use or output.

FORTRAN
SYMBOL

AXCLR	Stator to rotor axial clearance (in)
AXIL	Stator axial force (lbf)
CLAXIL	Closure plate axial force (lbf)
CLTRQR	Closure plate torque (ft-lb)
DH	Flow nozzle differential pressure (in H ₂ O)
DPFL	Flow calibration differential pressure (in H ₂ O)
DYNAR	Dynamometer torque (ft-lb)
ETAR	Rotor efficiency
ETAS	Stator efficiency
ETATS	Stage total to static efficiency
ETATT	Stage total to total efficiency
FAX	Stator axial force (lbf)
FLOWL	Labyrinth seal leak rate (lbm/sec)
FLOWN	Flow nozzle flow rate (lbm/sec)
FLOWT	Turbine flow rate (lbm/sec)
HP	Rotor horsepower (HP)
LASTPT	Check parameter (indicates last point of run)
NDAY	Day number

NMO	Month number
NP	Run point number
NRUN	Run number
NYEAR	Year
PATM	Atmospheric pressure (psia)
P13-P21	Rotor shroud pressure (in Hg abs) (psia)
PBAR	Barometric pressure (in Hg abs) (psia)
PCL1-PCL3	Closure plate pressure (in Hg abs) (psia)
PHD	Hood pressure (in Hg abs) (psia)
PHUB	Stator exit hub pressure (in Hg abs) (psia)
PNOZ	Flow nozzle inlet pressure (in Hg abs) (psia)
PR	Stage pressure ratio
PREF	Manometer board reference pressure (in Hg)
PRPL	Labyrinth seal pressure ratio
PTO	Stator inlet total pressure (in Hg abs) (psia)
PTIP	Stator exit tip pressure (in Hg abs) (psia)
PTPL	Stator labyrinth inlet pressure (in Hg abs) (psia)
RADCLR	Rotor tip radial clearance (in)
RE	Flow nozzle Reynold's Number
REFHP	Referred turbine horsepower
REFLOW	Referred turbine flow rate
REFMOM	Referred dynamometer moment
REFRPM	Referred rotor RPM
RFAX	Referred stator axial force
RPM	Rotor RPM
RTORQ	Referred stator torque
TBAR	Barometer temperature (°F)

TCR	Control room temp ($^{\circ}$ F)
THD	Hood air temperature (mv) ($^{\circ}$ R)
TNOZ	Flow nozzle inlet temperature (mv) ($^{\circ}$ R)
TORQ	Stator torque (ft-lb)
TTO	Stator inlet total temperature (mv) ($^{\circ}$ R)
XKIS	Stage isentropic head coefficient
ZETAR	Rotor loss coefficient
ZETAS	Stator loss coefficient

APPENDIX B

TTTR OPERATING PROCEDURES

1. COMPUTER ADMINISTRATIVE AND OPERATION CONSIDERATIONS

The on-line data reduction utilizes the Control Program (CP-67)/Cambridge Monitor System (CMS). This CP/CMS time sharing system with the IBM 360 allows each satellite station to simulate a complete IBM 360 system. Each station will have its own core storage, card-read-punch unit and a printer. A complete description and operating instructions for the CP/CMS system is contained in the User's Manual [Ref. 7].

Use of the CP/CMS system for data reduction requires use of a private USERID and disk storage at the computer center. These should be requested from the Information Services Manager at the computer center. It is recommended that a minimum of ten cylinders of disk storage and 256K bytes of core storage be requested. It is necessary to supply a password when requesting a private USERID. This protects access to programs and data on the disk storage.

Once a private USERID and disk storage are assigned, full use of the CP/CMS system is available using either the IBM remote terminals or the specially configured teletypewriter terminal. The data reduction program may be read into disk storage from a card reader or a complete program developed using CP/CMS. Both of these options are covered in detail in the User's Manual. The user may also find the disk storage handy for storing previous input data or output information which would be quickly available as a debugging aid.

Although covered in the User's Manual the following programming points are noted:

1. The FORTRAN instruction READ (5,xxx) will cause a READ command to be issued at the associated terminal under CP/CMS.
2. The instruction WRITE (I,xxx) causes the desired information to be stored on the user's disk under the title FILE FTOIF001 (I any integer except six, see below). This file may then be printed out using the command to off line print FILE FTOIF001 or punched out on cards with the command to off line punch FILE FTOIF001.
3. The instruction WRITE (6,xxx) will cause the desired information to print out on the associated CP/CMS terminal.

Once the FORTRAN data reduction program is complete it may be compiled into machine language and stored on the disk. It is recommended that a FORTRAN card deck of the reduction program be punched using the off line punch after any major modifications. This deck will then be available to read again should the disk program be accidentally erased or destroyed.

The flexibility and speed of CP/CMS programming and debugging is outstanding compared to punch card operation and these features should be considered in addition to the use of CP/CMS for on-line data reduction.

When using the teletypewriter vice the IBM terminals the following changes should be noted:

1. Dial extension 2611 for the teletype vice 2701 for the IBM terminal.
2. The teletype command X-OFF (upper case Q on keyboard) is used in place of the IBM ATTN; key to gain the attention of the CP system.
3. The teletype punch symbols for RETURN, LINE FEED, and RUB OUT are ignored by the CP/CMS system.

4. The teletype symbol > is printed to indicate the CP/CMS system is ready to accept input information. This takes the place of unlocking the IBM keyboard.

The teletype terminal is similar to the IBM terminal in all other aspects of operation.

2. INSTRUMENTATION AND CALIBRATION

The basic TTR instrumentation is described by Esdaile [Ref. 1] and modifications are described in Chapter II of this thesis. The required sensors and their calibration are listed in Table B-I.

The units shown in Table B-I are those calibrated for and sent to the B & F system. The manometer pressures and millivolt temperatures are converted to engineering units within the reduction program.

Since the B & F system accepts most inputs in blocks of ten channels, many channels are punched out and read as DUMMY. In addition some of the acquired data is not used directly by the reduction but collected as a check value or to facilitate future expansion of the analysis program.

The first 22 pressures are connected in parallel to a manometer board in the control room and the channel #1 scanning valve (the channel #1 scanning valve has 24 pressure ports). Calibration is conducted prior to each run using ambient pressure on port #1 and a calibration pressure of about two atmospheres on port #2. An iterative adjustment of the channel #1 bridge and power supply is then used to calibrate the scanning valve between the port #1 and #2 pressures. The mercury manometer board is a primary standard and no correction is needed if calibration is conducted near a room temperature of 68°F. The B & F output should read in. Hg. absolute to two decimal places. Once a good calibration is achieved it may be easily checked during the run by reference to the barometric pressure on port #1.

Table B-I. TTTR Instrumentation, Calibration and Units:

POINT	FORTRAN SYMBOL	DATA	UNITS
1	QPBAR	Barometric Pressure	In. Hg., Absolute
2	DUMMY	Calibration Press
3	QPNOZ	Flow Nozzle Inlet Press
4	QPTPL	Plenum Labyrinth Press
5-	QPT01-	Stator Inlet	
7	QPT03	Total Press (3)	...
8	QPHUB	Stator Exit Hub Press
9	QPTIP	Stator Exit Tip Press
10-	QP13-		
18	QP21	Rotor Shroud Press (9)	...
19-	QPCL1-		
21	QPCL3	Closure Plate Press (3)	...
22	QPHD	Turbine Hood Press
23	QDH	Nozzle Differential Press	In. H ₂ O
24	QLAXIL	Closure Plate Axial Force	Pounds Force
25	QLTRQR	Closure Plate Torque	Ft-Lbs Torque
26	QTNOZ	Flow Nozzle Inlet Temp.	Millivolts
27-	QTT01-		
28	QTT02	Stator Inlet Total Temp.(2)	...
29	QTHD	Hood Temp.	...
30	QRPM	Rotor RPM	RPM
31	QAXIL	Stator Axial Force	Pounds Force
32	QTORQ	Stator Torque	Ft-Lbs Torque
33	QDYNAR	Dynamometer Torque	Ft-Lbs Torque

Flow nozzle differential pressure is connected in parallel to a differential transducer and an H₂O manometer board in the control room. A differential pressure is applied to the transducer and the channel #10 bridge and power supply are used to marry the B & F reading to the manometer board. The B & F system should read in. H₂O differential with three decimal places. Again, no correction is required if calibration is conducted near 68°F. Once a good calibration is achieved a fixed resistance calibration step is applied to one leg of the bridge and the reading recorded. Subsequent calibration of the nozzle transducer is easily accomplished by adjusting the bridge to zero (with zero differential pressure on the transducer) and then applying the calibration step and adjusting the power supply to match the calibration reading.

The closure plate axial force is calibrated prior to putting the turbine rotor in place. Calibrate using dead weights hung on low friction rollers. The conditioner on channel #11 is used to calibrate the B & F system output to read pounds force with two decimal places. Again once a good calibration is achieved the constant resistor step is applied and the reading recorded to use in later calibration. Due to severe coupling from the axial force the closure plate torque was not calibrated and has been replaced by an analytic expression in the reduction program (see Appendix D). It may still be scanned if desired with its calibration similar to that of the closure plate axial force to read out in ft-lb.

The four temperatures have an electronic temperature reference junction and the only calibration required is to verify the output. This is easily accomplished using an ice bath. The temperatures should read out in millivolts with three decimal places.

Turbine RPM is taken from a flux cutter on the turbine shaft and read out to five figures. No calibration is required.

The stator axial force and torque and the dynamometer torque are calibrated using dead weights. At present these readings are taken from inductance force capsules independent of the B & F data system. They are calibrated to read out from 10,000 to 12,000 Hz by adjusting their zero, range and linearity potentiometers. Calibration should be checked prior to each run.

3. DATA ACQUISITION

The normal TTR run will contain between five and twenty points. The desired point parameters will be set by adjusting the turbine mass flow and dynamometer settings to achieve the desired turbine pressure ratio and RPM.

With the on-line system two options exist depending on whether one or two teletype units are available. The teletype terminals presently being used will accept active inputs from only one source at a time. Since a hold signal from the CP/CMS system will override an input from the B & F data system, the CP/CMS must be turned off or disconnected during data acquisition on the teletype tape punch. Because of this limitation one must either: (1) take a full set of points, then switch teletype inputs and initiate CP/CMS reduction on the whole run or (2) use two teletype punch/read units, one on acquisition punch and the other on CP/CMS. The last option allows for on-line return of reduction results following each point. In either case the acquisition phase is the same.

The B & F data acquisition system should be set to scan stations 1-9, 10-19, 20-29 and 90-99. The upper limit should be set at 90 and the

lower limit to 01. Valve #1 should be the only valve selected and its upper limit set at 22. The input constant wheels should be set with the run number, point number, day, month and year in groups of two. Following the last desired point of each run set the point number to 00 and allow the constant figures to punch. When the program reads the point number 00 it will discontinue reading and run to completion.

When the desired TTTR point has been set and stabilized, set the teletype to LINE, the tape punch ON and initiate the B & F data system scan with the START button. While the system is scanning, note the axial force, stator torque and dynamometer torque from the force capsules. Once the B & F punch cycle is complete, the three force capsule readings must be manually punched. These will be the actual frequency counts minus 1,000 (recall that the force capsules are zeroed at 1,000 counts). Switch the teletype to local and punch the axial force, stator torque and dynamometer torque using five characters each to include a decimal point and minus sign if needed. Each of the manual points will be followed by a RETURN, LINE FEED and two X-OFFs. No spaces may be skipped but errors may be corrected using RUB OUT and starting from that point again.

Following the dynamometer torque of each point a series of RUB OUTs should be punched to help identify points on the tape. This point may then be fed into the tape reader for CP/CMS or the next point started immediately depending on whether one or two teletype units are available.

4. ON-LINE REDUCTION

The general data reduction theory and program development are discussed in Appendix D. On-line data reduction utilizes the IBM 360 computer with the CP/CMS time sharing system. Program control and data

input use the Model 33 Teletypewriter and the Model B acoustically coupled data set built by Livermore Data Systems.. Detailed instructions on the use of the teletype and acoustic coupler are contained in their respective instruction manuals [Refs. 6 and 7].

At present the CP/CMS time sharing program at the Naval Postgraduate School is available weekdays from 1200 to 1600 in the afternoon. Access to the CP/CMS system may be obtained through: (1) approximately 25 IBM remote terminals throughout the campus or (2) three teletype units. Of these, one teletype unit and one IBM terminal are located in the Turbo-Propulsion Laboratory, Building #215. Although there are three teletype terminals, only one at a time may have access to the CP/CMS system (no restriction applies to the number of IBM terminals). For this reason it is recommended that one day advance notice be given to the operator in the computer center for planned data runs.

Prior to data reduction the program TTTR FORTRAN must be stored on the USERID disk and compiled into machine language as described in Chapter IV of the User's Manual [Ref. 7]. When the acquired punch tape data is available the following reduction procedures apply to both the one or two teletype operation (see Appendix C for sample TTTR run).

1. Dial the NPS telephone extension 2611 to verify CP/CMS operation. Operation will be indicated by a high frequency tone in the receiver.
2. Place the telephone receiver in the acoustic coupler, close the cover, turn the coupler ON and check the coupler in the HALF DUPLEX position. The white light on the coupler indicates power. Insure that the teletype input is connected to the coupler, teletype set to LINE and the tape punch OFF.

3. Break the previous telephone connection and again dial extension 2611. The red light should go on and the teletype will normally print CP-67 ONLINE indicating a good connection.
4. Hold the teletype CTRL button and hit Q to get the attention of the CP system. A > figure will print indicating that an input or request may now be made. The user will now log in with his USERID number and terminal number as follows: LOGIN 1888P31. Hold the CTRL and hit X-OFF to enter this line. The computer will then ask for the password. Again the figure > indicates that the computer is ready to accept input. Type the password and again enter it using X-OFF. The next request will be for the user's project number and cost center code. These numbers should be assigned when requesting the USERID. When the project number and cost center code have been entered the system will be ready to implement the CMS.
5. Implement the CMS time sharing system by entering I.CMS.
6. The first CMS operation will be to check the status of the disk storage and erase unneeded files. Check the contents of the disk with the command LISTF. The computer will then return a listing of the stored files. Normally the files TTTR FORTRAN and TTTR TEXT will be listed and should not be erased. Other files, generally FILE FT08F001, FILE FT07F001 and LOAD MAP are from a previous run and may be erased. Erasing these old files will maintain enough free disk storage to accept the new run results. In addition the old files will print out with the new results. Files may be erased with a command of the type ERASE FILE FT08F001. After erasing unneeded files a check of the storage area remaining may be obtained with the command STAT.

7. Prior to executing the reduction program insure the tape reader control switch is in the FREE position. Begin execution of the program with the command LOAD TTTR (XEQ). Following the initial program statements a request will be printed to enter the turbine rotor axial and radial clearances. These should be entered in decimal inches when requested. At this time the program will indicate that it is ready to accept the punch tape data.
8. The program will stand-by for an indefinite period waiting to read the input data. The tape should be mounted in the reader and the control put momentarily to START when the program indicates it is ready. The computer will then automatically control the reading of the data tape. The tape reader may be stopped at any point by putting the reader control to FREE and resumed by returning momentarily to START (this is an easy method of correcting a punch tape error without repunching the entire tape). If two teletype operation is in effect the program will read the first point and stop to return the selected results. During this return phase the reader should be set to FREE until the next data tape is loaded. If one teletype operator is in effect the reader may be left in the AUTO position and all the points of the run will be read with the parameter returns between each point. Following the last desired data point of the run the program will read the point number 00 as described on page 57. This will kick the program out of its read loop and it will run to completion. Completion of execution will be indicated by a print out of the form R; R = 0.07/0.39 19.54.47.

9. Upon completion of the run data reduction the smooth results must be printed and cards punched for use with the CALCOMP plotting program. For the smooth print-out use the CMS command `PRINTCC FILE FT08F001`. Completion of print or punch commands will be indicated by a return of the form `R; T = 0.01/0.03`
13.48.57.
10. The run is now completed and the system may be secured. Use the CMS command `LOGOUT` to return to CP. The system will then ask for a CP request at which time enter the command `LOG`. The system will then close out, the telephone may be disconnected and the teletype and coupler turned off.
11. The smooth run results may be picked up at the computer center. The punch deck from FILE FT07F001 should be inserted as data in the regular FORTRAN program for plotting (see Appendix E). This program will then plot the important run results using the CALCOMP plotters.

APPENDIX C

SAMPLE TTTR ON-LINE REDUCTION RUN

```
-- CP-67 ONLINE
ENTER PASSWORD:
XXXXXXXXXX
TTTR
ENTER 4-DIGIT PROJECT NUMBER FOLLOWED BY 4-CHARACTER COST CENTER CODE:
>0441AT04
CP/CMS WILL TERMINATE AT 1600.
READY AT 13.47.13 ON 01/28/72
CP
>I CMS
CMS.. VERSION 01/21/71
>LSITF
FILENAME FILTYPE MODE NO.REC. DATE
TTTR TEXT P5 82 1/18
FILE FT08F001 P1 145 1/28
FILE FT07F001 P1 1 1/28
LOAD MAP P5 8 1/28
TTTR FORTRAN P1 79 1/28
R; T=0.03/0.17 13.47.47
>ERASE FILE FT08F001
R; T=0.02/0.05 13.48.30
>ERASE FILE FT07F001
R; T=0.01/0.03 13.48.45
>ERASE LOAD MAP
R; T=0.01/0.03 13.48.57
>STAT
P (191): 2 FILES; 170 REC IN USE. 230 LEFT (OF 400), 43% FULL(10 CYL)
R; T=0.01/0.04 13.40.05
>LOAD TTTR (XEQ)
EXECUTION BEGINS...
-TRANSONIC TURBINE TEST RIG (ON LINE DATA REDUCTION)-
```

HI THERE TTTR FANS, THIS SYSTEM SHOULD INPUT FROM THE B&F DATA COLLECTION SYSTEM COUPLED TO A STANDARD ASCII T/T. YOU SHOULD BE SCANNING CHANNELS 1-29 AND 90-99 WITH THE UPPER LIMIT SET AT 90. VALVE 1 SHOULD BE THE ONLY VALVE SELECTED AND ITS UPPER LIMIT SET AT 22. THE RUN NUMBER, POINT NUMBER, DAY, MONTH AND YEAR SHOULD BE ENTERED IN THE CONSTANT WHEELS IN GROUPS OF TWO.

