DOE/NASA/51040-22
NASA TM-81660

Test Results of the Chrysler Upgraded Automotive Gas Turbine Engine—Initial Design

David Horvath, Guy H. Ribble, Jr.,
Edward L. Warren, and James C. Wood
National Aeronautics and Space Administration
Lewis Research Center

July 1981

Prepared for
U.S. DEPARTMENT OF ENERGY
Conservation and Renewable Energy
Office of Vehicle and Engine R&D

DOE/NASA/51040-22
NASA TM-81660

Test Results of the Chrysler Upgraded Automotive Gas Turbine Engine—Initial Design

David Horvath, Guy H. Ribble, Jr.,
Edward L. Warren, and James C. Wood
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

July 1981

Work performed for
U.S. DEPARTMENT OF ENERGY
Conservation and Renewable Energy
Office of Vehicle and Engine R&D
Washington, D.C. 20585
Under Interagency Agreement DE-AI01-77CS51040

N81-30562#

E-676

TEST RESULTS OF THE CHRYSLER UPGRADED AUTOMOTIVE GAS TURBINE ENGINE - INITIAL DESIGN

David Horvath, Guy H. Ribble, Jr.,
Edward Warren, and James C. Wood

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

SUMMARY

As part of the Department of Energy Heat Engine project the Chrysler Corp., with aerodynamic design support provided by the NASA Lewis Research Center, built a two-shaft, regenerated automotive gas turbine engine. The engine is commonly known as the "upgraded engine." When the engine was first built, serious deficiencies in power and fuel consumption were observed. A highly instrumented upgraded engine was tested at Lewis to assist in identifying the sources of the engine deficiencies. This report describes the engine and instrumentation and discusses the test results.

During the initial tests the engine was not able to reach 100 percent of design gas generator speed (58 500 rpm). Therefore actual engine performance could not be compared with design performance at design operating conditions. However, at 95 percent of design gas generator speed the engine developed a power of 33 kilowatts and a specific fuel consumption of 0.488 gram per watt-hour (g/W-hr). This corresponds to a 52 percent deficiency in power and an 83 percent increase in specific fuel consumption as compared with the corresponding design values. Analysis of the data shows that the main deficiencies were low compressor efficiency, low power turbine efficiency, and an excessive interstage duct pressure loss.

The engine was later run without full internal instrumentation in order to evaluate exhaust emissions. A minor modification to the fuel system allowed the engine to reach full design gas generator speed. Engine performance also improved slightly, reaching 50 percent of its goal in power at 100 percent of design gas generator speed. The results of the emissions test showed high carbon monoxide and hydrocarbon emissions at idle, especially when the combustor inlet air temperature was less than design, and also high oxides-of-nitrogen emissions at high engine speeds.

Some test data were also obtained from this same engine by Chrysler. In addition, compressor, compressor turbine, and regenerator tests were conducted in separate component test facilities at Lewis. There is good general agreement between the Lewis and Chrysler engine data. The Lewis engine and component data for the regenerator also showed good general agreement. However, the results of the turbomachinery component tests and component data from the engine tests disagreed significantly. The probable causes for this are differences in heat transfer between the engine and component facilities, different running clearances, interactions between components in the engine that were not present in component tests, and difficulties in measuring mean temperatures and pressures at certain locations within the engine.

SYMBOLS

C_p	specific heat at constant pressure
C_v	specific heat at constant volume
h	total enthalpy, kJ/kg
L_{par}	parasitic losses
M	Mach number
$\dot{m}$	mass flow rate, kg/sec
ND	dynamometer (propeller shaft) speed, rpm
NGG	gas generator speed, rpm
NGGP	corrected gas generator speed expressed in percent of 58 500 rpm
P	absolute total pressure, kPa
$\mathcal{P}$	power
T	absolute total temperature, K
TORO	output shaft torque, N-m
U	turbine blade speed at mean blade height, m/sec
V	fluid velocity, m/sec
W	relative velocity, m/sec
$\mathcal{W}_{comp}$	compressor work
WA	engine inlet air mass flow, kg/sec
WF	fuel mass flow, kg/hr
γ	ratio of specific heats
γ_{std}	1.4
δ	absolute error
ε	$\left[\gamma_{std}\left(\frac{2}{\gamma_{std}+1}\right)^{\left(\frac{\gamma_{std}}{\gamma_{std}-1}\right)}\right]\Bigg/\left[\gamma\left(\frac{2}{\gamma+1}\right)^{\left(\frac{\gamma}{\gamma-1}\right)}\right]$

η	efficiency
σ	standard deviation
θ	$\left(\frac{\gamma}{\gamma + 1}\right) T \Big/ \left(\frac{\gamma_{std}}{\gamma_{std} + 1}\right) T_{std}$

Subscripts:

A,B,C	designates which probe at a given station
calc	calculated
comp	compressor
corr	corrected
cr	critical
ct	compressor turbine
cv	combustor-vortex
des	design
exh	engine exhaust
f	fuel
id	ideal
in	inlet
leak	leakage based on design predictions
net	net
par	parasitic losses
pt	power turbine
r	regenerator
ref	reference conditions (101.3 kPa; 302.6 K)
s	static
std	standard
T	total
w	wall

x	axial
0.5	engine inlet
1	variable-inlet-guide-vane inlet
1.1	compressor rotor inlet
1.5	compressor rotor outlet
1.9	compressor diffuser outlet
2	compressor collector outlet
3	high-pressure-side regenerator inlet
4	high-pressure-side regenerator outlet
5	combustor outlet
5.2	compressor turbine stator inlet
5.5	compressor turbine rotor inlet
6	compressor turbine rotor outlet
6.3	power turbine stator inlet
7	power turbine rotor outlet
7.5	power turbine diffuser outlet
8	low-pressure-side regenerator inlet
9	low-pressure-side regenerator outlet

INTRODUCTION

A program started by the Environmental Protection Agency (EPA) and presently continued by the Department of Energy (DOE) to find alternatives to the standard automotive spark ignition engine has been in progress for several years. The Chrysler Corp., with funding through DOE contract and assistance from the NASA Lewis Research Center in the design of aerodynamic components, developed a state-of-the-art design for an automotive gas turbine engine that was intended to demonstrate lower emissions and better fuel economy than a standard spark ignition engine.

