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

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Naval Postgraduate School

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

John Victor DeThomas
THESIS

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

by

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Thesis Advisor R. D. Zucker

March 1972

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

by

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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 (mesh #60) to reduce inlet pressure gradients radially and help prevent turbine damage from foreign objects.

2. Flow baffles were installed inside the stator plenum casing and are arranged axially at the two, six and ten o'clock positions (Figure 4). The purpose of the baffles is to reduce tangential swirl velocities within the plenum.

3. In the center portion of the turbine plenum the large drilled sleeve was entirely removed and replaced by thin rods covered with three layers of fine copper screen (mesh #60). This was done to introduce a pressure drop so that the plenum would be at a more constant higher pressure (Figure 3). Hopefully, this would result in a more even radial flow into the floating stator assembly.

4. On the inner or floating stator inlet sleeve the inlet holes were increased from one inch to one and one quarter inches in diameter to help maintain the now equalized flow.
The problem of thermal expansion and stator torque is described by Esdaile [Ref. 1]. Basically, the warmer air inside the stator caused the horizontal flexures and stator to expand more or less than the support frame. This differential expansion produced a moment which was measured with the stator torque.

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

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

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

During disassembly of the stator, particle accumulations were noted on the inner walls of the stator case. These buildups followed the support struts for the stator closure assembly indicating probable flow wakes. These wakes were verified by later circumferential velocity surveys. The stator inlet total pressure and temperature probes, which were originally located downstream of these struts, have been relocated. The present
arrangement consists of three Kiel type total pressure probes and two semi-hooded total temperature, iron-constantan thermocouples. The pressure probes are located at the twelve, four and eight o'clock positions looking downstream. All three probes are located radially near the mean blade radius. A radial total pressure survey was conducted in the twelve o'clock probe position. The survey probe was then set to read a mean pressure (very near the mean radius) and the stator inlet probes adjusted to correspond with the survey probe readings.

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

C. DATA ACQUISITION SYSTEM

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

The pressure lines connect to mercury manometer banks in the control room and parallel into a pressure selector valve. This valve controls which cell inputs to the B & F system. The thermocouple, transducer/strain
gage and frequency leads enter the control room and are routed to rotary switches which connect the desired input cell to the B & F acquisition system.

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

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

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

The teletype is a Teletype Corp. Model 33 with a minor modification to allow computer control of the tape reader [Ref. 5]. The teletype terminal uses a regular telephone and a Livermore Data Systems, Inc.,
acoustically coupled data set to gain on-line access to the IBM 360/67 computer on the main campus of the Naval Postgraduate School [Ref. 6].
III. GENERAL ACQUISITION AND REDUCTION PLANNING

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

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

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

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

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

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

1. On line return of certain key results to check input data and help in readjusting equipment following each data point.
2. Complete result output for each run (this is the normal FORTRAN program output).

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

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

1. Program Editing

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

2. Program Debugging

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

3. Error Analysis

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

For planning on-line data acquisition and reduction the following general organization is recommended:
1. Insure desired experiment is amenable to digital analysis with the physical data available.

2. Determine best instrumentation compatible with the experimental machine and the B & F data acquisition system. Consideration should be given to such things as:
   a. Pressure Transducers
      (1) Absolute Pressure vs. Gage Pressure
      (2) Calibration and Units
   b. Thermocouples; Millivolt to Degree Conversion
   c. Forces; Strain Gage vs. Inductance Force 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 sub-
routine. 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 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 10. Stage Efficiencies vs. Isentronic Head Coefficient

DETHOMAS TTRR RUN #16  DAY 11 NO. 02  YEAR72
EFCICIENCY(T-S, ROTOR&STATOR) VS TS. HEAD COEF.
Figure 11. Stage Efficiencies vs. Referred RPM

X-SCALE: 5.000E+03 UNITS INCH
Y-SCALE: 2.000E+01 UNITS INCH

DETHOMAS TTTR RUN #16  DAY 11  MO.  02  YEAR72
EFFICIENCIES(T-S, ROTOR&STATOR) VS. REFERRED RPM
FIGURE 13
TURBINE AND SHROUD DETAILS
### STATOR RESULTS

**CONFIGURATION:** CONVERGING NOZZLES, SHOWN 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.)

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### FLOW RATES(LBM/SEC.), RPM, NOZ, FLOW FAC. AND STATOR BLOCKAGE FACTOR

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ROTOR RESULTS

CONFIGURATION- CIRCULAR ARC, SHARP LE ROTOR, P/N 1054-A, AXIAL CLNG 0.250 IN, RADIAL CLNG 0.079 IN

RUN NUMBER 16  DAY 11  MONTH 02  YEAR 72

METHOD J= 1

PRESSURE(SI) AND PRESSURE RATIOS

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**GENERAL RESULTS**

**RUN NUMBER 1A**

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*This is the general result output using method J = 1 or continuing and blockage factors to help determine the stator exit velocities.*
### Force and Moment Balance and FT-L951

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**Rotor Results**

**Configuration:** Circular Arc, Sharp LF Rotor, P/N 1034-A, Axial CLNC 0.250 in, Radial CLNC 0.009 in

**Run Number:** 16  **Day:** 11  **Month:** 02  **Year:** 72  **Method J = 2**

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</table>
**GENERAL RESULTS**

**RUN NUMBER 16 | DAY 11 | MONTH 02 | YEAR 72**

<table>
<thead>
<tr>
<th>POINT</th>
<th>PRESSURE RATIO</th>
<th>REFERRED SPEED RPM</th>
<th>ISENTROPIC HEAD COEFF</th>
<th>EFFICIENCY TOT-STATIC PERCENT</th>
<th>EFFICIENCY TOT-TOT PERCENT</th>
<th>REFERRED FLOW RATE FT-LB/SEC</th>
<th>REFERRED MOMENT FT-LB</th>
<th>REFERRED POWER HP</th>
<th>DEGREE OF REACTION (HUB)</th>
<th>DEGREE OF REACTION (MEAN)</th>
<th>DEGREE OF REACTION (TIP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.4961</td>
<td>935%</td>
<td>5.3176</td>
<td>79.45</td>
<td>81.90</td>
<td>1.7674</td>
<td>10.627</td>
<td>18.079</td>
<td>-0.007</td>
<td>-0.0077</td>
<td>0.1942</td>
</tr>
<tr>
<td>2</td>
<td>1.4797</td>
<td>105%</td>
<td>4.234</td>
<td>81.33</td>
<td>83.02</td>
<td>1.7599</td>
<td>9.427</td>
<td>19.019</td>
<td>-0.0166</td>
<td>0.0411</td>
<td>0.2340</td>
</tr>
<tr>
<td>3</td>
<td>1.4716</td>
<td>135%</td>
<td>1.545</td>
<td>85.61</td>
<td>85.54</td>
<td>1.7445</td>
<td>8.007</td>
<td>18.014</td>
<td>-0.0074</td>
<td>0.1312</td>
<td>0.2447</td>
</tr>
<tr>
<td>4</td>
<td>1.4667</td>
<td>120%</td>
<td>3.767</td>
<td>81.63</td>
<td>85.27</td>
<td>1.7082</td>
<td>7.750</td>
<td>18.051</td>
<td>-0.0082</td>
<td>0.1951</td>
<td>0.2790</td>
</tr>
<tr>
<td>5</td>
<td>1.4593</td>
<td>140%</td>
<td>7.621</td>
<td>79.80</td>
<td>84.81</td>
<td>1.7008</td>
<td>7.676</td>
<td>17.630</td>
<td>0.00012</td>
<td>0.2366</td>
<td>0.2970</td>
</tr>
<tr>
<td>6</td>
<td>1.4407</td>
<td>134%</td>
<td>7.239</td>
<td>76.49</td>
<td>82.06</td>
<td>1.7038</td>
<td>7.608</td>
<td>17.642</td>
<td>0.00311</td>
<td>0.2602</td>
<td>0.3271</td>
</tr>
<tr>
<td>7</td>
<td>1.4678</td>
<td>130%</td>
<td>5.947</td>
<td>71.14</td>
<td>81.13</td>
<td>1.7009</td>
<td>7.556</td>
<td>16.622</td>
<td>0.00770</td>
<td>0.2362</td>
<td>0.3675</td>
</tr>
<tr>
<td>8</td>
<td>1.4687</td>
<td>115%</td>
<td>1.763</td>
<td>66.06</td>
<td>75.17</td>
<td>1.7067</td>
<td>7.417</td>
<td>15.094</td>
<td>0.01022</td>
<td>0.3152</td>
<td>0.3775</td>
</tr>
<tr>
<td>9</td>
<td>1.4679</td>
<td>170%</td>
<td>1.577</td>
<td>62.44</td>
<td>71.80</td>
<td>1.7155</td>
<td>7.315</td>
<td>15.435</td>
<td>0.01296</td>
<td>0.2521</td>
<td>0.4002</td>
</tr>
<tr>
<td>10</td>
<td>1.4667</td>
<td>140%</td>
<td>1.405</td>
<td>51.93</td>
<td>64.95</td>
<td>1.7182</td>
<td>7.115</td>
<td>10.667</td>
<td>0.01541</td>
<td>0.1758</td>
<td>0.4203</td>
</tr>
</tbody>
</table>

* 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.

<table>
<thead>
<tr>
<th>FORTRAN SYMBOL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AXCLR</td>
<td>Stator to rotor axial clearance (in)</td>
</tr>
<tr>
<td>AXIL</td>
<td>Stator axial force (lbf)</td>
</tr>
<tr>
<td>CLAXIL</td>
<td>Closure plate axial force (lbf)</td>
</tr>
<tr>
<td>CLTRQR</td>
<td>Closure plate torque (ft-lb)</td>
</tr>
<tr>
<td>DH</td>
<td>Flow nozzle differential pressure (in H₂O)</td>
</tr>
<tr>
<td>DPFL</td>
<td>Flow calibration differential pressure (in H₂O)</td>
</tr>
<tr>
<td>DYNAR</td>
<td>Dynamometer torque (ft-lb)</td>
</tr>
<tr>
<td>ETAR</td>
<td>Rotor efficiency</td>
</tr>
<tr>
<td>ETAS</td>
<td>Stator efficiency</td>
</tr>
<tr>
<td>ETATS</td>
<td>Stage total to static efficiency</td>
</tr>
<tr>
<td>ETATT</td>
<td>Stage total to total efficiency</td>
</tr>
<tr>
<td>FAX</td>
<td>Stator axial force (lbf)</td>
</tr>
<tr>
<td>FLOWL</td>
<td>Labyrinth seal leak rate (lbm/sec)</td>
</tr>
<tr>
<td>FLOWN</td>
<td>Flow nozzle flow rate (lbm/sec)</td>
</tr>
<tr>
<td>FLOWT</td>
<td>Turbine flow rate (lbm/sec)</td>
</tr>
<tr>
<td>HP</td>
<td>Rotor horsepower (HP)</td>
</tr>
<tr>
<td>LASTPT</td>
<td>Check parameter (indicates last point of run)</td>
</tr>
<tr>
<td>NDAY</td>
<td>Day number</td>
</tr>
</tbody>
</table>
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 Reynolds Number
REFHP Referred turbine horsepower
REFLOW Referred turbine flow rate
REFMOM Referred dynamometer moment
REFRPM Referred rotor RPM
RFAIX 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 FTOIFO01 (I any integer except six, see below). This file may then be printed out using the command to off line print FILE FTOIFO01 or punched out on cards with the command to off line punch FILE FTOIFO01.