FOLLOWING THE LAST AUTOMATIC DATA POINT YOU MUST MANUALLY PUNCH THE STATOR FORCE AND TORQUE AND DYNAMOMETER TORQUE. THESE WILL BE 5 CHARACTERS WITH PROPER SIGNS AND DECIMAL POINTS. FOLLOWING THE LAST POINT OF EACH RUN SET POINT NUMBER 00 AND ALLOW THE CONSTANT VALUES TO PUNCH. ALL MANUAL POINTS WILL BE FOLLOWED BY C.R.,L.F.,X-OFF,X-OFF AND NO SPACES MAY BE SKIPPED.

THIS PROGRAM WILL PROBABLE DESTRUCT IN 10 SEC. GOOD LUCK!

--- PLEASE ENTER AXIAL CLEARANCE
.2500

--- PLEASE ENTER RADIAL CLEARANCE
.0090

--NOW START READING THE PUNCH TAPE POINTS
13 01 210172

>001 01 +03016 0

>001 02 +04969 0

>001 03 +06240 0

>001 04 +05556 0

>001 05 +05511 0

>001 06 +05529 0

>001 07 +05530 0

>001 08 +02888 0

>001 09 +03453 0

>001 10 +03512 0

>001 11 +03568 0

>001 12 +03015 0

>001 13 +03016 0

>001 14 +03016 0

>001 15 +03033 0

>001 16 +03015 0

>001 17 +03016 0

>001 18 +02997 0

>001 19 +03015 0

>001 20 +02894 0

>001 21 +03016 0

>001 22 +03015 0

>010 00 +11785 0

>011 00 +02022 0
>012 00 -01405 0
>013 00 +82103 0
>014 00 +82102 0
>015 00 +82106 0
>016 00 +82104 0
>017 00 +82103 0
>018 00 +92113 0
>019 00 -03237 0
>020 00 +02119 0
>021 00 +01941 0
>022 00 +01943 0
>023 00 +01946 0
>024 00 +01911 0
>025 00 +00515 0
>026 00 +14649 0
>027 00 +82093 0
>028 00 +82102 0
>029 00 +00003 0
> 12730
>-159.
>703.0
>721.0

POINT NUMBER 1

RPM -----	12730.00
STAGE PRESSURE RATIO -----	1.84
TURBINE MASS FLOW -----	2.39 LB/SEC
STATOR TORQUE -----	23.43 FT-LB

> 13 00 210172
R; T=1.93/5.48 14.07.47
>0 PRINTCC FILE FT08F001
R; T=0.68/2.07 14.08.13
>0 PUNCH FILE FT07F001
R; T=0.02/0.07 14.08.27
>LOGOUT
T=2.64/7.86 14.08.38
CP ENTERED, REQUEST, PLEASE.
CP
>LOG
CONNECT=00.26.04 VIRTCPU=000.02.21, TOTCPU 000.08.46
LOGOUT AT 20.01.02 ON 02/04/72

APPENDIX D

ANALYTIC DETERMINATION OF CLOSURE PLATE TORQUE

Considerable non-linear coupling between the axial force and torque measurements on the closure plate was observed during calibration. While the torque had little effect on the closure plate axial force, the axial force, when applied at expected operating values, created errors of up to 50% in the closure plate torque. Since the wiping torque of the rotor is such a small contribution to the total stator torque an analytic expression will be introduced to account for this effect.

The equation for the closure plate torque comes from page 609, Schlichting [Ref. 9]. If we consider a turbulent boundary layer between the rotor and closure plate and use a rotating disk model the torque moment is:

$$M = \frac{.0622}{4} \left(\frac{R^2 \omega}{\nu} \right)^{-0.2} \rho \omega^2 R^5 \quad (\text{ft-lbf}) \quad (\text{D-1})$$

where:

- R = closure plate radius (ft)
- ω = frequency (rad/sec)
- ν = kinematic viscosity (ft²/sec)
- ρ = density (lbf-sec²/ft⁴)

If one assumes standard conditions, i.e.,

- T = 68°F
- ν = 160×10^{-6} ft²/sec
- ρ = .00234 lbf-sec²/ft⁴

the torque equation reduces to:

$$M = 5.98 \times 10^{-10} (\text{rpm})^{1.8} \quad (\text{ft-lbf}) \quad (\text{D-2})$$

This yields a moment of .033 ft-lbf at 20,000 rpm and .009 ft-lbf at 10,000 rpm. Both values agree reasonably well with measured data and account for roughly 0.2% of the total stator torque. Since this contribution is so small, further refinement of the viscosity and density of the air was not considered.

Equation D-2 is used in the data reduction program to determine the stator torque (see subroutine CNVERT in Appendix E).

APPENDIX E

REDUCTION THEORY AND COMPUTER PROGRAMS

1. THEORY

The reduction theory for the TTTR is composed of two basic problems. First, a total stage efficiency for the turbine is determined using the known inlet flow conditions and the energy delivered to the dynamometer. The second major step involves determining the velocity and pressure distribution at the stator exit so that the stage losses may be divided between the stator and rotor. This is a one-dimensional performance analysis following the development of Vavra [Ref. 8]. The analysis assumes steady axisymmetric flow through the stage with a mean stream surface at the arithmetic mean stator radius. Detailed development of the reduction equations are described by several authors, perhaps best by Lenzini [Ref. 3], and will not be repeated here. The performance parameters follow generally those of Vavra and the results are presented using the NASA referred values.

Among the values of primary interest is the total to static stage efficiency:

$$\eta = \frac{\Delta T_w}{\Delta T_{IS}} = \frac{M_d \dot{W} / W C_p J}{\Delta T_{IS}} \quad (E-1)$$

where:

$$\begin{aligned} M_d &= \text{dynamometer moment (ft-lbf)} \\ \dot{W} &= \text{turbine mass flow rate (lbm/sec)} \\ \Delta T_{IS} &= \text{stage isentropic temperature change (}^\circ\text{R)} \\ \omega &= \text{turbine rotational velocity (rad/sec)} \end{aligned}$$

The stator efficiency is defined as:

$$\eta_s = \frac{V_1^2}{V_{1TH}^2} \quad (E-2)$$

with

V_1 = actual exit-velocity (ft/sec)

V_{1TH} = theoretical or isentropic velocity (ft/sec)

The rotor efficiency:

$$\eta_R = \frac{W_2^2}{W_{2TH}^2} \quad (E-3)$$

where:

W_2 = the actual relative rotor exit velocity (ft/sec)

W_{2TH} = theoretical relative exit velocity (ft/sec)

Another important parameter is the isentropic head coefficient:

$$K_{IS} = \frac{C_0^2}{U_1^2} \quad (E-4)$$

with:

C_0 = theoretical fluid velocity obtained in an isentropic expansion from stator inlet pressure to rotor exhaust pressure; $C_0 = 2(g_c J C_p \Delta T_{IS})^{1/2}$ (ft/sec)

U_1 = rotor blade mean radius velocity (ft/sec)

In defining the NASA referred values the referred temperature:

$$\theta = \frac{T_{T0}}{518.4} \quad (E-5)$$

and the referred pressure

$$\delta = \frac{P_{T0}}{14.7} \quad (E-5)$$

are used with T_{T0} ($^{\circ}R$) being the stator inlet total temperature and P_{T0} (psia) the stator inlet total pressure.

The referred mass flow rate is:

$$\dot{W}_{REF} = \frac{\dot{W}\sqrt{\theta}}{\delta} \quad (E-7)$$

the referred RPM;

$$N_{REF} = \frac{N}{\sqrt{\theta}} \quad (E-8)$$

The referred moment:

$$M_{REF} = \frac{M_d}{\delta} \quad (E-9)$$

and the referred horsepower:

$$HP_{REF} = \frac{HP}{\delta\sqrt{\theta}} \quad (E-10)$$

2. FLOW NOZZLE CALIBRATION

Test cell space limitations require the use of a non-standard TTTR flow measurement nozzle. The mass flow rate through the nozzle is:

$$\dot{W} = .1638 D_2^2 \gamma Y C (P_{NOZ} \Delta H / T_{NOZ})^{\frac{1}{2}} \quad (lbm/sec) \quad (E-11)$$

where:

- D_2 = nozzle diameter (ft)
- γ = coefficient of thermal expansion
- Y = nozzle expansion coefficient
- C = nozzle discharge coefficient
- P_{NOZ} = nozzle inlet total press (psi)
- T_{NOZ} = nozzle inlet total temp. ($^{\circ}R$)
- ΔH = nozzle differential pressure (in. H_2O at $68^{\circ}F$)

For the non-standard nozzle C is assumed to be a function of the nozzle Reynold's Number and must be determined by flow comparison with a standard orifice.

The nozzle mass flow equation and calibration procedures were carefully reviewed prior to calibration runs. Three calibration runs were carried out and the last two used to determine a new nozzle flow coefficient. The TTR flow nozzle calibration program was used to calculate the nozzle coefficient and curve fit it as shown in Figure E-1. The optimum polynomial

$$C = 9.38917 \times 10^{-1} + 6.17669 \times 10^{-7} \text{ Re} - 1.29859 \times 10^{-12} \text{ Re}^2 + 1.25920 \times 10^{-18} \text{ Re}^3 - 4.75948 \times 10^{-25} \text{ Re}^4 \quad (\text{E-12})$$

agrees within 0.1% of the previous values of Esdaile [Ref. 1] over the range of expected Reynolds Numbers.

TRANSONIC TURBINE TEST RIG
FLOW NOZZLE CALIBRATION

THIS PROGRAM CALCULATES AND PLOTS THE FLOW NOZZLE CALIBRATION
COEFFICIENT FOR THE TTTR. INPUT THE NUMBER OF RUNS, THEN FOR EACH
RUN THE NUMBER OF POINTS, PBAR(IN. HG.), TBAR(DEG. F.), TCR(DEG. F.),
DH(IN. H2O), PREF1(IN. HG.), PNOZ(IN. HG.), TNOZ(MV.), DPFL(IN. H2O),
PREF(IN. HG.), POR(IN. HG.), TOR(MV.).....

```

REAL*8 RE2,OKN2,WI,OKNEST,DELOKN,COEFKN,SB
REAL*8 TTTR(10)/10*,V/
REAL*8 ITITLE(12)//'DETHOMAS 1888 TTTR NOZZLE CAL ./'
2 REAL LABEL/4H /
  INTEGER*4 MMM
  DIMENSION DH(100),PREF1(100),PNOZ(100),TNOZ(100),TNOZR(100),
  1DPFL(100),PREF(100),POR(100),TOR(100),TORG(100),WFL(100),
  2OKN(100),RE(100),SB(100),OKN4(100),KEY(100)
  3,RE2(100),OKN2(100),WI(100),OKNEST(100),DELOKN(100),COEFKN(10)
  MMM=0
  LLL=0

```

READ INPUT DATA

```

WRITE(6,14)
READ(5,15)L
DO 114 M=1,L
  READ(5,15)N
  WRITE(6,127) L,N TBAR,TCR
  READ(5,16) PBAR,TBAR,TCR
  WRITE(6,23) PBAR,TCR
  READ(5,16) (DH(I),I=1,N)
  WRITE(6,333) (PREF1(I),I=1,N)
  READ(5,16) (PREF(I),I=1,N)
  WRITE(6,333) (PNOZ(I),I=1,N)
  READ(5,16) (TNOZ(I),I=1,N)
  WRITE(6,333) (DPFL(I),I=1,N)
  READ(5,16) (DPFL(I),I=1,N)
  WRITE(6,333) (POR(I),I=1,N)
  READ(5,16) (POR(I),I=1,N)
  WRITE(6,333) (TOR(I),I=1,N)
  READ(5,16) (TOR(I),I=1,N)
  WRITE(6,333) (TOR(I),I=1,N)
  FORMAT(1,24F5.1)

```



```

DO C9 I=1,N
WRITE(6,24) I, DH(I), PREF1(I), PNOZ(I), TNOZ(I), DPFL(I), PREF(I),
1POR(I), TOR(I)
99 CONTINUE
23 FORMAT(' ', 3E10.4)
24 FORMAT('0', 11I0, 5X, 8E10.4)

```

C C

INPUT CONSTANTS

```

DO 7 II=1,100
WI(II)=1.0
CONTINUE
D10=6.065
D20=4.2443
DIN=7.975
D2N=4.25
BETA0=D20/D10
BETAN=D2N/D1N
GAM=1.4
EX1=GAM/(GAM-1.)
EX2=(GAM-1.)/GAM
EX3=2./GAM
A=D20*(830.-5000.*BETA0+9000.*BETA0**2-4200.*BETA0**3+530./SORT(
1 D10))
B=0.5993+0.067/D10
C=0.3640+0.076/SORT(D10)
OKE=B+C*BETA0**4
OKINF=OKE/(1.+A*(0.15E-04/D20))

```

C C

COMPUTE CORRECTED PRESS AND TEMPS

```

GHGBR=13.63905-0.00136303*IBAR
HGCR=13.63905-0.00136303*TCR
CHGBR=0.4891585*GHGBR/13.54
CHGCR=0.4891585*HGCR/13.54
GW68=C.9983763+68.*C.106058E-03-(68.**2)*C.159319E-05
GWCR=C.9983763+TCR*C.106058E-03-(TCR**2)*C.159319E-05
PAMB=PBAR*CHGBR

```

C C

CALCULATIONS FOR DRIFTED FLOW RATE

```

DO 12 I=1,N
ODPFL=DPFL(I)
DPFL(I)=ODPFL*GWCR*62.42732/1728.
POR(I)=CHGCR*(PREF(I)-POR(I))+PAMB
TOR(I)=33.252+34.86*TOR(I)-0.1855*TOR(I)**2
TCRR(I)=TOR(I)+459.69
ALPHA0=1.+1.93*(TOR(I)-68.)*0.1E-04
Y0=1.-C.41+C.35*BETA0**4)*DPFL(I)/(GAM*POR(I))
Z0=1.9+2.4*(TOR(I)-100.)*0.1E-C2
HW680=ODPFL*GWCRP/GW68

```



```

FR=1.0
WFL(I)=0.1638427*D20**2*ALPHA0*QKINF*FR*YO*SQRT(POR(I))*HW680/
  TORP(I))
10 XO=2.27376*WFL(I)/(D20*ZO)
FR=1.+(A/XO)*0.1E-05
WFLC=C.1638427*D20**2*ALPHA0*QKINF*FR*YO*SQRT(POR(I))*HW680/
  TORR(I))
11 IF(ABS(WFLC-WFL(I)).LE.0.0001) GO TO 11
WFL(I)=WFLC
GO TO 10
11 WFL(I)=WFLC

          CC          CC
          CALCULATIONS FOR NOZZLE DISCHARG COEFFICIENT
QDH=DH(I)*GWCR*62.42732/1728.
DH(I)=QDH*(PREF1(I)-PNOZ(I))+PAMB
TNOZ(I)=33.252+34.86*TNOZ(I)-0.1855*TNOZ(I)**2
TNOZR(I)=TNOZ(I)+459.69
ALPHAN=1.+2.52*(TNOZ(I)-68.)*0.1E-04
R=1.-(DH(I)/PNOZ(I))
YN=SQRT(R**EX3*XI*((1.-R)**EX2)/(1.-R))*((1.-BETAN**4)/(1.-R**EX3*
  BETAN**4))
1 ZN=1.9+2.4*(TNOZ(I)-100.)*0.1E-02
HW68N=QDH*GWCR/GW68
QKN(I,1)=6.10342*WFL(I)*SQRT(TNOZR(I))/(HW68N*PNOZ(I))/(D2N**2*YN
  *ALPHAN)
12 CONTINUE
RE(I)=2.27376*WFL(I)/(D2N*ZN)*0.1E+07

          CC          CC          CC
          WRITE OUTPUT DATA
WRITE(6,17)
WRITE(6,18)M,PNOZ(I)
WRITE(6,19)
WRITE(6,20)PAMB,N,GAM
WRITE(6,21)
DO 13 I=1,N
WRITE(6,22) I,WFL(I),QKN(I,1),RE(I)

RE2(I+MMM)=RE(I)
QKN2(I+MMM)=QKN(I,1)
QKN4(I)=QKN(I,1)
CONTINUE
MMM=MMM+N
LLL=LLL+1
CALL OSPLOT (RE,QKN,N,100,1,0,0,0,0,0,0,0,0)
13

```



```

WRITE(6,127) MMM,LLL,N
MODCUR=2
IF(LLL.EQ.1) MODCUR=1
ITYPE=LLL
CALL DRAW(N,RE,QKN4,MODCUR,ITYPE,LABEL,ITITLE,0,0,0,1,1,9,12,1
2,LAST)
WRITE(6,127) MMM,LLL,N,L,M
114 CONTINUE
DO 115 I=1,MMM
KEY(I)=RE2(I)
RE(I)=RE2(I)
QKN4(I)=QKN2(I)
115 CONTINUE
WRITE(6,127) MMM,LLL,N
CALL SHSORT(RE,KEY,MMM)
WRITE(6,127) MMM,LLL,N
DO 116 I=1,MMM
RE2(I)=RE(I)
C      LEAST WEIGHT FUNCTION "WI" WILL KICK ANY BAD DATA POINTS OUT OF THE
C      LEAST SQUARES DATA CURVE FIT. POINTS WILL STILL BE PLOTTED.
C      KICK OUT BAD POINTS BY SETTING WI(#)=0.00001
IF(RE(I).LT.3.0E 05) WI(I)=.00001
IF(RE(I).GT.9.0E 05) WI(I)=.00001
WI(27)=.00001
C
C      QKN2(I)=QKN4(KEY(I))
C      WRITE(6,128) I,KEY(I),RE2(I),QKN2(I)
116 CONTINUE
C
NOPOLY=4
DO 31 KM=1,NOPOLY
CALL LSOPL2(MMM,KM,RE2,QKN2,WI,QKNEST,DELOKN,COEFKN,SB,TITLE)
C
DO 30 I=1,MMM
QKN4(I)=QKNEST(I)
WRITE(6,126) RE(I),QKN2(I),QKN4(I)
30 CONTINUE
MODCUR=2
IF(KM.EQ.NOPOLY) MODCUR=3
CALL DRAW(MMM,RE,QKN4,MODCUR,0,LABEL,ITITLE,0,0,0,1,1,9,12,1
2,LAST)
31 CONTINUE
14 FORMAT(1H1,32X,'FLOW NOZZLE CALIBRATION FOR THE TRANSONIC TURBINE
1 TEST RIG')
15 FORMAT(I3)

```



```

16 FORMAT(8F10.0)
17 FORMAT(//32X, 'TEST SERIES', 25X, 'NOZZLE SUPPLY PRESSURE', )
18 FORMAT(/35X, I3, 38X, F5.2)
19 FORMAT(/32X, 'ATMOSPHERIC PRESSURE', 11X, 'DATA POINTS', 11X, 'GAMMA', )
20 FORMAT(/35X, F6.2, 19X, I2, 17X, F3.1)
21 FORMAT(/34X, 'POINT', 8X, 'FLOW RATE', 8X, 'DISCHARGE', 8X, 'REYNOLDS', /
1 47X, ' (LBM/SEC)', 7X, 'COEFFICIENT', 8X, 'NUMBER', //)
22 FORMAT( , 10X, 1F20.6)
25 FORMAT( , 3F12.4)
126 FORMAT( , 5I3)
127 FORMAT( , 2I6, 2F10.2)
128 STOP

```

END

TABLE E-1. Flow Nozzle Calibration Results.