This state-of-the-art engine is termed the Chrysler "upgraded gas turbine engine." It is a design upgraded from Chrysler's sixth-generation (baseline) gas turbine engine. When first tested at Chrysler in July 1976, the engine was substantially deficient in power and exhibited high specific fuel consumption. A program to correct this deficiency was undertaken. One of the first steps was to test a highly instrumented original version of the upgraded engine at Lewis in order to better define the cause or causes of the performance shortfall. Separate component test facilities were also used to evaluate the performance of the regenerator and the turbomachinery. This report briefly describes the engine, the test procedures, the instrumentation, the facility, and the data acquisition system and summarizes the test results. The appendixes contain a more detailed description of the engine and instrumentation, an estimate of errors, and a tabular summary of the data. The test performance of the engine and individual components is presented and is compared with the Chrysler design performance predictions in order to identify the problems and to quantify shortfalls. Lewis component test results and Chrysler engine test results were also compared.

ENGINE DESCRIPTION

The Chrysler upgraded gas turbine engine is a two-shaft, regenerative configuration. It has variable inlet guide vanes (VIGV) in front of the compressor for power augmentation, a radial backswept compressor, a single ceramic regenerator, two axial-flow turbines, and variable stator vanes in the power turbine nozzle. The tests were conducted with the VIGV in a fixed axial position. Design output power without augmentation is 78 kilowatts with a compressor pressure ratio of 4.185 and a turbine inlet temperature of 1325 K at 100 percent of design gas generator speed (58 500 rpm). The engine housing is of nodular cast iron with a linerless ceramic insulation. A schematic of the engine with the temperatures and pressures at the 100-percent-gas-generator-speed design point condition is shown in figure 1. A partially disassembled display engine is shown in figure 2.

A more detailed description of the engine and its components is given in appendix A and references 1 and 2.

ENGINE INSTRUMENTATION

The engine was instrumented extensively, both internally and externally. The external instrumentation was used to measure engine inlet air temperature and pressure; the flow rates of engine inlet air, fuel, and lubricating oil; the lubricating oil temperatures (engine inlet and exit); and engine output shaft speed and torque. Internal instrumentation consisted of pressure and temperature probes to measure gas conditions at various locations (or stations) and a magnetic pulse counter to measure gas generator speed.

Placement of the internal instrumentation was chosen primarily to correspond to the stations used in the analytical design of the engine. Another criterion was to choose stations matching those used in the individual component tests - the purpose being to compare engine test data with both analytical predictions and component test results. A schematic diagram of the engine gas flow path showing the numbering and positions chosen for the instrumentation stations is given in figure 3. Details of the location and type of measuring probes used at each station are given in appendix B.

At most stations, multiple temperature and pressure measurements were made in order to determine whether or not large spatial distribution of temperature and pressure occurred. Total pressure probes were installed only at stations where the gas velocity was predicted to exceed Mach 0.2. Below that velocity the difference between static and total pressure would be less than 3 percent. All pressures were measured with strain gage transducers, and all temperatures were measured with thermocouples. The rotational speeds of the gas generator and output shafts were measured with magnetic pulse counters, and the torque on the output shaft was measured with a load cell on the dynamometer. Turbine flowmeters were used to measure the flow rates of engine inlet air, fuel, and lubricating oil. The accuracy of these measurements has been estimated by summing the potential root-mean-square errors for each element between (and including) the measuring instrument and the data reduction system. These values and their subsequent effect on some of the more sensitive calculated parameters are given in appendix C.

FACILITY AND DATA ACQUISITION SYSTEM

The Lewis test facility, shown in figure 4, is equipped to perform steady-state engine tests. The facility is also described in reference 3. Air is supplied to the engine at atmospheric pressure by a blower located on the roof. A heating and cooling system controls inlet air temperature. The engine power is absorbed by a direct-coupled, water-cooled, eddy current dynamometer that uses a strain-gage load cell. An emissions analyzer has the capability of measuring exhaust emissions of hydrocarbons, carbon monoxide, and oxides of nitrogen. Figure 5 shows the engine installed in the test facility. The data were scanned and recorded by a minicomputer system tailored for this test cell. Each data point presented herein is based on an average of five scans across every piece of instrumentation. Each scan took 12 milliseconds to cover all 240 data channels, and there was a 3-second pause between scans, so that each steady-state data reading lasted 12 seconds. The minicomputer system was interfaced with an IBM 360 computer that was programmed to perform the detailed data reduction and to print out the raw data and calculated parameters on a line printer. All the measured parameters and some of the more important calculated parameters, such as corrected speed, airflow, fuel flow, and some corrected temperatures, were monitored in real time by using the minicomputer along with cathode-ray-tube and light-emitting-diode displays located in the control room. A schematic diagram of the data acquisition system is shown in figure 6. The system is described in detail in reference 4.

TEST PROCEDURES

Two types of steady-state tests were run on the engine. First, performance testing was done with the full instrumentation described in appendix B. More than a year later, after the test facility had been used for another project, the same engine was reinstalled for evaluation of the exhaust emissions. Most of the internal engine instrumentation was not required for the emissions testing and therefore was not used. During the initial performance tests the engine would not operate stably at high speeds. To remedy this problem, a minor modification was made to the fuel system before the emissions tests were conducted. A smaller orifice was used to throttle the fuel flow that bypasses the main fuel injector. This resulted in more stable operation at high speeds.

The reference inlet air temperature condition for all the testing was 303 K, which conforms to SAE Gas Turbine Engine Test Code J116a for automotive engines. The reference inlet air pressure was 1 standard atmosphere. All the engine performance parameters were corrected for reference conditions in accordance with the test code. Part way into the testing, equipment installed in the test facility to hold the engine inlet air temperature at 303 K was put into operation. Most of the data from the engine performance tests and all the data from the emissions tests were taken with the engine inlet air temperature held at 303 K. The lubricating oil temperature at the engine inlet was set at 339 K for all testing.