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 places. Once a good calibration is achieved it may be easily checked during the run by reference to the barometric pressure on port #1.
### Table B-I. TTTR Instrumentation, Calibration and Units:

<table>
<thead>
<tr>
<th>POINT</th>
<th>FORTRAN SYMBOL</th>
<th>DATA</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>QPBAR</td>
<td>Barometric Pressure</td>
<td>In.Hg. Absolute:</td>
</tr>
<tr>
<td>2</td>
<td>DUMMY</td>
<td>Calibration Press</td>
<td>...</td>
</tr>
<tr>
<td>3</td>
<td>QPNOZ</td>
<td>Flow Nozzle Inlet Press</td>
<td>...</td>
</tr>
<tr>
<td>4</td>
<td>QPTPL</td>
<td>Plenum Labyrinth Press</td>
<td>...</td>
</tr>
<tr>
<td>5-18</td>
<td>QPT01-9</td>
<td>Stator Inlet Press</td>
<td>...</td>
</tr>
<tr>
<td>7</td>
<td>QPT03</td>
<td>Total Press (3)</td>
<td>...</td>
</tr>
<tr>
<td>8</td>
<td>QPHUB</td>
<td>Stator Exit Hub Press</td>
<td>...</td>
</tr>
<tr>
<td>9</td>
<td>QPTIP</td>
<td>Stator Exit Tip Press</td>
<td>...</td>
</tr>
<tr>
<td>10-21</td>
<td>QP13-21</td>
<td>Rotor Shroud Press (9)</td>
<td>...</td>
</tr>
<tr>
<td>19-23</td>
<td>QPCL1-3</td>
<td>Closure Plate Press (3)</td>
<td>...</td>
</tr>
<tr>
<td>22</td>
<td>QPHD</td>
<td>Turbine Hood Press</td>
<td>...</td>
</tr>
<tr>
<td>23</td>
<td>QDH</td>
<td>Nozzle Differential Press</td>
<td>In. H₂O</td>
</tr>
<tr>
<td>24</td>
<td>QLAXIL</td>
<td>Closure Plate Axial Force</td>
<td>Pounds Force</td>
</tr>
<tr>
<td>25</td>
<td>QLTRQR</td>
<td>Closure Plate Torque</td>
<td>Ft-Lbs Torque</td>
</tr>
<tr>
<td>26</td>
<td>QTNOZ</td>
<td>Flow Nozzle Inlet Temp.</td>
<td>Millivolts</td>
</tr>
<tr>
<td>27-28</td>
<td>QTTO1-2</td>
<td>Stator Inlet Total Temp.(2)</td>
<td>...</td>
</tr>
<tr>
<td>29</td>
<td>QTHD</td>
<td>Hood Temp.</td>
<td>...</td>
</tr>
<tr>
<td>30</td>
<td>QRPM</td>
<td>Rotor RPM</td>
<td>RPM</td>
</tr>
<tr>
<td>31</td>
<td>QAXIL</td>
<td>Stator Axial Force</td>
<td>Pounds Force</td>
</tr>
<tr>
<td>32</td>
<td>QTORQ</td>
<td>Stator Torque</td>
<td>Ft-Lbs Torque</td>
</tr>
<tr>
<td>33</td>
<td>QDYNAR</td>
<td>Dynamometer Torque</td>
<td>Ft-Lbs Torque</td>
</tr>
</tbody>
</table>
Flow nozzle differential pressure is connected in parallel to a differential transducer and an H₂O manometer board in the control room. A differential pressure is applied to the transducer and the channel #10 bridge and power supply are used to marry the B & F reading to the manometer board. The B & F system should read in. H₂O differential with three decimal places. Again, no correction is required if calibration is conducted near 68°F. Once a good calibration is achieved a fixed resistance calibration step is applied to one leg of the bridge and the reading recorded. Subsequent calibration of the nozzle transducer is easily accomplished by adjusting the bridge to zero (with zero differential pressure on the transducer) and then applying the calibration step and adjusting the power supply to match the calibration reading.

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

The four temperatures have an electronic temperature reference junction and the only calibration required is to verify the output. This is easily accomplished using an ice bath. The temperatures should read out in millivolts with three decimal places.
Turbine RPM is taken from a flux cutter on the turbine shaft and read out to five figures. No calibration is required.

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

3. DATA ACQUISITION

The normal 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.
APPENDIX C

SAMPLE TTTR ON-LINE REDUCTION RUN

-- CP-67 ONLINE
ENTER PASSWORD: $$$$$$$$$

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 PROBABLY 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 FT03F001
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 VIRT_CPU=000.02.21, TOT_CPU 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:

\[ M = \frac{0.0622}{4} \left( \frac{R^2 \omega}{\nu} \right) - 0.2 \rho \omega R^5 \quad \text{(ft-lbf)} \]  \hfill (D-1)

where:

- \( R \) = closure plate radius (ft)
- \( \omega \) = frequency (rad/sec)
- \( \nu \) = kinematic viscosity (ft\(^2\)/sec)
- \( \rho \) = density (lbf-sec\(^2\)/ft\(^4\))

If one assumes standard conditions, i.e.,

- \( T = 68^\circ F \)
- \( \nu = 160 \times 10^{-6} \text{ ft}^2/\text{sec} \)
- \( \rho = 0.00234 \text{ lbf-sec}^2/\text{ft}^4 \)

the torque equation reduces to:

\[ M = 5.98 \times 10^{-10} \text{ (rpm)}^{1.8} \quad \text{(ft-lbf)} \]  \hfill (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:

\[ n = \frac{\Delta T_w}{\Delta T_{IS}} = \frac{M_d \omega}{\dot{W} C_p J} \]  
(E-1)

where:

- \( M_d \) = dynamometer moment (ft-lbf)
- \( \dot{W} \) = turbine mass flow rate (lbm/sec)
- \( \Delta T_{IS} \) = stage isentropic temperature change (°R)
- \( \omega \) = turbine rotational velocity (rad/sec)
The stator efficiency is defined as:

$$\eta_s = \frac{V_1^2}{V_{1\text{TH}}^2}$$

(E-2)

with

$$V_1 = \text{actual exit-velocity (ft/sec)}$$
$$V_{1\text{TH}} = \text{theoretical or isentropic velocity (ft/sec)}$$

The rotor efficiency:

$$\eta_R = \frac{W_2^2}{W_{2\text{TH}}^2}$$

(E-3)

where:

$$W_2 = \text{the actual relative rotor exit velocity (ft/sec)}$$
$$W_{2\text{TH}} = \text{theoretical relative exit velocity (ft/sec)}$$

Another important parameter is the isentropic head coefficient:

$$K_{IS} = \frac{C_0^2}{U_1^2}$$

(E-4)

with:

$$C_0 = \text{theoretical fluid velocity obtained in an isentropic expansion from stator inlet pressure to rotor exhaust pressure; } C_0 = 2(gCp\Delta T_{IS})^{\frac{1}{2}} \text{ (ft/sec)}$$
$$U_1 = \text{rotor blade mean radius velocity (ft/sec)}$$

In defining the NASA referred values the referred temperature:

$$\theta = \frac{T_{TO}}{518.4}$$

(E-5)

and the referred pressure

$$\delta = \frac{P_{TO}}{14.7}$$

(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:

\[
\dot{W}_{\text{ref}} = \frac{\dot{W} \sqrt{\theta}}{\delta} \tag{E-7}
\]

the referred RPM;

\[
N_{\text{REF}} = \frac{N}{\sqrt{\theta}} \tag{E-8}
\]

The referred moment:

\[
M_{\text{REF}} = \frac{M_d}{\delta} \tag{E-9}
\]

and the referred horsepower:

\[
HP_{\text{REF}} = \frac{HP}{\delta \sqrt{\theta}} \tag{E-10}
\]

2. FLOW NOZZLE CALIBRATION

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

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

where:

\[
\begin{align*}
D_2 & = \text{nozzle diameter (ft)} \\
\gamma & = \text{coefficient of thermal expansion} \\
Y & = \text{nozzle expansion coefficient} \\
C & = \text{nozzle discharge coefficient} \\
P_{\text{NOZ}} & = \text{nozzle inlet total press (psi)} \\
T_{\text{NOZ}} & = \text{nozzle inlet total temp. (°R)} \\
\Delta H & = \text{nozzle differential pressure (in. H_2O at 68°F)}
\end{align*}
\]
For the non-standard nozzle \( C \) is assumed to be a function of the nozzle Reynolds 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

\[
C = 9.38917 \times 10^{-1} + 6.17669 \times 10^{-7} \text{Re} - 1.29859 \times 10^{-12} \text{Re}^2 \\
+ 1.25920 \times 10^{-18} \text{Re}^3 - 4.75948 \times 10^{-25} \text{Re}^4
\]  

(E-12)

agrees within 0.1% of the previous values of Esdaile [Ref. 1] over the range of expected Reynolds Numbers.
TRANSONIC TURBINE TEST RIG
FLOW NOZZLE CALIBRATION

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

REAL*8 PB, OKN2, WI, OKNEST, DFLOKN, COEFKN, SB
REAL*8 TITLE(16)/IO*
REAL*8 TITLE(12)'/DETHOMAS 1888 TTR NOZZLE CAL

2
REAL LABEL/4H
INTEGER*4 MMM
DIMENSION DH(100), PREF1(100), PNOZ(100), TNOZ(100), TNOZR(100),
DPFL(100), PORE(100), POR(100), TOP(100), TOPR(100), WFL(100).
OZNK(100, 1), PB(100), OKN4(100), KEY(100)
3, RE2(100), OKN2(100), WI(100), OKNEST(100), DFLOKN(100), COEFKN(10)
MMM=0
LLL=0

