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

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THESIS

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and
Instrumentation Improvements
for the
Transonic Turbine Test Rig

by

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March 1972

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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.

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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 penum 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 (mest #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 Capsule

   Consideration 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 TTTR 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.

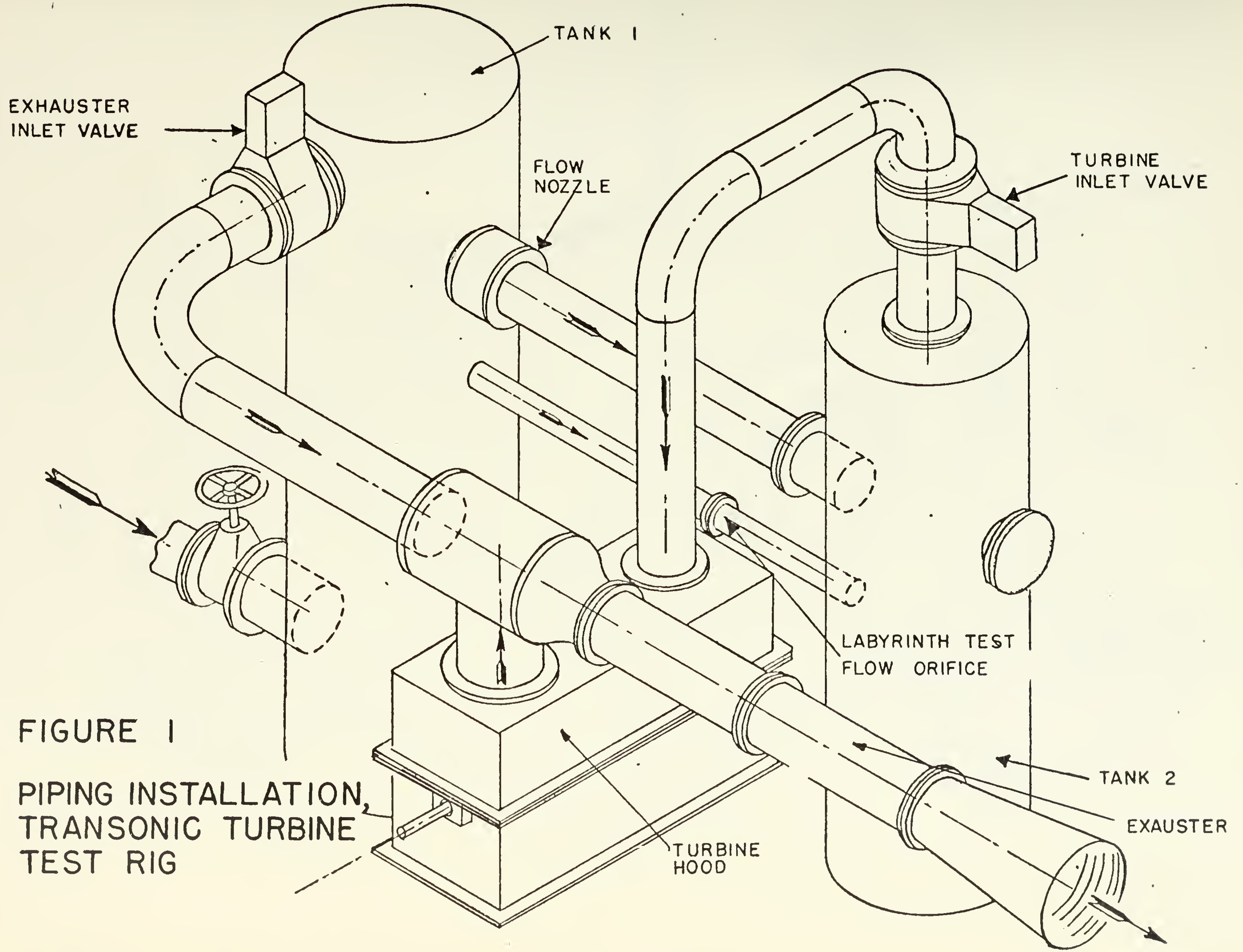

FIGURE I

PIPING INSTALLATION,
TRANSONIC TURBINE
TEST RIG

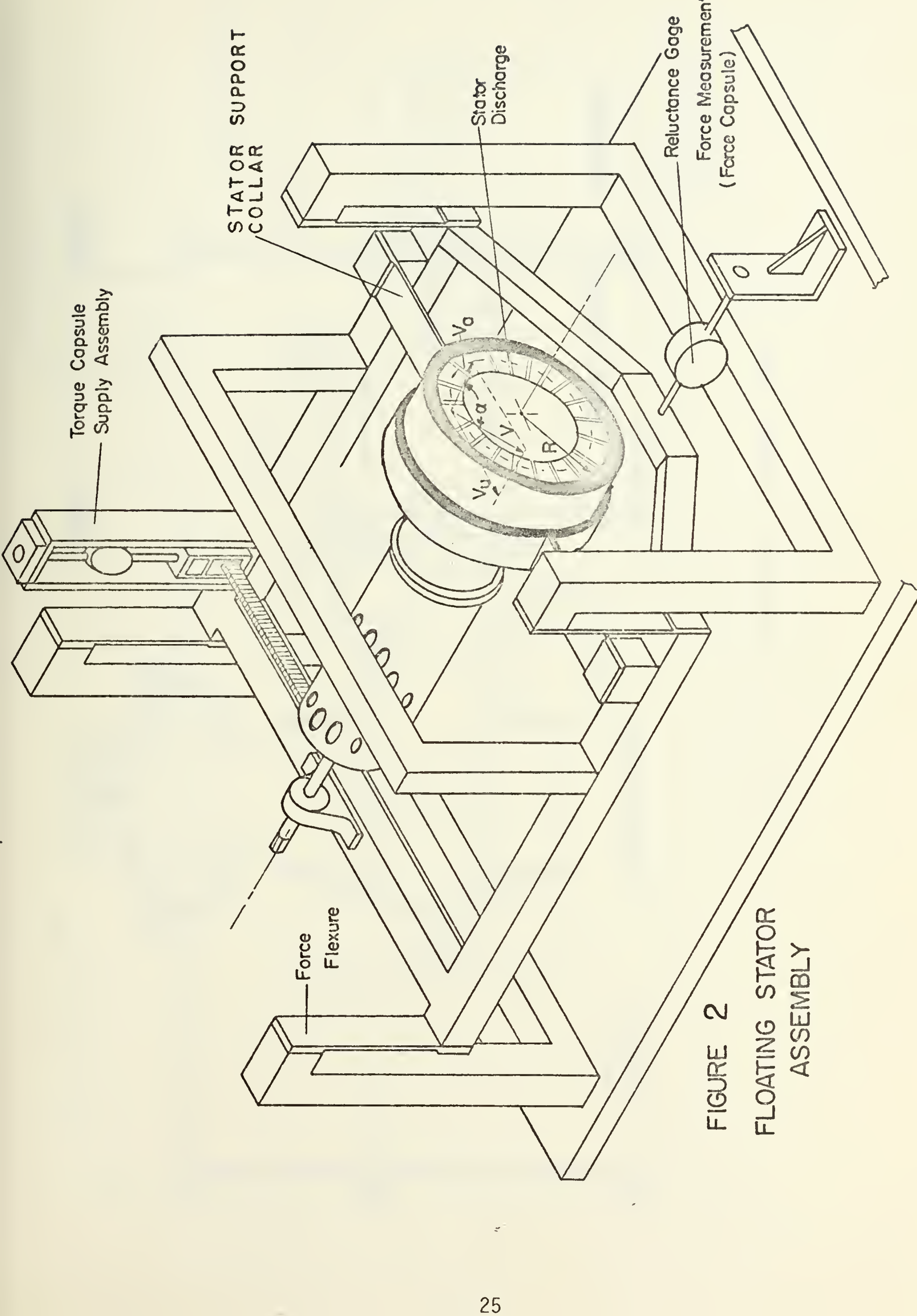

FIGURE 2
FLOATING STATOR
ASSEMBLY

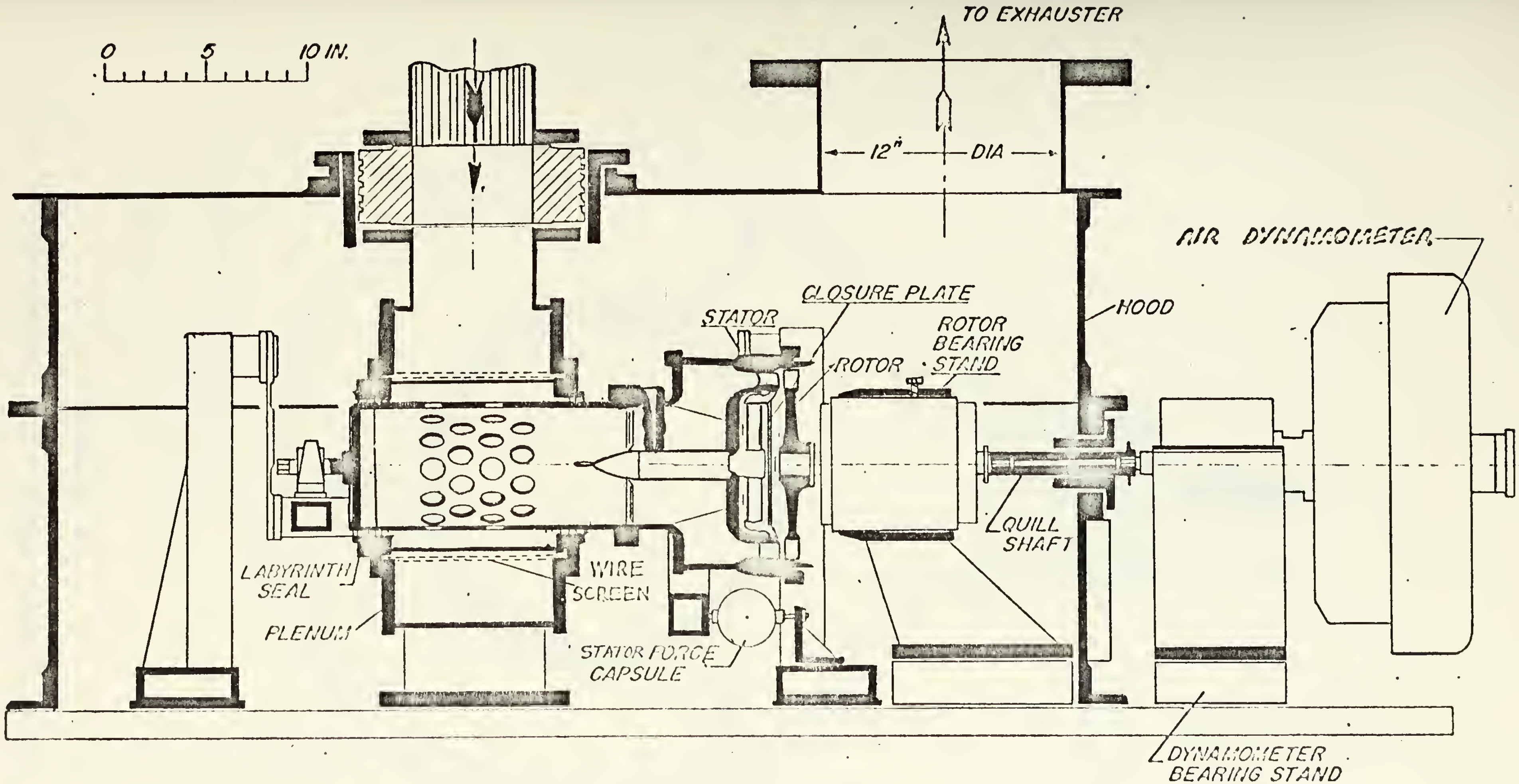

FIGURE 3 TRANSONIC TURBINE TEST RIG

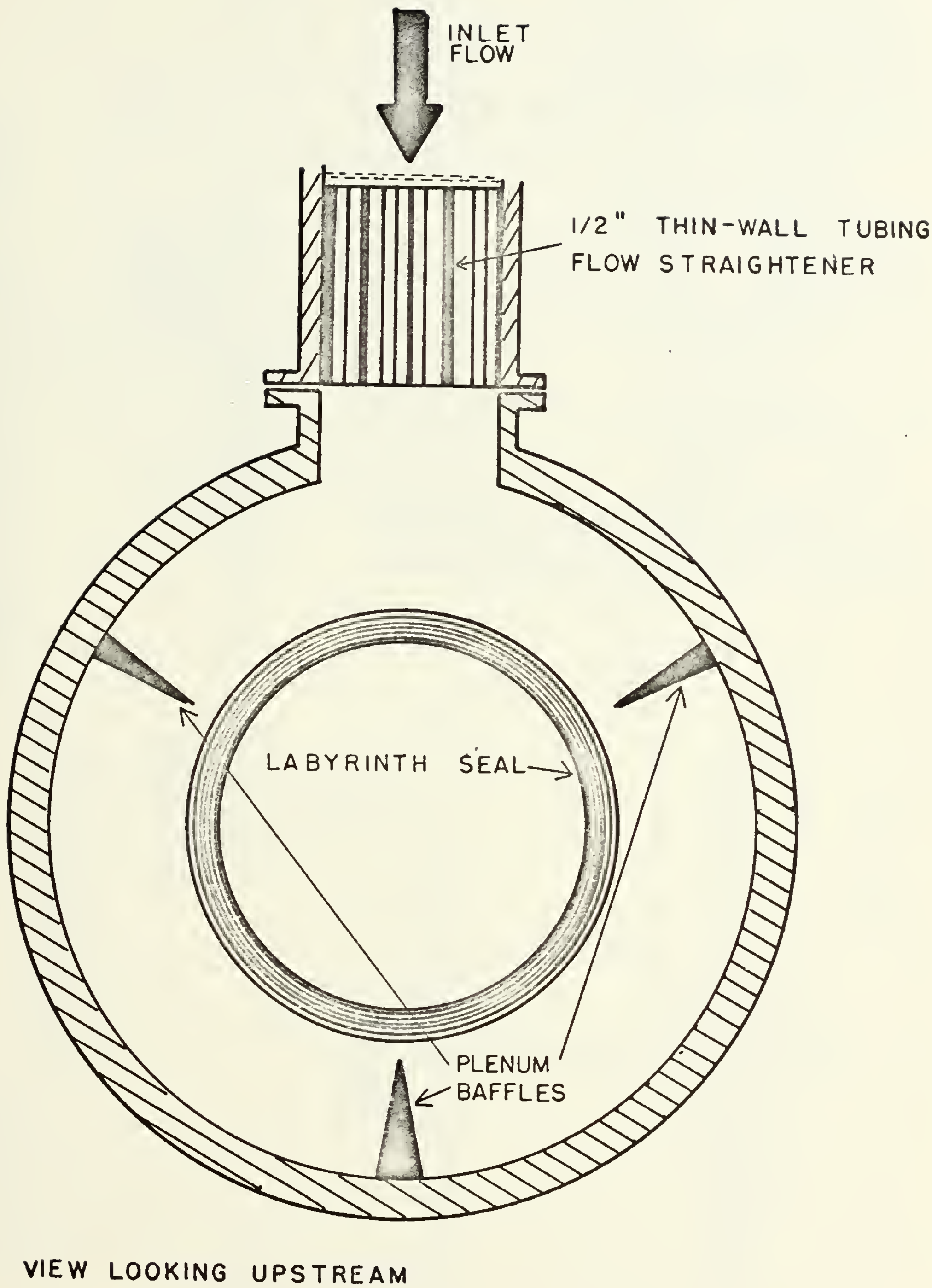

FIGURE 4