The pressure transducers were calibrated before each day of testing. With the engine at idle, at least 15 minutes was required for all the temperatures within the engine to reach equilibrium. Therefore all the data presented in this report were taken after this warmup period.

The test operator had three basic controls on the engine:

(1) Gas generator speed
(2) Dynamometer load
(3) Power turbine stator position

The engine control was programmed to adjust the engine fuel flow to match the gas generator speed demand supplied by the test operator. The dynamometer load was varied to obtain the required output shaft speed. The power turbine stator position was adjusted to limit the low-pressure-side regenerator inlet temperature T_8 to about 1021 K. This was the station 8 temperature limit recommended by Chrysler.

All the engine operating points were set in this manner, and all the engine data were taken with a T_8 of 1021±5 K and the VIGV set at 0° (no power augmentation).

RESULTS AND DISCUSSION

Engine Performance

The Chrysler upgraded gas turbine engine, as tested at Lewis in its original condition, showed poor performance and high fuel consumption over the entire engine operating range. The design specifications of the engine and the individual components are contained in reference 2, and predicted performance at various operating conditions is summarized in table I. The flow leaks and heat leaks are also tabulated in table I and shown schematically in figure 7. Table II shows the performance test results and corresponding design performance for the engine's maximum power point at 100 percent of design gas generator speed. At that operating point power was 50 percent below and specific fuel consumption 84 percent above the design goal.

An engine performance map showing the relationship between power, output shaft speed, and gas generator speed is presented in figure 8. The map clearly shows the deficiency in power and output shaft speed. There is noticeable scatter among the 90 and 95 percent gas generator speed points in figure 8. For a given gas generator speed the higher values of power were obtained while the engine was being tested for exhaust emissions. It was found that the reason for this scatter is that the engine performance was very sensitive to small variations in actual T_8. When the engine was performance tested, a 14-thermocouple average was used to control T_8; but when the emissions data were taken, only four thermocouples were used. The result was a difference of about 10 K. Reference 5 presents a sensitivity analysis of various operating parameters on this engine and shows that a 10 K increase in T_8 causes a 2.5-kilowatt increase in engine power.

The specific fuel consumption is presented in figures 9 and 10. Figure 10 shows the relationship between propeller shaft speed, gas generator speed, and specific fuel consumption at the maximum power operating conditions for each gas generator speed.

Overall engine performance is summarized by the following observations:

(1) The engine power was about 50 percent below the design goal at 100 percent of design gas generator speed (58 500 rpm) and remained at about 50 percent below the design prediction all the way down to idle.

(2) The specific fuel consumption was 84 percent higher than the design goal at 100 percent of design gas generator speed and over 100 percent greater than the design prediction at idle.

(3) The engine's peak power point occurred at an output shaft speed that was about 30 percent below the design goal at 100 percent of design gas generator speed and about 44 percent below the design prediction at idle. This shift in peak power speed is primarily due to a mismatch in component performance.

Further conclusions were drawn about the performance of the individual components, and these conclusions are discussed in the following sections. However, the poor performance of the engine is indicated qualitatively by the temperature-entropy diagram of the engine's thermodynamic cycle based on engine test points. Figure 11 shows the temperature-entropy diagram of data taken at 95 percent of design gas generator speed. The heavy solid lines are constant-pressure lines that can be used as a reference to indicate pressure drops in the ducting. The diagram shows low efficiency in both the compression and expansion processes. Figure 12 is a temperature-entropy diagram of the turbine stages and is an enlargement of the expansion portion of figure 11. It clearly indicates that the major problems in the turbine stages are high interstage (interturbine) duct pressure loss and low power turbine efficiency at that engine operating point.

The engine exhibited some mechanical and stability problems as well as low power and high specific fuel consumption. During the performance testing the engine intermittently showed unstable fuel flow at high engine speed, and this resulted in temperature and pressure fluctuations. Another symptom of this unstable combustor condition was that oxides-of-nitrogen (NO_x) emissions showed high spikes. At these times NO_x emissions would jump from between 5 and 15 ppm to between 100 and 250 ppm. After the orifice change in the fuel system at the end of the engine performance tests, the engine was much more stable, but the spikes in NO_x emissions at high engine speed continued. This is discussed in more detail in the exhaust emissions section of this report. A problem was also encountered with the durability of the gas generator air bearing. It failed twice during these tests as the bearing foil weld failed. Except for the bearing and the shaft seals no significant damage to the engine occurred as a result of the air bearing failures.

Compressor Performance

At 95 percent of design gas generator speed the test data indicated a total-to-total efficiency of 73 percent, almost 7 percentage points below the design goal at this speed. Figures 13 and 14 present the installed-compressor performance as determined from the engine measurements and the performance measured from the component tests, respectively. In addition, the predicted compressor operating points taken from table I are shown. The test data shown in figures 13 and 14 were calculated from temperatures and pressures taken at the VIGV inlet (station 1) and the compressor collector outlet (station 2), respectively.

The speed lines in figure 14 represent constant gas generator speed and are taken from Lewis component data presented in reference 6. In reference 6 the compressor component data are presented for an inlet temperature of 289 K and for a 1.259-times-size scale model of the actual compressor used in the engine. Therefore the component data presented in figure 14 have been corrected for size and temperature.

The compressor pressure ratio was significantly lower than expected. A predicted performance map for the compressor is contained in reference 2. When the map is entered with compressor weight flow and 95 percent of design gas generator speed, the map shows a pressure ratio of about 3.88. The pressure ratio obtained from the engine test was 3.55, 9 percent below the design prediction. Figure 14 shows that a low compressor pressure ratio was encountered for all conditions above 70 percent of design gas generator speed. However, the component data show no significant deficiency in pressure ratio and efficiencies that are very close to design. The most probable reasons for the disagreement between engine and component test data are the following:

(1) There may have been different tip clearances in the engine and component test rigs.