WRITE(6,14)
READ(5,15)L
DO 114 M=1,L
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) (POR(I), I=1,N)
WRITE(6,333) (POR(I), I=1,N)
READ(5,16) (TOP(I), I=1,N)
WRITE(6,333) (TOP(I), I=1,N)
333 FORMAT(333, 24F5.1)
DO 9 I=1,N
WRITE(6,24) I, DH(I), PREF(I), PNOZ(I), TNOZ(I), DPFL(I), PREF(I),
1 POR(I), TOR(I)
9 CONTINUE
23 FORMAT(' ',3E10.4)
24 FORMAT(' ',11E10,5X,8E10.4)

C

INPUT CONSTANTS

DO 7 II=1,100
WI(II)=1.0
7 CONTINUE
D10=6.365
D20=4.2443
DIN=7.975
D2N=4.25
BETA0=D20/D10
BETAN=D2N/D1N
GAM=1.4
EX1=GAM/(GAM-1.)
EX2=(GAM-1.)/GAM
EX3=2./GAM
A=D20*(830.5*500.0*BETA0+9000.*BETA0**2-4200.*BETA0**3+530.)/SORT(D10))
B=7.59934+.007/D10
C=0.3640+.0.776/SORT(D10)
OK=EX=EX2*EXP**4
OKINF=OKES/(1.+A*(0.15E-04/D20))

C

COMPUTE CORRECTED PRESS AND TEMPS

GHGBR=13.63965-.00136303*TPAR
GHGBR=13.63965-.00136303*TPAR
CHGBR=13.63965-.00136303*TPAR
CHGBR=13.63965-.00136303*TPAR
CHGBR=0.4891585*GHGBR/13.54
CHGBR=0.4891585*GHGBR/13.54
GW68=0.983763+.68.*CHGBR
GW68=0.983763+.68.*CHGBR
GWCR=1.160568-(-0.0068*2)*0.159319E-05
GWCR=1.160568-(-0.0068*2)*0.159319E-05
PAMB=PBAR*GHGBR
PAMB=PBAR*GHGBR

C

CALCULATIONS FOR ORIFICE FLOW RATE

DO 12 I=1,N
DPFL(I)=DPFL(I)*GWC/62.42732/1728.
POR(I)=CHGBR*(PREF(I)-POR(I)) PAMB
TOR(I)=CHGBR*(PREF(I)-POR(I))*1.855/TOR(I)**2
TOR(I)=TOR(I)+459.69
ALPHA0=1.+1.93*(TOR(I)-.68.0)*0.1E-04
Yo=1.+0.41+C.35*BETA0**4*DPFL(I)/(GAM*POR(I))
Z0=1.+0.24*(TOR(I)-10.0)*0.1E-02
HW680=DPFL(I)*GW68/GW68
FR=1.0
WFL(I)=0.1638427*D2O**2*ALPHAO*QKINF*FR*YO*SQRTPOR(I)*HW680/
1 TORR(I)
10 X0=2.27376*WFL(I)/(D2O*Z0)
FR=1.0*(A/X0)*0.1E-05
WFLC=0.1638427*D2O**2*ALPHAO*QKINF*FR*YO*SQRTPOR(I)*HW680/
1 TORR(I)
IF(ABS(WFLC-WFL(I))<0.0001) GO TO 11
WFL(I)=WFLC
GO TO 10
11 WFL(I)=WFLC

CALCULATIONS FOR NOZZLE DISCHARGE COEFFICIENT

QDH=DH(I)
DH(I)=QDH*GWC/R*62.42732/1728.
PMOZ(I)=CHCR*(PREF1(I)-PNOZ(I))*PAMB
TNOZ(I)=53.252*34.86*TNOZ(I)-3.1855*TNOZ(I)**2
TNOZR(I)=TNOZ(I)+459.69
ALPHA*H=1.2*52*(TNOZ(I)-68.)*0.1E-04
R=1.0*(DH(I)/PNOZ(I))
YN=SQRTP(R**2*Z3*Z1*(((1.-R**2*Z2)/(1.-R))*(1.-BETAN**4)/(1.-R**2*Z3*Z1)))
1 B=TAN**4)
ZM=1.9+2.4*(TNOZ(I)-100.)*0.1E-02
HW68N=QDH*GWC/6W68
QKN(I,1)=6.10342*WFL(I)*SQRTPZOR(I)/(HW68N*PNOZ(I))/(D2N**2*YN
1*ALPHAN)
RE(I)=2.27376*WFL(I)/(D2N*ZM)*0.1E+07
12 CONTINUE

WRITE OUTPUT DATA

WRITE(6,17)
WRITE(6,18)M,PNOZ(I)
WRITE(6,19)
WRITE(6,20)PAMB,N,GAM
WRITE(6,21)
DO 13 I=1,N
WRITE(6,22) I,WFL(I),QKN(I,1),RE(I)
RE2(I+MMD)=RE(I)
QKN2(I+MMD)=QKN(I,1)
QKN4(I)=QKN(I,1)
13 CONTINUE
MMD=MMD+N
LLL=LLL+1
CALL OSPLOR (RE,QKN,N,100,1.0,0.0,0.0,0.0,0.0,0.0)
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,0,0,0,0,1,1,9,12,1,2,50)
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
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
C
IF(RE(I).LT.3.E-05) WI(I)=.00001
IF(RE(I).GT.9.8.E-05) WI(I)=.00001
WI(8) = .00001
WI(27) = .00001

QKN2(I)=QKN4(KEY(I))
WRITE(6,128) I,KEY(I),RE2(I),QKN2(I)
116 CONTINUE

C NOPOLY=4
DO 31 KM=1,NOPOLY
CALL LSOLPL2(MMM,KM,RE2,QKN2,WI,QKNEST,DELQKN,COEFKN,SB,TITLE)
31 CONTINUE

C
C
C NOPOLY=4
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,0,0,0,0,1,1,9,12,1,2,50)
31 CONTINUE
14 FORMAT(1H1,32X,'FLOW NOZZLE CALIBRATION FOR THE TRANSONIC TURBINE
1 TEST RIG')
15 FORMAT(T3)
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,'(LB/SEC)',7X,'EFFICIENT',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

<table>
<thead>
<tr>
<th>POINT</th>
<th>FLOW RATE (LBM/SEC)</th>
<th>DISCHARGE COEFFICIENT</th>
<th>REYNOLDS NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3333</td>
<td>1.07321</td>
<td>97383.44</td>
</tr>
<tr>
<td>2</td>
<td>0.4692</td>
<td>1.02266</td>
<td>136285.44</td>
</tr>
<tr>
<td>3</td>
<td>0.6765</td>
<td>1.03890</td>
<td>194124.13</td>
</tr>
<tr>
<td>4</td>
<td>0.8338</td>
<td>1.02855</td>
<td>238953.19</td>
</tr>
<tr>
<td>5</td>
<td>0.9800</td>
<td>1.03587</td>
<td>280366.06</td>
</tr>
<tr>
<td>6</td>
<td>1.1435</td>
<td>1.03959</td>
<td>327711.44</td>
</tr>
<tr>
<td>7</td>
<td>1.2644</td>
<td>1.04350</td>
<td>360309.88</td>
</tr>
<tr>
<td>8</td>
<td>1.4301</td>
<td>1.04643</td>
<td>406644.50</td>
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<tr>
<td>9</td>
<td>1.6974</td>
<td>1.04931</td>
<td>450399.81</td>
</tr>
<tr>
<td>10</td>
<td>1.8496</td>
<td>1.05194</td>
<td>529164.81</td>
</tr>
<tr>
<td>11</td>
<td>2.0126</td>
<td>1.05259</td>
<td>562659.56</td>
</tr>
<tr>
<td>12</td>
<td>2.1460</td>
<td>1.05529</td>
<td>605166.31</td>
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<td>642331.75</td>
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<td>681821.44</td>
</tr>
<tr>
<td>15</td>
<td>2.5703</td>
<td>1.055220</td>
<td>722029.00</td>
</tr>
<tr>
<td>16</td>
<td>2.7281</td>
<td>1.05496</td>
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<td>2.8714</td>
<td>1.04955</td>
<td>805576.00</td>
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<tr>
<td>18</td>
<td>3.0038</td>
<td>1.04902</td>
<td>841254.50</td>
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<tr>
<td>19</td>
<td>3.1846</td>
<td>1.03917</td>
<td>892876.19</td>
</tr>
<tr>
<td>20</td>
<td>3.3206</td>
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<td>1058612.00</td>
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<td>21</td>
<td>3.7879</td>
<td>0.99500</td>
<td>1162145.00</td>
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<tr>
<td>22</td>
<td>4.1620</td>
<td>1.04259</td>
<td>1349941.00</td>
</tr>
<tr>
<td>23</td>
<td>4.8386</td>
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<td></td>
</tr>
<tr>
<td>24</td>
<td>5.1460</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### TEST SERIES 2

<table>
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<tr>
<th>POINT</th>
<th>FLOW RATE (LBM/SEC)</th>
<th>DISCHARGE COEFFICIENT</th>
<th>REYNOLDS NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3883</td>
<td>1.00618</td>
<td>111678.06</td>
</tr>
<tr>
<td>2</td>
<td>0.6027</td>
<td>1.04201</td>
<td>177419.81</td>
</tr>
<tr>
<td>3</td>
<td>0.7089</td>
<td>1.04152</td>
<td>202088.56</td>
</tr>
<tr>
<td>4</td>
<td>0.8637</td>
<td>1.04269</td>
<td>248257.10</td>
</tr>
<tr>
<td>5</td>
<td>0.9702</td>
<td>1.04955</td>
<td>272885.75</td>
</tr>
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<td>6</td>
<td>1.1179</td>
<td>1.03972</td>
<td>313904.81</td>
</tr>
<tr>
<td>7</td>
<td>1.2341</td>
<td>1.04268</td>
<td>345920.38</td>
</tr>
<tr>
<td>8</td>
<td>1.3822</td>
<td>1.04482</td>
<td>396788.13</td>
</tr>
<tr>
<td>9</td>
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Figure E-1. Flow Nozzle Calibration Plot (Nozzle Coefficient vs. Reynolds 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:

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

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)
- \( \theta_L \) = some function of the pressure ratio across the labyrinth seal.

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

The leak polynomial:

\[
\theta_L = -3.7487 \times 10^{-1} + 8.7014 \times 10^{-1} PR - 7.2633 \times 10^{-1} PR^2 \\
+ 3.158 \times 10^{-1} PR^3 - 6.9744 \times 10^{-2} PR^4 + 6.1683 \times 10^{-3} PR^5
\]

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

\[
PR = \frac{P_{TPL}}{P_{HD}}
\]
Values of the calculated leak rate are plotted against actual test point in Figures E-2.1 and E-2.2. (Run number three was at a higher temperature to check the temperature correction.)
TRANSONIC TURBINE TEST RIG
LABYRINTH LEAK RATE CALIBRATION

THIS IS THE CALIBRATION PROGRAM FOR THE LABYRINTH LEAK RATE OF THE TTTR.