FLOW STRAIGHTENER AND PLENUM BAFFLE INSTALLATION

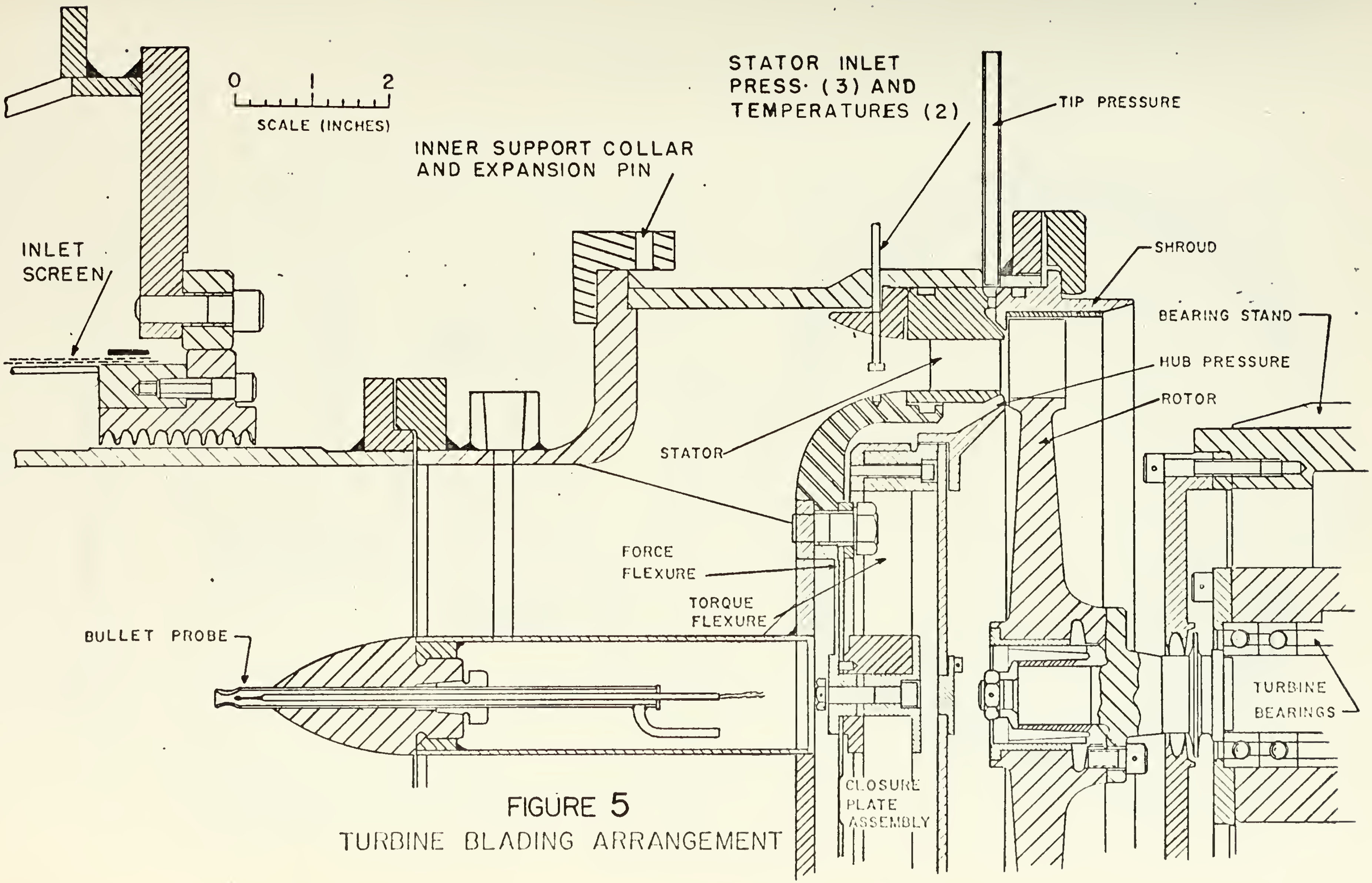

FIGURE 5
TURBINE BLADING ARRANGEMENT

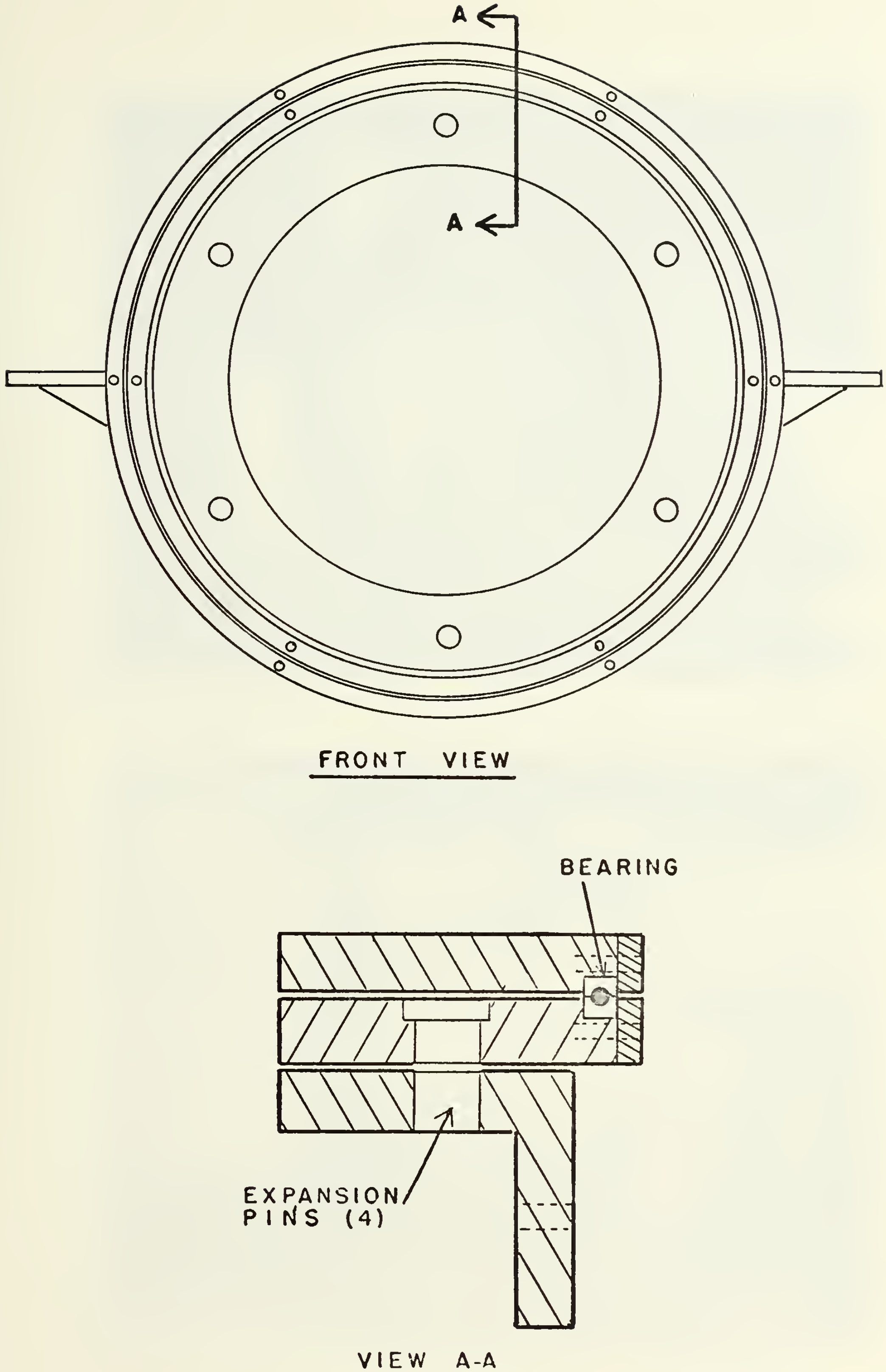

FIGURE 6 STATOR SUPPORT COLLAR

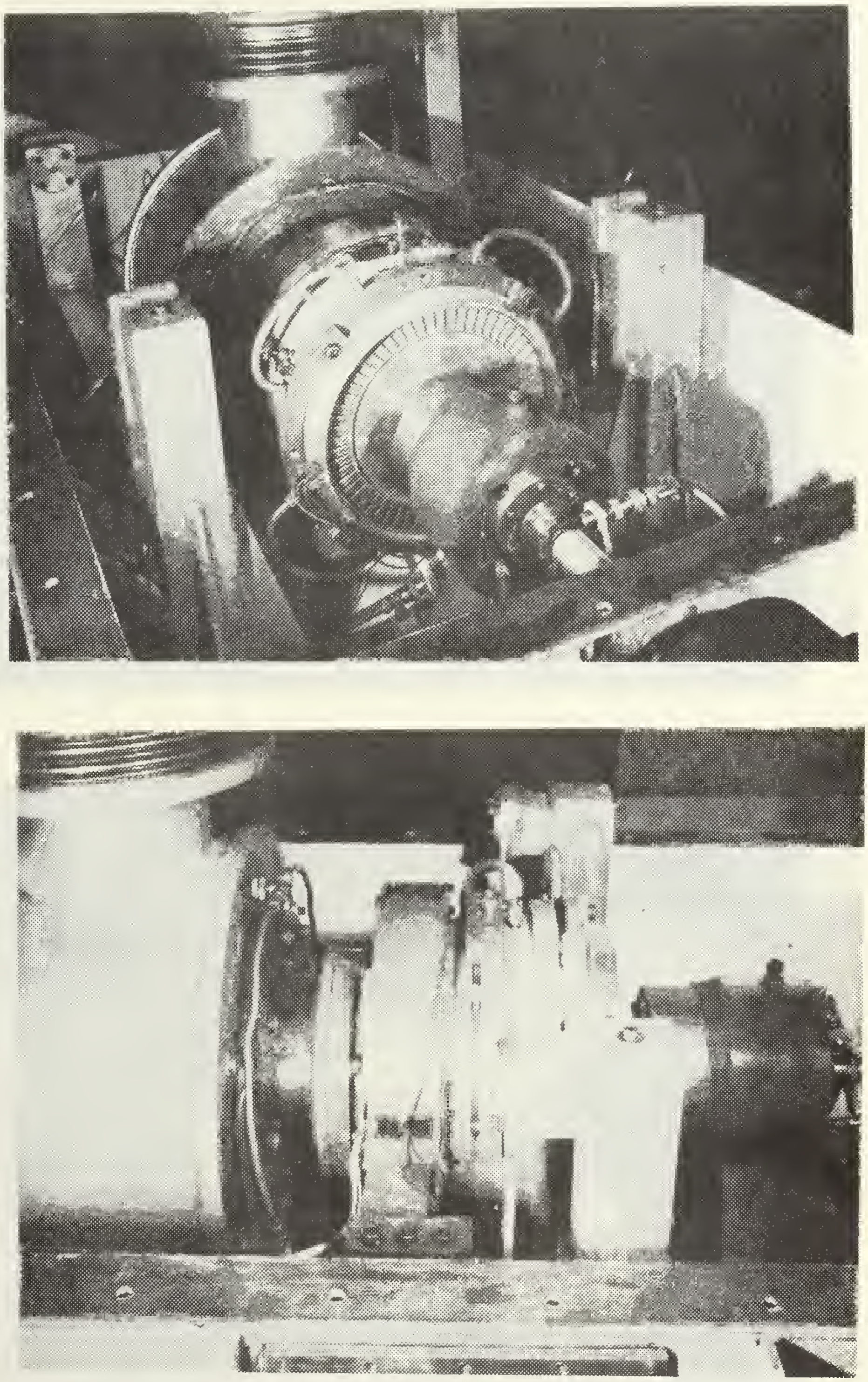

Figure 7. Stator Support Collar Installation.

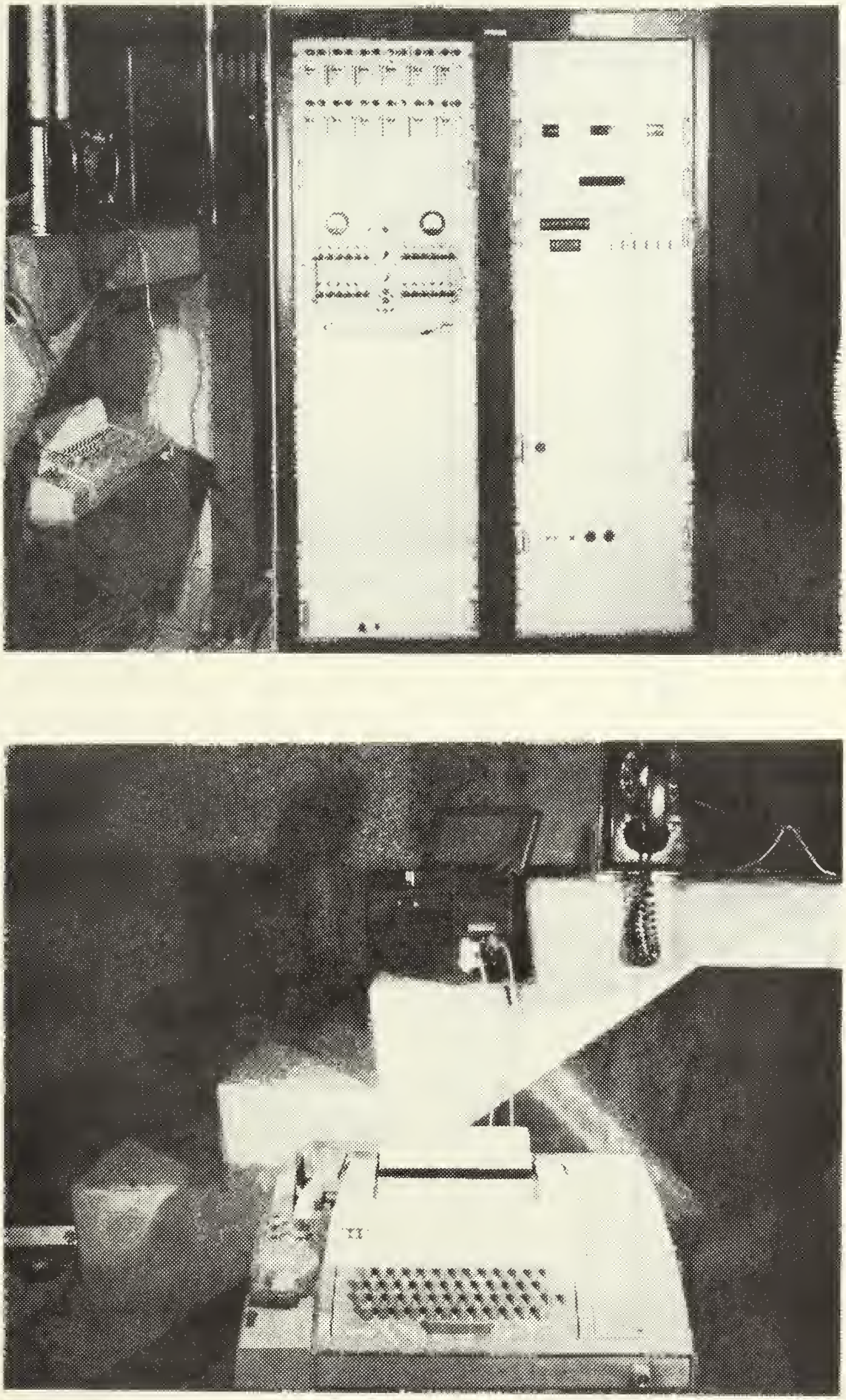

Figure 8. Data Acquisition Equipment.

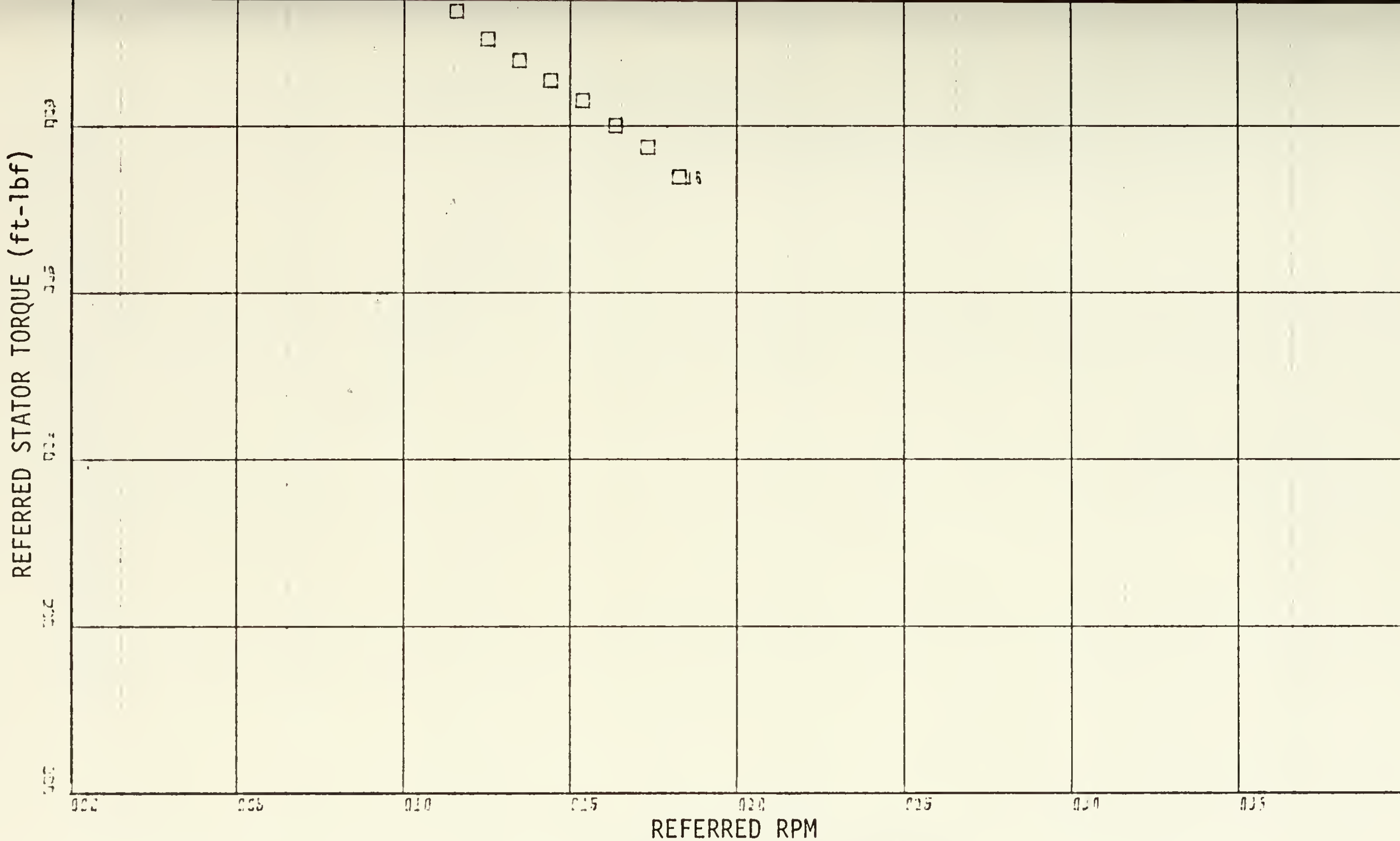

Figure 9. Referred Stator Torque vs. Referred RPM

K-SCALE=5.00E+03 UNITS INCH.
Y-SCALE=2.00E+00 UNITS INCH.
DETHOMAS TTTR RUN #16 DAY 11 MO. 02 YEAR72
REFERRED STATOR TORQUE VS. REFERREDRPM

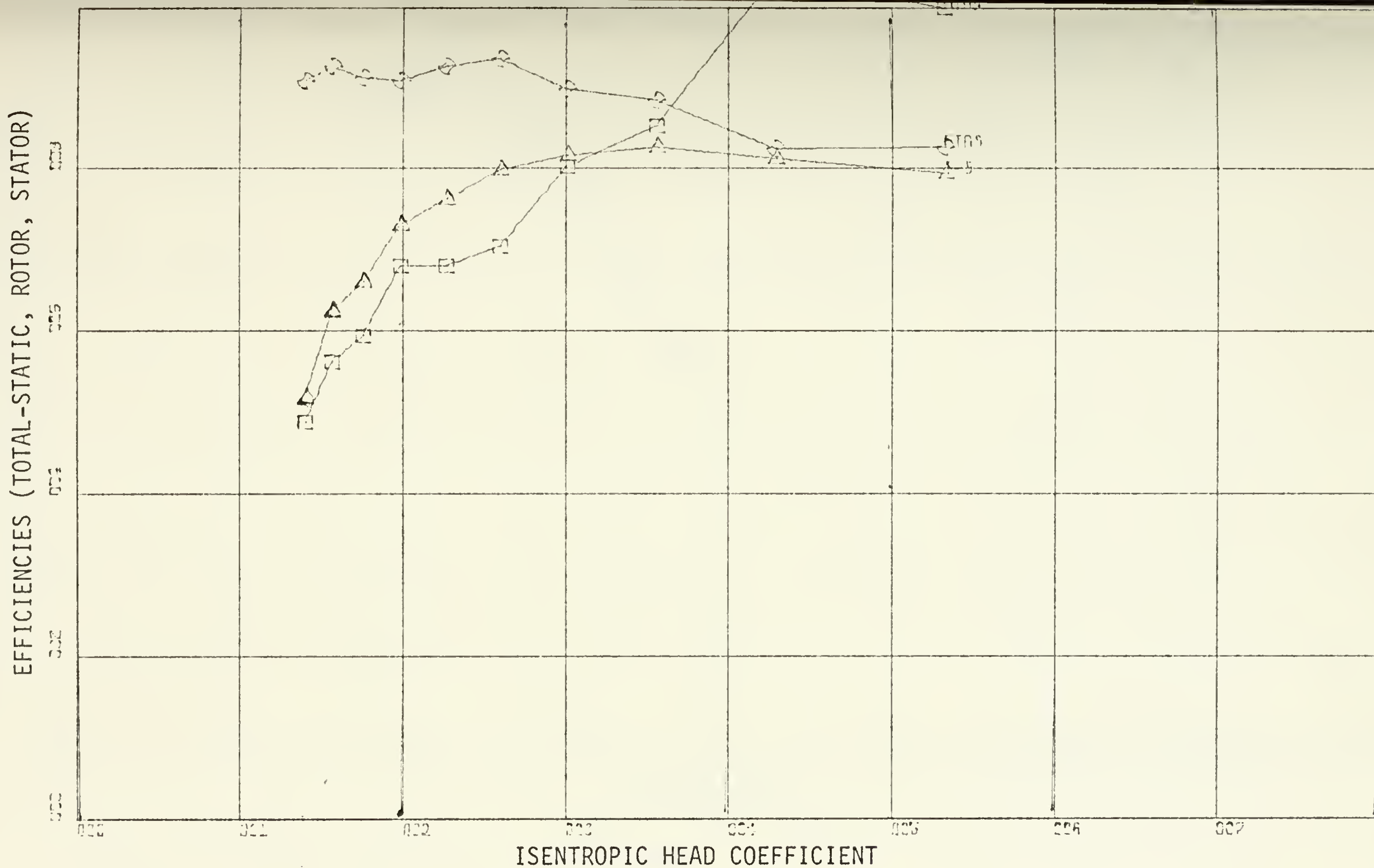

Figure 10. Stage Efficiencies vs. Isentronic Head Coefficient

X-SCALE=1.00E+00 UNITS INCH.
Y-SCALE=2.00E+01 UNITS INCH.
DETHOMAS TTIR RUN #16 DAY 11 MO. 02 YEAR72
EFFICIENCIES(T-S,ROTOR&STATOR) VS IS. HEAD COFF.

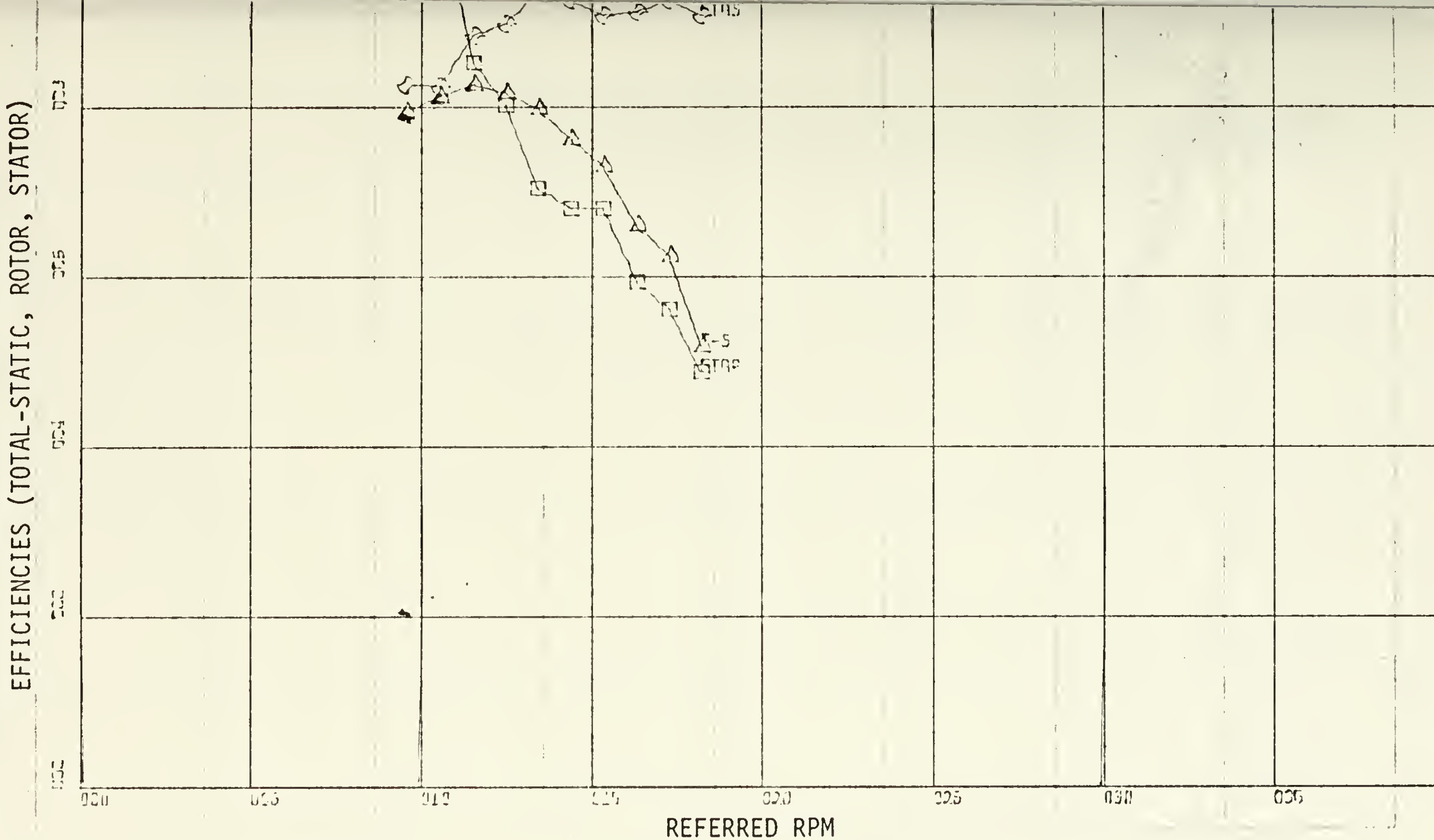

Figure 11. Stage Efficiencies vs. Referred RPM

X-SCALE=5.00E+03 UNITS INCH.
Y-SCALE=2.00E+01 UNITS INCH.
DETHOMAS TTTR RUN #16 DAY 11 MO. 02 YEAR72
EFFICIENCIES(T-S,ROTOR&STATOR) VS. REFERRED RPM