TEST SERIES 1			
ATMOS. PRESS. 14.63	DATA POINTS 24	GAMMA 1.4	
POINT	FLOW RATE (LBM/SEC)	DISCHARGE COEFFICIENT	REYNOLDS NUMBER
1	0.3333	1.07321	97383.44
2	0.4692	1.02266	136285.44
3	0.6765	1.03890	194124.13
4	0.8338	1.02855	238953.19
5	0.9800	1.03587	280366.06
6	1.1485	1.03959	327711.44
7	1.2644	1.04350	360309.88
8	1.4301	1.05083	406644.50
9	1.5875	1.04879	450399.81
10	1.6974	1.04643	480956.50
11	1.8496	1.04931	523164.81
12	1.9926	1.05194	562659.56
13	2.1460	1.05291	605166.31
14	2.2807	1.05045	642331.75
15	2.4241	1.05164	681821.44
16	2.5703	1.05220	722029.00
17	2.7281	1.04986	765681.25
18	2.8714	1.05067	805576.00
19	3.0038	1.04965	841254.50
20	3.1846	1.04902	891531.56
21	3.3206	1.03917	928796.19
22	3.7879	1.04843	1058612.00
23	4.1620	0.99500	1162145.00
24	4.8386	1.04259	1349941.00

TEST SERIES 2			
ATMOS. PRESS. 14.66	DATA POINTS 27	GAMMA 1.4	
POINT	FLOW RATE (LBM/SEC)	DISCHARGE COEFFICIENT	REYNOLDS NUMBER
1	0.3883	1.00618	111678.06
2	0.6027	1.04201	172419.81
3	0.7089	1.04152	202088.56
4	0.8637	1.02969	245257.19
5	0.9702	1.04955	272885.75
6	1.1179	1.03972	313904.81
7	1.2341	1.04268	345920.38
8	1.3822	1.04482	386788.13
9	1.4791	1.04626	413189.63
10	1.6592	1.05085	462916.69
11	1.8092	1.05366	503880.94
12	1.9038	1.05274	529557.06
13	2.0132	1.05229	559527.50
14	2.1660	1.05232	601236.75
15	2.2768	1.05099	631443.88
16	2.4154	1.05157	669038.75
17	2.5146	1.05808	695913.81
18	2.6629	1.05663	736042.50
19	2.8178	1.05025	777873.75
20	3.0729	1.05259	847576.06
21	3.2794	1.04997	903390.31
22	3.5108	1.05053	966729.75
23	3.7611	1.04980	1034773.81
24	4.0358	1.04690	1109443.00
25	4.3377	1.04724	1191432.00
26	4.5584	1.04628	1250477.00
27	4.9524	1.04310	1358001.00

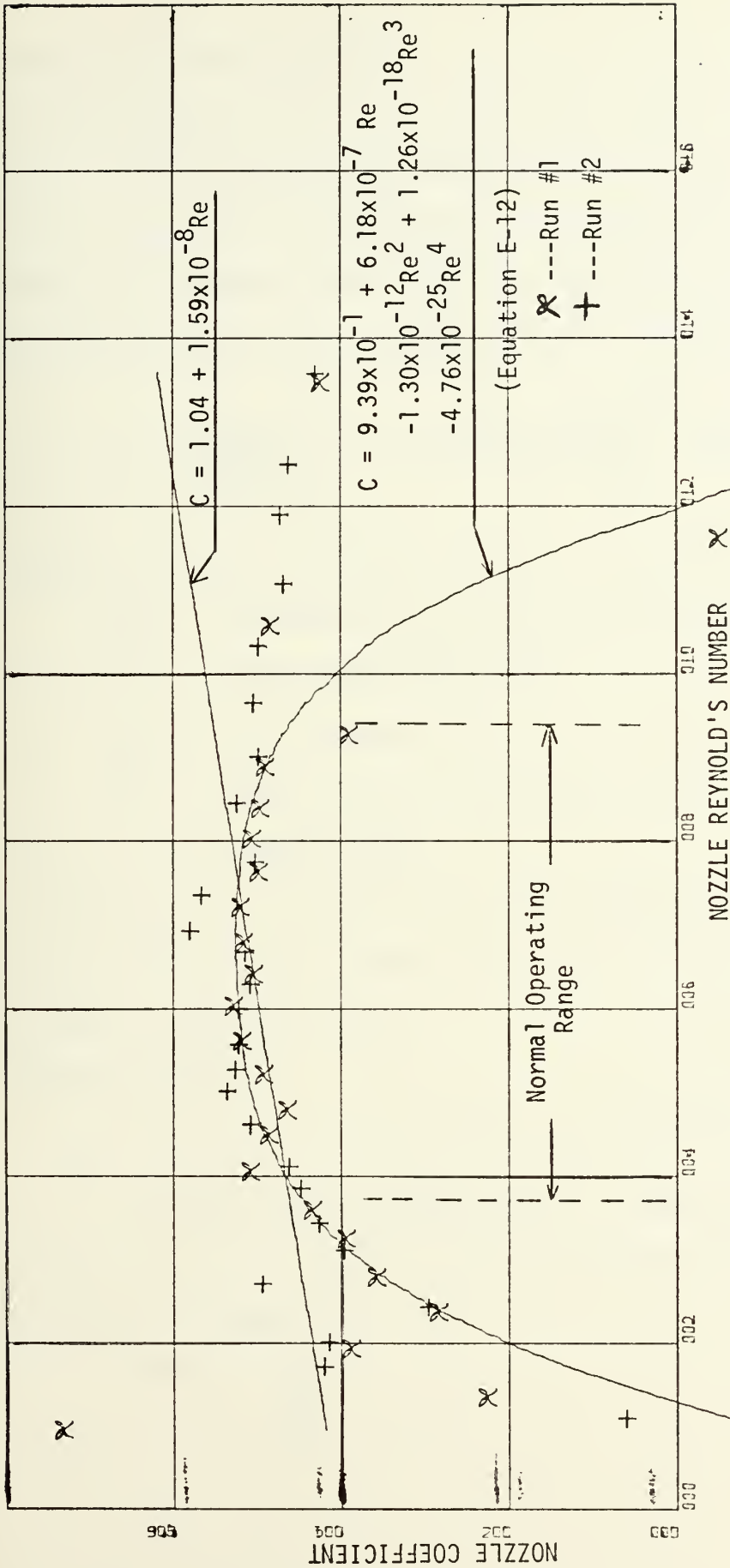


Figure E-1. Flow Nozzle Calibration Plot (Nozzle Coefficient vs. Reynold's Number)

X--SCALE=2.00E+05 UNITS INCH.

Y--SCALE=2.00E-02 UNITS INCH.

DETHOMAS 1888 TTTR NOZZLE CAL

ADD +1.00E+00 UNITS TO ALL Y VALUES.

3. LABYRINTH LEAK RATE CALIBRATION

Due to the changes in the stator plenum a new stator labyrinth seal leak rate was determined using the program on page 81. The labyrinth leak rate is assumed to be a function of the pressure ratio across the labyrinth and a correction factor which is a function of the temperature change from the plenum to the hood [Ref. 3]. The equation:

$$\dot{W}_L = \frac{\theta_L P_{TPL}}{\sqrt{T_{PL}} R/G} \left[1.0 + 0.32 \left(\frac{T_{PL} - T_{HD}}{T_{PL}} \right) \right]^{\frac{1}{2}} \quad (\text{lbm/sec}) \quad (\text{E-13})$$

was determined to best fit the test run data. In this equation:

P_{TPL} = pressure on the plenum side of the labyrinth (psia)

T_{PL} = plenum temperature (°F)

T_{HD} = hood temperature (°F)

θ_L = some function of the pressure ratio across the labyrinth seal.

Two labyrinth leak calibration runs were conducted using a cover plate to seal the stator exit and a small orifice to determine the mass flow through the labyrinth seals.

The leak polynomial:

$$\theta_L = -3.7487 \times 10^{-1} + 8.7014 \times 10^{-1} PR - 7.2633 \times 10^{-1} PR^2 + 3.158 \times 10^{-1} PR^3 - 6.9744 \times 10^{-2} PR^4 + 6.1683 \times 10^{-3} PR^5 \quad (\text{E-14})$$

was determined using the labyrinth leak rate FORTRAN program. The pressure ratio is defined by:

$$PR = \frac{P_{TPL}}{P_{HD}}$$

Values of the calculated leak rate are plotted against actual test point in Figures E-2.1 and E-2.2. (Run number three was at a higher temperature to check the temperature correction.)

TRANSONIC TURBINE TEST RIG
LABYRINTH LEAK RATE CALIBRATION

THIS IS THE CALIBRATION PROGRAM FOR THE LABYRINTH LEAK RATE OF THE TTTR.
 USE INPUT DATA PATM(IN.HG.), PLAB(IN.HG.), PHD(IN.HG.), TTPLD(MV), THD(MV)
 TTD1(MV), PFL(IN.HG.), HWFL INM.H2O), PBAR(IN.HG.), TCR(DEG.F), TCR(DEG.F)
 PBAR(IN.HG.)
 CTTD1(MV), PFL(IN.HG.), HWFL(CM.H2O), PBAR(IN.HG.)
 CTCL(DEGREES F.), TCR(DEGREES F.), PREF(IN.HG.)

```

REAL*8 PRCF, WREFCF, WI, YY, DELY, BB, SB
REAL*8 TITL(10)/10*, I1, I2, I3, I4, I5, I6, I7, I8, I9, I10
REAL*8 ITITL(12)/10*, DETHOMAS 1888 TTTR LAB LEAK CAL
2 REAL LABEL/4H /
DIMENSION PATM(80), PSPL(80), PHD(80), TTPLD(80), ERROR(80), TTD1(80),
1 PFL(80), HWFL(80), WREF(80), WLABR(80), WREF(80), RE(80), PR(80)
2, PRCF(80), THD(80), MW(80)
3, PRCF(80), WREFCF(80), WI(80), YY(80), DELY(80), BB(10), SB(10)
A1=-3.74875E-01
A2=8.70142E-01
A3=-7.26335E-01
A4=3.15835E-01
A5=-6.197437E-02
A6=6.16826E-03
READ(5,99)I
DO 50 M=1,L
  READ(5,100)PBAR,N,NRUN
  READ(5,101)TCR,TCL,TCR
  WRITE(6,203)PBAR,TCR
  READ(5,101)(PATM(I),I=1,N)
  READ(5,101)(PSPL(I),I=1,N)
  READ(5,101)(PHD(I),I=1,N)
  READ(5,101)(TTPLD(I),I=1,N)
  READ(5,101)(TTD1(I),I=1,N)
  READ(5,101)(THD(I),I=1,N)
  READ(5,101)(PFL(I),I=1,N)
  READ(5,101)(PREF(I),I=1,N)
  READ(5,101)(HWFL(I),I=1,N)
  WRITE(6,202)(I,PATM(I),PSPL(I),PHD(I),TTPLD(I),TTD1(I)
2,THD(I),PFL(I),PREF(I),HWFL(I),I=1,N)
  WRITE(6,200)
D1=2.067
D2=0.825
  
```



```

B= D2/D1
QKINF=0.609913
A=D2*(830.-5000.*B+9000.*B**2-4200.*B**3+530./SQRT(D1))
GAM=1.4
GHGRM=13.63905-.0013630303*TCR
CHGCL=13.63905-.0013630303*TCR
CHGCC=0.4891585*GHGCL/13.54
CHGCR=0.4891585*GHGRM/13.54
GW68=0.99837633+1.0605756*68./10000.-1.5931861*68.**2/1000000.
GWRM=0.99837633+1.0605756*TCR/10000.-1.5931861*TCR**2/1000000.
RATGW=GWRM/GW68
PAMB=PRAR
PAMB=PAMB*CHGC
R=53.3448
G=32.174
DO 49 I=1,N
WI(I)=1.0
QPATM=PATM(I)
QPSPL=PSPL(I)
QPHD=PHD(I)
QTTPLD=TTPLD(I)
QTTDI=TTDI(I)
QPEL=PFL(I)
QPREF=PREF(I)
QHWFL=HWFL(I)
THD(I)=32.+35.98*THD(I)-.435*THD(I)**2
TTPLD(I)=32.+35.98*QTTPLD-.435*QTTPLD**2
QTTDI=32.+35.98*QTTDI-.435*QTTDI**2
ALPH=1.+0.00193*((QTTDI-68.)/100.)
DPFL=QHWFL*GWRM/12.*62.42732/144.
QPFL=CHGCR*(QPREF-QPFL)+PAMB
Y=1.-(0.41+0.25*B**4)*DPFL/(GAM*QPFL)
HW68=QHWFL*PATGW
TTDIR=0TTDI+45S.7
Z=0.019+0.0024*(QTTDI/100.-1.)
WLABR(I)=0.1638427*D2**2*ALPH*QKINF*Y*SQRT(QPFL*HW68/TTDIR)
10 XO=2.27376*WLABR(I)/(D2*Z)
FR=1.+(A/XO)*0.1E-05
WPART=0.1638427*D2**2*ALPH*QKINF*FR*Y*SQRT(QPFL*HW68/TTDIR)
IF(ABS(WPART-WLABR(I)).LE.0.0001) GO TO 11
WLABR(I)=WPART
GO TO 10
11 WLABR(I)=WPART
RE(I)=27560.727*WLABR(I)/Z
QPSPL=CHGCR*(QPATM-QPSPL)+PAMB
QPHD=CHGCR*(QPATM-QPHD)+PAMB
PRCF(I)=PR(I)

```


TTR LABYRINTH LEAK RATE TEST RUN NUMBER 3

POINT	LABYRINTH LEAK RATE (LBM/SEC)	LABYRINTH PRESSURE RATIO	PLENUM TEMPERATURE (DEG F)	TOT. TEMPERATURE (DEG F)	REFERRED LEAK RATE (SQ IN)	ANALYTICAL REFERRED LEAK RATE	PERCENT ERROR	HOOD TEMP (DEG F)
1	0.114612	2.9079	78.596	78.596	0.077199	0.075322	-2.4308	69.299
2	0.109526	2.8106	78.945	78.945	0.076340	0.075032	-1.7135	69.580
3	0.109338	2.7141	79.188	79.188	0.079028	0.074760	-5.4005	70.036
4	0.102609	2.6044	79.362	79.362	0.077180	0.074357	-3.6585	69.860
5	0.195714	2.5055	79.432	79.432	0.074807	0.073847	-1.2838	69.825
6	0.093299	2.4066	79.119	79.119	0.076205	0.073159	-3.9979	70.421
7	0.085945	2.3161	78.945	78.945	0.072960	0.072358	-0.8252	70.351
8	0.081032	2.1977	78.666	78.666	0.072584	0.071061	-2.0978	70.421
9	0.070337	2.0974	78.352	78.352	0.071710	0.069733	-2.7575	70.386
10	0.064229	2.0022	77.934	77.934	0.069925	0.068271	-2.3663	70.596
11	0.059482	1.9033	77.342	77.342	0.066775	0.066526	-0.3727	70.561
12	0.053915	1.8108	76.714	76.714	0.065111	0.064652	-0.4055	70.456
13	0.048834	1.6907	76.051	76.051	0.063303	0.061788	-2.3944	70.281
14	0.043593	1.6059	75.562	75.562	0.060452	0.059382	-1.7703	70.211
15	0.036865	1.5030	74.039	74.039	0.057732	0.055901	-3.5846	70.071
16	0.030739	1.3957	74.480	74.480	0.052659	0.051403	-2.3846	69.965
17	0.030739	1.2766	73.851	73.851	0.048112	0.045005	-6.4578	69.930