(2) The component test rig used a symmetrical compressor diffuser and the engine did not.

(3) There was difficulty in accurately measuring temperatures and pressures within the engine.

(4) The component test rig had no VIGV.

(5) The component test was performed with a compressor that was scaled up in size by a factor of 1.259.

(6) Heat transfer effects in the engine tests were different from those in the component tests.

There was evidence of heat transfer effects in the engine compressor. The thermocouple measurements at stations 1.5, 1.9, and 2 (appendix B) showed a decline in the total temperature of the air as it passed through the diffuser and the collector. This decline in temperature, shown in figure 15, varied from about 1 K at idle to about 8 K at full throttle, a loss of about 4 percent of the heat gained during compression. This heat must have been conducted away through the aluminum diffuser and the outer compressor cover. There is also evidence of heat being transferred into the compression process through the shroud or impeller. The gas temperature rise in the compressor rotor is almost 7 percent higher than the design prediction when the engine is operating at steady state near full speed. This would contribute to poor compressor performance.

Compressor Turbine Performance

Turbine performance was difficult to determine because of the uncertainty of the temperature measurements. Stations 5.2, 6, 6.3, and 7 each had three combination probes (total temperature probe within a Kiel probe). These probes represent a compromise between obtaining a mean temperature and pressure at each station and not significantly impeding the flow with a large number of probes. However, the three thermocouples at each of the stations in the turbine section did not closely agree with each other and in some instances disagreed by as much as 40 K because of spatial distribution of temperature. Therefore there would be little confidence in the turbine efficiency calculations if the measured difference in temperature across the turbine were used to calculate specific work.

As a substitute for measured temperature differences, the Δh across the compressor turbine was calculated from the compressor work.

$$\Delta h_{ct} = \frac{(h_{1.5} - h_{1.1})\dot{m}_{in} + \mathscr{P}_{par}}{\dot{m}_{in} + \dot{m}_f - \dot{m}_{leak}}$$

The specific work of the compressor $(h_{1.5} - h_{1.1})$ was determined from the temperature measurements at the compressor rotor inlet and outlet (stations 1.1 and 1.5). The estimates for gas generator shaft parasitic power and regenerator seal leakage $\dot{m}_{leak}$ were taken from reference 2.

However, if there is a significant amount of heat being transferred into the compression process, as described in the compressor discussion, this method of calculating compressor turbine work may be high by as much as several percentage points.

A simple test was made to determine if there was general agreement between the calculated compressor turbine inlet temperature $(T_{5.2,calc})$ and the measured temperature. The turbine inlet temperature was calculated as follows:

$$T_{5.2,calc} = T_{6,T} + \frac{\Delta h_{ct}}{C_p}$$

where C_p is the specific heat for the temperature $(T_{5.2,T} + T_{6,T})/2$. Then $T_{5.2,calc}$ was compared with the measured compressor turbine inlet temperatures in figure 16. This plot shows that the calculated and measured temperatures tended to agree, except for the high-temperature points that were taken at very near full throttle. This agreement lends some evidence that at low speeds the three-temperature average is a close approximation to the mean fluid temperature and that the leakage and parasitic loss estimations made by Chrysler (refs. 1 and 2) are reasonable.

Compressor turbine efficiency is compared with the design predictions in figure 17. Here it is shown that the efficiency at idle was several percentage points low and that the efficiency at full throttle was about as predicted when measured at the design work factor. Also, the pressure ratio across the turbine was higher than predicted because of the low compressor efficiency. The compressor turbine pressure ratio was 13 percent high at full throttle and 4 percent high at idle. The relationship between pressure ratio, mass flow, and gas generator speed is shown in figure 18.

Data on compressor turbine performance were also obtained from engine tests done by Chrysler and from Lewis compressor turbine component tests. Care must be taken in comparing engine and component performance numbers because the pressure measurements used come from slightly different locations. The total adiabatic efficiency is based on engine data taken at two stations. The first is the compressor turbine nozzle inlet. The second station is about one chord length beyond the compressor turbine rotor outlet. Compressor turbine efficiency is shown in figure 17. The Chrysler engine test data and the Lewis component test data are not shown in figure 17. Chrysler evaluated compressor turbine efficiency from engine data by using an off-design vector diagram analysis computer program. This method modified loss parameters until the program closely predicted the work required to drive the gas generator and the tip static pressures measured at the stator and rotor exits. The Chrysler method resulted in a compressor turbine efficiency about 5 percentage points less than the efficiency shown in figure 17 for 80 percent of design gas generator speed.

The Lewis compressor turbine component data also showed significantly less efficiency than engine data indicated. At 95 percent equivalent speed conditions the component data showed about 7 percentage points less in adiabatic efficiency than any of the engine data.

Lewis engine data plotted on the compressor turbine component map are shown in figure 19. All the lines in the plot were derived from compressor turbine component test information that is yet unpublished. The equivalent specific work shown in the plot is corrected to 302.6 K. Figure 19 shows that for any speed, turbine inlet temperature, and specific work, the mass flow - speed parameter from the engine test is 5 percent higher than the component test data indicate. It is expected that thermal expansion of the engine caused at least 2 percent greater equivalent flow than experienced during the compressor turbine component tests, which were run near ambient temperature. The cause of the remainder of the disagreement is not known. The large symbols in figure 19 represent the off-design predictions and were calculated from the temperatures, pressures, speeds, flows, and heat leaks given in table I.

An interstage duct located between the compressor turbine and the power turbine transmits the exhaust from the compressor turbine into the power turbine. The design total pressure loss in the interstage duct is 2 percent at 100 percent of design gas generator speed. The total pressure loss in the engine is shown in figure 20. At 98 percent of design gas generator speed the loss was 7.4 percent, and at idle (50 percent gas generator speed) the loss was 1.1 percent. The reason for the excessive loss is probably flow separation. Component tests reported in reference 7 revealed severe flow separation on the outer wall of the duct. Chrysler reported similar results (excessive pressure loss) at gas generator speeds up to 80 percent (ref. 8). The performance of a similar interstage duct is reported in reference 9, showing very bad separation on the duct walls. It is important to note that the high pressure loss shown in figure 20 contains some of the mixing loss associated with the compressor turbine exhaust.