USE INPUT DATA PATM(IN.HG.), PLAB(IN.HG.), PHD(IN.HG.), TTPLD(MV), THD(MV)
TTD1(MV), PFL(IN.HG.), HWFL(INM H2O), PBAR(IN.HG.), TCL(DEG.F), TCR(DEG.F)

C REAL*8 PRCF, WREFCF, WI, YY, DELY, BB, SB
REAL*8 TITLE(10) /10x'/'
REAL*8 ITITLE(12) '/DETHOMAS 1888 TTTR LAB LEAK CAL'

REAL LABEL/4H
DIMENSION PATM(90), PSPL(80), PHD(80), TTPLD(80), ERROR(80), TTD1(80),
1PFL(80), HWFL(80), WREFT(80),
2WLABR(80), WREF(80), RE(80), PR(80)
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-02
READ(5,99) L
DO 50 M=1,L
READ(5,100) PBAR, N, NNRUN
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) (TTD1(I), I=1,N)
READ(5,101) (TTPLD(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)
1, THD(I), PFL(I), PREF(I), HWFL(I), I=1,N)
WRITE (6,199) NNRUN
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
GHGC=0.4*915.95*GHGCL/13.54
GHGR=0.4989155*GHGRM/13.54
GW68=0.99837633+1.050576*68.-1.00000.-1.5931861*68.*2/1000000.
GW70=0.99837633+1.050576*TCL/10000.-1.5931861*TCL**2/1000000.
RATGW=GW70/GHGRM
PAMB=PRAR
PAMB=PAMB*CHGC
R=53.3448
G=32.174
DO 49 I=1,N
WII(I)=.0
QPATM=QPATM(I)
QPSTS=QPST(I)
QPHD=QPHD(I)
QTPLD=QTPLD(I)
QTD1=QTD1(I)
QPLF=QPLF(I)
QPF=QPF(I)
QHWFL=QHWFL(I)
THD(I)=32.*35.98*THD(I)-.435*THD(I)**2
TTPLD(I)=32.*35.98*TTPLD-.435*TTPLD**2
QTD1=32.*35.98*QTD1-.435*QTD1**2
ALPH=1.+0.00193*((QTD1-68.)/100.)
QPF=QPHD*GAM/I2.-62.42732/144.
QPF=QPHD*(QPF-QPF)+PAMB
Y=1.-0.41+0.25*(P**4)*QPF/(GAM*QPF)
HW68=QHWFL*QPATGW
TTD1R=QTD1+45.7
Z=.019+.0137*(QTD1/100.-1.)
WLABP(I)=0.1634827*D2**2*ALPH*QKINF*Y*SQRT(QPF*HW68/TTD1R)
10 X0=2.273766*WLABP(I)/(D2*Z)
FR=1.*XI/X0**0.1-0.5
WPART=0.1634827*D2**2*ALPH*QKINF*FR*Y*SQRT(QPF*HW68/TTD1R)
IFABS(WPART-WLABP(I))<=0.0001) GO TO 11
WLABP(I)=WPART
GO TO 10
11 WLABP(I)=WPART
RE(I)=27550.757*WLABP(I)/Z
QPSTS=CHGC*(QPSTM-QPSTS)+PAMB
QPHD=CHGC*(QPHDM-QPHD)+PAMB
PR(I)=QPSTS/QPHD
QPF(I)=QPF/QPHD
QPF(I)=QPF/I
TTPLDR=TTPLD(I)+459.7
CORR=(1.0+.22*{(TTPLD(I)-THD(I))/TTPLD(I)})**1.2
WREF(I)=WLBR(I)/QPSPL*SQRT(TTPLDR/R/G)/CORR
WREFCF(I)=WREFF(I)
504 WREFE=A1+A2*PR(I)+A3*PR(I)**2+A4*PR(I)**3+A5*PR(I)**4+A6*PR(I)**5
WREFT(I)=WREFP
IF(WREF(I)-WREFF(I))>20,20,30
20 ERROR(I)=-(WREF(I)-WREFF(I))/WREF(1)*100.
GO TO 51
30 ERRORP(I)=(WREFF(I)-WREFF(I))/WREF(I)*100.
51 CONTINUE
WW(I)=WREFF*QPSPL/SQRT(TTPLDR/R/G)*CORR**1.2
WRITE(6,201)I,WLBR(I),PR(I),TTPLD(I),RE(I),WREF(I),WREFF(I),ERROR(1(I),THD(I)
49 CONTINUE
CALL LSQPL2(N,-5,PREF,WWCF,WREFCF,WI,YY,DELY,PP,SB,TITLE)
CALL DPAWN(W,PR,WLABR,1,1,LABEL,ITITLE,0.,0.,0,0,1,1,9,12,1,LAST)
CALL DPAWN(W,PR,WW,3,0, LABEL,ITITLE,0.,0.,0,0,1,1,9,12,1,LAST)
50 CONTINUE
99 FORMAT(I2)
100 FORMAT(F10.4, I2, I3)
101 FORMAT(8F10.4)
199 FORMAT(1H1/54X,16HTTRSS RUN NUMBER3X,I3)
200 FORMAT(1X//39X,5HHLABRINT LEAK RATE OF THE TRANSONIC TURBINE
1TEST RIG//2X,5HPOINT6X,9HLABRINT7X,9HLABRINT4X,12HPLENUM TOTAL
26X,8HRRF YNOLDS 9X,8HREFREPB6X,11HANALYTICAL 6X,7HPERCENT9X,4HHHD/313X9HLABR RATE7X,8HPRESURE5X,11HTEMPERATURE8X,6HNUMBER10X,9HLABR
4RATER8X,8HREFREPB9X,5HERROR5X,11HTEMPERATURE/13X,9H(LBM/SEC)9X,5H
5RATIO8X, 7H(DEG F)17X, 7H(SQ IN)19X,9HLEAK RATE21X,7H(DEG F)///
201 FORMAT(3X,I2,8X,F8.5,8X,F7.4,8X,F7.3,8X,F10.2,7X,F9.5, 9X,F8.6,7X,
1F8.4,7X,F7.2)
202 FORMAT(' ',I2,3X,9E12.6)
203 FORMAT(' ',3E9.3)
204 FORMAT(' ',3E12.6)
STOP
END
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<th>LABYRINTH PRESSURE RATIO</th>
<th>PLENUM TOT. TEMPERATURE (DEG F)</th>
<th>REFERRED LEAK RATE (SQ IN)</th>
<th>ANALYTICAL REFERRED LEAK RATE</th>
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Figure E-2.1. Labyrinth Leak Calibration Plot (Run #2)

- Actual Labyrinth Mass Flow Rate
- Labyrinth Mass Flow Rate Approximation Using Analytic Expression

K-scale: 2.00E-02 units in K
Y-scale: 5.00E-02 units in Y

Dethomas 1888 TTTA Lab Leak Cal
Figure E-2.2. Labyrinth Leak Calibration Plot (Run #3)

- Actual Labyrinth Mass Flow Rate
- Labyrinth Mass Flow Rate Approximation Using Analytic Expression

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
02 FORMAT(1, 'TRANSONIC TURBINE TEST RIG (ON LINE DATA REDUCTION) = ', TTT00010
1//', HI THERE TITF FAN, THIS SYSTEM SHOULD INPUT FROM THE!
1//', TTT00020
2//', B&F DATA COLLECTION SYSTEM COUPLED TO A STANDARD ASCII T/F!
2//', TTT00030
3//', YOU SHOULD BE SCANNING CHANNELS 1-29 AND 86-99 WITH THE URGER!
3//', TTT00040
4//', LIMIT SET AT 90. VALVE 1 SHOULD BE THE ONLY VALVE SELECTED!
4//', TTT00050
5//', AND ITS UPPER LIMIT SET AT 22. THE RUN NUMBER, POINT NUMBER!
5//', TTT00060
6//', DAY, MONTH AND YEAR SHOULD BE ENTERED IN THE CONSTANT WHEELS!
6//', TTT00070
7//', IN GROUPS OF TWO.
7//', TTT00080
8//', FOLLOWING THE LAST AUTOMATIC DATA POINT YOU MUST MANUALLY!
8//', TTT00090
9//', PUNCH THE STATOR FORCE AND TORQUE AND DYNAMOMETER TORQUE.!
9//', TTT00100
B//', THESE WILL BE CHARACTERS WITH PROPER SIGNS AND DECIMAL.
B//', TTT00110
C//', POINTS. FOLLOWING THE LAST POINT OF EACH RUN SET POINT NUMBER!
C//', TTT00120
D//', 00 AND ALLOW THE CONSTANT VALUES TO PUNCH. ALL MANUAL POINTS!
D//', TTT00130
E//', WILL BE FOLLOWED BY C.R.L.F., X-OFF, X-OFF AND NO SPACES MAY BE!
E//', TTT00140
F//', SKIPPED.'
F//', TTT00150
G//', THIS PROGRAM WILL PROBABLY DESTRUCT IN 10 SEC. GOOD LUCK!}
G//', TTT00160

REAL#4 MVA1M, MVA1, MV1M, MV1C, MV1, MW1, MV2, MW2

DIMENSION DH(50), PREF1(50), RNOZ(50), PTPL(50), PTO(50), PREF2(50),
1 PHUI(50), PTIP(50), P13(50), P14(50), P15(50), P16(50), P17(50), P18(50),
2 P19(50), P2C(50), P2L(50), P19(50), P2C(50), P2L(50), P19(50), P2C(50), P2L(50),
3 TNOZ(50), TTPL(50), TTO(50), TTHD(50), AXILV(50), TORQR(50), DYNAR(50),
4 RPM(50), CLAXILV(50), CLTRQR(50)