TTR LABYRINTH LEAK RATE TEST RUN NUMBER 2

POINT	LABYRINTH LEAK RATE (LBM/SEC)	LABYRINTH PRESSURE RATIO	PLENUM TEMPERATURE (DEG F)	TOT. TEMPERATURE (DEG F)	REFERRED LEAK RATE (SQ IN)	ANALYTICAL REFERRED LEAK RATE	PERCENT ERROR	HOOD TEMP (DEG F)
1	0.017078	1.0948	65.472	65.472	0.031293	0.031131	-0.5181	64.170
2	0.030765	1.1943	65.999	65.999	0.039085	0.039443	0.9078	64.170
3	0.036384	1.3082	66.210	66.210	0.047012	0.046872	-0.2992	64.170
4	0.042837	1.4020	66.421	66.421	0.051809	0.051698	-0.2146	64.100
5	0.047774	1.5169	66.491	66.491	0.056359	0.056415	0.0932	64.100
6	0.053337	1.6063	66.456	66.456	0.059328	0.059396	0.1142	63.994
7	0.058931	1.7068	66.456	66.456	0.062324	0.062220	-0.1910	63.959
8	0.063758	1.8140	66.421	66.421	0.064673	0.064597	-0.1232	63.959
9	0.068361	1.9071	66.421	66.421	0.066619	0.066559	-0.1849	63.924
10	0.073841	2.0006	66.491	66.491	0.068119	0.068245	0.1849	63.889
11	0.078771	2.1108	66.597	66.597	0.069730	0.069922	0.2752	63.854
12	0.083534	2.2024	66.702	66.702	0.071264	0.071223	-0.2554	63.894
13	0.088584	2.3029	66.878	66.878	0.072262	0.072223	-0.2563	63.924
14	0.094701	2.4069	67.088	67.088	0.073262	0.073162	-0.2554	63.924
15	0.096237	2.5158	67.475	67.475	0.074951	0.073908	-1.3911	63.959
16	0.101962	2.6145	67.685	67.685	0.073347	0.074387	1.3911	64.170
17	0.101962	2.7145	67.685	67.685	0.074787	0.074387	-1.0299	64.206
18	0.106123	2.8129	67.896	67.896	0.075192	0.075041	-0.2005	64.980

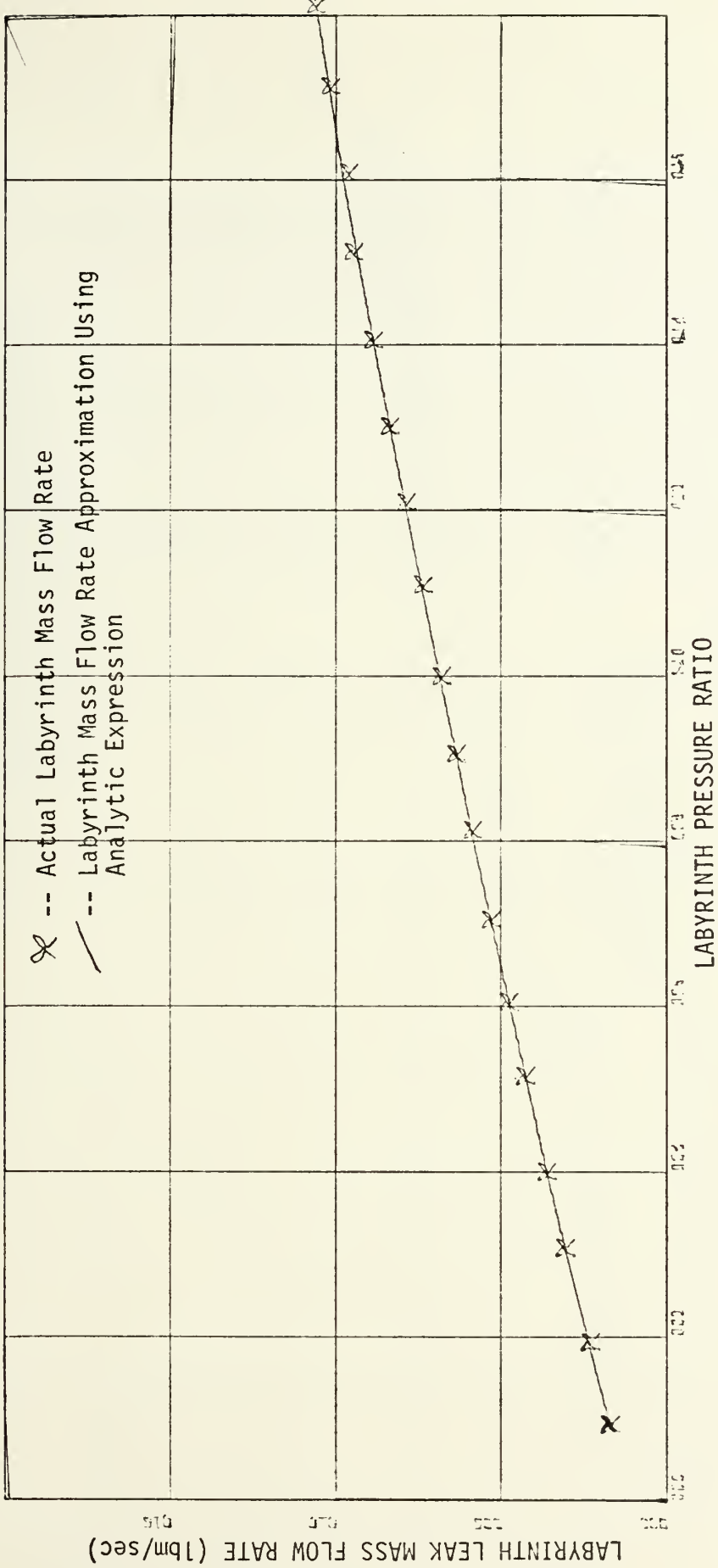


Figure E-2.1. Labyrinth Leak Calibration Plot (Run #2)

X-SCALE=2.00E-01 UNITS INCH

Y-SCALE=5.00E-02 UNITS INCH

DETHOMAS 1888 TTTA LAB LEAK CAL

912 1.00E+02 UNITS TO ALL X VALUES.

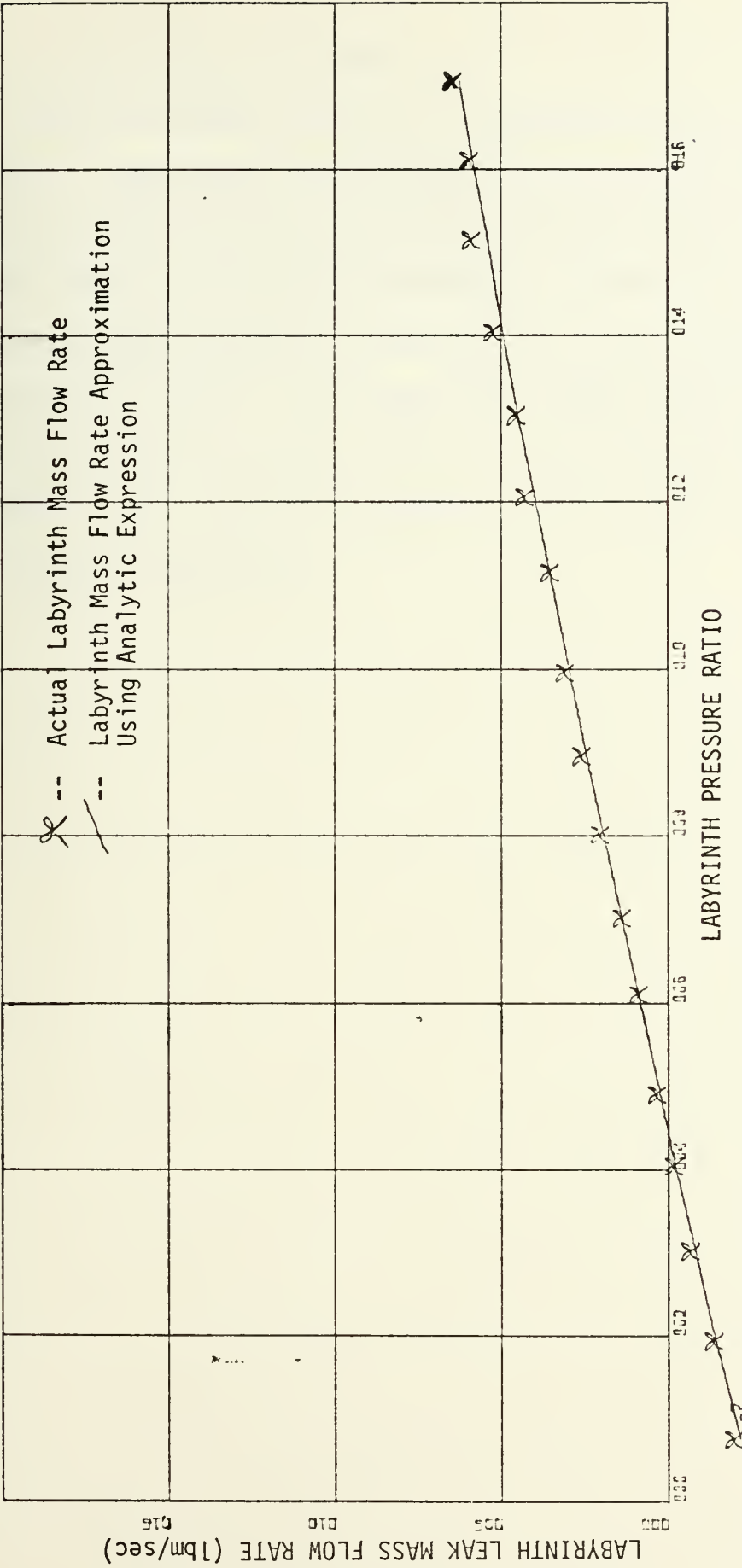


Figure E-2.2. Labyrinth Leak Calibration Plot (Run #3)

X-SCALE=2.00E-01 UNITS INCH. ADD +1.20E+00 UNITS TO ALL X VALUES.
 Y-SCALE=5.00E-02 UNITS INCH. ADD +5.00E-02 UNITS TO ALL Y VALUES.
 DETHOMAS 1888 TTTR LAB LEAK CAL

4. TTTR MAIN REDUCTION PROGRAM

The main reduction program is an adaptation from that of Esdaile [Ref. 1]. The program was designed to be run using the IBM 360 time sharing CP/CMS system for on-line data acquisition and reduction. It will read data as explained in Appendix B, perform certain operations, return selected values to the operator and finally produce a detailed tabulation of the run. The program also punches cards for later use in machine plotting of desired results. The program flow chart, Figure E-3, and the program itself are designed for maximum flexibility through use of extensive subroutines.

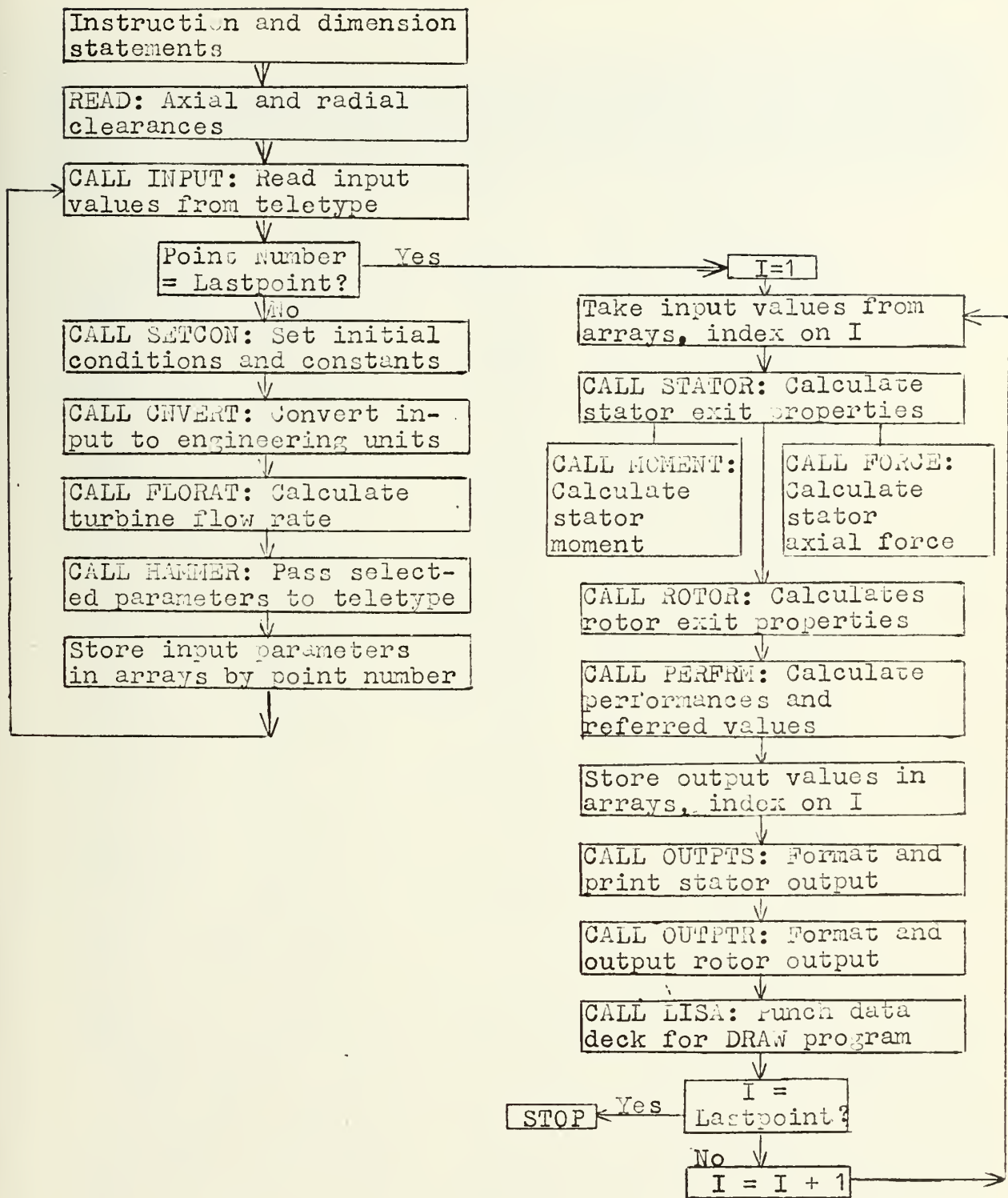


Figure E-3 TTR On-Line Data Reduction Flow Chart


```

C
02 FORMAT( ' -TRANSONIC TURBINE TEST RIG (ON LINE DATA REDUCTION)= ',
1//, ' HI THERE TTTTR FANS, THIS SYSTEM SHOULD INRUT FROM THE TTTT000010
2//, ' B&F DATA COLLECTION SYSTEM COUPLED TO A STANDARD ASCII TTTT000020
3//, ' YOU SHOULD BE SCANNING CHANNELS 1-29 AND 96-98 WITH THE TURBER TTTT000030
4//, ' LIMIT SET AT 90. VALVE 1 SHOULD BE THE ONLY VALVE SELECTED TTTT000040
5//, ' AND ITS UPPER LIMIT SET AT 22. THE RUN NUMBER, POINT NUMBERS TTTT000050
6//, ' IN GROUPS OF TWO. LAST AUTOMATIC DATA POINT YOU MUST MANUALLY TTTT000060
7//, ' FOLLOWING THE FORCE AND TORQUE AND DYNAMOMETER TORQUE. TTTT000070
8//, ' PUNCH THE START CHARACTER WITH PROPER SIGNS AND DECIMAL. TTTT000080
9//, ' THESE WILL BE 5 CHARACTERS WITH POINT OF EACH RUN SET POINT NUMBER TTTT000090
B//, ' POINTS. FOLLOWING THE LAST VALUES TO PUNCH. ALL MANUAL POINTS TTTT000100
C//, ' 00 AND FOLLOWING THE CONSTANT VALUES TO PUNCH. ALL MANUAL POINTS TTTT000110
D//, ' WILL BE FOLLOWED BY C.R., L.F., X-OFF, X-OFF AND NO SPACES MAY BE TTTT000120
E//, ' SKIPPED. THIS PROGRAM WILL PROBABLY DESTROY IN 10 SEC. GOOD LUCK !} TTTT000130
F//, ' TTTT000140
G//, ' TTTT000150
TTT000160
TTT000170
TTT000180
TTT000190
TTT000200
TTT000210
TTT000220
TTT000230
TTT000240
TTT000250
TTT000260
TTT000270
TTT000280
TTT000290
TTT000300
TTT000310
TTT000320
TTT000330
TTT000340
TTT000350
TTT000360
TTT000370
TTT000380
TTT000390
TTT000400
TTT000410
TTT000420
TTT000430
TTT000440
TTT000450
TTT000460
TTT000470
TTT000480

REAL#4 MVAIM,MVA1,MVIM,MVIC,MV1,MW1,MV2,MW2
DIMENSION DH(50),PREF1(50),PNOZ(50),PTPL(50),PTO(50),PREF2(50),
1PHUB(50),PTIP(50),P13(50),P14(50),P15(50),P16(50),P17(50),P18(50),
2P19(50),P20(50),P21(50),PHD(50),PCL1(50),PCL2(50),PCL3(50),
3TNOZ(50),TTPL(50),TTO(50),THD(50),AXIL(50),TORQR(50),DYNAR(50),
4RPM(50),CLAXIL(50),CLTRQR(50)
DIMENSION FAX(50),CLFAX(50),FQ(50),F1(50),F2(50),F3(50),F4(50),
5F5(50),F6A(50),FNET(50),TORQ(50),CLTORQ(50),FLOWN(50),FLOWT(50),
6FLOWL(50),RE(50),PHI(50),XI(50),PIAV(50),PRPL(50),PRS(50),T1(50),
7T1IS(50),VAI(50),VUI(50),V1(50),V1IS(50),ALPH1(50),VCOFS(50),
8MVI(50),MVA1(50),WAI(50),WUI(50),WI(50),UI(50),BETA1(50),MWI(50),
9ZETAS(50),ETAS(50),PTI2(50),PR(50),WTE(50),TIT2(50),T2IS(50),
0T2TH(50),T2TIS(50),DELTW(50),DELTI(50),DELHW(50),T2IS(50),
1VA2(50),WU2(50),V2(50),VOIS(50),ALPH2(50),WA2(50),WU2(50),
2U2(50),W2IS(50),BETA2(50),DBETA(50),WCOFS(50),ZETA(50),ETAR(50),
3REFRPM(50),XKIS(50),ETATS(50),ETATT(50),WREFLOW(50),REFMDM(50),
4HP(50),REFHP(50),REACHB(50),REACMN(50),REACTP(50),F(50),MV2(50),
5MW2(50),REACEF(50),QNOZ(50),QTPL(50),PTO(50),QHD(50),TTPQ(50),
6TTP(50),SFF(50),RFAX(50),RTORQ(50),RVA1(50),RVUI(50)
WRITE(6,02)
WRITE(6,05)
READ(5,06) AXCLR
WRITE(6,07)
READ(5,06) RADCLR
WRITE(6,08)
FORMAT(' ',//, '----PLEASE ENTER AXIAL CLEARANCE')
05
06