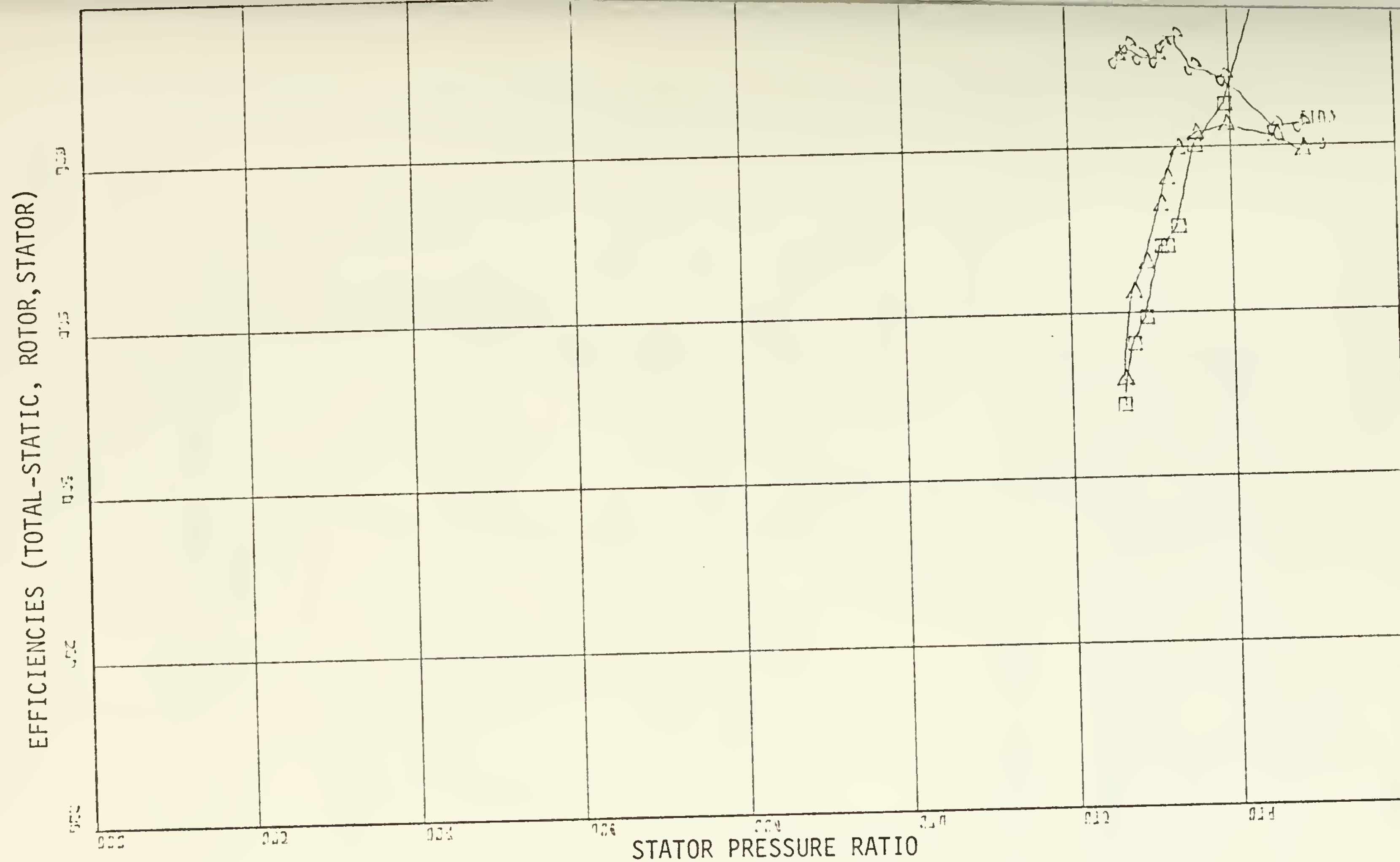

Figure 12. Stage Efficiencies vs. Stator Pressure Ratio

X-SCALE=2.00E-01 UNITS INCH.
Y-SCALE=2.00E+01 UNITS INCH.
DETHOMAS TTTR RUN #16 DAY 11 MO. 02 YEAR72
EFFICIENCIES(T-S,ROTOR&STATOR) VS. STATOR P.R.

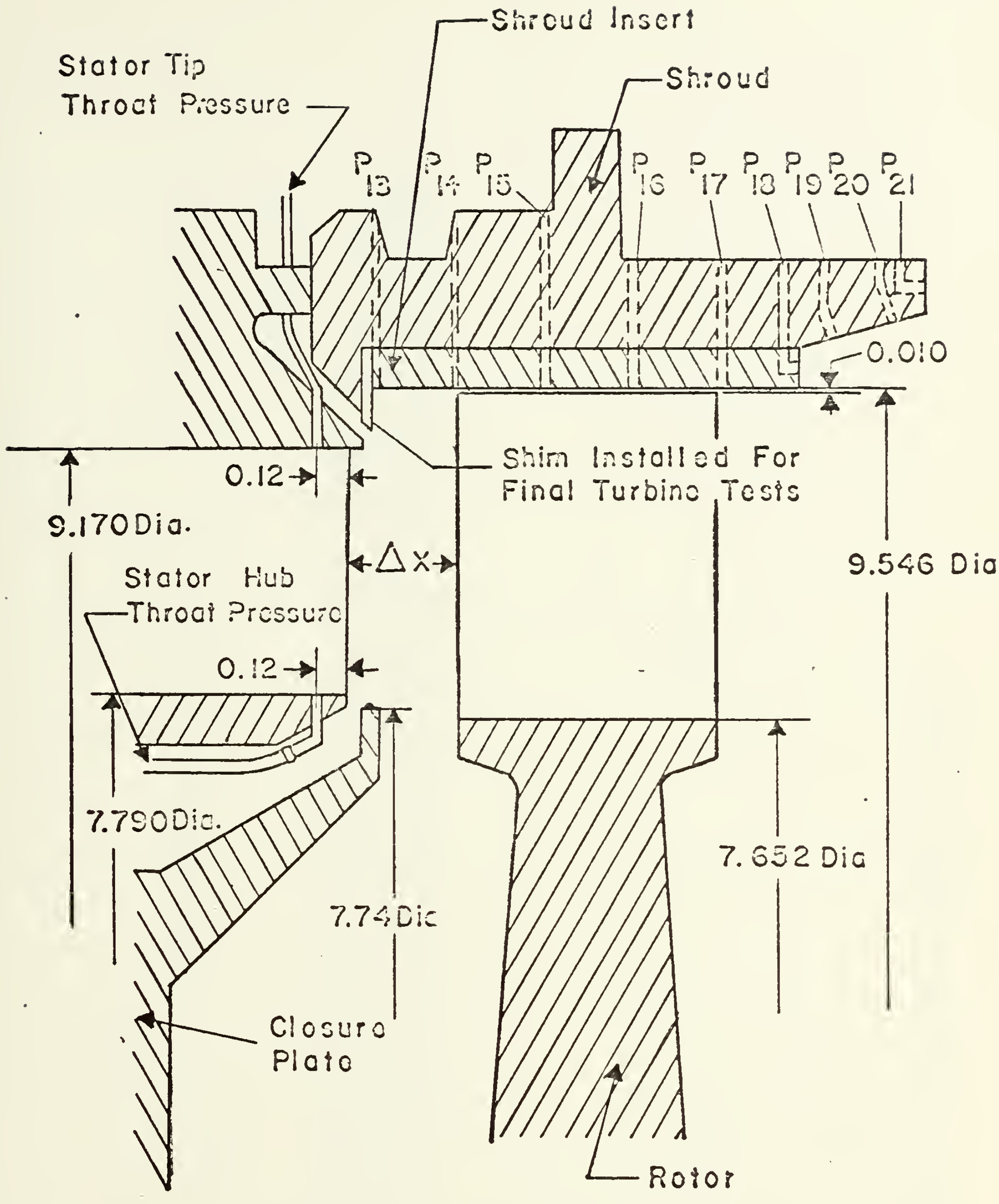

FIGURE 13
TURBINE AND SHROUD DETAILS

TRANSONIC TURBINE TEST RIG INPUT DATA

RUN NUMBER 16 DAY 11 MONTH 02 YEAR 72

NO	BAR	NOZ	PTO	HUB	TIP	P13	P18	P19	P20	P21	PHD	DH	TNOZ	TTO	THD	RPM	AXIL	TORQR	DYNAR	CLAXI
1	30.05	66.02	44.26	29.25	32.33	32.62	30.22	30.01	29.96	29.96	29.78	6.21	2.06	1.88	1.03	9910.	-265.	444.	461.	13.
2	30.06	68.46	44.07	29.60	32.77	33.09	30.20	29.97	29.89	29.91	29.78	5.80	2.11	1.93	1.19	11005.	-52.	425.	415.	14.
3	30.05	68.72	44.10	29.88	33.14	33.46	30.20	29.89	29.81	29.90	29.97	5.70	2.11	1.94	1.20	12000.	121.	414.	379.	15.
4	30.06	68.86	44.04	30.14	33.45	33.77	30.21	29.76	29.69	29.84	30.04	5.63	2.12	1.95	1.23	12995.	291.	398.	341.	15.
5	30.05	68.89	44.11	30.43	33.85	34.16	30.32	29.63	29.51	30.03	30.06	5.37	2.13	1.96	1.23	14000.	476.	387.	303.	16.
6	30.06	68.99	44.06	30.70	34.15	34.48	30.37	29.63	29.52	30.15	30.05	5.30	2.13	1.97	1.22	14980.	631.	376.	269.	17.
7	30.05	69.08	44.13	31.00	34.51	34.85	30.56	29.64	29.55	30.22	30.05	5.25	2.14	1.97	1.31	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	30.06	5.09	2.14	1.98	1.32	17020.	972.	353.	202.	18.
9	30.06	69.05	44.14	31.63	35.24	35.55	30.96	29.69	29.64	30.50	30.07	4.99	2.14	1.98	1.32	18005.	1146.	342.	178.	19.
10	30.06	68.09	44.03	31.97	35.58	35.88	31.24	29.71	29.75	30.66	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)

RUN NUMBER 16 DAY 11 MONTH 02 YEAR 72

METHOD J= 1

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	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	1202.02	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	57.47	90.03	696.62	10.37	13.80	0.01	6.59	9.40
4	23.28	18.87	1212.52	285.89	56.66	46.15	57.49	90.87	702.68	14.93	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	16.75	12.90	0.02	25.92	8.78
6	50.48	14.27	1212.92	291.56	57.25	45.91	57.79	92.77	715.74	16.65	12.53	0.02	34.40	8.54
7	62.56	13.12	1212.92	294.52	57.38	45.94	58.15	93.76	722.73	16.10	12.20	0.02	42.57	8.30
8	77.76	10.20	1213.32	297.49	57.63	45.99	58.51	94.68	729.96	17.02	11.77	0.02	52.95	8.01
9	91.68	9.13	1213.73	300.64	57.91	46.05	58.91	95.69	737.42	17.90	11.40	0.03	62.38	7.76
10	105.76	7.67	1213.32	303.70	58.22	46.15	59.45	96.60	745.35	17.30	10.83	0.03	72.13	7.39

FLOW RATES(LBM/SEC), RE(NOZ), FLOW FNC, AND STATOR BLOCKAGE FACTOR

POINT	NOZZLE FLOW	TURBINE FLOW	LABLEAK	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	0.0431	579094.	0.5666	0.8996
4	1.7926	1.7498	0.0427	575956.	0.5645	0.9031
5	1.7508	1.7080	0.0429	562545.	0.5503	0.8867
6	1.7404	1.6976	0.0429	559206.	0.5477	0.8897
7	1.7331	1.6906	0.0426	556853.	0.5447	0.8914
8	1.7136	1.6712	0.0424	550574.	0.5389	0.8907
9	1.6890	1.6466	0.0425	542671.	0.5306	0.8854
10	1.6600	1.6179	0.0420	533337.	0.5227	0.8840

PRESSURES(PSIA) AND PRESSURE RATIOS

PAMB=14.70

POINT	PNOZ	PTPL	PTO	P1AV	PHO	PLENUM PR(PTPL/PHO)	STATOR PR(PTO/P1AV)
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	1.3852
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	1.3589
7	33.79	21.72	21.59	16.02	14.70	1.4779	1.3474
8	34.07	21.70	21.57	16.18	14.70	1.4760	1.3330
9	33.78	21.71	21.59	16.35	14.71	1.4762	1.3201
10	33.31	21.66	21.54	16.52	14.70	1.4734	1.3036

TEMPERATURES(DEG R)

POINT	TTO	T1	T1IS
1	557.64	511.53	502.73
2	559.55	515.41	506.91
3	559.84	516.95	508.56
4	560.18	518.29	510.38
5	560.56	521.08	512.07
6	560.80	522.30	513.75
7	561.05	523.47	515.24
8	561.21	525.00	516.96
9	561.31	526.68	518.50
10	561.48	528.49	520.52

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

POINT	VA1	VU1	V1	V1TS	ALPHA 1	VCOEFS	MV1	MVA1	RVA1	RVU1
1	181.01	721.96	744.30	812.23	75.93	0.9164	0.6714	0.1633	0.1564	0.6237
2	177.08	706.30	728.16	795.22	75.93	0.9157	0.6543	0.1591	0.1527	0.6091
3	174.55	696.23	717.78	784.90	75.93	0.9145	0.6440	0.1566	0.1505	0.6003
4	172.52	688.10	709.40	773.51	75.93	0.9171	0.6357	0.1546	0.1487	0.5931
5	167.48	668.00	688.68	763.26	75.93	0.9023	0.6155	0.1497	0.1443	0.5756
6	165.38	659.64	680.06	751.84	75.93	0.9045	0.6070	0.1476	0.1425	0.5683
7	163.41	651.77	671.94	741.92	75.93	0.9057	0.5991	0.1457	0.1407	0.5613
8	160.39	639.72	659.52	729.13	75.93	0.9045	0.5872	0.1428	0.1381	0.5509
9	156.87	625.69	645.05	717.19	75.93	0.8994	0.5734	0.1394	0.1351	0.5388
10	153.12	610.72	629.62	701.54	75.93	0.8975	0.5587	0.1359	0.1318	0.5258

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

POINT	WA1	WU1	W1	U1	BETA 1	MW1
1	181.01	355.28	398.73	366.68	63.00	0.3596
2	177.08	299.11	347.60	407.20	59.37	0.3123
3	174.55	252.22	306.73	444.01	55.31	0.2752
4	172.52	207.27	269.67	480.83	50.23	0.2417
5	167.48	149.99	224.82	519.01	41.85	0.2009
6	165.38	105.37	196.10	554.28	32.50	0.1750
7	163.41	59.38	173.86	592.39	19.97	0.1553
8	160.39	9.97	160.70	629.76	3.56	0.1431
9	156.87	-40.51	162.02	666.23	-14.48	0.1440
10	153.12	-93.41	179.36	704.13	-31.39	0.1592

EFFICIENCIES

POINT	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	0.1859	0.8141
6	0.1818	0.8182
7	0.1798	0.8202
8	0.1818	0.8182
9	0.1910	0.8030
10	0.1945	0.8055

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(PSIA) AND PRESSURE RATIOS

PAMB=14.70

POINT	PT0	P1AV	PT2	P2=PHD	OVERALL PR(PT0/P2)
1	21.65	15.06	14.78	14.57	1.4861
2	21.56	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	T1	TE	TT2	T2	T2IS	T2TH	TT2IS	DELTA TIS	DELTA TW
1	557.64	511.53	525.05	510.23	508.16	506.68	497.96	499.99	59.68	47.41
2	559.55	515.41	525.83	511.35	509.57	508.67	500.28	502.02	59.27	48.20
3	559.84	516.95	525.21	511.50	509.63	509.60	501.33	503.17	58.51	48.33
4	560.18	518.29	524.84	512.83	510.37	509.95	502.17	504.59	58.01	47.35
5	560.56	521.08	525.86	514.12	511.13	511.21	502.37	505.31	58.19	46.43
6	560.80	522.30	526.16	516.42	512.21	511.07	502.70	506.83	58.09	44.38
7	561.05	523.47	526.74	518.38	512.88	510.74	502.70	508.09	58.35	42.67
8	561.21	525.00	528.01	522.75	515.12	510.82	502.99	510.43	58.22	38.46
9	561.31	526.68	529.82	524.92	516.19	510.95	503.02	511.52	58.29	36.39
10	561.48	528.49	532.23	531.36	519.70	511.18	503.47	514.77	58.01	30.13

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

POINT	VA2	VU2	V2	V0IS	ALPHA 2	MV2	STAGE LOADING FACTOR	STAGE FLOW FACTOR
1	147.98	-54.11	157.56	846.75	-20.09	0.1426	2.09	0.40
2	145.93	-4.69	146.00	843.83	-1.84	0.1319	1.72	0.35
3	144.01	41.77	149.95	838.40	16.17	0.1355	1.46	0.32
4	143.11	95.37	171.98	834.86	33.68	0.1553	1.22	0.29
5	139.81	127.89	189.48	836.09	42.45	0.1710	1.03	0.27
6	139.30	176.40	224.77	835.44	51.70	0.2026	0.86	0.25
7	138.91	216.29	257.05	837.27	57.29	0.2316	0.73	0.23
8	137.87	269.38	302.61	836.34	62.90	0.2720	0.58	0.22
9	136.07	293.79	323.77	836.86	65.15	0.2907	0.49	0.20
10	134.66	349.22	374.28	834.83	68.91	0.3349	0.37	0.19

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

POINT	WA2	WU2	W2	U2	W2IS	BETA 2	DBETA	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	432.98	-70.56	125.87	0.9992	0.3909
4	143.11	-391.64	416.96	487.01	422.97	-69.93	120.15	0.9858	0.3765
5	139.81	-396.78	420.69	524.67	419.55	-70.59	112.44	1.0027	0.3796
6	139.30	-385.00	409.43	561.40	425.80	-70.11	102.61	0.9615	0.3691
7	138.91	-383.71	408.08	600.00	438.51	-70.10	90.07	0.9306	0.3676
8	137.87	-368.47	393.42	637.85	454.46	-69.49	73.04	0.8657	0.3536
9	136.07	-380.98	404.55	674.77	476.05	-70.34	55.86	0.8498	0.3633
10	134.66	-363.96	388.08	713.18	502.90	-69.70	38.31	0.7717	0.3473

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

POINT	ZETA ROTOR	ETA ROTOR(1.-ZETAR)	RPM	HP	DELTA HIS	DELTA HW	REHEAT FACTOR	EFF DEGREE OF REACTION
1	0.0806	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	0.1169
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	-0.0054	1.0054	14000.	26.92	13.96	11.14	1.0176	0.2012
6	0.0754	0.9246	14980.	25.57	13.94	10.65	1.0167	0.2077
7	0.1340	0.8660	16010.	24.49	14.00	10.24	1.0160	0.2198
8	0.2506	0.7494	17020.	21.82	13.97	9.23	1.0156	0.2144
9	0.2778	0.7222	18005.	20.34	13.99	8.73	1.0158	0.2323
10	0.4045	0.5955	19030.	16.55	13.92	7.23	1.0153	0.2104

*

GENERAL RESULTS

RUN NUMBER 16 DAY 11 MONTH 02 YEAR 72

POINT	PRESSURE RATIO	REFERRED SPEED RPM	ISENTROPIC HEAD COEFF	EFFICIENCY TOT-STATIC PERCENT	EFFICIENCY TOT-TOT PERCENT	REFERRED FLOW RATE LBM/SEC	REFERRED MOMENT FT-LB	REFERRED POWER HP	DEGREE OF REACTION (HUB)	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	10596.	4.2944	81.33	83.79	1.2539	9.427	19.019	-0.0146	0.1119	0.2339
3	1.4716	11551.	3.5655	82.61	85.30	1.2445	8.602	18.919	-0.0074	0.1236	0.2497
4	1.4662	12505.	3.0147	81.61	85.17	1.2399	7.750	18.453	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	1.4672	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	14.80	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	284.21	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	15.87	9.05
5	38.08	16.34	1213.32	297.12	57.02	45.91	57.70	91.94	709.44	8.63	12.90	0.02	25.92	8.78
6	50.48	14.27	1212.92	299.72	57.25	45.91	57.79	92.77	715.74	8.48	12.53	0.02	34.40	8.54
7	62.56	13.12	1212.92	302.25	57.38	45.94	58.15	93.76	722.73	8.37	12.20	0.02	42.57	8.30
8	77.76	10.20	1213.32	306.41	57.63	45.99	58.51	94.68	729.96	8.10	11.77	0.02	52.95	8.01
9	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(LBM/SEC), RE(NOZ), FLOW FNC, AND STATOR BLOCKAGE FACTOR

POINT	NOZZLE FLOW	TURBINE FLOW	LABLEAK	RE	PHI	XI
1	1.8459	1.8014	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	1.7508	1.7080	0.0429	562545.	0.5503	0.9083
6	1.7404	1.6976	0.0429	559206.	0.5477	0.9127
7	1.7331	1.6906	0.0426	556853.	0.5447	0.9141
8	1.7136	1.6712	0.0424	550574.	0.5389	0.9188
9	1.6890	1.6466	0.0425	542671.	0.5306	0.9193
10	1.6600	1.6179	0.0420	533337.	0.5227	0.9191