Power Turbine Performance

Power turbine performance was evaluated from the power measured with the dynamometer and the measured pressures and temperatures at stations 6.3 and 7. To obtain turbine power, the parasitic losses given in reference 2 were added to the engine output power. Chrysler obtained these losses by motoring a power turbine shaft, with no power turbine disk, and turning the regenerator. Oil temperature was 339 K. These parasitic losses are shown in figure 21.

The power turbine efficiency calculations use the following relationships:

$$\eta_{pt} = \frac{\Delta h_{pt}}{\Delta h_{id}}$$

$$\Delta h_{pt} = \frac{\mathcal{P}_{net} + \mathcal{P}_{par}}{\dot{m}_{in} + \dot{m}_f - \dot{m}_{leak}}$$

$$\Delta h_{id} = T_{6.3,T}\, C_p \left[1 - \left(\frac{P_{7,T}}{P_{6.3,T}}\right)^{\left(\frac{\gamma-1}{\gamma}\right)}\right]$$

where $\mathcal{P}_{net}$ is the power measured at dynamometer, $\mathcal{P}$ is the parasitic losses shown in figure 21, $\dot{m}_{leak}$ is the predicted leakage based on figure 7 and table I, and C_p and γ are the specific heat and ratio of specific heats for air with water vapor and combustion products at the average temperature through the stage.

A comparison similar to that used on the compressor turbine was made to determine if there was a general agreement between the power turbine work measured with the dynamometer and the work calculated from the temperature measurements and flow rate. Figure 22 shows the comparison. In almost every case the measured temperature was significantly higher than the calculated temperature, and the difference was fairly consistent. This difference might be due to heat losses and leakage flow from cooler and higher pressure parts of the engine coming in through the variable stator mechanism. The points above the line, where the calculated power turbine inlet temperature is greater than the measured, represent engine operating conditions above 95 percent of design gas generator speed. Considering that temperature drop across the power turbine stage is as small as 24 K at idle, there can be little confidence in using measured temperature difference to calculate the power turbine efficiency.

The power turbine performance is summarized in figures 23 and 24. Figure 23 shows the relationship between pressure ratio, mass flow, and gas generator speed. Gas generator speed can be related to actual mass flow by referring back to figure 14. The design-goal engine operating line is also plotted in figure 23 in order to show the disparity between the operating conditions and the predicted conditions. The efficiency is compared with the design prediction in figure 24. Here efficiency based on measured engine output power and turbine pressure ratio is plotted against work factor. The plot shows that efficiency was at least 17 percentage points low at the design work factor of 1.25. The design work factor and efficiency were taken from reference 2.

The power turbine was also tested in a component test facility at Lewis. The results showed significantly higher efficiency for the component tests than for the engine tests. Entering the power turbine component map with corrected engine parameters shows a difference in efficiency of about 7 percentage points. This lower efficiency in the engine test may be caused by severely distorted inlet flow conditions resulting from separation in the interstage duct.

There was also a consistent disagreement between the power turbine stator angle measurements made in the Lewis component and engine tests and in the Chrysler engine tests for any given set of equivalent conditions. The stator angles measured in the turbine component tests must be the most accurate, since the problems of gears and linkages and inaccessibility are not as great for the component tests as for the engine tests. It appears, then, from the component tests that the stator angle measurement presented in appendix D may be consistently 3° or 4° high.

The total pressure loss in the power turbine diffuser is shown as a function of gas generator speed and output shaft speed in figure 25. The lines of constant gas generator speed also represent constant flow rate in the power turbine diffuser inlet for the range of conditions tested. The minimum pressure loss in each line of constant gas generator speed should represent the speed of the output shaft at which the total velocity of the fluid is at a minimum. Since the flow is axial when the total velocity is at a minimum, the output shaft speeds associated with the minimum in figure 25 are the speeds that will cause axial flow for a given flow rate and gas generator speed. The locus of points that form the engine operating line of maximum power tends to follow the minimums, as would be expected, since a large swirl at the rotor exit would cause a large pressure drop in the diffuser.

Regenerator Performance

The data show that the regenerator was performing at or better than the design effectiveness. Figure 26 shows a comparison between measured effectiveness and the predicted effectiveness shown in table I. Regenerator effectiveness is defined by

$$\text{Effectiveness} = \frac{(T_4 - T_3)}{(T_8 - T_3)}$$

where T_3 is the average value of 12 temperatures at station 3 (T_{3B} to T_{3Q}), T_4 is the average value of 12 temperatures at station 4 (T_{4B} to T_{4Q}), and T_8 is the average value of 14 temperatures at station 8 (T_{8B} to T_{8Q}). The temperatures T_{3A}, T_{4A}, T_{8A}, T_{3H}, T_{3M}, T_{4M}, T_{3N}, T_{4N}, and T_{8N} are not contained in the average because the flow by those thermocouples was obstructed to an unknown extent by engine insulation. The regenerator instrumentation is shown in figures 27 and 28.

Velocity distribution across the regenerator faces was determined in a separate regenerator component test rig and was used to evaluate the mass-averaged mean temperatures at stations 3, 4, 8, and 9 for some data points. However, the arithmetic average temperatures were generally used in the analyses because spot checks of the mass average temperature differed only slightly from the arithmetic averages. The thermocouples adjacent to the regenerator surface were not radiation shielded, and therefore their accuracy might be questioned. The radiation error could not be determined accurately enough to report; however, the engine test results do agree very well with regenerator component test results, in which the design engine conditions were simulated and shielded thermocouples were used. The corresponding regenerator component test results are shown in figure 29 and were taken from reference 10.