```


TTTT00490
 TTTT00500
 TTTT00510
 TTTT00520
 TTTT00530
 TTTT00540
 TTTT00550
 TTTT00560
 TTTT00570
 TTTT00580
 TTTT00590
 TTTT00600
 TTTT00610
 TTTT00620
 TTTT00630
 TTTT00640
 TTTT00650
 TTTT00660
 TTTT00670
 TTTT00680
 TTTT00690
 TTTT00700
 TTTT00710
 TTTT00720
 TTTT00730
 TTTT00740
 TTTT00750
 TTTT00760
 TTTT00770
 TTTT00780
 TTTT00790
 TTTT00800
 TTTT00810
 TTTT00820
 TTTT00830
 TTTT00840
 TTTT00850
 TTTT00860
 TTTT00870
 TTTT00880
 TTTT00890
 TTTT00900
 TTTT00910
 TTTT00920
 TTTT00930
 TTTT00940
 TTTT00950
 TTTT00960

07 FORMAT(' ://, '---PLEASE ENTER RADIAL CLEARANCE')
 08 FORMAT(' ://, '---NOW START READING THE PUNCH TAPE POINTS')
 LASTPT=0
 NP=0

C C 11 CONTINUE
 C CALL INPUT(NRUN, NP, NDAY, NMO, NYEAR, QPBAR, QPNOZ, QPTO, QPHD,
 1 QPHUB, QPTIP, QP13, QP14, QP15, QP16, QP17, QP18, QP19, QP20, QP21, QPHD,
 2 QPCL1, QPCL2, QPCL3, QPTPL, QDH, QLAXIL, QLTRQR, QTNOZ, QTTT, QTHD,
 3 QRP, QAXIL, QTORQR, QDYNAR, AXCLR, RADCLR, LASTPT)
 IF (LASTPT.EQ.1) GO TO 13
 C CALL SETCON(D1N, D2N, BETAN, RG, GAM, GC, CP, CJ, C, EX1, EX2, EX3, PI,
 1 ZNS, TETS, RTIP1, RHUB1, RTIP2, RHUB2, AAXS, AAXR, ATHS, RM1, RM2, SKT, RKT,
 2 RADCLR, B1, B2, B3, B4, B5, D1, D2, D3, D4, D5, D6, CL1, CL2, CL3, J, MODRAD)
 C CALL CONVERT(NP, QPBAR, QDH, QPNOZ, QPTO, QPHUB, QPTIP, QP13, QP14,
 1 QP15, QP16, QP17, QP18, QP19, QP20, QP21, QPTPL, QPHD, QTNOZ, QTTT,
 2 QTHD, PAMR, QHW68, QTNOZR, QTTOR, QFAX, QTORQ, DYNA, QLFAX, QLTORQ,
 3 QAXIL, QTORQR, QDYNAR, QLAXIL, QPCL1, QPCL2, QPCL3, QRP)
 C CALL FLORAT(D2N, RG, GC, EX1, EX2, EX3, QHW68, QDH, QPNOZ, QPTPL, QPHD,
 1 PRP, QTNOZ, QTNOZR, QTTT, QTTOR, QTHD, B1, B2, B3, B4, B5, D1, D2, D3, D4, D5, D6,
 2 NRUN, NP, QRE, QFLOWN, QFLOWL, QFLOWT, BETAN)
 C QNOZ(NP)=QPNOZ
 PTO(NP)=QPTO
 PHUB(NP)=QPHUB
 PTIP(NP)=QPTIP
 P13(NP)=QP13
 P14(NP)=QP14
 P15(NP)=QP15
 P16(NP)=QP16
 P17(NP)=QP17
 P18(NP)=QP18
 P19(NP)=QP19
 P20(NP)=QP20
 P21(NP)=QP21
 QTPL(NP)=QPTPL
 QHD(NP)=QPHD
 PCL1(NP)=QPCL1
 PCL2(NP)=QPCL2
 PCL3(NP)=QPCL3
 TTT(NP)=QTTOR
 THD(NP)=QTHD
 AXIL(NP)=QAXIL


```

TORQR(NP)=QTORQR
DYNAR(NP)=DYNA
CLFAX(NP)=QLFAX
FAX(NP)=QFAX
TORQ(NP)=QTORQ
CLTORQ(NP)=QLTORQ
RPM(NP)=QRPM
CLAXIL(NP)=QLAXIL
CLTRQR(NP)=QLTRQR
FLOWN(NP)=QFLOWN
FLOWT(NP)=QFLOWT
FLOWL(NP)=QFLOWL
PRPL(NP)=PRP
RE(NP)=QRE

```

C

```

IF(MODRAD.EQ.0) GO TO 12
CALL HAMMER(NP,QTORQ,QRPM,QFLOWT,PRP)
CONTINUE

```

12

```

GO TO J1

```

13

```

CONTINUE
DO 15 J=1,2
DO 14 I=1,NP
QPTO=PTO(I)
QPHUB=PHUB(I)
QPTIP=PTIP(I)
QPI3=PI3(I)
QPI4=PI4(I)
QPI5=PI5(I)
QPI6=PI6(I)
QPI7=PI7(I)
QPI8=PI8(I)
QPI9=PI9(I)
QP20=PI20(I)
QP21=PI21(I)
QPHD=PHD(I)
QTT0=TT0(I)
QTHD=THD(I)
QAXIL=AXIL(I)
QTORQR=TORQR(I)
QDYNAR=DYNAR(I)
QRPM=RPM(I)
QLAXIL=CLAXIL(I)
QLTRQR=CLTRQR(I)
TTOR=TT0(I)
QFAX=QFAX(I)
QLFAX=CLFAX(I)
QTORQ=QTORQ(I)
QLTORQ=CLTORQ(I)

```

```

TTTT00970
TTTT00980
TTTT00990
TTTT01000
TTTT01010
TTTT01020
TTTT01030
TTTT01040
TTTT01050
TTTT01060
TTTT01070
TTTT01080
TTTT01090
TTTT01100
TTTT01110
TTTT01120
TTTT01130
TTTT01140
TTTT01150
TTTT01160
TTTT01170
TTTT01180
TTTT01190
TTTT01200
TTTT01210
TTTT01220
TTTT01230
TTTT01240
TTTT01250
TTTT01260
TTTT01270
TTTT01280
TTTT01290
TTTT01300
TTTT01310
TTTT01320
TTTT01330
TTTT01340
TTTT01350
TTTT01360
TTTT01370
TTTT01380
TTTT01390
TTTT01400
TTTT01410
TTTT01420
TTTT01430
TTTT01440

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TTTT01450
 TTTT01460
 TTTT01470
 TTTT01480
 TTTT01490
 TTTT01500
 TTTT01510
 TTTT01520
 TTTT01530
 TTTT01540
 TTTT01550
 TTTT01560
 TTTT01570
 TTTT01580
 TTTT01590
 TTTT01600
 TTTT01610
 TTTT01620
 TTTT01630
 TTTT01640
 TTTT01650
 TTTT01660
 TTTT01670
 TTTT01680
 TTTT01690
 TTTT01700
 TTTT01710
 TTTT01720
 TTTT01730
 TTTT01740
 TTTT01750
 TTTT01760
 TTTT01770
 TTTT01780
 TTTT01790
 TTTT01800
 TTTT01810
 TTTT01820
 TTTT01830
 TTTT01840
 TTTT01850
 TTTT01860
 TTTT01870
 TTTT01880
 TTTT01890
 TTTT01900
 TTTT01910
 TTTT01920

DYNA=DYNAR(I)
 QFLOWT=FLOWT(I)
 CALL STATOR(RG,GAM,GC,C,PI,EX1,EX2,EX3,EP3,RTIP1,RHUB1,RM1,QPHUB,
 CALL STATOR(QPTO,QP13,QP18,QP19,QP20,QP21,QPHD,QPRS,QFLOWT,AAXS,
 CALL TIP,QPIAV,QPTO,QPI8,QPI9,QP20,QP21,QPHI,QXI,QRPM,VAIM,
 1 ATHS,SKT,J,TTOR,TIRM,TIISR,QZETAS,QPHI,QWU1,QWU1,QWU1,QBFAT1,
 2 QVU1,VIM,QV11S,VCOEFS,ALPHIM,MVIM,QU1,QF5,QF6A,QFNET,
 3 QMW1,QTORQ,QLTORQ,QFAX,QFC,QF1,QF2,QF3,QF4,QF5,QF6A,QFNET,
 4 QRFAX,ORTORQ,QRVA1,QRVU1)

C

CALL ROTOR(RG,GC,CJ,CP,C,PI,EX1,EX2,EX3,EP3,RTIP1,RHUB1,RM1,QPHUB,
 1 QPIAV,QPHD,QPT2,PRM,DYNA,QFLOWT,TTOR,TIRM,T2R,QDEL TW,T2ISR,
 2 TER,QVU1,QU1,QBETA1,QVU2,QVA2,QV2,CALPH2,QU2,QWU2,QWA2,QW2,
 3 QW2IS,QBETA2,QDBETA,WCOEFS,QZETAR,QETAR,QMV2,QMW2,GAM,QRPM,QSLF,
 4 QSFF)

C

CALL PERFORM(C,PI,EX2,QPTO,QPHUB,QPTIP,QPHD,QPT2,DYNA,QRPM,
 1 QFLOWT,TTOR,T2THR,T2ISR,QDLHS,QDELHW,QDLTIS,QDEL TW,QVU1S,
 2 QVU1S,QU1,QV2,QETA1,QEACMN,QEACHR,QEACTP,QXKIS,QEFLOW,
 3 QEF RPM,QEFMOM,QHP,QEFHP,T2ISR,QF,VIM,QW1,QU2,QW2,QEACEF,CP)

C

F0(I)=QF0
 F1(I)=QF1
 F2(I)=QF2
 F3(I)=QF3
 F4(I)=QF4
 F5(I)=QF5
 F6A(I)=QF6A
 FNF(I)=QFNET
 PHI(I)=QPHI
 XI(I)=QXI
 P1AV(I)=QP1AV
 PRS(I)=QPRS
 T1(I)=TIRM
 T1IS(I)=T1ISR
 VAL(I)=VALM
 VU1(I)=QVU1
 V1(I)=VIM
 V1IS(I)=QV1IS
 ALPH1(I)=ALPH1M
 VCOFS(I)=VCOEFS
 MV1(I)=MV1M
 MVA1(I)=MVA1M
 WA1(I)=QWA1
 WU1(I)=QWU1
 W1(I)=QW1
 U1(I)=QU1
 BETA1(I)=QBETA1
 MW1(I)=QMW1

ZETAS(I)=QZETAS

ETAS(I)=QETAS

PT2(I)=QPT2

PR(I)=QPRM

TE(I)=QTT2R

TT2(I)=QTT2R

T2(S(I))=QTT2R SR

TT2(S(I))=QTT2R SR

TT2(S(I))=QTT2R SR

DELTHS(I)=QDELTHS

DELTHS(I)=QDELTHS

DELTHS(I)=QDELTHS

DELTHS(I)=QDELTHS

VA2(I)=QVA2

VU2(I)=QVU2

VU2(I)=QVU2

V2(I)=QV2

VQ(S(I))=QVQ(S)

VQ(S(I))=QVQ(S)

ALPH2(I)=QALPH2

ALPH2(I)=QALPH2

MV2(I)=QMV2

MA2(I)=QMA2

MU2(I)=QMU2

MU2(I)=QMU2

MW2(I)=QMW2

MW2(I)=QMW2

U2(S(I))=QU2

U2(S(I))=QU2

BEETS(I)=QBEETS

DRBETS(I)=QDRBETS

DRBETS(I)=QDRBETS

WCDFAR(I)=QWCDFAR

WCDFAR(I)=QWCDFAR

ZETAR(I)=QZETAR

ZETAR(I)=QZETAR

REFRPM(I)=QREFRPM

REFRPM(I)=QREFRPM

REFRPM(I)=QREFRPM

XK(I)=QXK(I)

XK(I)=QXK(I)

EF(I)=QEF(I)

EF(I)=QEF(I)

EFLOW(I)=QEFLOW

EFLOW(I)=QEFLOW

EFLOW(I)=QEFLOW

REFMOM(I)=QREFMOM

REFMOM(I)=QREFMOM

REFMOM(I)=QREFMOM

HP(I)=QHP

HP(I)=QHP

HP(I)=QHP

REACHB(I)=QREACHB

REACHB(I)=QREACHB

REACHB(I)=QREACHB

REACHMN(I)=QREACHMN

REACHMN(I)=QREACHMN

REACTP(I)=QREACTP

REACTP(I)=QREACTP

REACTP(I)=QREACTP

SELF(I)=QSELF

SELF(I)=QSELF

SELF(I)=QSELF

SFFAX(I)=QSFFAX

SFFAX(I)=QSFFAX

SFFAX(I)=QSFFAX

RTORQ(I)=QRTORQ

RTORQ(I)=QRTORQ

RTORQ(I)=QRTORQ

TTT01930
TTT01940
TTT01950
TTT01960
TTT01970
TTT01980
TTT01990
TTT02000
TTT02010
TTT02020
TTT02030
TTT02040
TTT02050
TTT02060
TTT02070
TTT02080
TTT02090
TTT02100
TTT02110
TTT02120
TTT02130
TTT02140
TTT02150
TTT02160
TTT02170
TTT02180
TTT02190
TTT02200
TTT02210
TTT02220
TTT02230
TTT02240
TTT02250
TTT02260
TTT02270
TTT02280
TTT02290
TTT02300
TTT02310
TTT02320
TTT02330
TTT02340
TTT02350
TTT02360
TTT02370
TTT02380
TTT02390
TTT02400


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TTTT02410
TTTT02420
TTTT02430
TTTT02440
TTTT02450
TTTT02460
TTTT02470
TTTT02480
TTTT02490
TTTT02500
TTTT02510
TTTT02520
TTTT02530
TTTT02540
TTTT02550
TTTT02560
TTTT02570
TTTT02580
TTTT02590

```

```

RVAI(I)=QRVAL
RVUI(I)=ORVUI
14 CONTINUE
CALL
  1 TORQ,CLTORQ,FLOWN,FP, FAX,CLFAX,FC,F1,F2,F3,F4,F5,F6A,FNET,
  2 PRPL,PRS,TTG,TT,TTIS,VAL,V1,VIIS,ALPH1,VCOFS,MV1,MVAI,
  3 WAI,WU1,W1,UI,BETA1,MW1,ZETAS,ETAS,PAMB,NDAY,NMO,NYEAR,RFAX,
  4 RTORQ,RVAL,RVUI,J)
CALL
  1 T10,T1,TE,TT2,T2,T2IS,T2TH,TT2IS,DELTIIS,DELTIW,VA2,VU2,V2,VOIS,
  2 ALPH2,WA2,WU2,W2,U2,W2IS,BETA2,DBETA,WCOFS,ZETAR,ETAR,RPM,HP,
  3 DELHIS,DELHW,REFRPM,XKIS,ETATS,ETATT,REFLOW,REFMOM,REFHP,J,
  4 REACHB,REACMN,REACTP,NDAY,NMO,NYEAR,F,REACEF,MV2,MW2,SLF,SFF)
15 CONTINUE
CALLPMB,ETAR,ETAS,LISA(NP,NRUN,NDAY,NMO,NYEAR,XKIS,ETATS,PRS,ZETAS,
  1 REFRPM,ETAR,ETAS,RTORQ)
STOP
END

```

C

```

TTTT02600
TTTT02610
TTTT02620
TTTT02630
TTTT02640
TTTT02650
TTTT02660
TTTT02670
TTTT02680
TTTT02690
TTTT02700
TTTT02710
TTTT02720
TTTT02730
TTTT02740
TTTT02750
TTTT02760
TTTT02770
TTTT02780
TTTT02790
TTTT02800
TTTT02810
TTTT02820
TTTT02830
TTTT02840
TTTT02850
TTTT02860

```

```

SUBROUTINE SETCON(D1N,D2N,BETAN,RG,GAM,GC,CP,CJ,C,EX1,EX2,EX3,PI,
  1 ZNS,TEFS,RTIPI,RHUB1,RTIP2,RHUB2,AAXS,AAXR,ATHS,RM1,RM2,SKT,RKT,
  2 RADCLR,B1,B2,B3,B4,B5,D1,D2,D3,D4,D5,D6,CL1,CL2,CL3,J,MODRAD)
D1N=7.975
D2N=4.250
BETAN=D2N/D1N
RG=53.3448
GAM=1.4
GC=32.174
CJ=778.16
EX1=GAM/(GAM-1.)
EX2=(GAM-1.)/GAM
EX3=2./GAM
CP=EX1*RG/CJ
C=2.*GC*CJ*CP
PI=3.1416
ZNS=31.
DTHS=0.205
SS=0.8594
TEFS=0.224
DTHR=0.1314
SR=0.4495
TETR=0.020
RTIPI=4.585
RHUB1=3.895
RTIP2=4.763
RHUB2=3.826