DIMENSION FAX(50), CLFAX(50), FC(50), F1(50), F2(50), F3(50), F4(50),
1 F5(50), F6A1(50), F61(50), FTO(50), FCTRQR(50), FLOWN(50), FLOWT(50),
2 FLOWL(50), FREL(50), PHI(50), XI(50), PIAV(50), PRPL(50), PRS(50), T1(50),
3 T1S(50), VAT1(50), VUI1(50), V1(50), V1S(50), ALPH1(50), VCOFS(50),
4 MV1(50), MVA1(50), VA1(50), WUI1(50), W1(50), W1S(50), ETA1(50), MVW1(50),
5 Zetas(50), ETAS(50), PT2(50), P3(50), PT3(50), TE(50), TT2(50), TT3(50),
6 T2(50), T2(50), T21S(50), T21S(50), T21S(50), T21S(50),
7 T2TH(50), TT2IS(50), DELFW(50), DELTIS(50), DELFW(50), DELTIS(50),
8 VA2(50), VU2(50), V2(50), VOIS(50), ALPH2(50), W2A1(50), WU2(50), W2(50),
9 U2(50), N2S(50), BETAV(50), BETAV(50), WCIFS(50), WCIFS(50), ZETAR(50), ETAR(50),
10 REFPRM(50), XKT(50), ETATS(50), ETAI(50), REFLOW(50), REFMOM(50),
* HP(50), REFHP(50), REACHB(50), REACHN(50), REACTP(50), F(50), MV2(50),
* MW2(50), REACCF(50), QNOZ(50), QTPL(50), QTO(50), QHD(50), TPQ(50),
* TTP(50), SLF(50), SFF(50), RFAX(50), RQ(50), RV1A(50), RV1U(50)

WRITE(6, 01)
WRITE(6, 05)
READ(5, 06) AXCLR
READ(5, 07) AXCLR
WRITE(6, 08)
05 FORMAT(1, '///', '---PLEASE ENTER AXIAL CLEARANCE')
06 FORMAT(F20.5)
TORQR(NP)=QTORQR
DYNAR(NP)=QDYN
CLFAX(NP)=QLFAX
FAX(NP)=QFAX
TORQ(NP)=QTORQ
CLTORQ(NP)=QLTORQ
RPM(NP)=QRPM
CLAXIL(NP)=QLAXIL
CLTRQR(NP)=QLTRQR
FLOWT(NP)=QFLOWT
FLOWL(NP)=QFLOWL
PRPL(NP)=PRP
RF(NP)=QRE

IF(MODPAD.EQ.0) GO TO 12
    CALL HAMMER(NP, QTORQ, QRPM, QFLOWT, PRP)
12 CONTINUE
    GO TO 11
13 CONTINUE
    DO 15 J=1,2
        DO 14 I=1,NP
    10 OPTO=PTO(I)
    11 QPHUB=PHUB(I)
    12 QPTIP=PTIP(I)
    13 QP13=P13(I)
    14 QP14=P14(I)
    15 QP15=P15(I)
    16 QP16=P16(I)
    17 QP17=P17(I)
    18 QP18=P18(I)
    19 QP19=P19(I)
    20 QP20=P20(I)
    21 QP21=P21(I)
    22 QPHD=QHD(I)
    23 QTO=QTO(I)
    24 QTHD=QTHD(I)
    25 QAXIL=AXIL(I)
    26 QTORQ=TORQR(I)
    27 QDYNAR=DYNAR(I)
    28 QRPM=RPM(I)
    29 QLAXIL=CLAXIL(I)
    30 QLTORQ=CLTORQ(I)
    31 TTR=TTORQ(I)
    32 QFAX=FAX(I)
    33 QLFAX=CLFAX(I)
    34 QTORQ=TORQ(I)
    35 QLTORQ=CLTORQ(I)
RVA1(I)=QRVA1
RUV1(I)=ORUV1

14 CONTINUE
CALL OUTPTS(NRUN, NP, FAX, CLFAJ, FC, F1, F2, F3, F4, F5, F6A, FNET,
TQR, CLTQR, FLOWN, FLOWT, FLOWL, RE, PHI, XI, OMOZ, QTPL, PTO, PIAV, QHD,
PRPL, PRS, TTO, T1, T1IS, VA1, VU1, V1, V1IS, ALPH1, VCOFS, MV1, MVA1,
3 WA1, WU1, W1, U1, BETAS, ETAS, ETATS, PRS, PAMR, NDAY, NMO, NYEAR, RFAX,
4RTQR, RVA1, RUV1, J)

CALL OUTTPS(NRUN, NP, AXCLR, RADCLR, PAMR, PTO, PIAV, PT2, QHD, PR,
1 TTO, T1, TE, T2, T2IS, T2TH, T2IS, DLTIS, DLTW, VA2, VU2, V2, V0IS,
2 ALPH2, WA2, WU2, W2, U2, W2IS, ETA2, DETA, WCOFS, ZETAR, ETAR, RPM, HP,
3 DTHS, DTHW, REFRPM, KIIS, ETATS, ETATT, REFLOW, REFMOF, REFPH, J,
4 REACH, REACMN, REACTP, NDAY, NMO, NYEAR, F, REACEF, RV2, MW2, SLF, SFF)

15 CONTINUE
CALL LISA(NP, NRUN, NDAY, NMO, NYEAR, KIIS, ETATS, PRS, ZETAS,
1REFRPM, ETAR, ETAS, RTQR)
STOP
END

SUBROUTINE SETCON(D1N, D2N, BETAN, RG, GAM, GC, CP, CJ, C, EX1, EX2, EX3, PI,
1 ZNS, TETS, RTHING, RHUB1, RTHING, RHUB2, AAxs, AAxR, ATHS, RM1, RM2, SKT, RKT,
2 RADCLR, B1, B2, B3, B4, B5, D1, D2, D3, D4, D5, D6, CL1, CL2, CL3, J, MODRAD)
D1N=7.975
D2N=4.250
BETAN=D2N/D1N
RG=53.3448
GAM=1.4
GC=32.174
CJ=778.16
EX1=GAM/(GAM-1.)
EX2=(GAM-1.)/GAM
EX3=2./GAM
CP=EX1*RG/CJ
C=2.*GC*CJ*CP
PI=3.1416
ZNS=31.
DTHS=0.205
SS=0.8594
TETS=0.224
DTHR=0.1314
SR=0.4495
TETR=0.620
RTHI=4.585
RHUB1=3.895
RTHING=4.763
RHUB2=3.826

T002410
T002420
T002440
T002460
T002480
T002490
T002500
T002510
T002520
T002530
T002540
T002550
T002560
T002570
T002580
T002590
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T002740
T002750
T002760
T002770
T002780
T002790
T002800
T002810
T002820
T002830
T002840
T002850
T002860
AAXS=PI*{(RTIP1)**2-(RHUB1)**2}
AAXR=PI*{(RTIP2)**2-(RHUB2)**2}
ATHS=RTIP1*RTIP1-RHUB1)*ZNS
RM1=RTIP1+RHUB1/2.
RM2=RTIP2+RHUB2/2.
SKT=1.1277/100)3)*{(TETS/SS**3.3)*DTHS/SS
RAT=1.1277/100)3)*{(TETS/SS**3.3)*DTHR/SR)*{(AAXR+PI*
1 RADCLR*{RTIP2+RADCLR/2.)}/AAXR)

B1=9.38917E-01
B2=6.17669E-07
B3=1.29359E-12
B4=1.58232E-18
B5=4.75646E-25
D1=3.7487E-01
D2=8.7914E-01
D3=7.2633E-01
D4=3.1583E-01
D5=6.9744E-02
D6=6.1633E-03
CL1=2.7923457E-03
CL2=5.105617E-04
CL3=9.110660E-08
J=2

SET MODRAD=0 FOR NORMAL REDUCTION. IF MODRAD=1 THE ON-LINE
PARAMETER RETURN LOOP WILL BE ACTUATED....

MODRAD=1
RETURN
END

SUBROUTINE INPUT(NRUN, NP, NDAY, NMO, NYEAR, QPBAR, QPNOZ, QPT0,
QPHUB, QPTIP, QP13, QP14, QP15, QP16, QP17, QP18, QP19, QP20, QP21, QPHD,
QPCL1, QPCL2, QPCL3, QPPTL, QDH, QLAXIL, QMTRQR, CTNO2, QTTO, QTHD,
QPMP, QAXIL, QTQROR, QDYNAR, AXCCLR, RADCLR, LASTPT)
NPCHBK=NP
READ(5,101)NRUN, NP, NDAY, NMO, NYEAR
IF (NP .LT. 0) GO TO 103
NP=NPCHBK
LASTPT=1
RETURN
CONTINUE
READ(5,102)QPBAR, DUMMY, QPNOZ, QPPTL, QPT01, QPT02, QPT03, 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, QMTRQR, DUMMY, DUMMY, DUMMY, DUMMY, QDH, DUMMY, DUMMY
QTTO=(QPT01+QPT02+QPT03)/3
READ(5,103)CTNO2, DUMMY, QTTO1, QTTO2, DUMMY, QTHD, DUMMY, DUMMY, DUMMY, QTHD, DUMMY, DUMMY, DUMMY, DUMMY, DUMMY, DUMMY
\begin{verbatim}
QTTO=(QTTO1+QTTO2)/2.
READ(5,104) Q RPM
READ(5,105) QAXIL,QTORQR,QDYNAR
101 FORMAT(1X,A2,1X,I2,1X,3A2)
102 FORMAT(7X,F6.2)
103 FORMAT(7X,F6.3)
104 FORMAT(8X,F5.0)
105 FORMAT(F5.0)
IF(NP,NE,1) GO TO 114
WRITE(8,113) NRUN,NDAY,NMD,NYEAR
WRITE(8,112)
114 WRITE(8,111) NP,QPBAR,QPNOZ,QPTO,QPHUB,QPTIP,QP13,QP18,QP19,QP20,
1QP21,QPDH,QTNOZ,QTTO,QTHD,QRPM,QAXIL,QTORQR,QDYNAR,QLAXIL
111 FORMAT(' ',112,1X,1L16.6,2*4F5.2,3H5.0)
112 FORMAT(' ',112,1X,1L16.6,2*4F5.2,3H5.0)
'P13', '3X', 'P18', '3X', 'P19', '3X', 'P20', '3X', 'P21', '3X', 'PHD', '2X', 'DH', '3X',
'2', 'TN0Z', '2X', 'TTO', '2X', 'THD', '3X', 'RPM', '3X', 'AXIL', '2X', 'TORQR', '1X', 'DYNAR',
31X,'CLAXIL'//)
113 FORMAT('!',T41,'TRANSOPC TURBINE TEST RIG INPUT DATA',/,'T41',
1' ',/,'2X','RUN NUMBER','A2',
2'I5X','DAY','A2','I0X','MONTH','A2','I0X','YEAR ','A2',/)
RETURN
END

SUBROUTINE CONVERT(NP,QPBAR,QPDH,QPNOZ,QPTO,QPHUB,QPTIP,QP13,QP14,
1QP15,QP16,QP17,QP18,QP20,QP21,QP22,QP23,QP24,
2QTORQR,QTNOZ,QTTO,QTHD,QRPM,QAXIL,QLAXIL,QL12,QL24,QL13,QL33,RPM)
TEMPR(X) = 32 + 4.35*98*X - 1435*X**2 + 459.69
PPSIA(X) = .4891585*X
QPARB = .4891585*QPBAR
QPDH=QPDBH*62.42732/1728.
QPNOZ=PPSIA(QPNOZ)
QPTO=PPSIA(QPTO)
QPHUB=PPSIA(QPHUB)
QPTIP=PPSIA(QPTIP)
QP13=PPSIA(QP13)
QP14=PPSIA(QP14)
QP15=PPSIA(QP15)
QP16=PPSIA(QP16)
QP17=PPSIA(QP17)
QP18=PPSIA(QP18)
QP19=PPSIA(QP19)
QP20=PPSIA(QP20)
QP21=PPSIA(QP21)
\end{verbatim}
C C C

QPCL1=PPSIA(QPCL1)
QPCL2=PPSIA(QPCL2)
QPCL3=PPSIA(QPCL3)
QTPPL=PPSIA(QTPPL)
QPMD=PPSIA(QPMD)
QTONR=TEMPR(QTONR)
QTOT=TEMPR(QTOT)
QTHD=TEMPR(QTHD)
FAX=0.48-AXIL
TORD=TORD2/20
DYN=TORD3/30

USE THE FIRST OR THE SECOND CLEAX TERM DEPENDING
ON THE METHOD USED TO MEASURE THE CLOSURE
PLATE AXIAL FORCE, STRAIN GAGES OR PRESSURES.