PRESSURES(PSIA) AND PRESSURE RATIOS

PAMB=14.70

POINT	PNOZ	PTPL	PTO	P1AV	PHO	PLENUM PR(PTPL/PHO)	STATOR PR(PTO/P1AV)
1	32.29	21.80	21.65	14.54	14.57	1.4966	1.4884
2	33.49	21.70	21.56	14.82	14.57	1.4899	1.4548
3	33.61	21.71	21.57	15.46	14.66	1.4808	1.3953
4	33.68	21.68	21.54	15.86	14.69	1.4754	1.3580
5	33.70	21.71	21.58	16.16	14.70	1.4764	1.3350
6	33.75	21.69	21.55	16.31	14.70	1.4755	1.3219
7	33.79	21.72	21.59	16.44	14.70	1.4779	1.3129
8	34.07	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	T1	T1IS
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	524.82	521.34
9	561.31	526.15	523.43
10	561.48	528.53	525.27

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

POINT	VA1	VU1	V1	V1IS	ALPHA 1	VCOEFS	MV1	MVA1	RVA1	RVU1
1	185.89	748.59	771.33	848.33	76.05	0.9092	0.6981	0.1682	0.1606	0.6467
2	180.98	728.77	750.91	826.29	76.05	0.9088	0.6766	0.1631	0.1561	0.6285
3	173.56	714.99	735.76	781.45	76.36	0.9415	0.6615	0.1561	0.1496	0.6165
4	169.39	691.16	711.62	750.67	76.23	0.9480	0.6378	0.1518	0.1460	0.5957
5	162.50	688.68	707.59	730.51	76.72	0.9686	0.6337	0.1455	0.1400	0.5934
6	160.80	673.35	692.28	718.60	76.57	0.9634	0.6188	0.1437	0.1385	0.5801
7	159.37	658.31	677.33	710.25	76.39	0.9536	0.6043	0.1422	0.1373	0.5670
8	156.02	642.48	661.15	692.09	76.35	0.9553	0.5888	0.1389	0.1344	0.5533
9	151.99	631.96	649.98	674.63	76.48	0.9635	0.5781	0.1352	0.1309	0.5442
10	148.69	611.40	629.22	659.58	76.33	0.9540	0.5584	0.1319	0.1280	0.5264

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

POINT	WA1	WU1	W1	U1	BETA 1	MW1
1	185.89	381.91	424.75	366.68	64.05	0.3844
2	180.98	321.57	369.00	407.20	60.63	0.3325
3	173.56	270.98	321.80	444.01	57.36	0.2893
4	169.39	210.34	270.06	480.83	51.15	0.2421
5	162.50	170.66	235.65	518.01	46.40	0.2110
6	160.80	119.07	200.09	554.28	36.52	0.1788
7	159.37	65.93	172.47	592.39	22.47	0.1539
8	156.02	12.72	156.53	629.76	4.66	0.1394
9	151.99	-34.25	155.80	666.20	-12.70	0.1386
10	148.69	-92.73	175.24	704.13	-31.95	0.1555

EFFICIENCIES

POINT	ZETA STATOR	ETA STATOR(1.-ZETAS)
1	0.1733	0.8267
2	0.1741	0.8259
3	0.1135	0.8865
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 LE ROTOR, P/N 1034-A, AXIAL CLNC 0.250 IN, RADIAL CLNC 0.009 IN

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METHOD J= 2

PRESSURES(PSIA) AND PRESSURE RATIOS

PAMB=14.70

POINT	PTO	P1AV	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	21.59	16.44	15.28	14.70	1.4687
8	21.57	16.67	15.49	14.70	1.4672
9	21.59	16.91	15.63	14.71	1.4678
10	21.54	17.06	15.90	14.70	1.4647

TEMPERATURES(DEG R)

POINT	TTO	T1	TF	TT2	T2	T2IS	T2TH	TT2IS	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	511.52	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	524.08	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	526.10	518.38	512.65	506.39	502.70	508.33	58.35	42.67
8	561.21	524.82	527.72	522.75	515.00	506.35	502.99	510.55	58.22	38.46
9	561.31	526.15	529.12	524.92	515.89	505.63	503.02	511.82	58.29	36.39
10	561.48	528.53	532.15	531.36	519.66	506.59	503.47	514.81	58.01	30.13

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

POINT	VA2	VU2	V2	VOIS	ALPHA 2	MV2	STAGE LOADING FACTOR	STAGE FLOW FACTOR
1	148.04	-27.82	150.63	846.75	-10.64	0.1363	2.09	0.40
2	145.92	17.49	146.96	843.83	6.83	0.1328	1.72	0.35
3	143.96	60.29	156.08	838.40	22.72	0.1411	1.46	0.32
4	143.10	98.40	173.67	834.86	34.51	0.1568	1.22	0.29
5	139.68	148.30	203.73	836.09	46.71	0.1839	1.03	0.27
6	139.18	189.93	235.47	835.44	53.77	0.2123	0.86	0.25
7	138.84	222.75	262.48	837.27	58.06	0.2365	0.73	0.23
8	137.83	272.10	305.02	836.34	63.14	0.2742	0.58	0.22
9	136.00	299.97	329.36	836.86	65.61	0.2958	0.49	0.20
10	134.65	349.89	374.90	834.83	68.95	0.3355	0.37	0.19

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

POINT	WA2	WU2	W2	U2	W2IS	BETA 2	DBETA	WCOEFS	MW2
1	148.04	-399.21	425.77	371.39	425.64	-69.65	133.70	1.0003	0.3852
2	145.92	-394.94	421.04	412.43	412.71	-69.72	130.35	1.0202	0.3805
3	143.96	-389.42	415.18	449.72	449.39	-69.71	127.07	0.9239	0.3752
4	143.10	-388.61	414.12	487.01	462.21	-69.78	120.94	0.8960	0.3740
5	139.68	-376.37	401.46	524.67	478.28	-69.64	116.04	0.8394	0.3624
6	139.18	-371.47	396.69	561.40	480.27	-69.46	105.98	0.8260	0.3577
7	138.84	-377.25	401.99	600.00	486.65	-69.79	92.27	0.8260	0.3622
8	137.83	-365.75	390.86	637.85	506.67	-69.35	74.01	0.7714	0.3514
9	136.00	-374.79	398.70	674.77	531.26	-70.06	57.36	0.7505	0.3581
10	134.65	-363.29	387.44	713.18	554.11	-69.66	37.71	0.6992	0.3467

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

POINT	ZETA ROTOR	ETA ROTOR(1.-ZETAR)	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	0.1053
4	0.1973	0.8027	12995.	28.12	13.92	11.36	1.0093	0.1546
5	0.2955	0.7045	14000.	26.92	13.96	11.14	1.0053	0.1647
6	0.3178	0.6822	14980.	25.57	13.94	10.65	1.0060	0.1858
7	0.3177	0.6823	16010.	24.49	14.00	10.24	1.0073	0.2111
8	0.4049	0.5951	17020.	21.82	13.97	9.23	1.0067	0.2126
9	0.4368	0.5632	18005.	20.34	13.99	8.73	1.0052	0.2258
10	0.5111	0.4889	19030.	16.55	13.92	7.23	1.0062	0.2121

GENERAL RESULTS *

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POINT	PRESSURE RATIO	REFERRED SPEED RPM	ISENTROPIC HEAD COEFF	EFFICIENCY TOT-STATIC PERCENT	EFFICIENCY TOT-TOT PERCENT	REFERRED FLOW RATE LBM/SEC	REFERRED MOMENT FT-LB	REFERRED POWER HP	DEGREE OF REACTION (HUB)	DEGREE OF REACTION (MEAN)	DEGREE OF REACTION (TIP)
1	1.4861	9558.	5.3326	79.45	81.99	1.2674	10.427	18.975	-0.0427	-0.0037	0.1982
2	1.4797	10596.	4.2944	81.33	83.82	1.2539	9.427	19.019	-0.0146	0.0411	0.2339
3	1.4716	11551.	3.5655	82.61	85.54	1.2445	8.602	18.919	-0.0074	0.1312	0.2497
4	1.4662	12565.	3.0147	81.61	85.27	1.2399	7.750	18.453	0.0082	0.1915	0.2700
5	1.4675	13467.	2.6051	79.80	84.81	1.2088	6.876	17.630	0.0302	0.2366	0.2979
6	1.4663	14407.	2.2719	76.39	82.94	1.2030	6.111	16.763	0.0531	0.2602	0.3221
7	1.4687	15394.	1.9977	73.13	81.03	1.1964	5.466	16.022	0.0770	0.2804	0.3475
8	1.4672	16363.	1.7637	66.06	76.12	1.1837	4.585	14.284	0.1012	0.3152	0.3735
9	1.4678	17308.	1.5779	62.43	73.80	1.1655	4.037	13.304	0.1256	0.3501	0.4002
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_2O)
DPFL	Flow calibration differential pressure (in H_2O)
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 (°F)
THD	Hood air temperature (mv) (°R)
TNOZ	Flow nozzle inlet temperature (mv) (°R)
TORQ	Stator torque (ft-lb)
TTO	Stator inlet total temperature (mv) (°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 FTOIFOO1 (I any integer except six, see below). This file may then be printed out using the command to off line print FILE FTOIFOO1 or punched out on cards with the command to off line punch FILE FTOIFOO1.
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 TTTR 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 part #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 palces. 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	...
5-7	QPT01-QPT03	Stator Inlet Total Press (3)	...
8	QPHUB	Stator Exit Hub Press	...
9	QPTIP	Stator Exit Tip Press	...
10-18	QP13-QP21	Rotor Shroud Press (9)	...
19-21	QPCL1-QPCL3	Closure Plate Press (3)	...
22	QPHD	Turbine Hood Press	...
23	QDH	Nozzle Differential Press	In. H_2O
24	QLAXIL	Closure Plate Axial Force	Pounds Force
25	QLTRQR	Closure Plate Torque	Ft-Lbs Torque
26	QTNOZ	Flow Nozzle Inlet Temp.	Millivolts
27-28	QTT01-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 H_2O 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. H_2O 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 ACQUISITON

The normal TTTR 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 0 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.

<u>APPENDIX C</u>

SAMPLE TTTR ON-LINE REDUCTION RUN

```
-- CP-67 ONLINE
ENTER PASSWORD:
[redacted]
 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.RED. 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:

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

where:

R = closure plate radius (ft)

ω = frequency (rad/sec)

ν = kinematic viscosity (ft^2/sec)

ρ = density (lbf-sec^2/ft^4)

If one assumes standard conditions, i.e.,

T = 68°F

$\nu = 160 \times 10^{-6}\ ft^2/sec$

$\rho = .00234\ lbf\text{-}sec^2/ft^4$

thr torque equation reduces to:

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

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:

$$\eta = \frac{\Delta T_W}{\Delta T_{IS}} = \frac{M_d \omega / \dot{W} C_p J}{\Delta T_{IS}} \qquad \text{(E-1)}$$

where:

M_d = dynamometer moment (ft-lbf)

$\dot{W}$ = turbine mass flow rate (lbm/sec)

ΔT_{IS} = stage isentropic temperature change (°R)

ω = turbine rotational velocity (rad/sec)

The stator efficiency is defined as:

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

with

V_1 = actual exit velocity (ft/sec)

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

The rotor efficiency:

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

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:

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

with:

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

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

In defining the NASA referred values the referred temperature:

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

and the referred pressure

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

are used with T_{TO} (°R) being the stator inlet total temperature and P_{TO} (psia) the stator inlet total pressure.

The referred mass flow rate is:

$$\dot{W}_{ref} = \frac{\dot{W}\sqrt{\theta}}{\delta} \qquad (E\text{-}7)$$

the referred RPM;

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

The referred moment:

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

and the referred horsepower:

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

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:

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

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. (°R)

ΔH = nozzle differential pressure (in. H_2O at 68°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 TTTR flow nozzle calibration program was used to calculate the nozzle coefficient and curve fit it as shown in Figure E-1. The optimum polynomial

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

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

```
C                          TRANSONIC TURBINE TEST RIG
C                            FLOW NOZZLE CALIBRATION
C                          ----------------------------
C
C        THIS PROGRAM CALCULATES AND PLOTS THE FLOW NOZZLE CALIBRATION
C      COEFFICIENT FOR THE TTTR.  INPUT THE NUMBER OF RUNS, THEN FOR EACH
C      RUN THE NUMBER OF POINTS, PBAR(IN. HG.),TBAR(DEG. F.), TCR(DEG. F),
C      DH(IN. H2O), PREF1(IN. HG.), PNOZ(IN. HG.), TNOZ(MV.), DPFL(IN. H2O),
C      PREF(IN. HG.), POR(IN. HG.), TOR(MV.).......
C
      REAL*8 RE2,OKN2,WI,OKNEST,DELOKN,COEFKN,SB
      REAL*8 TITLE(10)/10*'  '/
      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),TORR(100),WFL(100),
     2OKN(100,1),RE(100),SB(10),OKN4(100),KEY(100)
     3,RE2(100),OKN2(100),WI(100),OKNEST(100),DELOKN(100),COEFKN(10)
      MMM=0
      LLL=0
C
C                               READ INPUT DATA
      WRITE(6,14)
      READ(5,15)L
      DO 114 M=1,L
      READ(5,15)N
      WRITE(6,127) L,N
      READ(5,16) PBAR,TBAR,TCR
      WRITE(6,23)PBAR,TBAR,TCR
      READ(5,16)  (DH(I),I=1,N)
      WRITE(6,333) (    DH(I),I=1,N)
      READ(5,16)  (PREF1(I),I=1,N)
      WRITE(6,333) (PREF1(I),I=1,N)
      READ(5,16)   (PNOZ(I),I=1,N)
      WRITE(6,333) (  PNOZ(I),I=1,N)
      READ(5,16)   (TNOZ(I),I=1,N)
      WRITE(6,333) ( TNOZ(I),I=1,N)
      READ(5,16)     (DPFL(I),I=1,N)
      WRITE(6,333) ( DPFL(I),I=1,N)
      READ(5,16)     (PREF(I),I=1,N)
      WRITE(6,333) ( PREF(I),I=1,N)
      READ(5,16)    (POR(I),I=1,N)
      WRITE(6,333) (    POR(I),I=1,N)
      READ(5,16)    (TOR(I),I=1,N)
      WRITE(6,333) (    TOR(I),I=1,N)
  333 FORMAT(' ',24F5.1)
```

```
      DO 09 I=1,N
      WRITE(6,24) I,DH(I),PREF1(I),PNOZ(I),TNOZ(I),DPFL(I),PREF(I),
     1POR(I),TOR(I)
   09 CONTINUE
   23 FORMAT(' ',3E10.4)
   24   FORMAT('0',1I10,5X,8E10.4)
C
C                                   INPUT CONSTANTS
      DO 7 II=1,100
      WI(II)=1.0
    7 CONTINUE
      D1O=6.065
      D2O=4.2443
      D1N=7.975
      D2N=4.25
      BETAO=D2O/D1O
      BETAN=D2N/D1N
      GAM=1.4
      EX1=GAM/(GAM-1.)
      EX2=(GAM-1.)/GAM
      EX3=2./GAM
      A=D2O*(830.-5000.*BETAO+9000.*BETAO**2-4200.*BETAO**3+530./SQRT(
     1    D1O))
      B=0.5993+0.007/D1O
      C=0.3640+0.076/SQRT(D1O)
      QKE=B+C*BETAO**4
      QKINF=QKE/(1.+A*(0.15E-04/D2O))
C
C                    COMPUTE CORRECTED PRESS AND TEMPS
      GHGBR=13.63905-0.00136303*TBAR
      GHGCR=13.63905-0.00136303*TCR
      CHGBR=0.4891585*GHGBR/13.54
      CHGCR=0.4891585*GHGCR/13.54
      GW68=0.9983763+68.*0.106058E-03-(68.**2)*0.159319E-05
      GWCR=0.9983763+TCR*0.106058E-03-(TCR**2)*0.159319E-05
      PAMB=PBAR*CHGBR
C
C                          CALCULATIONS FOR ORIFICED FLOW RATE
      DO 12 I=1,N
      QDPFL=DPFL(I)
      DPFL(I)=QDPFL*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
      TORR(I)=TOR(I)+459.69
      ALPHAO=1.+1.93*(TOR(I)-68.)*0.1E-04
      YO=1.0-(0.41+0.35*BETAO**4)*DPFL(I)/(GAM*POR(I))
      ZO=1.9+2.4*(TOR(I)-100.)*0.1E-02
      HW68O=QDPFL*GWCR/GW68
```

```
      FR=1.0
      WFL(I)=0.1638427*D20**2*ALPHAO*QKINF*FR*YO*SQRT(POR(I)*HW680/
     1  TORR(I))
   10 XO=2.27376*WFL(I)/(D20*ZO)
      FR=1.+(A/XO)*0.1E-05
      WFLC=0.1638427*D20**2*ALPHAO*QKINF*FR*YO*SQRT(POR(I)*HW680/
     1  TORR(I))
      IF(ABS(WFLC-WFL(I)).LE.0.0001) GO TO 11
      WFL(I)=WFLC
      GO TO 10
   11 WFL(I)=WFLC
C
C           CALCULATIONS FOR NOZZLE DISCHARG COEFFICIENT
C
      QDH=DH(I)
      DH(I)=QDH*GWCR*62.42732/1728.
      PNOZ(I)=CHGCR*(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*EX1*((1.-R**EX2)/(1.-R))*((1.-BETAN**4)/(1.-R**EX3*
     1  BETAN**4)))
      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
     1*ALPHAN)
      RE(I)=2.27376*WFL(I)/(D2N*ZN)*0.1E+07
   12 CONTINUE
C
C                 WRITE OUTPUT DATA
C
      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)
C
C
      RE2(I+MMM)=RE(I)
      QKN2(I+MMM)=QKN(I,1)
      QKN4(I)=QKN(I,1)
   13 CONTINUE
      MMM=MMM+N
      LLL=LLL+1
         CALL  OSPLOT (RE,QKN,N,100,1,0,0.0,0.0,0.0,0.0)
```

```
      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,0,0,0,0,1,1,9,12,1
     2,LAST)
      WRITE(6,127) MMM,LLL,N,L,M
  114 CONTINUE
      DO 115 I=1,MMM
      KEY(I)=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         THIS 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(08)=.00001
      WI(27)=.00001
C
      QKN2(I)=QKN4(KEY(I))
      WRITE(6,128) I,KEY(I),RE2(I),QKN2(I)
  116 CONTINUE
C
C
      NOPOLY=4
      DO 31 KM=1,NOPOLY
      CALL LSQPL2(MMM,KM,RE2,QKN2,WI,QKNEST,DELQKN,COEFKN,SB,TITLE)
C
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,0.0.0.0.1.1.9.12.1
     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,'ATMOS. PRESS.',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(36X,I2,9X,F8.4,8X,F9.5,7X,F11.2)
 25 FORMAT(' ',10X,1F20.6)
126 FORMAT(' ',3F12.4)
127 FORMAT(' ',5I3)
128 FORMAT(' ',2I6,2F10.2)
    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

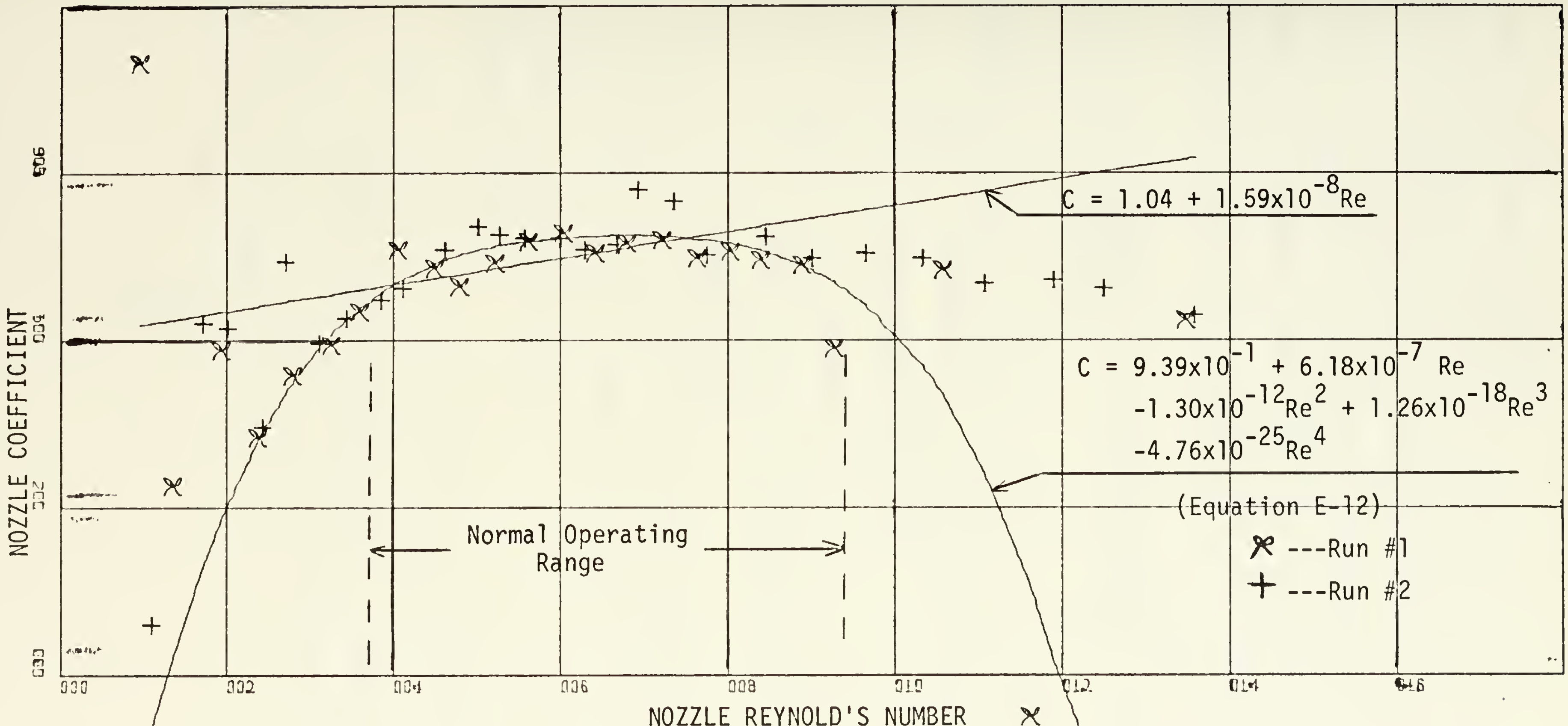

Figure E-1. Flow Nozzle Calibration Plot (Nozzle Coefficient vs. Reynold's Number)

X-SCALE=2.00E+05 UNITS INCH.