```


TTTT02870
TTTT02880
TTTT02890
TTTT02900
TTTT02910
TTTT02920
TTTT02930
TTTT02940
TTTT02950
TTTT02960
TTTT02970
TTTT02980
TTTT02990
TTTT03000
TTTT03010
TTTT03020
TTTT03030
TTTT03040
TTTT03050
TTTT03060
TTTT03070
TTTT03080
TTTT03090
TTTT03100
TTTT03110
TTTT03120
TTTT03130
TTTT03140

```
AXS=PI*((RTIPI1)**2-(RHUB1)**2)  
AAXR=PI*((RTIPI2)**2-(RHUB2)**2)  
ATHS=DTHS*(RHUB1)/2.  
RML=((RTIPI1+RHUB2)/2.)*((TETS/SS*100.)**3.3)*DTHR/SR)*((AAXR+PI)*  
RMT=1.-(2.7/1000.)*((TETR/SR*100.))**3.3)  
SKT=1.-(2.7/1000.)*((AAXR)/  
RADCLR*(RTIPI2+RADCLR/2.))/  
1 B1=9.38917E-07  
  B2=6.176699E-12  
  B3=-1.29859E-18  
  B4=1.25923E-18  
  B5=-4.75649E-25  
  D1=-3.7487E-01  
  D2=8.7014E-01  
  D3=-7.2633E-01  
  D4=3.1583E-01  
  D5=-6.1683E-03  
  D6=6.1683E-03  
  CL1=-2.7923457E-03  
  CL2=5.1056171E-04  
  CL3=9.1106005E-08  
J=2 SET MODRAD=0 FOR NORMAL REDUCTION. IF MODRAD=1 THE ON-LINE  
   PARAMETER RETURN LOOP WILL BE ACTUATED....  
MODRAD=1  
RETURN  
END
```

TTTT03150
TTTT03160
TTTT03170
TTTT03180
TTTT03190
TTTT03200
TTTT03210
TTTT03220
TTTT03230
TTTT03240
TTTT03250
TTTT03260
TTTT03270
TTTT03280
TTTT03290
TTTT03300
TTTT03310
TTTT03320
TTTT03330

```
C  
C  
SUBROUTINE INPUT(NRUN, NP, NDAY, NMO, NYEAR, QPBAR, QPNOZ, QPT0, QPHD,  
1 QPHUB, QPTIP, QP13, QP14, QP15, QP16, QP17, QP18, QP19, QP20, QP21, QPHD,  
2 QPC11, QPC12, QPC13, QPTPL, QDH, QLAXIL, QLTRQR, QINOZ, QITTO, QTHD,  
3 QTRPM, QAXIL, QTORQR, QDYNAR, AXCLR, RADCLR, LASTPT)  
  NPCHK=NP  
  READ(5, 101) NRUN, NP, NDAY, NMO, NYEAR  
  IF (NP.ME.0) GO TO 103  
  NP=NPCHEK  
  LASTPT=1  
  RETURN  
CONTINUE  
100 READ(5, 102) QPBAR, DUMMY, QPNOZ, QPTPL, QPT01, QPT02, QPT03, QPHUB, QPTIP  
  1, QP13, QP14, QP15, QP16, QP17, QP18, QP19, QP20, QP21  
  2, QPC11, QPC12, QPC13, QPHD  
  3, QPT01, QPT02, QPT03, QTRQR, DUMMY, QDUM, DUMMY, DUMMY, DUMMY, DUMMY, DUMMY, DUMMY, DUMMY,  
  READ(5, 103) QDH  
  READ(5, 102) QLAXIL, QLTRQR, DUMMY, DUMMY, DUMMY, DUMMY, QDUM, DUMMY, DUMMY, DUMMY, DUMMY, DUMMY, DUMMY,  
  QPT0=(QPT01+QPT02+QPT03)/3  
  READ(5, 103) QINOZ, DUMMY, QITTO1, QITTO2, DUMMY, QTHD, DUMMY, DUMMY, DUMMY, DUMMY, DUMMY, DUMMY,  
  READ(5, 103) QTRPM, QAXIL, QTORQR, QDYNAR, AXCLR, RADCLR, LASTPT
```



```

QTTO=(QTTO1+QTTO2)/2.
READ(5,104) QRPMM
READ(5,105) QAXIL,QTGRQR,QDYNAR
101 FORMAT(1X,A2,1X,I2,1X,3A2)
102 FORMAT(7X,F6.2)
103 FORMAT(7X,F6.3)
104 FORMAT(8X,F5.0)
105 FORMAT(F5.0)
IF(NP.NE.1) GO TO 114
WRITE(8,113) NRUN,NDAY,NMO,NYEAR
WRITE(8,112)
114 WRITE(8,111) NP,QPBAR,QPNOZ,QPTO,QPHUB,QPTIP,QP13,QP18,QP19,QP20,
1 QP21,QPHD,QDH,QTHD,QRPMM,QAXIL,QTGRQR,QDYNAR,QLAXIL
111 FORMAT(1X,11F6.2,4F5.2,1X,5F6.0)
112 FORMAT(1X,12X,1BAR,3X,1NOZ,3X,1PTO,3X,1HUB,3X,1TIP,3X,
1,1P13,3X,1P18,3X,1P19,3X,1P20,3X,1P21,3X,1PHD,2X,1DH,3X,
2,1TNOZ,2X,1TTO,2X,1THD,3X,1RPM,3X,1AXIL,2X,1TORQR,1X,1DYNAR,
3,1X,1CLAXI,111)
113 FORMAT(11,1T41,1TRANSONIC TURBINE TEST RIG INPUT DATA,1,1T41,
1,
2,15X,1DAY,1A2,10X,1MONTH,1A2,10X,1YEAR,1,1A2,111)
RETURN
END

```

```

TTTT03330
TTTT03340
TTTT03350
TTTT03360
TTTT03370
TTTT03380
TTTT03390
TTTT03400
TTTT03410
TTTT03420
TTTT03430
TTTT03440
TTTT03450
TTTT03460
TTTT03470
TTTT03480
TTTT03490
TTTT03500
TTTT03510
TTTT03520
TTTT03530
TTTT03540
TTTT03550

```

```

SUBROUTINE CONVERT(NP,QPBAR,QDH,QPNOZ,QPTO,QPHUB,QPTIP,QP13,QP14,
1QP15,QP16,QP17,QP18,QP19,QP20,QP21,QPTPL,QPHD,QTNOZ,QTTO,
2QTHD,QPAMB,QHW68,QTNOZR,QTGRQR,FAX,TORQ,DYNA,CLFAX,CLTORQ,AXIL,
3TORQR,DYNAR,CLAXIL,QPCL1,QPCL2,OPCL3,RPM)
TEMPR(X)=32.+35.98*X-.435*X**2
PPSIA(X)=.4891585*X
QPAMR=.4891585*QPBAR
QHW68=QDH
QDH=QDH*.62.42732/1728.
QPNOZ=PPSIA(QPNOZ)
QPTO=PPSIA(QPTO)
QPHUB=PPSIA(QPHUB)
QPTIP=PPSIA(QPTIP)
QP13=PPSIA(QP13)
QP14=PPSIA(QP14)
QP15=PPSIA(QP15)
QP16=PPSIA(QP16)
QP17=PPSIA(QP17)
QP18=PPSIA(QP18)
QP19=PPSIA(QP19)
QP20=PPSIA(QP20)
QP21=PPSIA(QP21)

```

```

TTTT03560
TTTT03570
TTTT03580
TTTT03590
TTTT03600
TTTT03610
TTTT03620
TTTT03630
TTTT03640
TTTT03650
TTTT03660
TTTT03670
TTTT03680
TTTT03690
TTTT03700
TTTT03710
TTTT03720
TTTT03730
TTTT03740
TTTT03750
TTTT03760
TTTT03770
TTTT03780

```


TTTT03790
 TTTT03800
 TTTT03810
 TTTT03820
 TTTT03830
 TTTT03840
 TTTT03850
 TTTT03860
 TTTT03870
 TTTT03880
 TTTT03890
 TTTT03900
 TTTT03910
 TTTT03920
 TTTT03930
 TTTT03940
 TTTT03950
 TTTT03960
 TTTT03970
 TTTT03980

TTTT03990
 TTTT04000
 TTTT04010
 TTTT04020
 TTTT04030
 TTTT04040
 TTTT04050
 TTTT04060
 TTTT04070
 TTTT04080
 TTTT04090
 TTTT04100
 TTTT04110
 TTTT04120
 TTTT04130
 TTTT04140
 TTTT04150
 TTTT04160
 TTTT04170
 TTTT04180
 TTTT04190
 TTTT04200
 TTTT04210
 TTTT04220
 TTTT04230
 TTTT04240

```

QPCL1=PPSIA(QPCL1)
QPCL2=PPSIA(QPCL2)
QPCL3=PPSIA(QPCL3)
QPTPL=PPSIA(QPTPL)
QPHD=PPSIA(QPHD)
QTNOZR=TEMPR(QTNOZ)
QTTOR=TEMPR(QTTOR)
QTTT=TEMP(QTTT)
QTHD=TEMP(QTHD)
FAX=0.08*AXIL
TORQ=TOROR/30.
DYNA=DYNAR/30.
USE THE FIRST OR THE SECOND CLFAX TERM DEPENDING
UPON WHICH OF THE METHODS OF MEASURING THE CLOSURE
PLATE AXIAL FORCE, STRAIN GAGES OR PRESSURES.
CLFAX=CCLAXIL
CLFAX=(17.74**2)*3.1416/4.C)*(OPHUB-(QPCL1+QPCL2+QPCL3)/3.0)
CLTOPQ=.598E-09*RPMM**1.8
RETURN
END

```

C
 C
 C

```

SUBROUTINE FLORAT(D2N, RG, GC, EX1, EX2, EX3, HW68, DH, PNOZ, PTPL, PHD, PR,
1 TNOZ, TNOZR, TTPL, TTPLR, THD, B1, B2, B3, B4, B5, D1, D2, D3, D4, D5, D6, NRUN,
2 I, RE, FLOWN, FLOWL, FLOWT, BETAN)
ALPHAN=1.+2.52*(TNOZ-68.)*C.1E-04
R=1.-(DH/PNOZ)
Y1=R**EX3
Y2=EX1-R**EX2
Y3=1.-R**EX2
Y4=1.-P
Y5=1.-BETAN**4
Y6=1.-R**EX3*BETAN**4
ARG=Y1*Y2*(Y3/Y4)**(Y5/Y6)
YN=SQRT(ARG)
ZN=1.04071+2.4*(TNOZ-100.)*C.1E-02
CN=1.04071+27*D2N**2*ALPHAN*YN*CN*SQRT(PNOZ*HW68/TNOZR)
WN=0.1638427*D2N*ZN)*0.1E+07 WITH NEW NOZZLE CAL.
RE=2.27376*WN/(D2N*ZN)*0.1E+07 TO AGREE WITH
NEED TO CHANGE (B3+RE*(B4+B5*RE))
CN=B1+RE*(B2+RE*(B3+RE*(B4+B5*RE)))
WNC=0.1638427*D2N**2*ALPHAN*YN*CN*SQRT(PNOZ*HW68/TNOZR)
IF (ABS(WNC-WN).LE.0.001) GO TO 401
WN=WNC
GO TO 400
FLOWN=WNC
FLOWL=WNC
RE=2.27376*FLOWN/(D2N*ZN)*0.1E+07
401

```

C

C

TTTT04250
 TTTT04260
 TTTT04270
 TTTT04280
 TTTT04290
 TTTT04300
 TTTT04310
 TTTT04320
 TTTT04330
 TTTT04340
 TTTT04350

```
IF(RE.GT.1.2E+06) GO TO 404
PR=PTPL/PHD
WREF=D1+PR*(D2+PR*(D3+PR*(D4+PR*(D5+D6*PR))))
CORR=(1.+0.32*((TTPL-IHD)/TTPL))*1.2
FLOWL=WREF*PTPL/SQRT(TTPLR*RG/GC)*CORR
FLOWT=FLOWL-FLOW
```

```
GO TO 416
404 WRITE(8,405) NRUN,I
405 FORMAT(/33X,A4,7X,36HFLOW RATE TOO HIGH, CHECK INPUT DATA/)
406 RETURN
END
```

```
SUBROUTINE STATOR(RG,GAM,GC,C,PI,EX1,EX2,EX3,EPS,RTIPI,RHUB1,RM1,
1 PHUB,PTIP,PIAV,PTO,P13,P18,P19,P20,P21,PHD,PRS,AAXS,ATHS,
2 J,TTOR,TIRM,MVALM,MV1M,MV1C,MV1,MW1,MW2,MW2,MW2,
3 VCOEFS,ALPH1M,MVALM,MV1M,MV1C,MV1,MW1,MW2,MW2,
4 CLFAX,F4,F1,F2,F3,F4,F5,F6A,FNET,RFAX,RTORQ,RVAL,RVUI)
IF(J.GE.2) GO TO 500
```

```
C IN THIS SECTION, M SUBSCRIPT REPRESENTS VALUES COMPUTED BY CONTINUITY
PIAV=(PHUB+PTIP)/2
THIS=SECTION, M SUBSCRIPT REPRESENTS VALUES COMPUTED BY CONTINUITY
C2=(C*PIAV*ATHS)/(RG*FLOWT)
```

```
V1M=SQRT(C*TIR*M**2/C
TIRM=TTOR-V1M**2/C
VALM=(FLOWT*RG*TIRM)/(PIAV*AAXS*SKT)
VR=VALM/V1M
IF(ABS(VR).GE.1.0) VR=1.0
AN=ARCOS(VR)
VU1=V1M*SIN(AN)
```

```
ALPH1M=AN*180./PI
MV1M=V1M/SQRT(GAM*GC*RG*TIRM)
MVALM=VALM/SQRT(GAM*GC*RG*TIRM)
CALL FORCE(PI,RTIPI,RHUB1,AAXS,PHUB,PIAV,PTIP,P13,P18,P19,
1 P20,P21,PHD,FAX,CLFAX,F0,F1,F2,F3,F4,F5,F6A,FNET)
```

```
GO TO 506
500 WRITE(8,501)
501 FORMAT(1I,9X,3HEPS8X,4HP1AV9X,3HT1M10X,4HVALC9X,
14HMV1M9X,4HMVIC7X,8HALPHA 1C/)
EPS=0.
```

```
PIAV=PHUB/3.*((1.+EPS)*(RTIPI)**2+(RHUB1)**2+(RHUB1)*(RTIPI)-(2.+EPS)*(RTIPI)
1 (RHUB1)**2)/(RTIPI)**2-(RHUB1)**2)+PTIP/3.*((2.+EPS)*(RTIPI)**2)
2 **2-(PHUB1)*(RTIPI)-(1.+EPS)*(RHUB1)**2)/(RTIPI)**2-(RHUB1)**2)
CALL MOMENT(RG,GAM,GC,C,RM1,AAXS,TORQ,CLTORQ,FLOWT,PI,RTIPI,
1 RHUB1,FAX,CLFAX,PHUB,PTIP,PIAV,P13,P18,P19,P20,P21,PHD,TTOR,TIRM,
2 VU1,VALM,V1M,ALPH1M,MV1M,MV1C,MV1,MW1,MW2,MW2,
C1=FLOWT*RG/(PIAV*AAXS*SKT)
VAIC=SQRT(C*TTOR-VU1**2+(C/(2.*C1)**2)-C/(2.*C1))
```

TTTT04360
 TTTT04370
 TTTT04380
 TTTT04390
 TTTT04400
 TTTT04410
 TTTT04420
 TTTT04430
 TTTT04440
 TTTT04450
 TTTT04460
 TTTT04470
 TTTT04480
 TTTT04490
 TTTT04500
 TTTT04510
 TTTT04520
 TTTT04530
 TTTT04540
 TTTT04550
 TTTT04560
 TTTT04570
 TTTT04580
 TTTT04590
 TTTT04600
 TTTT04610
 TTTT04620
 TTTT04630
 TTTT04640
 TTTT04650
 TTTT04660
 TTTT04670
 TTTT04680
 TTTT04690
 TTTT04700

TTTT04710
 TTTT04720
 TTTT04730
 TTTT04740
 TTTT04750
 TTTT04760
 TTTT04770
 TTTT04780
 TTTT04790
 TTTT04800
 TTTT04810
 TTTT04820
 TTTT04830
 TTTT04840
 TTTT04850
 TTTT04860
 TTTT04870
 TTTT04880
 TTTT04890
 TTTT04900
 TTTT04910
 TTTT04920
 TTTT04930
 TTTT04940
 TTTT04950
 TTTT04960
 TTTT04970
 TTTT04980
 TTTT04990
 TTTT05000
 TTTT05010
 TTTT05020
 TTTT05030
 TTTT05040
 TTTT05050
 TTTT05060
 TTTT05070
 TTTT05080
 TTTT05090

TTT05100
 TTT05110
 TTT05120
 TTT05130
 TTT05140
 TTT05150
 TTT05160

```

ALPHIC=ATAN(WUI/VAIC)
ALPHIC=ALPHIC*180./PI
VIC=SQRT(VAIC**2+WUI**2)
TIRC=TTOR-(VIC**2)/C*RG*TIRC)
MVIC=VIC/SQRT(GAM*GC*RG*TIRC)
WRITE(8,503)EPS,PIAV,TIRM,TIRC,VALM,VAIC,MV1M,MVIC,ALPH1M,ALPHIC
FORMAT(10F13.5)
DIFF=ABS(TIRM-TIRC)
IF(DIFF<.01) 506,504
IF(TIRC.LT.TIRM) GO TO 505
EPS=EPS+DIFF/500.
GO TO 502
EPS=EPS-DIFF/500.
GO TO 502
PRS=PIAV/PTO
IF(PRS.GE.1.0) PRS=0.9990
TISR=TTOR*PRS**EX2
ZETAS=(TIRM-TISR)/(TTOR-TISR)
ETAS=1.-ZETAS
VLE=SQRT(C*(TTOR-TISR))
VCOEFS=V1M/VLE
PHI=FLOWT/(PTO*ATHS)*SQRT(TTOR*RG/GC)
PRTHS=PRS
IF(PRTHS.LT.0.52828) PRTHS=0.52828
XI=PHI/SQRT(2.*EX1*(PRTHS**EX3-PRTHS**((GAM+1.)/GAM)))
PRS=1./PRS
UI=PI*RP*RM1/360.
WUI=VUI-UI
WAI=VALM
BETAI=ATAN(WUI/WAI)
W1=WAI/COS(BETAI)
BETAI=BETAI*180./PI
MW1=W1/SQRT(GAM*PG*GC*TIRM)
RFAX=FAX/(PTO/14.69)
RTORQ=TORQ/(PTO/14.69)
RVAI=VALM/SQRT(GAM*GC*RG*TTOR)
RVUI=WUI/SQRT(GAM*GC*RG*TTOR)
RETURN
END

SUBROUTINE MOMENT(RG,GAM,GC,C,RM1,AAXS,TORQ,CLTORQ,FLOWT,PI,RTIPI,
1 RHUB1,FAX,CLFAX,PHU3,PTIP,PIAV,PI3,PI8,PI9,P2C,P21,PHD,TTOR,TIRM,
2 VUI,VALM,V1M,ALPH1M,MV1M,MVA1M,F0,F1,F2,F3,F4,F5,F6A,FNET)
REAL*4 MVA1M,MVA1,MV1M,MVIC,MV1,MW1,MV2,MW2
VUI=(TORQ+CLTORQ)*12.*GC/(FLOWT*RM1)
AO=PI*5.125**2