CLEAX=CLAX1!
CLEAX=((7.74**2)*.1416/4.0)*((QPHUB-(QPCL1+QPCL2+QPCL3)/3.0)
CLTOPQ=598e-09*RPM**1.8
RETURN
END

SUBROUTINE FLORAT(D2N, RG, GC, EX1, EX2, EX3, HW68, DH, PNOZ, PTPL, PHD, PR,
1 TNOZ, TNOZR, TTP, TTPL, THD, B1, B2, B3, B4, R5, D1, D2, D3, D4, D5, D6, NRUN,
2 I, RE, FLOWN, FLOWL, FLOWT, BETAN)

ALPHAN=1.0+2.52*(TNOZ-68.)*C.1E-04
R=1.0-(DH/PNOZ)
Y1=R**EX3
Y2=EX1
Y3=1.-P**EX2
Y4=1.-P
Y5=1.-BETAN**4
Y6=1.-P**EX3*BETAN**4
ARG=Y1*Y2*(Y3/Y4)**(5/6)
YN=SQR(TARG)
ZNE=1.0+2.4*(TNOZ-100.)*C.1E-02
CN=1.0
WNE=0.1635+27*D2N**2*ALPHAN*YN*CN*SQR((PNOZ*HW68/TNOZ))
400 RE=2.27376*WNE/(D2N**2)*C.1E+07
C NEED TO CHANGE THIS TO AGREE WITH NEW NOZZLE CAL.
C NEED TO CHANGE THIS TO AGREE WITH NEW NOZZLE CAL.
CN=RE**(B3+RE**(B4+RE**(B5+RE**)))
WNC=0.1635+27*D2N**2*ALPHAN*YN*CN*SQR((PNOZ*HW68/TNOZ))
401 FLOWN=WNC
402 RE=2.27376*FLOWN/(D2N**2)*C.1E+07
IF (REF. GT. 1.2E+06) GO TO 404
PR = PTPL/PHO
WREF = D1 + PR * (D2 + PR * (D3 + PR * (D4 + PR * (D5 + D6 * PR)))))
CORR = (1 + 0.32 * ((TTPP*THD)/TTPP)) * 1.2
FLOW = WREF * PTPL / SQRT (TTPPL * RG * GC) * CORR
FLOW = FLOW - FLOW
GO TO 416
404 WRITE (8, 405) NRUN, I
405 FORMAT ('/ 33X, A4, 7X, 36H FLOW RATE TOO HIGH, CHECK INPUT DATA/)
406 RETURN
END

SUBROUTINE STATOR (RG, GAM, GC, C, P1, EX1, EX2, EX3, EPS, RTIP1, RHUB1, RM1, TTPP)
1 PHUB, PTIP, P1AV, PTD, P13, P18, P19, P21, PHD, PRS, FLOW, AAXS, ATHS,
2 SKT, J, TITOR, TIRM, TISR, ZETAS, ETAS, PHI, XI, RPM, VA1M, VI1M, VI1S, T1M1,
3 VCDEFS, ALPH1M, MV1M, MV1A, U1, W1, WU1, VI1, BETA1, MW1, TOR3, CLTORG, FAX,
4 CLFA, X, F1, F2, F3, F4, F5, F6A, FNET, RAFA, RTO, RVTORG, RV1AL, RVU1)
REAL * 4, MVA1M, MAV1M, MV1M, MV1C, MV1, MW1, MW2
IF (J.GE. 2) GO TO 50
P1AV = (PHUB + PTIP) / 2.
C IN THIS SECTION, M SUBSCRIPT REPRESENTS VALUES COMPUTED BY CONTINUITY
C2 = (C + P1AV) * ATHS / (RG * FLOW)
V1M = SQRT (C * TITOR + (C2 / 2.)) ** 2 - C2 / 2.
TIRM = TITOR - V1M * 2 / C
VA1M = (FLOW * RG * TIRM) / (P1AV * AAXS * SKT)
VR = VA1M / V1M
IF (ABS (VR) .GE. 1.5) VR = 1.0
AN = ARCOS (VR)
V1M = V1M * SIN (AN)
ALPH1M = AN / (180 / PI)
MV1M = V1M / SQRT (GAM * GC * RG * TIRM)
MV1A = VA1M / SQRT (GAM * GC * RG * TIRM)
CALL FORCE (PI, RTIP, RHUB1, AAXS, PHUB, P1AV, PTIP, P13, P18, P19,
1 P21, P21, PHD, FAX, CLFAX, F0, F1, F2, F3, F4, F5, F6A, FNET)
GO TO 536
500 WRITE (8, 501)
501 FORMAT (14H 'V9X, 3H EPS8X, 4H PLAV8X, 3HT1M10X, 3HT1C9X, 4H VALM10X, 4H VAI1C8X,'/
14H MV1M9X, 4HMV1C7X, 8H BHALPHA 1C7/
EPS = 0.0
502 P1AV = PHUB / 3. * (((1. + EPS) * (RTIP1) + 2. + (RHUB1) * (RTIP1) - (2. + EPS) *
1 (RHUB1)) ** 2 / ((RTIP1) + 2. - (RHUB1) ** 2) / PTIP3, ** (((2. + EPS) * (RTIP1) -
2 ** 2 - (PHUB1) * (RTIP1) - (1. + EPS) * (RHUB1) ** 2) / ((RTIP1) + 2. - (RHUB1) ** 2) / PTIP1,
CALL MOMENT (RG, GAM, GC, C, RM1, AAXS, TOR3, CLTORG, FLOW, PI, RTIP1,
1 RHUB1, FAX, CLFAX, PHUB, PTIP, P1AV, P13, P18, P19, P21, PHD, T1M, TIRM,
2 VI1M, VI1A, ALPH1M, MV1M, MAV1, F0, F1, F2, F3, F4, F5, F6A, FNET)
C = SQRT (C * TITOR - VU1) ** 2 + (C / (2. * C1)) ** 2 - C / (2. * C1)
503 STOP
ALPH1C=ATAN(V1/C/VA1C)
ALPH1C=ALPH1C+180./PI
V1C=SORT(V1C**2+VU1**2)
TIRC=TOR=(V1C**2)/C
MV1C=V1C/SORT(GAM*GC*RG*TIRC)
WRITE(8,503)EPS,PLAV,T1RM,TIRC,VA1M,VA1C,MV1M,MV1C,ALPH1M,ALPH1C

FORMAT(10F13.5)
DIFF=ABS(T1RM-TIRC)
IF(DIFF<1.0) 506,506,504
IF(TIRC.LT.T1RM) GO TO 505
EPS=EPS+DIFF/500.
GO TO 502
EPS=EPS-DIFF/500.
GO TO 502
504 PRS=PLAV/PT0
IF(PRS.GE.1.0) PRS=0.9990
T1ISR=TOR*PRS**EX2
ZETAS=(T1RM-T1ISR)/(TOR-T1ISR)
ETAS=1.0-ZETAS
V1IS=SORT(C*(TOR-T1ISR))
VCOES=V1H/V1IS
PHI=FLOWT/(PT0*ATHS)*SQR(TOR*RG/GC)
PRTHS=PRS
IF(PRTHS.LT.0.52828) PRTHS=0.52828
XI=PHI/SQRT(2.*EX1*(PRTHS**EX3-PRTHS**{(GAM+1.)/GAM}))
PPS=1./PRS
UI=PI**RPM**RML/36
W1U=VU1-UI
W1=VA1M
BETA1=ATAN(WU1/WA1)
W1=WA1/COS(BETA1)
BETA1=BETA1+180./PI
MV1=W1/SORT(GAM*RG*GC*T1RM)
FAX=FAX/(PT0/14.69)
RTOR=TORQ/(PT0/14.69)
RVA1=VA1M/SORT(GAM*GC**RG*T1R)
RVU1=VU1/SQRT(GAM*GC**RG*T1R)
RETURN
END

SUBROUTINE MOMENT(RG,GAM,GC,C,RML,AAXS,TORQ,CLTORQ,FLOWT,PI,RTIP1,TTT05100
1 RUBI,FAX,CLFAX,PHUS,PTIP,PLAV,P123,P18,P19,P2C,P21,PHD,TTOR,T1RM,TTT05110
2 VU1,VA1M,V1M,ALPH1M,MV1M,MVA1M,F0,F1,F2,F3,F4,F5,F6A,FNET)
C
REAL=4. MVA1M,MVA1,MV1M,MV1C,MV1,WM1,MV2,MW2
VU1=(TOPQ*CLTORQ)*12.*GC/(FLOWT*RML)
AC=PI*3.125*20

TTT04710
TTT04720
TTT04730
TTT04740
TTT04750
TTT04760
TTT04770
TTT04780
TTT04790
TTT04800
TTT04810
TTT04820
TTT04830
TTT04840
TTT04850
TTT04860
TTT04870
TTT04880
TTT04890
TTT04900
TTT04910
TTT04920
TTT04930
TTT04940
TTT04950
TTT04960
TTT04970
TTT04980
TTT04990
TTT05000
TTT05010
TTT05020
TTT05030
TTT05040
TTT05050
TTT05060
TTT05070
TTT05080
TTT05090