Y-SCALE=2.00E-02 UNITS INCH. ADD +1.00E+00 UNITS TO ALL Y VALUES.

DETHOMAS 1888 TTTR NOZZLE CAL

3. LABYRINTH LEAK RATE CALIBRATION

Due to the changes in the stator plenum a new stator laybrinth 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:

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

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:

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

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.)

```
C
C                          TRANSONIC TURBINE TEST RIG
C                       LABYRINTH LEAK RATE CALIBRATION
C                      -----------------------------------
C
C
C    THIS IS THE CALIBRATION PROGRAM FOR THE LABYRINTH LEAK RATE OF THE TTTR.
C  USE INPUT DATA PATM(IN.HG.),PLAB(IN.HG.),PHD(IN.HG.),TTPLD(MV),THD(MV)
C  TTD1(MV),PFL(IN.HG.),HWFL INM.H2O),PBAR(IN.HG.),TCL(DEG.F),TCR(DEG.F)
C  PBAR(IN.HG.)
CTTD1(MV),PFL(IN.HG.),              HWFL(CM.H2O),                 PBAR(IN.HG.)
CTCL(DEGREES F.),TCR(DEGREES F.),PREF(IN.HG.)
C
      REAL*8 PRCF,WREFCF,WI,YY,DELY,BB,SB
      REAL*8 TITLE(10)/10*' '/
      REAL*8 ITITLE(12)/'DETHOMAS 1888 TTTR LAB LEAK CAL
     2                                                      '/
      REAL LABEL/4H    /
      DIMENSION PATM(80),PSPL(80),PHD(80),TTPLD(80),ERROR(80),TTD1(80),
     1PFL(80),HWFL(80),WREFT(80),        WLABR(80),WREF(80),RE(80),PR(80)
     2,PREF(80),THD(80),WW(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=-6.97437E-02
      A6=6.16826E-03
      READ(5,99)L
      DO 50 M=1,L
      READ(5,100)PBAR,N,NRUN
      READ(5,101)TCL,TCR
      WRITE(6,203)PBAR,TCL,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 (6,199)NRUN
      WRITE(6,200)
      D1= 2.067
      D2= 0.825
```

```
      B= D2/D1
      QKINF=0.608913
      A=D2*(830.-5000.*B+9000.*B**2-4200.*B**3+530./SQRT(D1))
      GAM=1.4
      GHGRM=13.63905-.0013630303*TCR
      GHGCL=13.63905-.0013630303*TCL
      CHGC=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=PBAR
      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)
      QTTD1=TTD1(I)
      QPFL=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
      QTTD1=32.+35.98*QTTD1-.435*QTTD1**2
      ALPH=1.+.00193*((QTTD1-68.)/100.)
      DPFL=QHWFL*GWRM/12.*62.42732/144.
      QPFL=CHGCR*(QPREF-QPFL)+PAMB
      Y=1.-(0.41+0.35*B**4)*DPFL/(GAM*QPFL)
      HW68=QHWFL*RATGW
      TTD1R=QTTD1+459.7
      Z=0.019+0.0024*(QTTD1/100.-1.)
      WLABR(I)=0.1638427*D2**2*ALPH*QKINF*Y*SQRT(QPFL*HW68/TTD1R)
   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/TTD1R)
      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
      PR(I)=QPSPL/QPHD
      PRCF(I)=PR(I)
```

```
      TTPLDR=TTPLD(I)+459.7
      CORR=(1.0+.32*((TTPLD(I)-THD(I))/TTPLD(I)))**1.2
      WREF(I)=WLABR(I)/QPSPL*SQRT(TTPLDR*R/G)/CORR
      WREFCF(I)=WREF(I)
  504 WREFR=A1+A2*PR(I)+A3*PR(I)**2+A4*PR(I)**3+A5*PR(I)**4+A6*PR(I)**5
      WREFT(I)=WREFR
      IF(WREFT(I)-WREF(I))20,20,30
   20 ERROR(I)=-(WREF(I)-WREFT(I))/WREF(I)*100.
      GO TO 51
   30 ERROR(I)=(WREFT(I)-WREF(I))/WREFT(I)*100.
   51 CONTINUE
      WW(I)=WREFR*QPSPL/SQRT(TTPLDR*R/G)*CORR**1.2
      WRITE(6,201)I,WLABR(I),PR(I),TTPLD(I),RE(I),WREF(I),WREFT(I),ERROR
     1(I),THD(I)
   49 CONTINUE
      CALL LSQPL2(N,-5,PRCF,WREFCF,WI,YY,DELY,BB,SB,TITLE)
      CALL DRAW(N,PR,WLABR,1,1,LABEL,ITITLE,0.,0.,0,0,1,1,9,12,1,LAST)
      CALL DRAW(N,PR,WW,3,0,   LABEL,ITITLE,0.,0.,0,0,1,1,9,12,1,LAST)
   50 CONTINUE
   99 FORMAT(I3)
  100 FORMAT(F10.4,I2,I3)
  101 FORMAT(8F10.4)
  199 FORMAT (1H1//54X,16HTTRSS RUN NUMBER3X,I3)
  200 FORMAT (    ///39X,53HLABYRINTH LEAK RATE OF THE TRANSONIC TURBINE
     1TEST RIG//2X,5HPOINT6X,9HLABYRINTH7X,9HLABYRINTH4X,12HPLENUM TOTAL
     26X,8HREYNOLDS 9X,8HREFERRED8X,11HANALYTICAL 6X,7HPERCENT9X,4HHOOD/
     313X,9HLEAK RATE7X,8HPRESSURE5X,11HTEMPERATURE8X,6HNUMBER10X,9HLEAK
     4 RATE8X,8HREFERRED9X,5HERROR5X,11HTEMPERATURE/13X,9H(LBM/SEC)9X,5H
     5RATIO8X,7H(DEG F)27X,7H(SQ IN)9X,9HLEAK RATE21X,7H(DEG F)//)
  201 FORMAT(3X,I2,8X,F8.6,8X,F7.4,8X,F7.3,8X,F10.2,7X,F9.6, 9X,F8.6,7X,
     1F8.4,7X,F7.3)
  202 FORMAT(' ',I2,3X,9E12.6)
  203 FORMAT(' ',3F9.3)
  204 FORMAT(' ',3E12.6)
      STOP
      END
```

TTTR LABYRINTH LEAK RATE TEST RUN NUMBER 3

POINT	LABYRINTH LEAK RATE (LBM/SEC)	LABYRINTH PRESSURE RATIO	PLENUM 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	0.077199	0.075322	-2.4308	69.299
2	0.109526	2.8106	78.945	0.076340	0.075032	-1.7135	69.580
3	0.109338	2.7141	79.188	0.079028	0.074760	-5.4005	70.036
4	0.102609	2.6044	79.362	0.077180	0.074357	-3.6585	69.860
5	0.095714	2.5055	79.432	0.074807	0.073847	-1.2838	69.825
6	0.093299	2.4066	79.119	0.076205	0.073159	-3.9979	70.421
7	0.085945	2.3161	78.945	0.072960	0.072358	-0.8252	70.351
8	0.081032	2.1977	78.666	0.072584	0.071061	-2.0978	70.421
9	0.076337	2.0974	78.352	0.071710	0.069733	-2.7575	70.386
10	0.070887	2.0022	77.934	0.069925	0.068271	-2.3663	70.596
11	0.064229	1.9033	77.342	0.066775	0.066526	-0.3727	70.561
12	0.059482	1.8108	76.714	0.065111	0.064652	-0.7055	70.456
13	0.053915	1.6907	76.051	0.063303	0.061788	-2.3944	70.281
14	0.048834	1.6059	75.562	0.060452	0.059382	-1.7703	70.211
15	0.043593	1.5030	75.039	0.057732	0.055901	-3.1721	70.071
16	0.036865	1.3957	74.480	0.052659	0.051403	-2.3846	69.965
17	0.030739	1.2766	73.851	0.048112	0.045005	-6.4578	69.930

TTTR LABYRINTH LEAK RATE TEST RUN NUMBER 2

POINT	LABYRINTH LEAK RATE (LBM/SEC)	LABYRINTH PRESSURE RATIO	PLENUM 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	0.031293	0.031131	-0.5181	64.170
2	0.023328	1.1943	65.999	0.039085	0.039443	0.9078	64.170
3	0.030765	1.3082	66.210	0.047012	0.046872	-0.2992	64.170
4	0.036384	1.4020	66.421	0.051809	0.051698	-0.2146	64.100
5	0.042837	1.5169	66.491	0.056359	0.056415	0.0982	64.100
6	0.047774	1.6063	66.456	0.059328	0.059396	0.1142	63.994
7	0.053337	1.7068	66.456	0.062324	0.062205	-0.1910	63.959
8	0.058931	1.8140	66.421	0.064802	0.064722	-0.1232	63.959
9	0.063758	1.9071	66.421	0.066673	0.066597	-0.1145	63.924
10	0.068361	2.0006	66.421	0.068119	0.068245	0.1849	63.854
11	0.073841	2.1108	66.491	0.069730	0.069922	0.2752	63.889
12	0.078771	2.2106	66.597	0.071035	0.071217	0.2554	63.994
13	0.083534	2.3024	66.702	0.072264	0.072223	-0.0563	63.924
14	0.088584	2.4069	66.878	0.073262	0.073162	-0.1361	63.959
15	0.094701	2.5158	67.088	0.074951	0.073908	-1.3911	64.170
16	0.096237	2.6113	67.475	0.073347	0.074387	1.3984	64.206
17	0.101962	2.7145	67.685	0.074787	0.074764	-0.0299	64.628
18	0.106123	2.8129	67.896	0.075192	0.075041	-0.2005	64.980

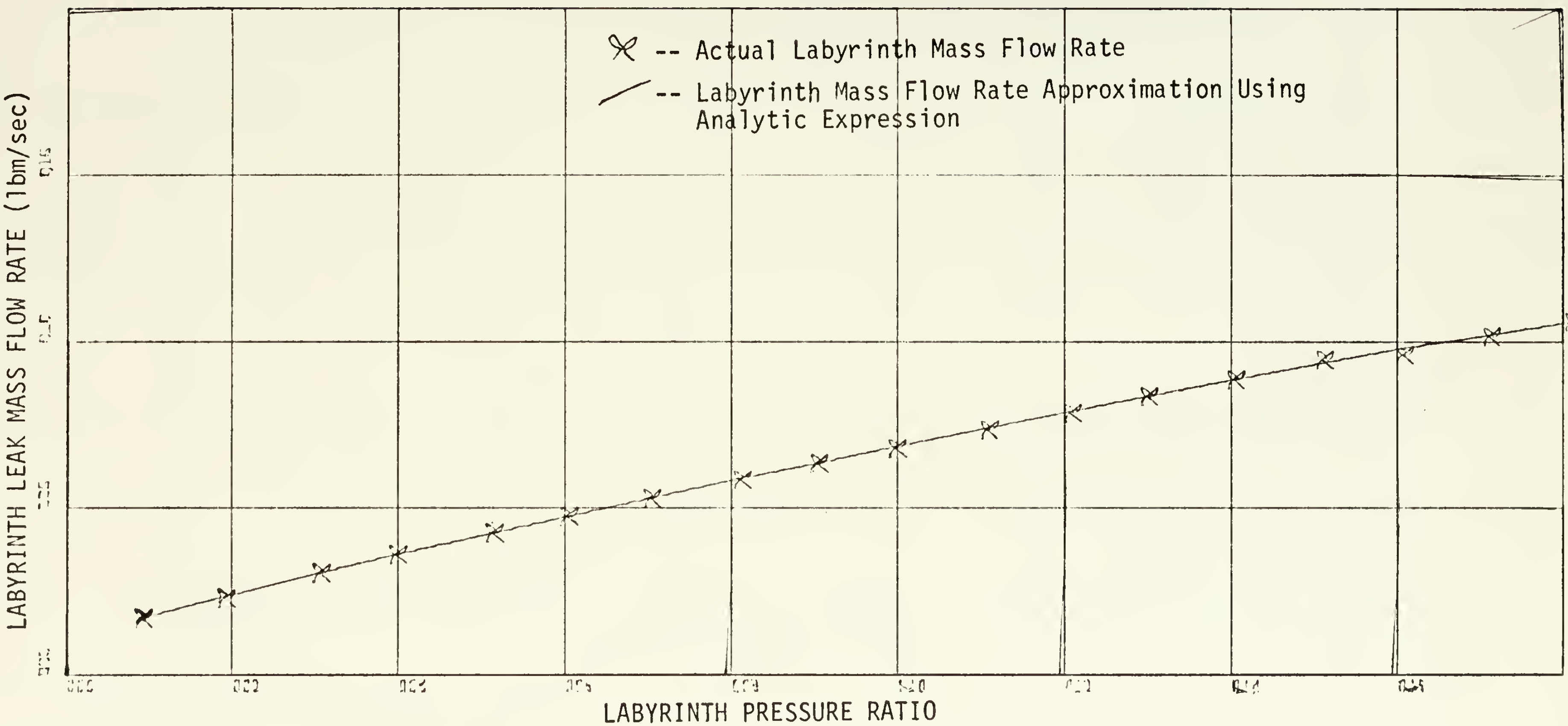

Figure E-2.1. Labyrinth Leak Calibration Plot (Run #2)

X-SCALE=2.00E-02 UNITS INCH. ADD +1.00E+00 UNITS TO ALL X VALUES.
Y-SCALE=5.00E-02 UNITS INCH.
DETHOMAS 1888 TTTR LAB LEAK CAL

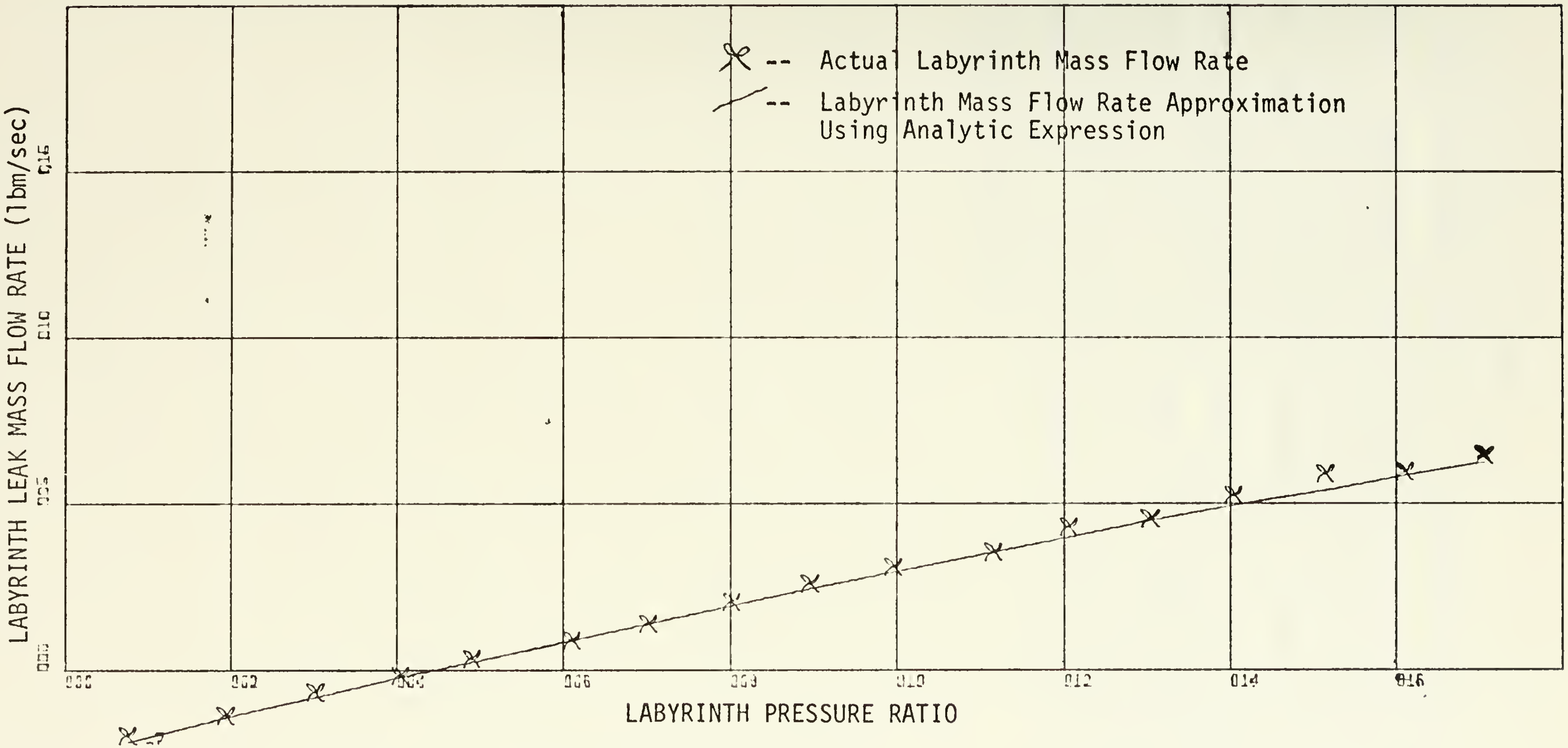

Figure E-2.2. Labyrinth Leak Calibration Plot (Run #3)

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.