```

C


```

TTTT05170
TTTT05180
TTTT05190
TTTT05200
TTTT05210
TTTT05220
TTTT05230
TTTT05240
TTTT05250
TTTT05260
TTTT05270
TTTT05280
TTTT05290
TTTT05300
TTTT05310
TTTT05320
TTTT05330
TTTT05340
TTTT05350
TTTT05360
TTTT05370
TTTT05380

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TTTT05390
TTTT05400
TTTT05410
TTTT05420
TTTT05430
TTTT05440
TTTT05450
TTTT05460
TTTT05470
TTTT05480
TTTT05490
TTTT05500
TTTT05510
TTTT05520
TTTT05530
TTTT05540
TTTT05550
TTTT05560
TTTT05570

```

```

A2=PI*(5.125**2-5.003**2)
A3=PI*(5.003**2-4.901**2)
A4=PI*(4.901**2-4.773**2)
A5=PI*(4.773**2-RTIPI**2)
A6A=PI*RHUB1**2
F0=A0*PHD
F1=AAXS*PIAV
F2=A2*((P20+P19)/2.)
F3=A3*((P20+P19)/2.)
F4=A4*((PTIP+P13)/2.)
F5=A5*((PHUB
F6A=A6A*CLFAX+F0-F1-F2-F3-F4-F5-F6A
FNET=FAFAX+CLFAX/FLQWT
VA1PHIM=ATAN(VU1/VA1M)
ALPHIM=ALPHIM**2+VU1**2)
V1M=SQRT(VA1M**2)/C
T1RM=V1M/SQRT(GAM*GC*RG*T1RM)
MV1M=VA1M/SQRT(GAM*GC*RG*T1RM)
MV1M=VA1M/SQRT(GAM*GC*RG*T1RM)
RETURN
END

```

```

SUBROUTINE FORCE(PI,RTIPI,RHUB1,AAXS,PHUB,PIAV,PIIP,P18,P19,
1 P20,P21,PHD,FAX,CLFAX,F0,F1,F2,F3,F4,F5,F6A,FNET)

```

```

C
A0=PI*5.125**2-5.003**2)
A2=PI*(5.003**2-4.901**2)
A3=PI*(4.901**2-4.773**2)
A4=PI*(4.773**2-RTIPI**2)
A5=PI*(4.773**2-
A6A=PI*RHUB1**2
F0=A0*PHD
F1=AAXS*PIAV
F2=A2*((P20+P19)/2.)
F3=A3*((PTIP+P13)/2.)
F4=A4*((PHUB
F5=A5*((PHUB
F6A=A6A*CLFAX+F0-F1-F2-F3-F4-F5-F6A
RETURN
END

```



```

SUBROUTINE ROTOR(RG,GC,CJ,CP,C,PI,EX1,EX2,RM1,RM2,AAXR,RKT,PTO,
1 P1AV,PHD,PT2,PRM,DYNA,FLOWT,TTOR,T1RM,T2R,TT2SR,DELTW,T2ISR,TER,
2 VU1,U1,W1,BETA1,VU2,VA2,V2,ALPH2,U2,WU2,WA2,W2,W2IS,BETA2,DBETA,
3 WCOEFS,ZETAR,ETAR,MV2,MW2,GAM,RPM,SFF,SFF)
REAL*4 MVA1M,MVA1,MV1M,MV1C,MV1,MW1,MV2,MW2
VU2=RM1/RM2*VU1-(12.*DYNA*GC)/(RM2*FLOWT)
U2=U1*RM2/RM1
DELTW=(DYNA*PI*PRM)/(30.*FLOWT*CJ*CP)
TT2R=TTOR-DELTW
T2ISR=T1RM*(PHD/P1AV)**EX2
TER=T1RM*(W1**2-U1**2+U2**2)/C
C3=FLOWT*RG/(PHD*AAXR*RKT)
VA2=SQR(C*TT2R-VU2**2+(C/(2.*C3))**2)-C/(2.*C3)
V2=SQR(VA2**2+VU2**2)
T2R=TT2R-(V2**2)/C
MV2=V2/SQR(GAM*RG*GC*T2R)
PT2=PHD*(TT2R/T2R)**EX1
PRM=PTO/PHD
WA2=VA2
MW2=SQR(WA2**2+WU2**2)
MW2=W2/SQR(GAM*RG*GC*T2R)
ALPH2=ATAN(VU2/VA2)
ALPH2=ALPH2*180./PI
BETA2=ATAN(WU2/WA2)
BETA2=BETA2*180./PI
DBETA=BETA1-BETA2
ZETAR=(T2R-T2ISR)/(TER-T2ISR)
ETAR=1.0-ZETAR
W2IS=SQR(C*(TER-T2ISR))
WCOEFS=W2/W2IS
IF(U2.LE.1.0) U2=0.001
SFF=(VU1-VU2)/U2
RETURN
END

```

C

```

TTTT05580
TTTT05590
TTTT05600
TTTT05610
TTTT05620
TTTT05630
TTTT05640
TTTT05650
TTTT05660
TTTT05670
TTTT05680
TTTT05690
TTTT05700
TTTT05710
TTTT05720
TTTT05730
TTTT05740
TTTT05750
TTTT05760
TTTT05770
TTTT05780
TTTT05790
TTTT05800
TTTT05810
TTTT05820
TTTT05830
TTTT05840
TTTT05850
TTTT05860
TTTT05870
TTTT05880
TTTT05890
TTTT05900
TTTT05910
TTTT05920
TTTT05930
TTTT05940

```

```

SUBROUTINE PERFRM(C,PI,EX2,PTO,PHUB,PTIP,PHD,PT2,DYNA,RPM,FLOWT,
1 TTOR,T2R,T2THR,T2ISR,DELHIS,DELHM,DELTIIS,DELTIW,VOIS,V1IS,UI,V2,
2 ETATS,ETATT,REACMN,REACHB,REACTP,XKIS,REFLOW,REFRPM,REFMOM,HP,
3 REFHP,T2ISR,F,V1,W1,U2,W2,REACEF,CP)
DELTIIS=TTOR*(1.0-(PHD/PTO)**EX2)
T2THP=TTOR-DELTIIS
TT2ISR=TTOR*(PT2/PTO)**EX2
DELHIS=CP*(TTOR-T2THR)

```

C

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TTTT05950
TTTT05960
TTTT05970
TTTT05980
TTTT05990
TTTT06000
TTTT06010
TTTT06020
TTTT06030

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```

DELHW=CP*(TTOR-TT2R)
DELTW=DELTTW/DELTTIS*100.
F=T2ISR/T2THR
ETATT=DELTW/(DELTTIS)
VOIS=SQRT(C**2-U2**2+U1**2)/(PTO/PHD)**EX2-1.)
REACMF=(W2**2-W1**2+U1**2+U2**2)/(PTO/PHD)**EX2-1.)
REACHMN=1.0-(VIIS/VOIS)**2
REACTP=((PHUB/PHD)**EX2-1.)/((PTO/PHD)**EX2-1.)
IF(U1.LE.1.)U1=0.001
XKIS=(VOIS/U1)**2
DEL=PTO/14.69
THETA=TTOR/518.69
REFLOW=FLOWT*SQRT(THETA)/DEL
REFRPM=RPM/SQRT(THETA)
REFMOM=DYNA/DEL
HP=(DYNA*PI*PPM)/(30.*550.)
REFHP=HP/(DEL*SQRT(THETA))
RETURN
END

```

```

TTTT06040
TTTT06050
TTTT06060
TTTT06070
TTTT06080
TTTT06090
TTTT06100
TTTT06110
TTTT06120
TTTT06130
TTTT06140
TTTT06150
TTTT06160
TTTT06170
TTTT06180
TTTT06190
TTTT06200
TTTT06210
TTTT06220
TTTT06230

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```

SUBROUTINE OUTPTS(NRUN, NP, FAX, CLFAX, F0, F1, F2, F3, F4, F5, F6A, FNET,
1 TORO, CLTORQ, FLOWN, FLOWT, FLOW, RE, PHI, XI, QNOZ, QTPL, PTO, PLAV, QHD,
2 PRPL, PRS, TIO, TI, TIIIS, VAI, VUI, VI, VIIIS, ALPH1, VCOFS, MVI, MVAL,
3 WAI, MUI, WI, UI, BETA1, MW1, ZETAS, ETAS, PAMB, NDAY, NMO, NYEAR, RFAX,
4 RTORQ, RVAL, RVUI, J)
REAL*4 MVAIM, MVAL, MVIM, MVIC, MVI, MW1, MV2, MW2
DIMENSION FAX(50), CLFAX(50), F0(50), F1(50), F2(50), F3(50), F4(50), F5(50), F6A(50),
1 F5(50), F6A(50), FNET(50), TORQ(50), CLTORQ(50), FLOWN(50), FLOWT(50),
2 FLOWL(50), PE(50), PHI(50), XI(50), QNOZ(50), QTPL(50), PTO(50),
3 PLAV(50), QHD(50), PRS(50), TTPQ(50), TIO(50), TI(50),
4 TIIIS(50), VAI(50), VUI(50), VI(50), VIIIS(50), ALPH1(50), VCOFS(50),
5 MVI(50), MVAL(50), WAI(50), WI(50), U1(50), BETA1(50), MW1(50),
6 ZETAS(50), ETAS(50), RTORQ(50), RVAL(50), RVUI(50)
WRITE(8,800) NRUN, NDAY, NMO, NYEAR, J
800 FORMAT(IH1, JX, 'STATOR RESULTS', //, JX, 'CONFIGURATION- CONVERGING
1 NOZZLES, SHROUD P/N 1050, INSERT P/N 2005-3(STRAIGHT)', //, IX, 'RU
2 NUMBER ', A3, 4X, 'DAY ', DAY, 'MONTH ', IA2, 4X, 'YEAR ', IA2,
3 //, 44X, 'METHOD J= ', I2)
WRITE(8,801)
801 FORMAT(//, //, 3CX, 'FORCE AND MOMENT BALANCE(LBS AND FT-LBS)', //, IX,
1 'POINT', 2X, 'FAX(+)', 1X, 'CLFAX(+)', 2X, 'F0(+)', 3X, 'F1(-)', //, IX,
2 '3X', 'F3(-)', 3X, 'F4(-)', 2X, 'F5(-)', 2X, 'F6A(-)', 4X, 'FNET', 2X, 'TORQ(+
3 '), 1X, 'CLTORQ(+)', 2X, 'RFAX', 5X, 'RTORQ', /)
DO 802 I=1, NP
802 WRITE(8,803) I, FAX(I), CLFAX(I), F0(I), F1(I), F2(I), F3(I), F4(I), F5(I)
1, F6A(I), FNET(I), TORQ(I), CLTORQ(I), RFAX(I), RTORQ(I)

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TTTT06240
TTTT06250
TTTT06260
TTTT06270
TTTT06280
TTTT06290
TTTT06300
TTTT06310
TTTT06320
TTTT06330
TTTT06340
TTTT06350
TTTT06360
TTTT06370
TTTT06380
TTTT06390
TTTT06400
TTTT06410
TTTT06420
TTTT06430
TTTT06440
TTTT06450
TTTT06460
TTTT06470
TTTT06480
TTTT06490

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803 FORMAT(I4,2X,9F8.2,9F9.2,2F8.2,2F9.2)
WRITE(8,804)
804 FORMAT(///,30X,'FLOW RATES(LBM/SEC), RE(NOZ), FLOW FNC, AND STATO
1R BLOCKAGE FACTOR',//,1X,'POINT',2X,'NOZZLE FLOW',2X,'TURBINE FLOW
2',3X,'LABELFAK',8X,'RE',9X,'PHI',7X,'XI',/)
DO 805 I=1,NP
805 WRITE(8,806) I,FLOWN(I),FLOWT(I),FLOWL(I),RE(I),PHI(I),XI(I)
806 FORMAT(I4,2X,F10.4,4X,F10.4,3X,F10.4,3X,F10.0,2F10.4)
WRITE(8,807) PAMB
807 FORMAT(///,30X,'PRESSURES(PSIA) AND PRESSURE RATIOS',//,1X,'PAMB=
1',F5.2,///,1X,'POINT',2X,'PNOZ',3X,'PTPL',3X,'PTQ',3X,'PIAV',4X,
2',PHD',3X,'PLENUM PR(PTPL/PHD)',2X,'STATOR PR(PTQ/PIAV)',/)
DO 808 I=1,NP
808 WRITE(8,809) I,QNOZ(I),QTPL(I),PTQ(I),PIAV(I),QHD(I),PRPL(I),PRS(I)
809 FORMAT(I4,1X,5F7.2,6X,F7.4,14X,F7.4)
WRITE(8,810)
810 FORMAT(///,30X,'TEMPERATURES(DEG R)',//,1X,'POINT',5X,
1',TTC',7X,'T1',7X,'T1IS',/)
DO 811 I=1,NP
811 WRITE(8,812) I,TTO(I),T1(I),T1IS(I)
812 FORMAT(I4,1X,3F10.2)
WRITE(8,813)
813 FORMAT(IH,30X,'ABSOLUTE VELOCITIES(FT/SEC), ANGLES(DEG), VEL COEF
1',AND MACH NOS',//,1X,'POINT',3X,'VAL',6X,'VU1',7X,'V1',6X,'V1IS',
2',3X,'ALPHA',2X,'VCOEFS',4X,'MVI',4X,'MVAL',4X,'RVAL',4X,'RVU1',/)
DO 814 I=1,NP
814 WRITE(8,815) I,VAL(I),VU1(I),V1(I),V1IS(I),ALPH1(I),VCOFS(I),
1'MVI(I),MVAL(I),RVAL(I),RVU1(I)
815 FORMAT(I4,1X,5F9.2,5F8.4)
WRITE(8,816)
816 FORMAT(///,30X,'RELATIVE VELOCITIES(FT/SEC), ANGLES(DEG), AND MAC
1H NOS',//,1X,'POINT',3X,'WAL',6X,'WU1',7X,'W1',7X,'U1',5X,'BETA',
2',4X,'MW1',/)
DO 817 I=1,NP
817 WRITE(8,818) I,WAL(I),WU1(I),W1(I),U1(I),BETA1(I),MW1(I)
818 FORMAT(I4,1X,5F9.2,5F8.4)
WRITE(8,819)
819 FORMAT(///,30X,'EFFICIENCIES',//,1X,'POINT',2X,'ZETA STATOR',2X,
1',ETA STATOR(1.-ZETAS)',/)
DO 820 I=1,NP
820 WRITE(8,821) I,ZETAS(I),ETAS(I)
821 FORMAT(I4,3X,F10.4,7X,F10.4)
RETURN
END

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TTTT06500
TTTT06510
TTTT06520
TTTT06530
TTTT06540
TTTT06550
TTTT06560
TTTT06570
TTTT06580
TTTT06590
TTTT06600
TTTT06610
TTTT06620
TTTT06630
TTTT06640
TTTT06650
TTTT06660
TTTT06670
TTTT06680
TTTT06690
TTTT06700
TTTT06710
TTTT06720
TTTT06730
TTTT06740
TTTT06750
TTTT06760
TTTT06770
TTTT06780
TTTT06790
TTTT06800
TTTT06810
TTTT06820
TTTT06830
TTTT06840
TTTT06850
TTTT06860
TTTT06870
TTTT06880
TTTT06890
TTTT06900
TTTT06910
TTTT06920
TTTT06930