The regenerator pressure losses are shown in figure 30. The small symbols represent data points, and the large symbols are the off-design predictions made by Chrysler and presented in table I. This plot shows that for a given flow rate, the regenerator pressure drop was close to the prediction.

Combustor Performance

Pressure loss in the combustor and vortex is shown in figure 31. The small symbols represent test data, and the large symbols are the off-design predictions made by Chrysler and presented in table I. Figure 31 shows that the actual pressure drop was slightly higher than that predicted for any given flow rate. Some of the scatter in the data of figure 31 was caused by a modification of the dilution holes in the reactor tube made during the test program. As a possible solution to a combustion instability problem, more air was directed through the primary air ports by reducing the area of the dilution holes on one side of the reactor tube. This did not have a noticeable effect on the combustor instability problem, but it did slightly increase the pressure loss of the combustor and thus accounted for some of the scatter shown in figure 31.

The combustor efficiency cannot be accurately determined from the test data because of the uncertainty of the temperature measurements at station 5. Station 5 was located on the instrumented combustor outlet. The instrumented combustor, shown in figure 32, was used for only a short time in order to preserve the instrumentation, as it was exposed to the most extreme temperatures. A slightly different orientation of the dilution holes in the reactor tube and the existence of the instrumentation rake were the only differences between the instrumented and noninstrumented combustors. When tested, the thermocouples at station 5 showed a temperature as much as 130 K lower than the temperature measured at station 5.2, which was downstream. Two likely possibilities for this are that either air from the dilution holes was impinging on the station 5 thermocouples, causing them to read a lower-than-average air temperature, or burning was taking place downstream of the combustor.

Also, at near full throttle a temperature increase between stations 6 and 6.3 (interstage duct) was measured for all the readings at and above 80 percent of design gas generator speed. At 97.5 percent speed this increase was about 11 K and occurred only when the instrumented combustor was used. This evidence shows that part of the problem may have been due to burning downstream of the combustor. However, figure 33 shows conflicting data. This plot of the temperature difference between the regenerator outlet and the compressor turbine nozzle inlet shows a higher ΔT for the instrumented than for the noninstrumented combustor at high fuel-air ratios (and high speeds).

The combustor-vortex efficiency has been determined by considering a control volume around the engine cavity that contains the high-pressure-side regenerator outlet and the combustor and vortex (stations 4 to 5.2).

$$\eta_{cv} = \frac{(T_4 - T_{5.2,T})}{(T_4 - T_{5,id})}$$

where $T_{5,id}$ is the ideal combustor outlet temperature based on the measured T_4, P_4, airflow, fuel flow, heating value, hydrogen-to-carbon mass ratio, and regenerator leakage. Based on an average of 85 data points, a combustor-vortex efficiency of about 88 percent was calculated. Therefore it is estimated that, if combustion was complete, heat energy equivalent to 12 percent of the fuel flow was transferred out of the cavity to the engine bulkhead cooling air, the compressor region, the oil and gas bearing fluids, and the outside air. The heat picked up by the bulkhead cooling air and the compressor diffuser was sent back into the high-pressure-side regenerator inlet (station 3). This accounts for the measured increase in temperature between stations 2 and 3. The heat transferred to the outside air was lost. The heat transmitted to the compressor rotor increased the work required to compress the gas.

No correlation could be made between the combustor-vortex efficiency and fuel flow, engine speed, or duration of engine operation.

Exhaust Emissions

A separate test was run to evaluate the exhaust emissions from the engine. The results of this test show the performance of the premixed-prevaporized combustor and its fuel system in an actual operating engine environment. The data from this test are included at the end of appendix D.

Oxides-of-nitrogen emissions were definitely bimodal at high overall fuel-air ratios, which correspond to gas generator speeds of over 80 percent of design. Figures 34 and 35 relate gas generator speed and NO_x emissions index, respectively, to fuel-air ratio. These plots show that at fuel-air ratios above 0.007, NO_x emissions may vary by one or two orders of magnitude. High NO_x is symptomatic of "flashback," which occurs in a premixed-prevaporized combustor when the flame moves from the primary combustion zone back into the premixing zone. There droplet diffusion combustion occurs with a much higher flame temperature, which results in higher NO_x formation. Flashback apparently occurs in this combustor when the engine is operating at high speeds. It is characterized by a step change in NO_x emissions of one or two orders of magnitude. This problem is discussed in reference 11.

Figures 36 and 37 show that CO and HC emissions are very high at idle conditions. High levels of HC and CO, which are products of incomplete combustion, are thought to be caused by the torch burning rich at idle. The torch is kept burning in order to relight the combustor after it goes out when fuel flow shuts off during deceleration. It is thought that the torch burns fuel rich and that, while the engine is near idle, the combustion of the torch fuel is incomplete.

Emissions index is directly related to vehicle fuel economy and emissions level. Figure 38 shows this relationship for various vehicle fuel economies. It cannot be determined from only steady-state tests of the engine whether or not a vehicle with this engine will meet 1984 emissions standards (0.4 g NO_x/mile, 0.41 g HC/mile, 3.4 g CO/mile). However, figure 37 can be used to calculate whether or not the measured steady-state emissions are less than the emissions standards.

If it is assumed that a vehicle with an improved Chrysler upgraded engine could get at least 20-mpg fuel economy, an emissions index less than about 2.8 over the driving cycle would result in meeting the vehicle emissions standards for HC or NO_x. Any CO emissions index below 24 would meet the emissions standards for CO. As shown in figure 35 the only time the NO_x emissions index was above 2.8 was then the combustor was in "flashback" condition. Figure 36 shows that under normal steady-state operating conditions the CO emissions index exceeds its allowable level only at idle. Figure 37 shows that HC does not exceed the allowable emissions level, even at idle.

However, at idle conditions both the CO and HC emissions are very sensitive to regenerator inlet temperature. Figures 39 and 40 show that the emissions levels climb dramatically with only a 70 K decrease in regenerator inlet temperature. Therefore there would definitely be high emissions of HC and CO during a cold startup before the combustor inlet comes up to temperature.