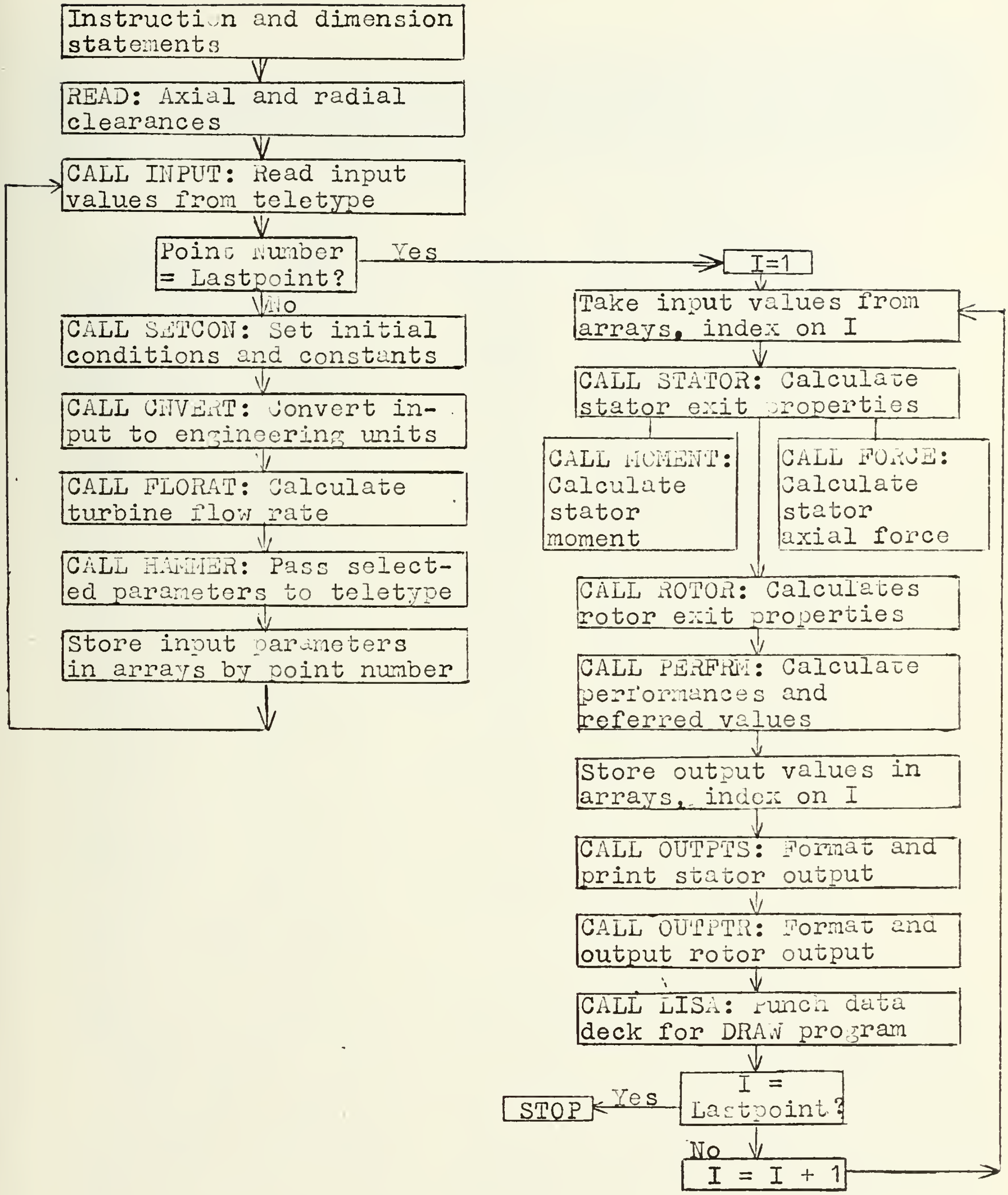

Figure E-3 TTTR On-Line Data Reduction Flow Chart

```
C
02 FORMAT( ' -TRANSONIC TURBINE TEST RIG (ON LINE DATA REDUCTION)= ',
  1//,'   HI THERE TTTR FANS, THIS SYSTEM SHOULD INPUT FROM THE!
  2/' B&F DATA COLLECTION SYSTEM COUPLED TO A STANDARD ASCII T/T.!
  3/' YOU SHOULD BE SCANNING CHANNELS 1-29 AND 80-99 WITH THE UPPER!
  4/' LIMIT SET AT 90.   VALVE 1 SHOULD BE THE ONLY VALVE SELECTED!
  5/' AND ITS UPPER LIMIT SET AT 22.  THE RUN NUMBER, POINT NUMBER,!
  6/' DAY,MONTH AND YEAR SHOULD BE ENTERED IN THE CONSTANT WHEELS!
  7/' IN GROUPS OF TWO.  '
  8/'    FOLLOWING THE LAST AUTOMATIC DATA POINT YOU MUST MANUALLY!
  9/' PUNCH THE STATOR FORCE AND TORQUE AND DYNAMOMETER TORQUE. !
  B/' THESE WILL BE 5 CHARACTERS WITH PROPER SIGNS AND DECIMAL !
  C/' POINTS. FOLLOWING THE LAST POINT OF EACH RUN SET POINT NUMBER!
  D/' 00 AND ALLOW THE CONSTANT VALUES TO PUNCH. ALL MANUAL POINTS!
  E/' WILL BE FOLLOWED BY C.R.,L.F.,X-OFF,X-OFF AND NO SPACES MAY BE!
  F/' SKIPPED.'
  G/'  THIS PROGRAM WILL PROBABLY DESTRUCT IN 10 SEC.  GOOD LUCK !)
C
C
   REAL*4 MVA1M,MVA1,MV1M,MV1C,MV1,MW1,MV2,MW2
C
   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)
C
   DIMENSION FAX(50),CLFAX(50),F0(50),F1(50),F2(50),F3(50),F4(50),
  1 F5(50),F6A(50),FNET(50),TORQ(50),CLTORQ(50),FLOWN(50),FLOWT(50),
  2 FLOWL(50),RE(50),PHI(50),XI(50),P1AV(50),PRPL(50),PRS(50),T1(50),
  3 T1IS(50),VA1(50),VU1(50),V1(50),V1IS(50),ALPH1(50),VCOFS(50),
  4 MV1(50),MVA1(50),WA1(50),WU1(50),W1(50),U1(50),BETA1(50),MW1(50),
  5 ZETAS(50),ETAS(50),PT2(50),PR(50),TE(50),TT2(50),T2(50),T2IS(50),
  6 T2TH(50),TT2IS(50),DELTW(50),DELTIS(50),DELHW(50),DELHIS(50),
  7 VA2(50),VU2(50),V2(50),VOIS(50),ALPH2(50),WA2(50),WU2(50),W2(50),
  8 U2(50),W2IS(50),BETA2(50),DBETA(50),WCOFS(50),ZETAR(50),ETAR(50),
  9 REFRPM(50),XKIS(50),ETATS(50),ETATT(50),REFLOW(50),REFMOM(50),
  * HP(50),REFHP(50),REACHB(50),REACMN(50),REACTP(50),F(50),MV2(50),
  * MW2(50),REACEF(50),QNOZ(50),QTPL(50),PTO(50),QHD(50),TTPQ(50),
  * TTO(50),SLF(50),SFF(50),RFAX(50),RTORQ(50),RVA1(50),RVU1(50)
   WRITE(6,02)
   WRITE(6,05)
   READ(5,06) AXCLR
   WRITE(6,07)
   READ(5,06)RADCLR
   WRITE(6,08)
05 FORMAT(' ',//,'---PLEASE ENTER AXIAL CLEARANCE')
06 FORMAT(F20.0)
```

```
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,
   1QPHUB,QPTIP,QP13,QP14,QP15,QP16,QP17,QP18,QP19,QP20,QP21,QPHD,
   2QPCL1,QPCL2,QPCL3,QPTPL,QDH,QLAXIL,QLTRQR,QTNOZ,QTTO,QTHD,
   3QRPM,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       CNVERT(NP,QPBAR,QDH,QPNOZ,QPTO,QPHUB,QPTIP,QP13,QP14,
   1QP15,QP16,QP17,QP18,QP19,QP20,QP21,QPTPL,QPHD,QTNOZ,QTTO,
   2QTHD,PAMB,QHW68,QTNOZR,QTTOR,QFAX,QTORQ,DYNA,QLFAX,QLTORQ,
   3QAXIL,QTORQR,QDYNAR,QLAXIL,QPCL1,QPCL2,QPCL3,QRPM)
C
    CALL FLORAT(D2N,RG,GC,EX1,EX2,EX3,QHW68,QDH,QPNOZ,QPTPL,QPHD,
   1PRP,QTNOZ,QTNOZR,QTTO,QTTOR,QTHD,B1,B2,B3,B4,B5,D1,D2,D3,D4,D5,D6,
   2NRUN,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
    TTO(NP)=QTTOR
    THD(NP)=QTHD
    AXIL(NP)=QAXIL
```

```
      TORQR(NP)=QTORQR                                                  TTT00970
      DYNAR(NP)=DYNA                                                    TTT00980
      CLFAX(NP)=QLFAX                                                   TTT00990
      FAX(NP)=QFAX                                                      TTT01000
      TORQ(NP)=QTORQ                                                    TTT01010
      CLTORQ(NP)=QLTORQ                                                 TTT01020
      RPM(NP)=QRPM                                                      TTT01030
      CLAXIL(NP)=QLAXIL                                                 TTT01040
      CLTRQR(NP)=QLTRQR                                                 TTT01050
      FLOWN(NP)=QFLOWN                                                  TTT01060
      FLOWT(NP)=QFLOWT                                                  TTT01070
      FLOWL(NP)=QFLOWL                                                  TTT01080
      PRPL(NP)=PRP                                                      TTT01090
      RE(NP)=QRE                                                        TTT01100
C                                                                       TTT01110
      IF(MODRAD.EQ.0) GO TO 12                                          TTT01120
        CALL HAMMER(NP,QTORQ,QRPM,QFLOWT,PRP)                           TTT01130
   12 CONTINUE                                                          TTT01140
      GO TO 11                                                          TTT01150
   13 CONTINUE                                                          TTT01160
      DO 15 J=1,2                                                       TTT01170
      DO 14 I=1,NP                                                      TTT01180
      QPTO=PTO(I)                                                       TTT01190
      QPHUB=PHUB(I)                                                     TTT01200
      QPTIP=PTIP(I)                                                     TTT01210
      QP13=P13(I)                                                       TTT01220
      QP14=P14(I)                                                       TTT01230
      QP15=P15(I)                                                       TTT01240
      QP16=P16(I)                                                       TTT01250
      QP17=P17(I)                                                       TTT01260
      QP18=P18(I)                                                       TTT01270
      QP19=P19(I)                                                       TTT01280
      QP20=P20(I)                                                       TTT01290
      QP21=P21(I)                                                       TTT01300
      QPHD=QHD(I)                                                       TTT01310
      QTTO=TTO(I)                                                       TTT01320
      QTHD=THD(I)                                                       TTT01330
      QAXIL=AXIL(I)                                                     TTT01340
      QTORQR=TORQR(I)                                                   TTT01350
      QDYNAR=DYNAR(I)                                                   TTT01360
      QRPM=RPM(I)                                                       TTT01370
      QLAXIL=CLAXIL(I)                                                  TTT01380
      QLTRQR=CLTRQR(I)                                                  TTT01390
      TTOR=TTO(I)                                                       TTT01400
      QFAX=FAX(I)                                                       TTT01410
      QLFAX=CLFAX(I)                                                    TTT01420
      QTORQ=TORQ(I)                                                     TTT01430
      QLTORQ=CLTORQ(I)                                                  TTT01440
```

```
      DYNA=DYNAR(I)
      QFLOWT=FLOWT(I)
      CALL STATOR(RG,GAM,GC,C,PI,EX1,EX2,EX3,EPS,RTIP1,RHUB1,RM1,QPHUB,
     1 QPTIP,QP1AV,QPTO,QP13,QP18,QP19,QP20,QP21,QPHD,QPRS,QFLOWT,AAXS,
     2 ATHS,SKT,     J,TTOR,T1RM,T1ISR,QZETAS,QETAS,QPHI,QXI,QRPM,VA1M,
     3 QVU1,V1M,QV1IS,VCOEFS,ALPH1M,MV1M,MVA1M,QU1,QWA1,QWU1,QW1,QBETA1,
     4 QMW1,QTORQ,QLTORQ,QFAX,QLFAX,QFC,QF1,QF2,QF3,QF4,QF5,QF6A,QFNET,
     5 QRFAX,QRTORQ,QRVA1,QRVU1)
C
      CALL       ROTOR(RG,GC,CJ,CP,C,PI,EX1,EX2,RM1,RM2,AAXR,RKT,QPTO,
     1 QP1AV,QPHD,QPT2,PRM,DYNA,QFLOWT,TTOR,T1RM,T2R,TT2R,QDELTW,T2ISR,
     2 TER,QVU1,QU1,QW1,QBETA1,QVU2,QVA2,QV2,QALPH2,QU2,QWU2,QWA2,QW2,
     3 QW2IS,QBETA2,QDBETA,WCOEFS,QZETAR,QETAR,QMV2,QMW2,GAM,QRPM,QSLF,
     4 QSFF)
C
      CALL       PERFRM(C,PI,EX2,QPTO,QPHUB,QPTIP,QPHD,QPT2,DYNA,QRPM,
     1 QFLOWT,TTOR,TT2R,T2THR,TT2ISR,QDLHIS,QDELHW,QDLTIS,QDELTW,QV0IS,
     2 QV1IS,QU1,QV2,QETATS,QETATT,QEACMN,QEACHB,QEACTP,QXKIS,QEFLOW,
     3 QEFRPM,QEFMOM,QHP,QEFHP,T2ISR,QF,V1M,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
       FNET(I)=QFNET
       PHI(I)=QPHI
       XI(I)=QXI
       P1AV(I)=QP1AV
       PRS(I)=QPRS
       T1(I)=T1RM
       T1IS(I)=T1ISR
       VA1(I)=VA1M
       VU1(I)=QVU1
       V1(I)=V1M
       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                                                   TTT01930
      ETAS(I)=QETAS                                                     TTT01940
      PT2(I)=QPT2                                                       TTT01950
      PR(I)=PRM                                                         TTT01960
      TE(I)=TER                                                         TTT01970
      TT2(I)=TT2R                                                       TTT01980
      T2(I)=T2R                                                         TTT01990
      T2IS(I)=T2ISR                                                     TTT02000
      T2TH(I)=T2THR                                                     TTT02010
      TT2IS(I)=TT2ISR                                                   TTT02020
      DELTW(I)=QDELTW                                                   TTT02030
      DELTIS(I)=QDLTIS                                                  TTT02040
      DELHW(I)=QDELHW                                                   TTT02050
      DELHIS(I)=QDLHIS                                                  TTT02060
      VA2(I)=QVA2                                                       TTT02070
      VU2(I)=QVU2                                                       TTT02080
      V2(I)=QV2                                                         TTT02090
      V0IS(I)=QV0IS                                                     TTT02100
      ALPH2(I)=QALPH2                                                   TTT02110
      MV2(I)=QMV2                                                       TTT02120
      WA2(I)=QWA2                                                       TTT02130
      WU2(I)=QWU2                                                       TTT02140
      W2(I)=QW2                                                         TTT02150
      MW2(I)=QMW2                                                       TTT02160
      U2(I)=QU2                                                         TTT02170
      W2IS(I)=QW2IS                                                     TTT02180
      BETA2(I)=QBETA2                                                   TTT02190
      DBETA(I)=QDBETA                                                   TTT02200
      WCOFS(I)=WCOEFS                                                   TTT02210
      ZETAR(I)=QZETAR                                                   TTT02220
      ETAR(I)=QETAR                                                     TTT02230
      REFRPM(I)=QEFRPM                                                  TTT02240
      XKIS(I)=QXKIS                                                     TTT02250
      ETATS(I)=QETATS                                                   TTT02260
      F(I)=QF                                                           TTT02270
      ETATT(I)=QETATT                                                   TTT02280
      REFLOW(I)=QEFLOW                                                  TTT02290
      REFMOM(I)=QEFMOM                                                  TTT02300
      HP(I)=QHP                                                         TTT02310
      REFHP(I)=QEFHP                                                    TTT02320
      REACEF(I)=QEACEF                                                  TTT02330
      REACHB(I)=QEACHB                                                  TTT02340
      REACMN(I)=QEACMN                                                  TTT02350
      REACTP(I)=QEACTP                                                  TTT02360
      SLF(I)=QSLF                                                       TTT02370
      SFF(I)=QSFF                                                       TTT02380
      RFAX(I)=QRFAX                                                     TTT02390
      RTORQ(I)=QRTORQ                                                   TTT02400
```

```
      RVA1(I)=QRVA1                                                     TTT02410
      RVU1(I)=QRVU1                                                     TTT02420
   14 CONTINUE                                                          TTT02430
      CALL    OUTPTS(NRUN,NP,FAX,CLFAX,FC,F1,F2,F3,F4,F5,F6A,FNET,      TTT02440
     1 TORQ,CLTORQ,FLOWN,FLOWT,FLOWL,RE,PHI,XI,QNOZ,QTPL,PTC,P1AV,QHD,  TTT02450
     2 PRPL,PRS,TTC,T1,T1IS,VA1,VU1,V1,V1IS,ALPH1,VCOFS,MV1,MVA1,       TTT02460
     3 WA1,WU1,W1,U1,BETA1,MW1,ZETAS,ETAS,PAMB,NDAY,NMO,NYEAR,RFAX,     TTT02470
     4RTORQ,RVA1,RVU1,J)                                                TTT02480
C                                                                       TTT02490
      CALL       OUTPTR(NRUN,NP,AXCLR,RADCLR,PAMB,PTO,P1AV,PT2,QHD,PR,  TTT02500
     1 TTO,T1,TE,TT2,T2,T2IS,T2TH,TT2IS,DELTIS,DELTW,VA2,VU2,V2,VOIS,   TTT02510
     2 ALPH2,WA2,WU2,W2,U2,W2IS,BETA2,DBETA,WCOFS,ZETAR,ETAR,RPM,HP,    TTT02520
     3 DELHIS,DELHW,REFRPM,XKIS,ETATS,ETATT,REFLOW,REFMOM,REFHP,J,      TTT02530
     4 REACHB,REACMN,REACTP,NDAY,NMO,NYEAR,F,REACEF,MV2,MW2,SLF,SFF)    TTT02540
   15 CONTINUE                                                          TTT02550
      CALL          LISA(NP,NRUN,NDAY,NMO,NYEAR,XKIS,ETATS,PRS,ZETAS,   TTT02560
     1REFRPM,ETAR,ETAS,RTORQ)                                           TTT02570
      STOP                                                              TTT02580
      END                                                               TTT02590


      SUBROUTINE SETCON(D1N,D2N,BETAN,RG,GAM,GC,CP,CJ,C,EX1,EX2,EX3,PI, TTT02600
     1 ZNS,TETS,RTIP1,RHUB1,RTIP2,RHUB2,AAXS,AAXR,ATHS,RM1,RM2,SKT,RKT, TTT02610
     2 RADCLR,B1,B2,B3,B4,B5,D1,D2,D3,D4,D5,D6,CL1,CL2,CL3,J,MODRAD)    TTT02620
      D1N=7.975                                                         TTT02630
      D2N=4.250                                                         TTT02640
      BETAN=D2N/D1N                                                     TTT02650
      RG=53.3448                                                        TTT02660
      GAM=1.4                                                           TTT02670
      GC=32.174                                                         TTT02680
      CJ=778.16                                                         TTT02690
      EX1=GAM/(GAM-1.)                                                  TTT02700
      EX2=(GAM-1.)/GAM                                                  TTT02710
      EX3=2./GAM                                                        TTT02720
      CP=EX1*RG/CJ                                                      TTT02730
      C=2.*GC*CJ*CP                                                     TTT02740
      PI=3.1416                                                         TTT02750
      ZNS=31.                                                           TTT02760
      DTHS=0.205                                                        TTT02770
      SS=0.8594                                                         TTT02780
      TETS=0.024                                                        TTT02790
      DTHR=0.1314                                                       TTT02800
      SR=0.4495                                                         TTT02810
      TETR=0.020                                                        TTT02820
      RTIP1=4.585                                                       TTT02830
      RHUB1=3.895                                                       TTT02840
      RTIP2=4.763                                                       TTT02850
      RHUB2=3.826                                                       TTT02860
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```
      AAXS=PI*((RTIP1)**2-(RHUB1)**2)
      AAXR=PI*((RTIP2)**2-(RHUB2)**2)
      ATHS=DTHS*(RTIP1-RHUB1)*ZNS
      RM1=(RTIP1+RHUB1)/2.
      RM2=(RTIP2+RHUB2)/2.
      SKT=1.-(2.7/1000.)*((TETS/SS*100.)**3.3)*DTHS/SS
      RKT=(1.-(2.7/1000.)*((TETR/SR*100.)**3.3)*DTHR/SR)*((AAXR+PI*
     1 RADCLR*(RTIP2+RADCLR/2.))/AAXR)
      B1=9.38917E-01
      B2=6.17669E-07
      B3=-1.29859E-12
      B4=1.25920E-18
      B5=-4.75948E-25
      D1=-3.7487E-01
      D2=8.7014E-01
      D3=-7.2633E-01
      D4=3.1583E-01
      D5=-6.9744E-02
      D6=6.1683E-03
      CL1=-2.7923457E-03
      CL2=5.1056171E-04
      CL3=9.1106005E-08
      J=2
C        SET MODRAD=0 FOR NORMAL REDUCTIION.  IF MODRAD=1 THE ON-LINE
C        PARAMETER RETURN LOOP WILL BE ACTUATED....
      MODRAD=1
      RETURN
      END


      SUBROUTINE INPUT(NRUN,NP,NDAY,NMO,NYEAR,QPBAR,QPNOZ,QPTO,
     1QPHUB,QPTIP,QP13,QP14,QP15,QP16,QP17,QP18,QP19,QP20,QP21,QPHD,
     2QPCL1,QPCL2,QPCL3,QPTPL,QDH,QLAXIL,QLTRQR,CTNOZ,QTTO,QTHD,
     3QRPM,QAXIL,QTORQR,QDYNAR,AXCLR,RADCLR,LASTPT)
      NPCHEK=NP
      READ(5,101) NRUN,NP,NDAY,NMO,NYEAR
      IF (NP.NE.00) GO TO 100
      NP=NPCHEK
      LASTPT=1
      RETURN
  100 CONTINUE
      READ(5,102) QPBAR,DUMMY,QPNOZ,QPTPL,QPTO1,QPTO2,QPTO3,QPHUB,QPTIP
     1,QP13,QP14,QP15,QP16,QP17,QP18,QP19,QP20,QP21
     2,QPCL1,QPCL2,QPCL3,QPHD
      READ(5,103) QDH
      READ(5,102) QLAXIL,QLTRQR,DUMMY,DUMMY,DUMMY,DUMMY,QDH,DUMMY,DUMM
      QPTO=(QPTO1+QPTO2+QPTO3)/3
      READ(5,103) QTNOZ,DUMMY,QTTO1,QTTO2,DUMMY,QTHD,DUMMY,DUMMY,DUMMY,D
```