TTT05100
TTT05110
TTT05120
TTT05130
TTT05140
TTT05150
TTT05160
A2=PI*(5.125**2-5.003**2)
A3=PI*(5.063**2-4.*901**2)
A4=PI*(4.901**2-4.*773**2)
A5=PI*(4.*773**2-RTIP1**2)
A6=PI*RHUB1**2
F0=AO*PHD
F1=AAXS*PIAV
F2=A2*P21
F3=A3*((P20+P19)/2.)
F4=A4*P18
F5=A5*((PTIP+P13)/2.)
F6A=A6A*PHUB
FNET=FAX+CLFAxF1-F2-F3-F4-F5-F6A

VA1M=FNET*GC/FLOWT
ALPH1M=ATAN(VU1/VA1M)
ALPH1M=ALPH1M/180./PI
V1=SQR((VA1M**2+VU1**2)
T1RM=T1OR-(V1M**2)/C
MV1M=V1M/SQR((GAM*GC*RG*T1RM)
V1A1M=V1A1M/SQR((GAM*GC*RG*T1RM)
RETURN

SUBROUTINE FORCE(PI,RTIP1,RHUB1,AAXS,PHUB,PIAV,PTIP,P13,P18,P19):
1 P20,P21,PHD,FAX,CLFAxF1,F2,F3,F4,F5,F6A,FNET)
SUBROUTINE ROTOR (RG, GC, CJ, CP, C, PI, EX1, EX2, RM1, RM2, AAXR, RKT, PTO, TT05580
PIAV, PHD, PT2, PRM, DYNA, FLOWT, TTOR, T1RM, T2R, TT2R, DELTW, T2ISR, TER, TT05590
VU1, U1, W1, BETA1, VU2, VA2, V2, ALPH2, U2, WU2, WA2, W2, W2IS, BETA2, DBETA, TT05600
WCDEFS, ZETAR, ETAR, MV2, MW2, GAM, RPM, SFL, EFF) TT05610
REAL*4 MVA1M, MVA1, WVA1M, WVA1, MV1, MW1, MV2, MW2
VU2=RM1/RM2*VU1-(12.0*DYNAXGC)/(RM2*FLOWT)
U2=U1*RM2/RM1
WU2=VU2-U2
DELTW=(DYNA*PI/RPM)/(30.*FLOWT*CJ*CP)
TT2R=TTOR-DELTW
T2ISR=T1RM+(PHD/PIAV)**EX2
TER=T1RM+(W1**2-U1**2+U2**2)/C
C3=FLOWT*RG/(PHD*AAXR*RKT)
VA2=SORT(C*T2R-VU2**2+(C/(2.*C3)**2)-C/(2.*C3))
V2=SORT((VA2**2+VU2**2)
T2=TT2R-(V2**2)/C
MV2=V2/SORT(GAM*RG*GC*T2R)
PT2=PHD*(TT2R/T2R)**EX1
PRM=P0/PHD
W2=W2/SORT((GA*RG*GC*T2R)
ALPH2=ATAN(VU2/VA2)
ALPH2=ALPH2*180./PI
BETA2=ATAN(WU2/VA2)
BETA2=BETA2*180./PI
DBETA=BETA1-BETA2
ZETAR=(T2R-T2ISR)/(TER-T2ISR)
ETAR=1.0-ZETAR
W2IS=SORT(C*(TER-T2ISR))
WCDEFS=W2/W2IS
IF(U2.LE.1.0) U2=0.001
SFL=(VU1-VU2)/U2
SFF=VA2/U2
RETURN
END

SUBROUTINE PERFOM(C, PI, EX2, PTO, PHUB, PTIP, PHD, PT2, DYNA, RPM, FLOWT, TT05950
TTOR, TT2R, T2THR, T2ISR, DELHIS, DELHN, DELTIS, DELTW, VOIS, V1IS, U1, V2, TT05960
ETAT5, ETATT, REACMN, REACTB, REACTP, XKIS, REFLOW, REFRPM, REFMOM, HP, TT05970
REFHP, T2ISP, F, V1, W1, U2, W2, REACEF, CP) TT05986
DELTIS=TTOR-(1.0-(PHD/PTO)***EX2)
T2THR=TTOR-DELHIS
T2ISR=TTOR-(PT2/PTO)***EX2
DELHIS=CP*(TTOR-T2THR) TT06010
TT06020
```
DELHW=CP*(TTOR-TT2R)
ETATS=DELTW/DELTUS*100.
F=T2ISR/T2THR
ETATS=DELTW/(DELTUS-(-V2**2)/(C*F))=100.
WC=SORT(C*DELTUS)
REACE=(W2**2-W1**2+U1**2-U2**2)/(V1**2+W2**2-W1**2+U1**2-U2**2)
REACHN=1.6-(V1**2+V1**2)*2
BP=(PHUB/PHD)**FX2-1.)/(PTO/PHD)**FX2-1.
BP=(PTO/PHD)**FX2-1.)/(PTO/PHD)**FX2-1.
IF(U1.LE.1.0) U1=0.001
XKIS=(VQIS/U1)**2
DEL=PTO/14.69
THETA=TTOR/518.69
RECFLOW=FLOW/SORT(THETA)/DEL
RECFM=PRM/SORT(THETA)
REFFM=?DYNA/DEL
HP=(DYNA/PT/PRM)/(J30**550.)
REFFHP=HP/(DEL/SORT(THETA))
RETURN
END

SUBROUTINE OUTPTS(NPUN, NP, FAX, CLFAX, F0, F1, F2, F3, F4, F5, F6A, FNEN, TTT06240
1 TORO, CLTORQ, FLOW, FRL, FLOWL, PHI, XI, QNOZ, QTPL, PTO, PIV, PIVAV, FHD, TTT06250
2 PRPL, PRS, TTO, T1, TII, S, WAI, WU1, WI, U1, BETAI, MW1, ZETAS, ETAS, PAMB, NDAY, NMID, NGEN, RFA,
3 WPOR, RP, RV1, RV1,
4 REAL*4 MVAM, MV1, MV1C, MV1, MV1, MV2, MW2
5 DIMENSION FAX(50), CLFAX(50), F0(50), F1(50), F2(50), F0(50), F3(50), F4(50), TTT06300
1 F5(50), F6A(50), FNEN(50), TOPO(50), CLTORQ(50), FLOW(50), FLOWL(50), TTT06310
2 FLOWL(50), F6A(50), PHI(50), XI(50), QNOZ(50), QTPL(50), PTO(50),
3 PIV(50), PIVAV(50), PRPL(50), PRS(50), TTO(50), T1(50), TII(50), TTO(50),
4 TII(50), TII(50), S, WAI(50), WAI(50), WAI(50), WAI(50), WAI(50), WAI(50),
5 MW1(50), MW1(50), MW1(50), MW1(50), MW1(50), MW1(50),
6 ZETAS(50), ETAS(50), FAX(50), RP(50), RP(50), RV1(50), RV1(50),
7 WRITE(8,800) NRUN, NDAY, NDAY, NDAY, J30
8 REAL*4 NPUN, NP, FAX, CLFAX, F0, F1, F2, F3, F4, F5, F6A, FNEN, TTT06380
1 800 FORMAT(1H1, 1X, 'STATOR RESULTS', 1X, 1X, 'CONFIGURATION-',
2 'NOZZLE: SHROUD P/N 1050, INSERT P/N 2005-3 (STRAIGHT)', 1X, 1X,
3 801 FORMAT(/ 1X, 'FORC mounting BALANCE (LBS AND FT-LBS)!', 1X, 1X,
4 1, 'POINT', 2X, 'FAX(+)', 1X, 'CLFAX(+)', 2X, 'FO(+)', 3X, 'F1(-)', 3X, 'F2(-)', 1X, 3X, 'F3(-)', 3X, 'F4(-)', 1X, 3X, 'F5(-)', 1X, 3X, 'F6A(-)', 4X, 'FNET', 2X, 'TORQ', 1X, 1X,
5 1, 'WRITE(8,800)', 1X, 'FAX(I), CLFAX(I), F0(I), F1(I), F2(I), F3(I), F4(I), F5(I), F6A(I), FNEN(I), TTT06400
1, TORQ(I), CLTORQ(I), RP(50), RP(50), RV1(50), RV1(50),
8C2 WRITE(8,800) I, FAX(I), CLFAX(I), F0(I), F1(I), F2(I), F3(I), F4(I), F5(I), F6A(I), FNEN(I), TTT06490
1, TORQ(I), CLTORQ(I), RP(50), RP(50), RV1(50), RV1(50),