COMMENTS ON ENGINE INSTRUMENTATION

In retrospect, some comments can be made about the extent, type, location, and adequacy of the engine instrumentation. These comments should be considered in the instrumentation of future automotive gas turbine engines:

Engine inlet and compressor. - The temperature measurements at the engine inlet showed that there was no measurable difference in air temperature between stations 1 and 1.1. Therefore the temperature rake at station 1.1 could have been eliminated. Also, the pressures measured at stations 1.9 and 2 were the same. Therefore the pressure measurements at station 1.9 could have been eliminated.

Regenerator. - The measurements showed that the temperatures near the surfaces of the regenerator do vary with location. Therefore a temperature rake is needed at each regenerator surface to obtain accurate averages. However, it is not known whether the radiation error was significant at any of these thermocouple locations, and in retrospect there would be more confidence in the individual temperature measurements if the thermocouples were shielded.

Combustor. - The instrumented combustor did not prove to be worthwhile. The temperature measured at station 5 could not have been the true average temperature at that station. It is felt that a true average temperature could not have been measured at that plane without a much more extensive rake, which would have affected engine performance. A thermocouple located within the premixing region would have been helpful for the immediate detection of flashback.

Compressor turbine and power turbine. - The amount of instrumentation in the turbine stages had to be limited so that engine performance would not be seriously affected. The locations were far too inaccessible for the type of traversing probes used in a turbine component test. It was noted that the temperatures in any plane varied from one location to the next to such an extent that the average of three thermocouple readings at each station was not reliable enough for performance calculations. It can then be concluded that the calculation of specific work cannot be accurately based on temperature measurements.

It is not known whether the extensive instrumentation within this engine significantly affected engine performance. However, partially instrumented engines of the same design showed similar poor performance.

CONCLUSIONS

A Chrysler upgraded gas turbine engine built of original design components was tested, and its steady-state performance was characterized. Because the engine tested was highly instrumented, certain conclusions could be made regarding component efficiencies, duct losses, and heat loss, in addition to overall engine performance.

Analysis of the data led to the following conclusions:

1. The engine power was about 50 percent below the design goal at 100 percent of design gas generator speed (58 500 rpm), and it remained at about 50 percent below the design prediction all the way down to idle.

2. The specific fuel consumption was 84 percent higher than the design goal at 100 percent of design gas generator speed and over 100 percent greater than the design prediction at idle.

3. The compressor total efficiency was about 7 percentage points lower than the design predictions over the entire engine operating range.

4. The compressor pressure ratio was 9 percent lower and mass flow was 8 percent lower than the design predictions at 95 percent of design gas generator speed, and about equal to the design predictions at idle.

5. Engine data indicate that the compressor turbine total efficiency approached its goal at 95 percent of its design speed but fell short at lower speeds.

6. The interstage duct had a significant total-pressure-loss ratio that increased from 1 percent at idle to about 7 percent at 95 percent of design gas generator speed.

7. Under all engine conditions the power turbine operated at a very low efficiency, at least partly as a result of poor inlet conditions.

8. The regenerator effectiveness was 2 percent higher than its design goal at 95 percent of design gas generator speed and met its predicted performance at idle.

9. The gas generator air bearing had poor durability as there were two air bearing failures during the testing of this engine.

10. Heat loss from the engine cavity, which contains the burner, vortex, and high-pressure regenerator outlet, was equivalent to about 12 percent of the energy in the fuel.

11. Carbon monoxide and hydrocarbon emissions were high at idle conditions, especially when the combustor inlet temperature was below design.

12. Oxides-of-nitrogen emissions suddenly increased one or two orders of magnitude above 80 percent of design gas generator speed as a result of apparent "flashback" of the flame into the premixing region.

Many of the performance problems encountered in this engine are being resolved by engine modifications and retrofitting with redesigned components.

APPENDIX A

ENGINE DESCRIPTION

The Chrysler upgraded gas turbine engine is a two-shaft, regenerated configuration. It has variable inlet guide vanes (VIGV) for power augmentation, a radial backswept compressor, a ceramic regenerator, two axial-flow turbines, and variable stator vanes in the power turbine nozzle. Design output power without augmentation is 78 kilowatts with a compressor pressure ratio of 4.185 at 100 percent of design gas generator speed (58 500 rpm). The engine housing is nodular cast iron. Heat loss is reduced through the use of linerless ceramic insulation. A schematic of the engine with the temperatures and pressures at the design point condition is shown in figure 1. An upgraded engine that has been expanded for display purposes is shown in figure 2.

This appendix contains a brief description of each major component that was in the original engine tested at Lewis. A more detailed description is given in references 1 and 2.

The compressor consists of variable inlet guide vanes, a 24-blade steel inducer, a 24-blade, 30°-backswept centrifugal rotor of cast aluminum, a 14-radial-vane diffuser, and 60 axial straightening vanes. Figure 41 shows the inducer and the compressor rotor. The rotor is 0.155 meter in diameter with a maximum operating speed of 58 500 rpm and a burst speed of 89 500 rpm. Compressed air is diffused into a three-chamber collector that is enclosed by the compressor cover. Two large chambers lead to the regenerator, and one smaller chamber sends cooling air first to the bulkhead located in the interstage area between the gas generator and power turbine sections and then to the regenerator inlet.

The regenerator is a single ceramic disk that rotates at 1/2204th of the power turbine speed on a self-alining graphite bearing. The disk is made of lithium aluminum silicate with a sinusoidal passage geometry and is 0.083 meter thick with an effective outside diameter of 0.502 meter. The high- and low-pressure halves of the regenerator are isolated by graphite D-shaped seals. The regenerator system is limited to a low-pressure-side inlet temperature of 748° C (1378° F) for all engine conditions.