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      QTTO=(QTTO1+QTTO2)/2.                                              TTT03330
      READ(5,104) QRPM                                                   TTT03340
      READ(5,105) QAXIL,QTORQR,QDYNAR                                    TTT03350
  101 FORMAT(1X,A2,1X,I2,1X,3A2)                                         TTT03360
  102 FORMAT(7X,F6.2)                                                    TTT03370
  103 FORMAT(7X,F6.3)                                                    TTT03380
  104 FORMAT(8X,F5.0)                                                    TTT03390
  105 FORMAT(F5.0)                                                       TTT03400
      IF(NP.NE.1) GO TO 114                                              TTT03410
      WRITE(8,113) NRUN,NDAY,NMO,NYEAR                                   TTT03420
      WRITE(8,112)                                                       TTT03430
  114 WRITE(8,111) NP,QPBAR,QPNOZ,QPTO,QPHUB,QPTIP,QP13,QP18,QP19,QP20,  TTT03440
     1QP21,QPHD,QDH,QTNOZ,QTTO,QTHD,QRPM,QAXIL,QTORQR,QDYNAR,QLAXIL      TTT03450
  111 FORMAT(' ',1I2,1X,11F6.2,4F5.2,1X,5F6.0)                           TTT03460
  112 FORMAT(' ','NO',2X,'BAR',3X,'NOZ',3X,'PTO',3X,'HUB',3X,'TIP',3X,   TTT03470
     1'P13',3X,'P18',3X,'P19',3X,'P20',3X,'P21',3X,'PHD',2X,'DH',3X,     TTT03480
     2'TNOZ',2X,'TTO',2X,'THD',3X,'RPM',3X,'AXIL',2X,'TORQR',1X,'DYNAR',TTT03490
     31X,'CLAXI'///)                                                     TTT03500
  113 FORMAT('1',T41,'TRANSONIC TURBINE TEST RIG INPUT DATA'/,T41,       TTT03510
     1'_____________________________________'//,20X,'RUN NUMBER ',A2,    TTT03520
     215X,'DAY ',A2,10X,'MONTH ',A2,10X,'YEAR ',A2///)                   TTT03530
      RETURN                                                             TTT03540
      END                                                                TTT03550

      SUBROUTINE CNVERT(NP,QPBAR,QDH,QPNOZ,QPTO,QPHUB,QPTIP,QP13,QP14,   TTT03560
     1QP15,QP16,QP17,QP18,QP19,QP20,QP21,QPTPL,QPHD,QTNOZ,QTTO,          TTT03570
     2QTHD,QPAMB,QHW68,QTNOZR,QTTOR,FAX,TORQ,DYNA,CLFAX,CLTORQ,AXIL,     TTT03580
     3TORQR,DYNAR,CLAXIL,QPCL1,QPCL2,QPCL3,RPM)                          TTT03590
      TEMP(X)=32.+35.98*X-.435*X**2                                      TTT03600
      TEMPR(X)=32.+35.98*X-.435*X**2+459.69                              TTT03610
      PPSIA(X)=.4891585*X                                                TTT03620
      QPAMB=.4891585*QPBAR                                               TTT03630
      QHW68=QDH                                                          TTT03640
      QDH=QDH*62.42732/1728.                                             TTT03650
      QPNOZ=PPSIA(QPNOZ)                                                 TTT03660
      QPTO=PPSIA(QPTO)                                                   TTT03670
      QPHUB=PPSIA(QPHUB)                                                 TTT03680
      QPTIP=PPSIA(QPTIP)                                                 TTT03690
      QP13=PPSIA(QP13)                                                   TTT03700
      QP14=PPSIA(QP14)                                                   TTT03710
      QP15=PPSIA(QP15)                                                   TTT03720
      QP16=PPSIA(QP16)                                                   TTT03730
      QP17=PPSIA(QP17)                                                   TTT03740
      QP18=PPSIA(QP18)                                                   TTT03750
      QP19=PPSIA(QP19)                                                   TTT03760
      QP20=PPSIA(QP20)                                                   TTT03770
      QP21=PPSIA(QP21)                                                   TTT03780
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```
      QPCL1=PPSIA(QPCL1)
      QPCL2=PPSIA(QPCL2)
      QPCL3=PPSIA(QPCL3)
      QPTPL=PPSIA(QPTPL)
      QPHD=PPSIA(QPHD)
      QTNOZR=TEMPR(QTNOZ)
      QTTOR=TEMPR(QTTO)
      QTTO=TEMP(QTTO)
      QTHD=TEMP(QTHD)
      FAX=0.08*AXIL
      TORQ=TORQR/30.
      DYNA=DYNAR/30.
C           USE THE FIRST OR THE SECOND CLFAX TERM DEPENDING
C           UPON WHICH OF THE METHODS OF MEASUREING THE CLOSURE
C           PLATE AXIAL FORCE, STRAIN GAGES OR PRESSURES.
      CLFAX=CLAXIL
      CLFAX=((7.74**2)*3.1416/4.0)*(QPHUB-(QPCL1+QPCL2+QPCL3)/3.0)
      CLTORQ=.598E-09*RPM**1.8
      RETURN
      END

      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)
C
      ALPHAN=1.+2.52*(TNOZ-68.)*0.1E-04
      R=1.-(DH/PNOZ)
      Y1=R**EX3
      Y2=EX1
      Y3=1.-R**EX2
      Y4=1.-R
      Y5=1.-BETAN**4
      Y6=1.-R**EX3*BETAN**4
      ARG=Y1*Y2*(Y3/Y4)*(Y5/Y6)
      YN=SQRT(ARG)
      ZN=1.9+2.4*(TNOZ-100.)*0.1E-02
      CN=1.0400
      WN =0.1638427*D2N**2*ALPHAN*YN*CN*SQRT(PNOZ*HW68/TNOZR)
  400 RE=2.27376*WN/(D2N*ZN)*0.1E+07
C           NEED TO CHANGE THIS TO AGREE WITH NEW NOZZLE CAL.
      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.0.0001) GO TO 401
      WN=WNC
      GO TO 400
  401 FLOWN=WNC
      RE=2.27376*FLOWN/(D2N*ZN)*0.1E+07
```

```
      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-THD)/TTPL))**1.2
      FLOWL=WREF*PTPL/SQRT(TTPLR*RG/GC)*CORR
      FLOWT=FLOWN-FLOWL
      GO TO 406
  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,RTIP1,RHUB1,RM1,
     1 PHUB,PTIP,P1AV,PTO,P13,P18,P19,P20,P21,PHD,PRS,FLOWT,AAXS,ATHS,
     2 SKT,    J,TTOR,T1RM,T1ISR,ZETAS,ETAS,PHI,XI,RPM,VA1M,VU1,V1M,V1IS,
     3 VCOEFS,ALPH1M,MV1M,MVA1M,U1,WA1,WU1,W1,BETA1,MW1,TORQ,CLTORQ,FAX,
     4 CLFAX,F0,F1,F2,F3,F4,F5,F6A,FNET,RFAX,RTORQ,RVA1,RVU1)
      REAL*4 MVA1M,MVA1,MV1M,MV1C,MV1,MW1,MV2,MW2
      IF(J.GE.2) GO TO 500
      P1AV=(PHUB+PTIP)/2.
C IN THIS SECTION, M SUBSCRIPT REPRESENTS VALUES COMPUTED BY CONTINUITY
      C2=(C*P1AV*ATHS)/(RG*FLOWT)
      V1M=SQRT(C*TTOR+(C2/2.)**2)-C2/2.
      T1RM=TTOR-V1M**2/C
      VA1M=(FLOWT*RG*T1RM)/(P1AV*AAXS*SKT)
      VR=VA1M/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*T1RM)
      MVA1M=VA1M/SQRT(GAM*GC*RG*T1RM)
      CALL       FORCE(PI,RTIP1,RHUB1,AAXS,PHUB,P1AV,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('1',9X,3HEPS8X,4HP1AV9X,3HT1M10X,3HT1C9X,4HVA1M9X,4HVA1C9X,
     14HMV1M9X,4HMV1C7X,8HALPHA 1M5X,8HALPHA 1C/)
      EPS=0.0
  502 P1AV=PHUB/3.*(((1.+EPS)*(RTIP1)**2+(RHUB1)*(RTIP1)-(2.+EPS)*
     1 (RHUB1)**2)/((RTIP1)**2-(RHUB1)**2))+PTIP/3.*(((2.+EPS)*(RTIP1)
     2 **2-(RHUB1)*(RTIP1)-(1.+EPS)*(RHUB1)**2)/((RTIP1)**2-(RHUB1)**2))
      CALL       MOMENT(RG,GAM,GC,C,RM1,AAXS,TORQ,CLTORQ,FLOWT,PI,RTIP1,
     1 RHUB1,FAX,CLFAX,PHUB,PTIP,P1AV,P13,P18,P19,P20,P21,PHD,TTOR,T1RM,
     2 VU1,VA1M,V1M,ALPH1M,MV1M,MVA1M,F0,F1,F2,F3,F4,F5,F6A,FNET)
      C1=FLOWT*RG/(P1AV*AAXS*SKT)
      VA1C=SQRT(C*TTOR-VU1**2+(C/(2.*C1))**2)-C/(2.*C1)
```

```
      ALPH1C=ATAN(VU1/VA1C)
      ALPH1C=ALPH1C*180./PI
      V1C=SQRT(VA1C**2+VU1**2)
      T1RC=TTOR-(V1C**2)/C
      MV1C=V1C/SQRT(GAM*GC*RG*T1RC)
      WRITE(8,503)EPS,P1AV,T1RM,T1RC,VA1M,VA1C,MV1M,MV1C,ALPH1M,ALPH1C
  503 FORMAT(10F13.5)
      DIFF=ABS(T1RM-T1RC)
      IF(DIFF-0.01) 506,506,504
  504 IF(T1RC.LT.T1RM) GO TO 505
      EPS=EPS+DIFF/500.
      GO TO 502
  505 EPS=EPS-DIFF/500.
      GO TO 502
  506 PRS=P1AV/PTO
      IF(PRS.GE.1.0) PRS=0.9990
      T1ISR=TTOR*PRS**EX2
      ZETAS=(T1RM-T1ISR)/(TTOR-T1ISR)
      ETAS=1.0-ZETAS
      V1IS=SQRT(C*(TTOR-T1ISR))
      VCOEFS=V1M/V1IS
      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
      U1=PI*RPM*RM1/360.
      WU1=VU1-U1
      WA1=VA1M
      BETA1=ATAN(WU1/WA1)
      W1=WA1/COS(BETA1)
      BETA1=BETA1*180./PI
      MW1=W1/SQRT(GAM*RG*GC*T1RM)
      RFAX=FAX/(PTO/14.69)
      RTORQ=TORQ/(PTO/14.69)
      RVA1=VA1M/SQRT(GAM*GC*RG*TTOR)
      RVU1=VU1/SQRT(GAM*GC*RG*TTOR)
      RETURN
      END

      SUBROUTINE MOMENT(RG,GAM,GC,C,RM1,AAXS,TORQ,CLTORQ,FLOWT,PI,RTIP1,
     1 RHUB1,FAX,CLFAX,PHUB,PTIP,P1AV,P13,P18,P19,P20,P21,PHD,TTOR,T1RM,
     2 VU1,VA1M,V1M,ALPH1M,MV1M,MVA1M,F0,F1,F2,F3,F4,F5,F6A,FNET)
C
      REAL*4 MVA1M,MVA1,MV1M,MV1C,MV1,MW1,MV2,MW2
      VU1=(TORQ+CLTORQ)*12.*GC/(FLOWT*RM1)
      A0=PI*5.125**2
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```
      A2=PI*(5.125**2-5.003**2)                                        TTT05170
      A3=PI*(5.003**2-4.901**2)                                        TTT05180
      A4=PI*(4.901**2-4.773**2)                                        TTT05190
      A5=PI*(4.773**2-RTIP1**2)                                        TTT05200
      A6A=PI*RHUB1**2                                                  TTT05210
      F0=A0*PHD                                                        TTT05220
      F1=AAXS*P1AV                                                     TTT05230
      F2=A2*P21                                                        TTT05240
      F3=A3*((P20+P19)/2.)                                             TTT05250
      F4=A4*P18                                                        TTT05260
      F5=A5*((PTIP+P13)/2.)                                            TTT05270
      F6A=A6A*PHUB                                                     TTT05280
      FNET=FAX+CLFAX+F0-F1-F2-F3-F4-F5-F6A                             TTT05290
      VA1M=FNET*GC/FLOWT                                               TTT05300
      ALPH1M=ATAN(VU1/VA1M)                                            TTT05310
      ALPH1M=ALPH1M*180./PI                                            TTT05320
      V1M=SQRT(VA1M**2+VU1**2)                                         TTT05330
      T1RM=TTOR-(V1M**2)/C                                             TTT05340
      MV1M=V1M/SQRT(GAM*GC*RG*T1RM)                                    TTT05350
      MVA1M=VA1M/SQRT(GAM*GC*RG*T1RM)                                  TTT05360
      RETURN                                                           TTT05370
      END                                                              TTT05380
      SUBROUTINE FORCE(PI,RTIP1,RHUB1,AAXS,PHUB,P1AV,PTIP,P13,P18,P19, TTT05390
     1 P20,P21,PHD,FAX,CLFAX,F0,F1,F2,F3,F4,F5,F6A,FNET)               TTT05400
C                                                                      TTT05410
      A0=PI*5.125**2                                                   TTT05420
      A2=PI*(5.125**2-5.003**2)                                        TTT05430
      A3=PI*(5.003**2-4.901**2)                                        TTT05440
      A4=PI*(4.901**2-4.773**2)                                        TTT05450
      A5=PI*(4.773**2-RTIP1**2)                                        TTT05460
      A6A=PI*RHUB1**2                                                  TTT05470
      F0=A0*PHD                                                        TTT05480
      F1=AAXS*P1AV                                                     TTT05490
      F2=A2*P21                                                        TTT05500
      F3=A3*((P20+P19)/2.)                                             TTT05510
      F4=A4*P18                                                        TTT05520
      F5=A5*((PTIP+P13)/2.)                                            TTT05530
      F6A=A6A*PHUB                                                     TTT05540
      FNET=FAX+CLFAX+F0-F1-F2-F3-F4-F5-F6A                             TTT05550
      RETURN                                                           TTT05560
      END                                                              TTT05570
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      SUBROUTINE ROTOR(RG,GC,CJ,CP,C,PI,EX1,EX2,RM1,RM2,AAXR,RKT,PTO,    TTT05580
     1 P1AV,PHD,PT2,PRM,DYNA,FLOWT,TTOR,T1RM,T2R,TT2R,DELTW,T2ISR,TER,   TTT05590
     2 VU1,U1,W1,BETA1,VU2,VA2,V2,ALPH2,U2,WU2,WA2,W2,W2IS,BETA2,DBETA,  TTT05600
     3 WCOEFS,ZETAR,ETAR,MV2,MW2,GAM,RPM,SLF,SFF)                        TTT05610
C                                                                        TTT05620
      REAL*4 MVA1M,MVA1,MV1M,MV1C,MV1,MW1,MV2,MW2                        TTT05630
      VU2=RM1/RM2*VU1-(12.*DYNA*GC)/(RM2*FLOWT)                          TTT05640
      U2=U1*RM2/RM1                                                      TTT05650
      WU2=VU2-U2                                                         TTT05660
      DELTW=(DYNA*PI*RPM)/(30.*FLOWT*CJ*CP)                              TTT05670
      TT2R=TTOR-DELTW                                                    TTT05680
      T2ISR=T1RM*(PHD/P1AV)**EX2                                         TTT05690
      TER=T1RM+(W1**2-U1**2+U2**2)/C                                     TTT05700
      C3=FLOWT*RG/(PHD*AAXR*RKT)                                         TTT05710
      VA2=SQRT(C*TT2R-VU2**2+(C/(2.*C3))**2)-C/(2.*C3)                   TTT05720
      V2=SQRT(VA2**2+VU2**2)                                             TTT05730
      T2R=TT2R-(V2**2)/C                                                 TTT05740
      MV2=V2/SQRT(GAM*RG*GC*T2R)                                         TTT05750
      PT2=PHD*(TT2R/T2R)**EX1                                            TTT05760
      PRM=PTO/PHD                                                        TTT05770
      WA2=VA2                                                            TTT05780
      W2=SQRT(WA2**2+WU2**2)                                             TTT05790
      MW2=W2/SQRT(GAM*RG*GC*T2R)                                         TTT05800
      ALPH2=ATAN(VU2/VA2)                                                TTT05810
      ALPH2=ALPH2*180./PI                                                TTT05820
      BETA2=ATAN(WU2/WA2)                                                TTT05830
      BETA2=BETA2*180./PI                                                TTT05840
      DBETA=BETA1-BETA2                                                  TTT05850
      ZETAR=(T2R-T2ISR)/(TER-T2ISR)                                      TTT05860
      ETAR=1.0-ZETAR                                                     TTT05870
      W2IS=SQRT(C*(TER-T2ISR))                                           TTT05880
      WCOEFS=W2/W2IS                                                     TTT05890
      IF(U2.LE.1.0) U2=0.001                                             TTT05900
      SLF=(VU1-VU2)/U2                                                   TTT05910
      SFF=VA2/U2                                                         TTT05920
      RETURN                                                             TTT05930
      END                                                                TTT05940

      SUBROUTINE PERFRM(C,PI,EX2,PTO,PHUB,PTIP,PHD,PT2,DYNA,RPM,FLOWT,   TTT05950
     1 TTOR,TT2R,T2THR,TT2ISR,DELHIS,DELHW,DELTIS,DELTW,VOIS,V1IS,U1,V2, TTT05960
     2 ETATS,ETATT,REACMN,REACHB,REACTP,XKIS,REFLOW,REFRPM,REFMOM,HP,    TTT05970
     3 REFHP,T2ISR,F,V1,W1,U2,W2,REACEF,CP)                              TTT05980
C                                                                        TTT05990
      DELTIS=TTOR*(1.0-(PHD/PTO)**EX2)                                   TTT06000
      T2THR=TTOR-DELTIS                                                  TTT06010
      TT2ISR=TTOR*(PT2/PTO)**EX2                                         TTT06020
      DELHIS=CP*(TTOR-T2THR)                                             TTT06030
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      DELHW=CP*(TTOR-TT2R)
      ETATS=DELTW/DELTIS*100.
      F=T2ISR/T2THR
      ETATT=DELTW/(DELTIS-(V2**2)/(C*F))*100.
      VOIS=SQRT(C*DELTIS)
      REACEF=(W2**2-W1**2+U1**2-U2**2)/(V1**2+W2**2-W1**2+U1**2-U2**2)
      REACMN=1.0-(V1IS/VOIS)**2
      REACHB=((PHUB/PHD)**EX2-1.)/((PTO/PHD)**EX2-1.)
      REACTP=((PTIP/PHD)**EX2-1.)/((PTO/PHD)**EX2-1.)
      IF(U1.LE.1.0) 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*RPM)/(30.*550.)
      REFHP=HP/(DEL*SQRT(THETA))
      RETURN
      END