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SUBROUTINE OUTPTR(NRUN, NP, AXCLR, RADCLR, PAMB, PTO, P1AV, PT2, QHD, PR,
1 T1, T2, T2IS, T2TH, T2IS, DELTIS, DELTW, VA2, VU2, V2, VCIS,
2 ALPHA2, WA2, WU2, W2IS, BETA2, DBETA, WCOEFS, ZETAR, ETAR, RPM, HP,
3 DELHIS, DELHW, REFRPM, XKIS, ETATS, ETATT, REFLOW, REFMOM, REFHP, J,
4 REACHB, REACMN, REACTP, NDAY, NMO, NYEAR, F, REACEF, MV2, MW2, SLF, SFF)
DIMENSION MVA1, MVA1M, MVA1C, MV1, MW1, MW2, MW2
1 TE(50), TT2(50), P1AV(50), PT2(50), QHD(50), PR(50), TT0(50), I1(50),
2 DELTW(50), VA2(50), VU2(50), T2IS(50), T2TH(50), T2IS(50), DELTIS(50),
3 WU2(50), W2IS(50), V2(50), VCIS(50), ALPH2(50), WA2(50),
4 ZETAR(50), ETAR(50), HP(50), BETA2(50), DBETA(50), WCOEFS(50),
5 XKIS(50), ETATS(50), ETATT(50), REFLOW(50), DELHW(50), REFRPM(50),
6 REACHB(50), REACMN(50), REACTP(50), F(50), REACEF(50), MV2(50), MW2(50),
7 SLF(50), SFF(50)
WRITE(8,900) AXCLR, RADCLR, NRUN, NDAY, NMO, NYEAR, J
900 FORMAT(1H1,1X,'ROTOR RESULTS',//,1X,'CONFIGURATION- CIRCULAR ARC
1, SHARP LE ROTOR, P/N 1034-A, AXIAL CLNC ',F6.3,' IN, RADIAL CLNC
2, F6.3,' IN, //,1X,'RUN NUMBER ',A3,4X,'DAY ',1A2,4X,'MONTH ',1A2,
34X,'YEAR ',1A2,//,44X,'METHOD J=',I2)
WRITE(8,901) PAMB
901 FORMAT(//,//,3CX,'PRESSURES(PSIA) AND PRESSURE RATIOS',//,1X,'PAMB=
1, F5.2, //,1X,'POINT',3X,'PT0',4X,'P1AV',3X,'PT2',3X,'P2=PHD',3X,
2 'OVERALL PR(PTO/P2)',//)
DO 902 I=1, NP
902 WRITE(8,903) I, PTO(I), P1AV(I), PT2(I), QHD(I), PR(I)
903 FORMAT(14,2X,4F7.2,6X,F7.4)
WRITE(8,904)
904 FORMAT(//,//,3CX,'TEMPERATURES(DEG R)',//,1X,'POINT',4X,'T10',5X,
1, T1,6X,'TE',6X,'T2',5X,'T2IS',4X,'T2TH',3X,'TT0',3X,
2 'DELTA TIS',2X,'DELTATW',//)
DO 905 I=1, NP
905 WRITE(8,906) I, TT0(I), T1(I), TE(I), TT2(I), T2(I), T2IS(I), T2TH(I), TT2
1 IS(I), DELTIS(I), DELTW(I)
906 FORMAT(14,2X,8F8.2,2F10.2)
WRITE(8,907)
907 FORMAT(1H1,30X,'ABSOLUTE VELOCITIES(FT/SEC) AND ANGLES(DEG)',//,
1 1X,'POINT',3X,'VA2',6X,'VU2',7X,'V2',6X,'VCIS',3X,'ALPHA 2',3X,'M
2 V2',4X,'STAGE LOADING FACTOR',2X,'STAGE FLOW FACTOR',7)
DO 908 I=1, NP
908 WRITE(8,909) I, VA2(I), VU2(I), V2(I), VOIS(I), ALPH2(I), MV2(I), SLF(I),
1 SFF(I)
909 FORMAT(14,1X,5F9.2,F3.4,F14.2,F21.2)
WRITE(8,910)
910 FORMAT(//,//,30X,'RELATIVE VELOCITIES(FT/SEC), ANGLES(DEG), AND REL
1 'VEL COEFS',//,1X,'POINT',3X,'WA2',6X,'WU2',7X,'W2',7X,'W2IS',6X,
2 'W2IS',4X,'BETA 2',4X,'DBETA',2X,'WCOEFS',3X,'MW2',//)
DO 911 I=1, NP
911 WRITE(8,912) I, WA2(I), WU2(I), W2(I), W2IS(I), BETA2(I), DBETA(I)

```

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TTTT06940
TTTT06950
TTTT06960
TTTT06970
TTTT06980
TTTT06990
TTTT07000
TTTT07010
TTTT07020
TTTT07030
TTTT07040
TTTT07050
TTTT07060
TTTT07070
TTTT07080
TTTT07090
TTTT07100
TTTT07110
TTTT07120
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TTTT07140
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TTTT07340
TTTT07350
TTTT07360
TTTT07370
TTTT07380
TTTT07390
TTTT07400
TTTT07410

```



```

1  WCOFS(I), MW2(I)
912  FORMAT(I4, I1X, 7F9.2, 2F8.4)
913  WRITE(8, 913)
913  FORMAT(///, 30X, 'EFFICIENCIES, RPM, WORK OUTPUT(HP), AND ENTHALPY
1  DROP(BTU/LBM)', //, 10X, 'POINT', 2X, 'ZETA ROTOR', 2X, 'ETA ROTOR(I)-ZETA
2R', 2X, 'RPM', 6X, 'HP', 3X, 'DELTA HIS', 2X, 'DELTA HW', 2X, 'REHEAT FACTO
3R', 2X, 'EFF DEGREE OF REACTION', /)
DO 914, I=1, NP
914  WRITE(8, 915) I, ZETAR(I), ETAR(I), RPM(I), HP(I), DELHIS(I), DELHW(I), F(
1  I), REACEF(I)
915  FORMAT(I4, 4X, F8.4, 8X, F8.0, F8.2, F8.2, F11.2, F13.4, F19.4)
916  WRITE(8, 916) I, X, 'GENERAL RESULTS', //, 1X, 'RUN NUMBER', A3, 4X,
1  'DAY', //, 1A2, 4X, 'MONTH', //, 1A2, 4X, 'YEAR', //, 1A2
1  'EFFICIENCY', 2X, 'PRESSURE', 2X, 'REFERRED', 2X, 'ISENTROPIC', 2X, '
2  'RED', 2X, 'DEGREE OF', 2X, 'EFFICIENCY', 2X, 'REFERRED', 3X, 'REFERRED', 2X, 'REFE
3  'X', 'SPEED', 3X, 'HEAD COEFF', 2X, 'TQ-STATIC', 4X, 'TOT-TOT', 3X, 'FLOW RA
4  'TE', 3X, 'MOMENT', 5X, 'POWER', 4X, 'REACTION', 3X, 'REACTION', 3X, 'FT-LB
5  'N', //, 21X, 'RPM', 18X, 'PERCENT', 5X, 'PERCENT', 4X, 'LBM/SEC', 4X, 'FT-LB
6  '77X, 'HP', 7X, '(HUB)', 6X, '(MEAN)', 5X, '(TIP)', /)
DO 917, I=1, NP
917  WRITE(8, 918) I, PR(I), REFRPM(I), XKIS(I), ETATS(I), ETATT(I), REFLOW(I
1  I), REFMOM(I), REFBHP(I), REACHB(I), REACMN(I), REACTP(I)
918  FORMAT(I4, F11.4, F10.0, F11.4, 2F12.2, F11.4, F11.3, F10.3, 3F11.4)
RETURN
END

SUBROUTINE LISA(NP, NRUN, NDAY, NMO, NYEAR, XKIS, ETATS, PRS, ZETAS,
1  REFRPM, ETAR, ETAS, RTORQ)
DIMENSION XKIS(50), ETATS(50), PRS(50), ZETAS(50), REFRPM(50)
1  ETAR(50), ETAS(50), RTORQ(50)
WRITE(7, 804) NP, NRUN, NDAY, NMO, NYEAR
WRITE(7, 806) (XKIS(I), ETATS(I), PRS(I), ZETAS(I), REFRPM(I)
1  ETAR(I), ETAS(I), RTORQ(I), I=1, NP)
804  FORMAT(1X, I2, 4A2)
806  FORMAT(1X, 8F9.3)
RETURN
END

SUBROUTINE HAMMER(NP, GTORQ, QRP, QFLOWT, PRP)
WRITE(6, 701) NP, QRP, PRP, QFLOWT, QTORQ
FORMAT(1, //, 20X, 'POINT NUMBER', I2, //,
1  10X, 'RPM-----', F8.2, /,
2  10X, 'STAGE PRESSURE RATIO-----', F6.2, /,
3  10X, 'TURBINE MASS FLOW-----', F4.2, ' LB/SEC', /,

```

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TTT07420
TTT07430
TTT07440
TTT07450
TTT07460
TTT07470
TTT07480
TTT07490
TTT07500
TTT07510
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TTT07530
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TTT07550
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TTT07580
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TTT07610
TTT07620
TTT07630
TTT07640
TTT07650
TTT07660
TTT07670
TTT07680

TTTC7690
TTT07700
TTT07710
TTT07720
TTT07730
TTT07740
TTT07750
TTT07760
TTT07770
TTT07780
TTT07790

TTT07800
TTT07810
TTT07820
TTT07830
TTT07840
TTT07850

```

```

701
1
2
3

```


4 10X, STATOR TORQUE-----, F6.2, FT-LB, //)
RETURN
END

TTT07860
TTT07870
TTT07880

5. DRAW PROGRAM

This program uses data cards punched from the TTTR on-line reduction to plot certain desired TTTR results. The program must be executed using the normal FORTRAN operating system since the CP/CMS system does not link with the CALCOMP plotters at present. The program is presented on the following pages and the results shown in Figures 9 - 12, in the main text.

CCCCC

TRANSONIC TURBINE TEST RIG
OUTPUT PLOT PROGRAM

THIS DRAWS TTTR GRAPHS USING THE PUNCHED CARDS FROM THE ON-LINE REDUCTION

```

DIMENSION XKIS(50), ETATS(50), PRS(50), ZETAS(50), ZETAS(50), REFRPM(50)
1, ETAR(50), ETAS(50), DUMTS(50), DUMR(50), DUMS(50), DUMT(50)
2, RTORQ(50), KEY(50)
READ(5,04) NP, NRUN, NDAY, NMO, NYEAR
04 FORMAT(1X, I2, 4A2)
READ(5,06) (XKIS(I), ETATS(I), PRS(I), ZETAS(I), REFRPM(I), ETAR(I)
1, ETAS(I), RTORQ(I), I=1, NP)
06 FORMAT(1X, 8F9.3)
CALL LISA(NP, NRUN, NDAY, NMO, NYEAR, XKIS, ETATS, PRS, ZETAS,
1 REFRPM, ETAR, ETAS, RTORQ)
1 STOP

```

END

```

SUBROUTINE LISA(NP, NRUN, NDAY, NMO, NYEAR, XKIS, ETATS, PRS, ZETAS,
1 REFRPM, ETAR, ETAS, RTORQ)
REAL*4 NRUN, NDAY, NMO, NYEAR
REAL*8 LABEL//
REAL LABELS// ETAR//
REAL LABELS// ETAS//
REAL LABEL// T-S //
REAL LABRT//
REAL ITI1(24)//DETH// OMAS// TTT// R R// UN #// ' , ' DAY '
1, EFFI// MO// YEAR//
2, HE// CIEN// CIES// (T-S// ROT// OR&S// TATO// R) V// 'S IS'
3, HE// AD C// DEF//
REAL ITI2(24)//DETH// OMAS// TTT// R R// UN #// ' , ' DAY '
1, EFFI// MO// YEAR//
2, HE// CIEN// CIES// (T-S// ROT// OR&S// TATO// R) V// 'S. '
3, STAT// OR P// R// OMAS// TTT// R R// UN #// ' , ' DAY '
REAL ITI3(24)//DETH// YEAR//
1, EFFI// MO// CIEN// CIES// (T-S// ROT// OR&S// TATO// R) V// 'S. '
2, REFE// RRED// RPM// OMAS// TTT// R R// UN #// ' , ' DAY '
3, REFE// RRED// RPM// STA// TOR// UE V// 'S. '
DIMENSION XKIS(50), ETATS(50), PRS(50), ZETAS(50), REFRPM(50)
1, ETAR(50), ETAS(50), DUMTS(50), DUMR(50), DUMS(50), DUMT(50)
2, RTORQ(50), KEY(50)
WRITE(6, 884)

```



```
IT1(6)=NRUN
IT1(8)=NDAY
IT1(10)=NMO
IT1(12)=NYEAR
IT2(6)=NRUN
IT2(8)=NDAY
IT2(10)=NMO
IT2(12)=NYEAR
IT3(6)=NRUN
IT3(8)=NDAY
IT3(10)=NMO
IT3(12)=NYEAR
IT4(6)=NRUN
IT4(8)=NDAY
IT4(10)=NMO
IT4(12)=NYEAR
DO 802 I=1, NP
KEY(I)=I
ETAS(I)=100.*ETAR(I)
ETAS(I)=100.*ETAS(I)
DUMTS(I)=ETATS(I)
DUMR(I)=ETAR(I)
DUMT(I)=RTORQ(I)
WRITE(6, 889) I, XKIS(I), PRS(I), REFRPM(I), ETATS(I), ETAR(I), ETAS(I)
CONTINUE
CALL SHSORT(XKIS, KEY, NP)
WRITE(6, 824)
FORMAT(1, 2X, 1, XKIS, 1, 4X, 'ETATS', 6X, 'ETAR', 6X, 'ETAS')
DO 804 I=1, NP
ETAS(I)=DUMTS(KEY(I))
ETAR(I)=DUMR(KEY(I))
ETAS(I)=DUMS(KEY(I))
KEY(I)=I
WRITE(6, 822) XKIS(I), ETATS(I), ETAR(I), ETAS(I)
CONTINUE
CALL DRAW(NP, XKIS, ETATS, 1, 5, LABEL, IT1, 0, 0, 0, 0, 0, 0, 2, 2, 8, 5, 1, LA)
CALL DRAW(NP, XKIS, ETATS, 2, 0, LABEL, IT1, 0, 0, 0, 0, 0, 0, 2, 2, 8, 4, 1, LA)
CALL DRAW(NP, XKIS, ETAR, 2, 3, LABEL, IT1, 0, 0, 0, 0, 0, 0, 2, 2, 8, 4, 1, LA)
CALL DRAW(NP, XKIS, ETAR, 2, 0, LABEL, IT1, 0, 0, 0, 0, 0, 0, 2, 2, 8, 4, 1, LA)
CALL DRAW(NP, XKIS, ETAS, 2, 4, LABEL, IT1, 0, 0, 0, 0, 0, 0, 2, 2, 8, 4, 1, LA)
CALL DRAW(NP, XKIS, ETAS, 3, 0, LABEL, IT1, 0, 0, 0, 0, 0, 0, 2, 2, 8, 4, 1, LA)
CALL SHSORT(PRS, KEY, NP)
WRITE(6, 826)
FORMAT(1, 2X, 1, PRS, 1, 4X, 'ETATS', 6X, 'ETAR', 6X, 'ETAS')
DO 806 I=1, NP
ETAS(I)=DUMR(KEY(I))
ETAR(I)=DUMR(KEY(I))
```



```

ETAS(I)=DUMS(KEY(I))
KEY(I)=I
WRITE(6,822) PRS(I),ETATS(I),ETAR(I),ETAS(I)
CONTINUE
CALL DRAW(NP, PRS,ETATS,1,5,LABEL,ITIT2,0,0,0,0,0,0,0,0,2,2,8,5,1,LA)
CALL DRAW(NP, PRS,ETATS,2,0,LABEL,ITIT2,0,0,0,0,0,0,0,0,2,2,8,4,1,LA)
CALL DRAW(NP, PRS, ETAR,2,3,LABEL,ITIT2,0,0,0,0,0,0,0,0,2,2,8,4,1,LA)
CALL DRAW(NP, PRS, ETAR,2,0,LABEL,ITIT2,0,0,0,0,0,0,0,0,2,2,8,4,1,LA)
CALL DRAW(NP, PRS, ETAS,2,4,LABEL,ITIT2,0,0,0,0,0,0,0,0,2,2,8,4,1,LA)
CALL DRAW(NP, PRS, ETAS,3,0,LABELS,ITIT2,0,0,0,0,0,0,0,0,2,2,8,4,1,LA)
CALL SHSORT (REFRPM,KEY,NP)
WRITE(6,828)
FORMAT(1,1,2X,REFRPM,4X,ETATS,6X,ETAR,6X,ETAS,6X,RTORQ)
DO 808 I=1,NP
ETATS(I)=DUMS(KEY(I))
ETAR(I)=DUMS(KEY(I))
ETAS(I)=DUMS(KEY(I))
RTORQ(I)=DUMS(KEY(I))
KEY(I)=I
WRITE(6,822)REFRPM(I),ETATS(I),ETAR(I),ETAS(I),RTORQ(I)
CONTINUE
FORMAT(1,1,5F10.4)
CALL DRAW(NP,REFRPM, ETATS,1,5,LABEL,ITIT3,0,0,0,0,0,0,0,0,2,2,8,5,1,LA)
CALL DRAW(NP,REFRPM, ETATS,2,0,LABEL,ITIT3,0,0,0,0,0,0,0,0,2,2,8,4,1,LA)
CALL DRAW(NP,REFRPM, ETAR,2,3,LABEL,ITIT3,0,0,0,0,0,0,0,0,2,2,8,4,1,LA)
CALL DRAW(NP,REFRPM, ETAS,2,0,LABEL,ITIT3,0,0,0,0,0,0,0,0,2,2,8,4,1,LA)
CALL DRAW(NP,REFRPM, ETAS,2,4,LABEL,ITIT3,0,0,0,0,0,0,0,0,2,2,8,4,1,LA)
CALL DRAW(NP,REFRPM, ETAS,3,0,LABELS,ITIT3,0,0,0,0,0,0,0,0,2,2,8,4,1,LA)
CALL DRAW(NP,REFRPM, RTORQ,0,3,LABRT,ITIT4,0,0,0,0,0,0,0,0,2,2,8,5,1,LA)
IF (LA,NE,0) WRITE(6,885)
WRITE(6,887) NP, NRUN, NDAY, NMO, NYEAR, LA
FORMAT(1H1,20X,-----PARAMETERS,//////)
884 FORMAT(1,1,12,6F10.4,7)
885 FORMAT(1,1,12,6F10.4,7)
887 FORMAT(1,1,12,6F10.4,7)
889 FORMAT(1,1,12,6F10.4,7)
RETURN
END

```


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13. ABSTRACT

The Transonic Turbine Test Rig located in the Turbo-Propulsion Laboratory of the Naval Postgraduate School is used to analyze axial turbine stage performance. The Test Rig is designed to separately measure stator and rotor losses without the use of velocity or pressure surveys. Various stator and rotor blade types can be investigated over wide ranges of axial and radial blade clearances in addition to variations in normal operating parameters.

This paper describes the development of on-line data acquisition and analysis for the Turbo-Propulsion Laboratory in conjunction with the Turbine Test Rig. It also describes various improvements to the Turbine Test Rig itself.

KEY WORDS:

Axial Turbine
 Turbine Test Rig
 Data Acquisition
 On-Line Data Acquisition

LINK A		LINK B		LINK
ROLE	WT	ROLE	WT	ROLE

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Thesis

D4535 DeThomas

c.1 On-line data acquisition and instrumentation improvements for the transonic test rig.

134594

Thesis

D4535 DeThomas

c.1 On-line data acquisition and instrumentation improvements for the transonic test rig.

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