```
SUBROUTINE OUTPTR(NRUN, NP, AXCLR, RADCLR, PAMB, PT0, P1AV, PT2, QHD, PR, TTT06940
1 TTO, T1, TE, TT2, T2, T2IS, T2TH, TT2IS, DELTIS, DELTW, VA2, VU2, V2, VOIS, TTT06960
2 ALPH2, W2A, W2U, W2, U2, U2IS, BETAA, DBETA, WC0FS, ZETAR, ETAR, RPM, HP, TTT06980
3 DELHIS, DELHW, REFPMP, XVIS, ETATS, ETATT, REFLOW, REFMON, REHPM, J, TTT06970
4 PEAChB, REACMN, REACTP, NDAY, NMO, NYEAR, F, REACTEF, MV2, MW2, SLF, SFF, TTT06990
REASI 4 MVA1M, MV1M, MV1C, MV1, MW1, MW2, MW2, TTT06990
DIlENSION PT(50), PTV(50), T4(50), QHD(50), PR(50), TTO(50), T1(50), TTT07030
1 TE(50), TT2(50), T2(50), T2IS(50), T2TH(50), TT2IS(50), DELTIS(50), TTT07020
2 DELT(50), VA2(50), W2U(50), W2(50), U2(50), W2IS(50), BETAA(50), DBETA(50), WC0FS(50), TTT07030
3 ZETAR(50), ETAR(50), PP(50), HP(50), DELHIS(50), DELHW(50), REFPMP(50), TTT07040
4 XVIS(50), ETATS(50), ETATT(50), REFPMP(50), REHPM(50), TTT07050
5 PEAChB(50), REACMN(50), REACTP(50), NDAY(50), NMO(50), NYEAR(50), F(50), TTT07060
6 REACTEF(50), MV2(50), MW2(50), MW2(50), TTT07070
7 SLF(50), SFF(50), TTT07080
WRITE(8, 900) AXCLR, RADCLR, NRUN, NDAY, NMO, NYEAR, J
900 FORMAT(1HI, 1X, 'TOR RESULTS', //, 1X, 'CONFIGURATION- CIRCULAR ARCT
1, SHARP LE ROTOR', P/M 1034-A, AXIAL CLNC', 'F6.3', 1X, 'IN, RADIAL CLNC', TTT07090
2, F6.3, 'IN', //, 1X, 'RUN NUMBER', 'A3,4X, 'DAY', 1A2, 4X, 'MONTH', '4X, 'DAY', '1A2, TTT07110
34X, 'YEAR', 1A2, 4X, 'METHOD J=', 1I2, 4X, 'METHOD J=', 1I2, TTT07120
WRITE(8, 901) PAMB
901 FORMAT(///, 30X, 'PRESSURES(PSIA) AND PRESSURE RATIOS', //, 1X, 'PAMB='TTT07140
1, F5.2, //, 1X, 'POINT', 3X, 'PT0', 4X, 'PIAV', 3X, 'PT2', 3X, 'P2-PHD', 3X, TTT07150
2 OVERALL PRESSURE(PT0/PT2), TTT07160
DO 902 I=1, NP
902 WRITE(8, 903) I, PT0(I), P1AV(I), PT2(I), QHD(I), PR(I)
903 FORMAT(14, 2X, 'F4.7, 2X, 6X, F7.4')
WRITE(8, 904)
904 FORMAT(///, 30X, 'TEMPERATURES(DEC R)', //, 1X, 'POINT', 4X, 'TT01', 5X, TTT07210
1 T1, 6X, 'TE', 6X, 'TT2', 5X, 'T2', 3X, 'T2IS', 4X, 'TT2TH', 3X, TTT07220
2 DELTA T1IS, 2X, 'DELTA TW' TTT07230
DO 905 I=1, NP
905 WRITE(8, 906) I, TTO(I), T1(I), TE(I), TT2(I), T2(I), T2IS(I), T2TH(I), TTT07240
1 LIS(I), DELTIS(I), DELTW(I), TTT07250
906 FORMAT(14, 2X, 'F8.2, 2F17.2')
WRITE(8, 907)
2 V2', 4X, 'STAGE LOADING FACTOR', 2X, 'STAGE FLOW FACTOR', //, 1X, 'RELEVANCE', 3X, TTT07310
DO 908 I=1, NP
908 WRITE(8, 909) I, VA2(I), VU2(I), V2(I), VOIS(I), ALPH2(I), MV2(I), SLF(I), TTT07320
1 SFF(I)
909 FORMAT(14, 1X, 'F5.9, 2F3.4, 14.2, F21.2')
WRITE(8, 910)
910 FORMAT(///, 30X, 'RELATIVE VELOCITIES(FT/SEC), ANGLES(DEC), AND REL', TTT07330
DO 911 I=1, NP
911 WRITE(8, 912) I, WA2(I), WU2(I), W2(I), U2(I), W2IS(I), BETAA(I), DBETA(I), TTT07410
1. WCOFS(I), MW2(I)
2. FORMAT(14,1X,7F9.2,2F8.4)
3. WRITE(8,913)
4. FORMAT(14,1X,'EFFICIENCIES, RPM, WORK OUTPUT(HP), AND ENTHALPY'
6. 3R, 2X, 'DEGREE OF REACTION', 1X, 'F(1)
7. DD 914 I=1, NP
8. WRITE(8,915) I, ZETAR(I), ETAR(I), RPM(I), HP(I), DELHIS(I), DELH(1), F(I)
9. FORMAT(14,4X,8F8,4,8X,6X,8F8,0,8F8,2,8F8,2,8F11,2,8F13,4,8F19,4)
10. WRITE(8,916) NRUN, NDAY, NMD, NYPAC
11. FORMAT(1H1, 1X, 'GENERAL RESULTS', 1X, 'RUN NUMBER', 1A3, 1A4, 1X, 'DAY', 1A2, 4X, 'MONTH', 1A2, 5X, 'YEAR', 1A2
13. 3R, 2X, 'DEGREE OF', 2X, 'DEGREE OF', 2X, 'DEGREE OF', 1X, 'F(1)
17. DD 917 I=1, NP
18. WRITE(8,918) I, PR(I), REFRPM(I), XKIS(I), ETATS(I), ETATT(I), REFLOW(I)
19. RETURN
END

SUBROUTINE LISA(NP, NRUN, NDAY, NMD, NYPAC, XKIS, ETATS, PRS, ZETAS, REFRPM, ETAR, ETAS, RTORQ)
1. DIMENSION XKIS(50), ETATS(50), PRS(50), ZETAS(50), REFRPM(50)
2. WRITE(7,804) NP, NRUN, NDAY, NMD, NYPAC
3. WRITE(7,806) (XKIS(I), ETATS(I), PRS(I), ZETAS(I), REFRPM(I)
4. DD 804 I=1, NP
5. DD 806 I=1, NP
6. RETURN
7. END

SUBROUTINE HAMMER(NP, RTORQ, ORPM, QFLOWT, PRP)
1. FORMAT(14,1X,7F9.1, NP, ORPM, PRP, QFLOWT, RTORQ
2. WRITE(6,701) NP, ORPM, PRP, QFLOWT, RTORQ
3. 701 FORMAT('10X,'RPM','20X,'POINT NUMBER','12,5F8.2', '/
4. 10X,'STAGE PRESSURE RATIO','12,5F8.2', '/
5. 10X,'TURBINE MASS FLOW','12,5F8.2', 'LB/SEC', '/
6. DD 701
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.
TRANSONIC TURBINE TEST RIG
OUTPUT PLOT PROGRAM

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

DIMENSION XKIS(50), ETATS(50), PRS(50), ZETAS(50), REF RPM(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(LX, 12, 4A2)
READ(5, 06) (XKIS(I), ETATS(I), PRS(I), ZETAS(I), REF RPM(I), ETAR(I)
1, ETAS(I), RTORQ(I), I = I, NP)
06 FORMAT(LX, 8F9.3)
cALL LISA(NP, NRUN, NDAY, NMO, NYEAR, XKIS, ETATS, PRS, ZETAS,
1, REFRPM, ETAR, ETAS, RTORQ)
STOP
END

SUBROUTINE LISA(NP, NRUN, NDAY, NMO, NYEAR, XKIS, ETATS, PRS, ZETAS,
1, REFRPM, ETAR, ETAS, RTORQ)
REAL*4 NRUN, NDAY, NMO, NYEAR
REAL*8 LABEL/
REAL LABER/ETAR/
REAL LABES/ETAS/
REAL LABEL/TS/
REAL LABRT/
REAL ITIT1(24)/DETH, 'OMAS', TTT, 'R R', 'UN #', 'T', 'DAY'
1, 'MO.', 'YEAR',
2, 'EFFI', 'CIEI', 'CIES', '(T-S)', 'ROT', 'OR & S', 'TATO', 'R V', 'S IS'
3, 'HEAD C', 'DEF',
REAL ITIT2(24)/DETH, 'OMAS', TTT, 'R R', 'UN #', 'T', 'DAY'
1, 'MO.', 'YEAR',
2, 'EFFI', 'CIEI', 'CIES', '(T-S)', 'ROT', 'OR & S', 'TATO', 'R V', 'S IS'
3, 'STAT', 'OR', 'R',
REAL ITIT3(24)/DETH, 'OMAS', TTT, 'R R', 'UN #', 'T', 'DAY'
1, 'MO.', 'YEAR',
2, 'EFFI', 'CIEI', 'CIES', '(T-S)', 'ROT', 'OR & S', 'TATO', 'R V', 'S IS'
3, 'REFE', 'RRED', 'RPM',
REAL ITIT4(24)/DETH, 'OMAS', TTT, 'R R', 'UN #', 'T', 'DAY'
1, 'MO.', 'YEAR',
2, 'REFE', 'RRED', 'STAT', 'TOR', 'TORQ', 'UEV', 'S IS'
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(' X',X,':',4X,'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,ITIT1,0,0,0,0,0,0,2,2,8,4,1,LA)
CALL DRAW(NP,XKIS,ETATS,2,0,LABEL,ITIT1,0,0,0,0,0,0,2,2,8,4,1,LA)
CALL DRAW(NP,XKIS,ETATS,2,3,LABEL,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,LABEL,ITIT1,0,0,0,0,0,0,2,2,8,4,1,LA)
CALL SHSORT(PR5,KEY,NP)
WRITE(6,826)
826 FORMAT(' X',X,':',4X,'XKIS',',',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))
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,ITIT2,0.0,0.0,0.2,2,8,5,1,LA)
CALL DRAW(NP,PRS,ETATS,2,0,LABEL,ITIT2,0.0,0.0,0.2,2,8,4,1,LA)
CALL DRAW(NP,PRS,ETAS,1,5,LABEL,ITIT2,0.0,0.0,0,2,2,8,4,1,LA)
CALL DRAW(NP,PRS,ETAR,2,3,LABEL,ITIT2,0.0,0.0,0,2,2,8,4,1,LA)
CALL DRAW(NP,PRS,ETAS,2,4,LABEL,ITIT2,0.0,0.0,0,2,2,8,4,1,LA)
CALL DRAW(NP,PRS,ETAR,3,0,LABEL,ITIT2,0.0,0.0,0,2,2,8,4,1,LA)
CALL SHSORT(REFRPM,KEY,NP)
WRITE(6,829)
828 FORMAT('1',5F10.4)
DO 808 I=1,NP
ETATS(I)=DUMTS(KEY(I))
ETAR(I)=DUMT(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('1',5F10.4)
CALL DRAW(NP,REFRPM,ETATS,1,5,LABEL,ITIT3,0.0,0.0,0,2,2,8,5,1,LA)
CALL DRAW(NP,REFRPM,ETAS,2,0,LABEL,ITIT3,0.0,0.0,0,2,2,8,4,1,LA)
CALL DRAW(NP,REFRPM,ETAR,2,3,LABEL,ITIT3,0.0,0.0,0,2,2,8,4,1,LA)
CALL DRAW(NP,REFRPM,ETAS,2,4,LABEL,ITIT3,0.0,0.0,0,2,2,8,4,1,LA)
CALL DRAW(NP,REFRPM,ETAR,3,0,LABEL,ITIT3,0.0,0.0,0,2,2,8,4,1,LA)
CALL DRAW(NP,REFRPM,RTORQ,3,0,LABEL,ITIT4,0.0,0.0,0,2,2,8,5,1,LA)
WRITE(6,837)NP,NRUN,NDAY,NMO,NYEAR,LA
884 FORMAT('1H1,20X,'---DRAW CHECK PARAMETERS-----',/,'/,'/
885 FORMAT('1H1,'DRAW HAS BOMBED OUT AGAIN STOOPID-',/,'/','/
887 FORMAT('1H1,'NP,NRUN,NDAY,NMO,NYEAR,LA',I6,4A8,I6)
889 FORMAT('1H1,'I2,6F10.4,/')
RETURN
END
REFERENCES


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

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

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

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