      SUBROUTINE OUTPTS(NRUN,NP,FAX,CLFAX,FO,F1,F2,F3,F4,F5,F6A,FNET,
     1 TORQ,CLTORQ,FLOWN,FLOWT,FLOWL,RE,PHI,XI,QNOZ,QTPL,PTO,P1AV,QHD,
     2 PRPL,PRS,TTO,T1,T1IS,VA1,VU1,V1,V1IS,ALPH1,VCOFS,MV1,MVA1,
     3 WA1,WU1,W1,U1,BETA1,MW1,ZETAS,ETAS,PAMB,NDAY,NMO,NYEAR,RFAX,
     4RTORQ,RVA1,RVU1,J)
      REAL*4 MVA1M,MVA1,MV1M,MV1C,MV1,MW1,MV2,MW2
      DIMENSION FAX(50),CLFAX(50),FO(50),F1(50),F2(50),F3(50),F4(50),
     1 F5(50),F6A(50),FNET(50),TORQ(50),CLTORQ(50),FLOWN(50),FLOWT(50),
     2 FLOWL(50),RE(50),PHI(50),XI(50),QNOZ(50),QTPL(50),PTO(50),
     3 P1AV(50),QHD(50),PRPL(50),PRS(50),TTPQ(50),TTO(50),T1(50),
     4 T1IS(50),VA1(50),VU1(50),V1(50),V1IS(50),ALPH1(50),VCOFS(50),
     5 MV1(50),MVA1(50),WA1(50),WU1(50),W1(50),U1(50),BETA1(50),MW1(50),
     6 ZETAS(50),ETAS(50),RFAX(50),RTORQ(50),RVA1(50),RVU1(50)
      WRITE(8,800) NRUN,NDAY,NMO,NYEAR,J
  800 FORMAT(1H1,1X,'STATOR RESULTS',///,1X,'CONFIGURATION-   CONVERGING
     1 NOZZLES, SHROUD P/N 1050, INSERT P/N 2005-3(STRAIGHT)',///,1X,'RU
     2N NUMBER ',A3,4X,'DAY ',1A2,4X,'MONTH ',1A2,4X,'YEAR ',1A2,
     3//44X,'METHOD J=',I2)
      WRITE(8,801)
  801 FORMAT(////,30X,'FORCE AND MOMENT BALANCE(LBS AND FT-LBS)',//,1X,
     1'POINT',2X,'FAX(+)',1X,'CLFAX(+)',2X,'FO(+)',3X,'F1(-)',3X,'F2(-)'
     2,3X,'F3(-)',3X,'F4(-)',3X,'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),FO(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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803 FORMAT(I4,2X,9F8.2,F9.2,2F8.2,2F9.2)                                TTT06500
    WRITE(8,804)                                                         TTT06510
804 FORMAT(////,30X,'FLOW RATES(LBM/SEC), RE(NOZ), FLOW FNC, AND STATOTTT06520
   1R BLOCKAGE FACTOR',//,1X,'POINT',2X,'NOZZLE FLOW',2X,'TURBINE FLOWTTT06530
   2',3X,'LABLEAK',8X,'RE',9X,'PHI',7X,'XI',/)                          TTT06540
    DO 805 I=1,NP                                                        TTT06550
805 WRITE(8,806) I,FLOWN(I),FLOWT(I),FLOWL(I),RE(I),PHI(I),XI(I)         TTT06560
806 FORMAT(I4,2X,F10.4,4X,F10.4,3X,F10.4,3X,F10.0,2F10.4)                TTT06570
    WRITE(8,807) PAMB                                                    TTT06580
807 FORMAT(////,30X,'PRESSURES(PSIA) AND PRESSURE RATIOS',//,1X,'PAMB=TTT06590
   1',F5.2,//,1X,'POINT',2X,'PNOZ',3X,'PTPL',3X,'PTO',3X,'P1AV',4X,     TTT06600
   2 'PHD',3X,'PLENUM PR(PTPL/PHD)',2X,'STATOR PR(PTO/P1AV)',/)         TTT06610
    DO 808 I=1,NP                                                        TTT06620
808 WRITE(8,809)I,QNOZ(I),QTPL(I),PTO(I),P1AV(I),QHD(I),PRPL(I),PRS(I)TTT06630
809 FORMAT(I4,1X,5F7.2,6X,F7.4,14X,F7.4)                                 TTT06640
    WRITE(8,810)                                                         TTT06650
810 FORMAT(////,30X,'TEMPERATURES(DEG R)',//,1X,'POINT',5X,             TTT06660
   1 'TTO',7X,'T1',7X,'T1IS',/)                                          TTT06670
    DO 811 I=1,NP                                                        TTT06680
811 WRITE(8,812) I,TTO(I),T1(I),T1IS(I)                                  TTT06690
812 FORMAT(I4,1X,3F10.2)                                                 TTT06700
    WRITE(8,813)                                                         TTT06710
813 FORMAT(1H1,30X,'ABSOLUTE VELOCITIES(FT/SEC), ANGLES(DEG), VEL COEFTTT06720
   1, AND MACH NOS',//,1X,'POINT',3X,'VA1',6X,'VU1',7X,'V1',6X,'V1IS',TTT06730
   2 3X,'ALPHA 1',2X,'VCOEFS',4X,'MV1',4X,'MVA1',4X,'RVA1',4X,'RVU1'/)TTT06740
    DO 814 I=1,NP                                                        TTT06750
814 WRITE(8,815) I,VA1(I),VU1(I),V1(I),V1IS(I),ALPH1(I),VCOFS(I),       TTT06760
   1 MV1(I),MVA1(I),RVA1(I),RVU1(I)                                      TTT06770
815 FORMAT(I4,1X,5F9.2,5F8.4)                                            TTT06780
    WRITE(8,816)                                                         TTT06790
816 FORMAT(////,30X,'RELATIVE VELOCITIES(FT/SEC), ANGLES(DEG), AND MACTTT06800
   1H NOS',//,1X,'POINT',3X,'WA1',6X,'WU1',7X,'W1',7X,'U1',5X,'BETA 1'TTT06810
   2,4X,'MW1',/)                                                         TTT06820
    DO 817 I=1,NP                                                        TTT06830
817 WRITE(8,818)I,WA1(I),WU1(I),W1(I),U1(I),BETA1(I),MW1(I)              TTT06840
818 FORMAT(I4,1X,5F9.2,F8.4)                                             TTT06850
    WRITE(8,819)                                                         TTT06860
819 FORMAT(////,30X,'EFFICIENCIES',//,1X,'POINT',2X,'ZETA STATOR',2X,   TTT06870
   1 'ETA STATOR(1.-ZETAS)',/)                                           TTT06880
    DO 820 I=1,NP                                                        TTT06890
820 WRITE(8,821) I,ZETAS(I),ETAS(I)                                      TTT06900
821 FORMAT(I4,3X,F10.4,7X,F10.4)                                         TTT06910
    RETURN                                                               TTT06920
    END                                                                  TTT06930
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      SUBROUTINE OUTPTR(NRUN,NP,AXCLR,RADCLR,PAMB,PTO,P1AV,PT2,QHD,PR,  TTT06940
     1 TTO,T1,TE,TT2,T2,T2IS,T2TH,TT2IS,DELTIS,DELTW,VA2,VU2,V2,VCIS,   TTT06950
     2 ALPH2,WA2,WU2,W2,U2,W2IS,BETA2,DBETA,WCOFS,ZETAR,ETAR,RPM,HP,    TTT06960
     3 DELHIS,DELHW,REFRPM,XKIS,ETATS,ETATT,REFLOW,REFMOM,REFHP,J,      TTT06970
     4 REACHB,REACMN,REACTP,NDAY,NMO,NYEAR,F,REACEF,MV2,MW2,SLF,SFF)    TTT06980
      REAL*4 MVA1M,MVA1,MV1M,MV1C,MV1,MW1,MV2,MW2                       TTT06990
      DIMENSION PTO(50),P1AV(50),PT2(50),QHD(50),PR(50),TTO(50),T1(50), TTT07000
     1 TE(50),TT2(50),T2(50),T2IS(50),T2TH(50),TT2IS(50),DELTIS(50),    TTT07010
     2 DELTW(50),VA2(50),VU2(50),V2(50),VCIS(50),ALPH2(50),WA2(50),     TTT07020
     3 WU2(50),W2(50),U2(50),W2IS(50),BETA2(50),DBETA(50),WCOFS(50),    TTT07030
     4 ZETAR(50),ETAR(50),RPM(50),HP(50),DELHIS(50),DELHW(50),REFRPM(50)TTT07040
     5,XKIS(50),ETATS(50),ETATT(50),REFLOW(50),REFMOM(50),REFHP(50),    TTT07050
     6 REACHB(50),REACMN(50),REACTP(50),F(50),REACEF(50),MV2(50),MW2(50)TTT07060
     7,SLF(50),SFF(50)                                                  TTT07070
      WRITE(8,900) AXCLR,RADCLR,NRUN,NDAY,NMO,NYEAR,J                   TTT07080
  900 FORMAT(1H1,1X,'ROTOR RESULTS',///,1X,'CONFIGURATION-  CIRCULAR ARCTTT07090
     1, SHARP LE ROTOR, P/N 1034-A, AXIAL CLNC ',F6.3,' IN, RADIAL CLNC'TTT07100
     2,F6.3,' IN',///,1X,'RUN NUMBER ',A3,4X,'DAY ',1A2,4X,'MONTH ',1A2,TTT07110
     34X,'YEAR ',1A2,//,44X,'METHOD J=',I2)                             TTT07120
      WRITE(8,901) PAMB                                                 TTT07130
  901 FORMAT(////,30X,'PRESSURES(PSIA) AND PRESSURE RATIOS',//,1X,'PAMB=TTT07140
     1',F5.2,//,1X,'POINT',3X,'PTO',4X,'P1AV',3X,'PT2',3X,'P2=PHD',3X,  TTT07150
     2 'OVERALL PR(PTO/P2)',/)                                          TTT07160
      DO 902 I=1,NP                                                     TTT07170
  902 WRITE(8,903) I,PTO(I),P1AV(I),PT2(I),QHD(I),PR(I)                 TTT07180
  903 FORMAT(I4,2X,4F7.2,6X,F7.4)                                       TTT07190
      WRITE(8,904)                                                      TTT07200
  904 FORMAT(////,30X,'TEMPERATURES(DEG R)',//,1X,'POINT',4X,'TTO',5X,  TTT07210
     1 'T1',6X,'TE',6X,'TT2',5X,'T2',5X,'T2IS',4X,'T2TH',3X,'TT2IS',3X, TTT07220
     2 'DELTA TIS',2X,'DELTA TW',/)                                     TTT07230
      DO 905 I=1,NP                                                     TTT07240
  905 WRITE(8,906) I,TTO(I),T1(I),TE(I),TT2(I),T2(I),T2IS(I),T2TH(I),TT2TTT07250
     1IS(I),DELTIS(I),DELTW(I)                                          TTT07260
  906 FORMAT(I4,2X,8F8.2,2F10.2)                                        TTT07270
      WRITE(8,907)                                                      TTT07280
  907 FORMAT(1H1,30X,'ABSOLUTE VELOCITIES(FT/SEC) AND ANGLES(DEG)',//,  TTT07290
     1 1X,'POINT',3X,'VA2',6X,'VU2',7X,'V2',6X,'VCIS',3X,'ALPHA 2',3X,'MTTT07300
     2V2',4X,'STAGE LOADING FACTOR',2X,'STAGE FLOW FACTOR',/)           TTT07310
      DO 908 I=1,NP                                                     TTT07320
  908 WRITE(8,909) I,VA2(I),VU2(I),V2(I),VOIS(I),ALPH2(I),MV2(I),SLF(I),TTT07330
     1 SFF(I)                                                           TTT07340
  909 FORMAT(I4,1X,5F9.2,F8.4,F14.2,F21.2)                              TTT07350
      WRITE(8,910)                                                      TTT07360
  910 FORMAT(////,30X,'RELATIVE VELOCITIES(FT/SEC), ANGLES(DEG), AND RELTTT07370
     1 VEL COEFS',//,1X,'POINT',3X,'WA2',6X,'WU2',7X,'W2',7X,'U2',6X,   TTT07380
     2 'W2IS',4X,'BETA 2',4X,'DBETA',2X,'WCOEFS',3X,'MW2',/)            TTT07390
      DO 911 I=1,NP                                                     TTT07400
  911 WRITE(8,912) I,WA2(I),WU2(I),W2(I),U2(I),W2IS(I),BETA2(I),DBETA(I)TTT07410
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      1,WCOFS(I),MW2(I)                                                 TTT07420
  912 FORMAT(I4,1X,7F9.2,2F8.4)                                         TTT07430
      WRITE(8,913)                                                      TTT07440
  913 FORMAT(////,30X,'EFFICIENCIES, RPM, WORK OUTPUT(HP), AND ENTHALPY TTT07450
     1DROP(BTU/LBM)',//,1X,'POINT',2X,'ZETA ROTOR',2X,'ETA ROTOR(1.-ZETATTT07460
     2R)',2X,'RPM',6X,'HP',3X,'DELTA HIS',2X,'DELTA HW',2X,'REHEAT FACTOTTT07470
     3R',2X,'EFF DEGREE OF REACTION',/)                                 TTT07480
      DO 914 I=1,NP                                                     TTT07490
  914 WRITE(8,915) I,ZETAR(I),ETAR(I),RPM(I),HP(I),DELHIS(I),DELHW(I),F(TTT07500
     1I),REACEF(I)                                                      TTT07510
  915 FORMAT(I4,4X,F8.4,8X,F8.4,6X,F8.0,F8.2,F8.2,F11.2,F13.4,F19.4)    TTT07520
      WRITE(8,916) NRUN,NDAY,NMO,NYEAR                                  TTT07530
  916 FORMAT(1H1,1X,'GENERAL RESULTS',///,1X,'RUN NUMBER ',A3,4X,       TTT07540
     1'DAY ',1A2,4X,'MONTH ',1A2,4X,'YEAR ',1A2                         TTT07550
     1   ,////,1X,'POINT',2X,'PRESSURE',2X,'REFERRED',2X,'ISENTROPIC',2XTTT07560
     2,'EFFICIENCY',2X,'EFFICIENCY',2X,'REFERRED',3X,'REFERRED',2X,'REFETTT07570
     3RRED',2X,'DEGREE OF',2X,'DEGREE OF',2X,'DEGREE OF',/,10X,'RATIO',5TTT07580
     4X,'SPEED',3X,'HEAD COEFF',2X,'TOT-STATIC',4X,'TOT-TOT',3X,'FLOW RATTT07590
     5TE',3X,'MOMENT',5X,'POWER',4X,'REACTION',3X,'REACTION',3X,'REACTIOTTT07600
     6N',/,21X,'RPM',18X,'PERCENT',5X,'PERCENT',4X,'LBM/SEC',4X,'FT-LB',TTT07610
     77X,'HP',7X,'(HUB)',6X,'(MEAN)',5X,'(TIP)',/)                      TTT07620
      DO 917 I=1,NP                                                     TTT07630
  917 WRITE(8,918)  I,PR(I),REFRPM(I),XKIS(I),ETATS(I),ETATT(I),REFLOW(ITTT07640
     1),REFMOM(I),REFHP(I),REACHB(I),REACMN(I),REACTP(I)                TTT07650
  918 FORMAT(I4,F11.4,F10.0,F11.4,2F12.2,F11.4,F11.3,F10.3,3F11.4)      TTT07660
      RETURN                                                            TTT07670
      END                                                               TTT07680


      SUBROUTINE   LISA(NP,NRUN,NDAY,NMO,NYEAR,XKIS,ETATS,PRS,ZETAS,    TTT07690
     1REFRPM,ETAR,ETAS,RTORQ)                                           TTT07700
      DIMENSION XKIS(50),ETATS(50),PRS(50),ZETAS(50),REFRPM(50)         TTT07710
     1,ETAR(50),ETAS(50),RTORQ(50)                                      TTT07720
      WRITE(7,804) NP,NRUN,NDAY,NMO,NYEAR                               TTT07730
      WRITE(7,806) (XKIS(I),ETATS(I),PRS(I),ZETAS(I),REFRPM(I)          TTT07740
     1,ETAR(I),ETAS(I),RTORQ(I),I=1,NP)                                 TTT07750
  804 FORMAT(1X,I2,4A2)                                                 TTT07760
  806 FORMAT(1X,8F9.3)                                                  TTT07770
      RETURN                                                            TTT07780
      END                                                               TTT07790


       SUBROUTINE HAMMER(NP,CTORQ,QRPM,QFLOWT,PRP)                      TTT07800
        WRITE(6,701) NP,QRPM,PRP,QFLOWT,QTORQ                           TTT07810
701    FORMAT(' ',/,20X,'POINT NUMBER',I2,//,                           TTT07820
     1  10X,'RPM------------------------',F8.2,/,                       TTT07830
     2  10X,'STAGE PRESSURE RATIO-----',F6.2,/,                         TTT07840
     3  10X,'TURBINE MASS FLOW--------',F4.2,' LB/SEC',/,               TTT07850
```

```
4  10X,'STATCR TORQUE-------------',F6.2,' FT-LB',//)                TTT07860
   RETURN                                                            TTT07870
   END                                                               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.

```
C                          TRANSONIC TURBINE TEST RIG
C                              OUTPUT PLOT PROGRAM
C                          ------------------------------
C
C     THIS DRAWS TTTR GRAPHS USING THE PUNCHED CARDS FROM THE ON-LINE REDUCTION
C
      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)
      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,
     1REFRPM,ETAR,ETAS,RTORQ)
      STOP
                          END

      SUBROUTINE    LISA(NP,NRUN,NDAY,NMO,NYEAR,XKIS,ETATS,PRS,ZETAS,
     1REFRPM,ETAR,ETAS,RTORQ)
      REAL*4 NRUN,NDAY,NMO,NYEAR
      REAL*8 LABEL/'        '/
      REAL LABER/'ETAR'/
      REAL LABES/'ETAS'/
      REAL LABET/'T-S '/
      REAL LABRT/'    '/
      REAL ITIT1(24)/'DETH','OMAS',' TTT','R  R','UN #','    ','DAY '
     1,'    ','MO. ','    ','YEAR','    '
     2,'EFFI','CIEN','CIES','(T-S',',ROT','OR&S','TATO','R) V','S IS'
     3,'. HE','AD C','OEF.'/
      REAL ITIT2(24)/'DETH','OMAS',' TTT','R  R','UN #','    ','DAY '
     1,'    ','MO. ','    ','YEAR','    '
     2,'EFFI','CIEN','CIES','(T-S',',ROT','OR&S','TATO','R) V','S.  '
     3,'STAT','OR P','.R. '/
      REAL ITIT3(24)/'DETH','OMAS',' TTT','R  R','UN #','    ','DAY '
     1,'    ','MO. ','    ','YEAR','    '
     2,'EFFI','CIEN','CIES','(T-S',',ROT','OR&S','TATO','R) V','S.  '
     3,'REFE','RRED',' RPM'/
      REAL ITIT4(24)/'DETH','OMAS',' TTT','R  R','UN #','    ','DAY '
     1,'    ','MO. ','    ','YEAR','    '
     2,'REFE','RRED',' STA','TOR ','TORQ','UE V','S.  '
     3,'REFE','RRED','RPM ','    ','    '/
      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)
```

```
      ITIT1(6)=NRUN
      ITIT1(8)=NDAY
      ITIT1(10)=NMO
      ITIT1(12)=NYEAR
      ITIT2(6)=NRUN
      ITIT2(8)=NDAY
      ITIT2(10)=NMO
      ITIT2(12)=NYEAR
      ITIT3(6)=NRUN
      ITIT3(8)=NDAY
      ITIT3(10)=NMO
      ITIT3(12)=NYEAR
      ITIT4(6)=NRUN
      ITIT4(8)=NDAY
      ITIT4(10)=NMO
      ITIT4(12)=NYEAR
      DO 802 I=1,NP
      KEY(I)=I
      ETAR(I)=100.*ETAR(I)
      ETAS(I)=100.*ETAS(I)
      DUMTS(I)=ETATS(I)
      DUMR(I)=ETAR(I)
      DUMS(I)=ETAS(I)
      DUMT(I)=RTORQ(I)
      WRITE(6,889) I,XKIS(I),PRS(I),REFRPM(I),ETATS(I),ETAR(I),ETAS(I)
  802 CONTINUE
      CALL SHSORT(XKIS,KEY,NP)
      WRITE(6,824)
  824 FORMAT(' ',2X,' XKIS ',4X,'ETATS',6X,'ETAR',6X,'ETAS')
      DO 804 I=1,NP
      ETATS(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)
  804 CONTINUE
      CALL DRAW(NP,XKIS,ETATS,1,5,LABEL,ITIT1,0.0,0.0,0,0,2,2,8,5,1,LA)
      CALL DRAW(NP,XKIS,ETATS,2,0,LABET,ITIT1,0.0,0.0,0,0,2,2,8,4,1,LA)
      CALL DRAW(NP,XKIS, ETAR,2,3,LABEL,ITIT1,0.0,0.0,0,0,2,2,8,4,1,LA)
      CALL DRAW(NP,XKIS, ETAR,2,0,LABER,ITIT1,0.0,0.0,0,0,2,2,8,4,1,LA)
      CALL DRAW(NP,XKIS, ETAS,2,4,LABEL,ITIT1,0.0,0.0,0,0,2,2,8,4,1,LA)
      CALL DRAW(NP,XKIS, ETAS,3,0,LABES,ITIT1,0.0,0.0,0,0,2,2,8,4,1,LA)
      CALL SHSORT(PRS,KEY,NP)
      WRITE(6,826)
  826 FORMAT(' ',2X,' PRS  ',4X,'ETATS',6X,'ETAR',6X,'ETAS')
      DO 806 I=1,NP
      ETATS(I)=DUMTS(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)
806   CONTINUE
      CALL DRAW(NP, PRS,ETATS,1,5,LABEL,ITIT2,0.0,0.0,0,0,2,2,8,5,1,LA)
      CALL DRAW(NP, PRS,ETATS,2,0,LABET,ITIT2,0.0,0.0,0,0,2,2,8,4,1,LA)
      CALL DRAW(NP, PRS, ETAR,2,3,LABEL,ITIT2,0.0,0.0,0,0,2,2,8,4,1,LA)
      CALL DRAW(NP, PRS, ETAR,2,0,LABER,ITIT2,0.0,0.0,0,0,2,2,8,4,1,LA)
      CALL DRAW(NP, PRS, ETAS,2,4,LABEL,ITIT2,0.0,0.0,0,0,2,2,8,4,1,LA)
      CALL DRAW(NP, PRS, ETAS,3,0,LABES,ITIT2,0.0,0.0,0,0,2,2,8,4,1,LA)
      CALL SHSORT (REFRPM,KEY,NP)
      WRITE(6,828)
828   FORMAT(' ',2X,'REFRPM',4X,'ETATS',6X,'ETAR',6X,'ETAS',6X,'RTORQ')
      DO 808 I=1,NP
      ETATS(I)=DUMTS(KEY(I))
      ETAR(I)=DUMR(KEY(I))
      ETAS(I)=DUMS(KEY(I))
      RTORQ(I)=DUMT(KEY(I))
      KEY(I)=I
      WRITE(6,822)REFRPM(I),ETATS(I),ETAR(I),ETAS(I),RTORQ(I)
808   CONTINUE
822   FORMAT(' ',5F10.4)
      CALL DRAW(NP,REFRPM,ETATS,1,5,LABEL,ITIT3,.0,.0,0,0,2,2,8,5,1,LA)
      CALL DRAW(NP,REFRPM,ETATS,2,0,LABET,ITIT3,.0,.0,0,0,2,2,8,4,1,LA)
      CALL DRAW(NP,REFRPM, ETAR,2,3,LABEL,ITIT3,.0,.0,0,0,2,2,8,4,1,LA)
      CALL DRAW(NP,REFRPM, ETAR,2,0,LABER,ITIT3,.0,.0,0,0,2,2,8,4,1,LA)
      CALL DRAW(NP,REFRPM, ETAS,2,4,LABEL,ITIT3,.0,.0,0,0,2,2,8,4,1,LA)
      CALL DRAW(NP,REFRPM, ETAS,3,0,LABES,ITIT3,.0,.0,0,0,2,2,8,4,1,LA)
      CALL DRAW(NP,REFRPM,RTORQ,0,3,LABRT,ITIT4,.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
884   FORMAT(1H1,20X,'-----DRAW CHECK PARAMETERS-----',///////)
885   FORMAT(' ','DRAW HAS BOMBED OUT AGAIN STOOPID------------------')
887   FORMAT(' ','NP,NRUN,NDAY,NMO,NYEAR,LA',I6,4A8,I6)
889   FORMAT(' ',I2,6F10.4,/)
      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.

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Data Acquisition						
On-Line Data Acquisition						

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