A single-stage, fixed-geometry, premixed-prevaporized combustor is used. The combustor and vortex layout is shown in figure 42. The hot air leaving the high-pressure side of the regenerator passes over the outside of the reactor tube, supplying air to the primary and secondary air ports and also cooling the reactor tube. Atomizing air is supplied to the fuel nozzle from the compressor discharge, and ignition is accomplished with a torch igniter and spark plug. The combustor discharges directly into the vortex. Swirling combustion products from the vortex enter the compressor turbine through its nozzle, which contains 15 fixed stator vanes. The compressor turbine rotor, shown in figure 43, is axial with 62 blades and has an outside diameter of 0.113 meter and a blade height of 0.0126 meter. It is made of MAR-M 246, can withstand an inlet temperature of 1052° C (1925° F) and a gas generator speed of 58 500 rpm at design point conditions, and has a burst speed of 95 500 rpm. A common shaft that holds the compressor and the compressor turbine is supported by an oil journal-thrust bearing and by an air bearing on the hot-compressor turbine end.

The power turbine nozzle has 23 variable stator vanes that can be closed down to 28° from radial or turned to 150° for maximum braking. The axial-flow power turbine has 53 blades with a tip diameter of 154.5 millimeters and a blade height of 17.8 millimeters, as shown in figure 44. The rotor material MAR-M 002, operates at design at an inlet temperature of 1142 K and a gas generator speed of 50 000 rpm and has a burst speed of 84 000 rpm. Oil journal bearings are used to support the power turbine shaft, which is geared to the output shaft by a 14.89-pressure-ratio, double-reduction speed reducer. In addition, the regenerator and the engine accessories are powered from the power turbine.

Air exits the power turbine diffuser and passes through the regenerator low-pressure side, where the air temperature drops from 1017 K to 560 K at engine design-point conditions, and is then exhausted from the engine. Table III summarizes the engine description. Detailed discussions of the compressor turbine and power turbine designs can be found in references 12 and 13, respectively.

APPENDIX B

ENGINE INSTRUMENTATION

The instrumentation was carefully positioned throughout the engine so as to obtain the most meaningful information without significantly impeding the flows. The following is a list of instrumentation that was used in these tests. Measured parameters are listed according to the station within the engine at which they are located. The station numbers are shown on a schematic diagram of the engine in figure 3 and on a cutaway view of the gas generator in figure 45.

Station 0 - filter inlet:
- T0R - right-side temperature
- T0L - left-side temperature

Station 0.5 - filter outlet:
- T0.5A, T0.5B - two thermocouples

Station 1 - VIGV inlet (fig. 46):
- T1A, T1B - two thermocouples
- P1TA, P1TB, P1TC - three total pressure probes
- P1SA, P1SB, P1SC - three static pressure taps

Station 1.1 - VIGV outlet (fig. 47):
- T1.1A to T1.1E - five thermocouples
- P1.1SA, P1.1SB, P1.1SC, P1.1SD - four static pressure taps

Station 1.5 - compressor diffuser (fig. 48):
- T1.5TA, T1.5TB, T1.5TC - three total temperature probes

Station 1.9 - compressor diffuser outlet (fig. 49):
- T1.9TA to T1.9TD - four total temperature probes
- P1.9SA to P1.9SJ - nine static pressure taps

Station 2 - compressor collector outlets (fig. 50):
- T2A to T2F - six thermocouples
- P2A to P2F - six total pressure probes

Stations 3, 4, 8, and 9 - high- and low-pressure sides of regenerator (figs. 51 and 52):
- T3A to T3Q - 16 thermocouples at each station
- T4A to T4Q, T8A to T8Q, T9A to T9Q } temperature measured at those positions where insulation obstructed the flow were not used in the calculations
- P3TA, P3TB, P3TC; P4TA, P4TB, P4TC; P8TA, P8TB, P8TC; P9TA, P9TB, P9TC } three total pressure probes at each station

Station 5 - combustor exit (fig. 53). Because of the high temperatures at this station, the instrumented combustor was only used for a short period of time:
- T5TA to T5TD - four total temperature probes
- T5WA to T5WD - four wall temperature thermocouples
- P5TA to P5TD - four total pressure probes
- P5SA to P5SD - four static pressure taps

Station 5.2 - compressor turbine inlet (fig. 54):
- T5.2TA, T5.2TB, T5.2TC - three shielded total temperature probes
- P5.2TA, P5.2TB, P5.2TC - three total pressure probes
- P5.2SA, P5.2SB, P5.2SC - three static pressure taps

Station 5.5 - compressor turbine stator outlet (fig. 55):
- P5.5SA, P5.5SB - two static pressure taps

Station 6 - compressor turbine outlet (figs. 56 and 57):
- T6TA, T6TB, T6TC - three shielded total temperature probes
- T6WA, T6WB, T6WC - three wall temperature thermocouples
- P6TA, P6TB, P6TC - three total pressure probes
- P6SA, P6SB, P6SC - three static pressure taps

Station 6.3 - power turbine inlet (fig. 58):
- T6.3TA, T6.3TB, T6.3TC - three shielded total temperature probes
- T6.3WA, T6.3WB, T6.3WC - three wall temperature thermocouples
- P6.3TA, P6.3TB, P6.3TC - three total pressure probes
- P6.3SA, P6.3SB, P6.3SC - three static pressure taps

Station 7 - power turbine outlet (fig. 59):
- T7TA, T7TB, T7TC - three shielded total temperature probes
- T7WA, T7WB, T7WC - three wall temperature thermocouples
- P7TA, P7TB, P7TC - three total pressure probes
- P7SA, P7SB, P7SC - three static pressure taps

Exhaust flange:
- TEXHA, TEXHB - two thermocouples
- PEXHA, PEXHB - two static pressure probes

In addition to these temperatures and pressures some parameters external to the engine were measured:

- Airflow to right-side engine inlet
- Airflow to left-side engine inlet
- Fuel flow
- Fuel temperature
- Right-side air inlet temperature
- Left-side air inlet temperature
- Torque at dynamometer
- Dynamometer speed
- Turbine nozzle position
- Engine oil inlet temperature
- Engine oil outlet temperature
- Oil flow rate
- Dewpoint

The accuracy of the measurements has been estimated and is presented in appendix C.

APPENDIX C

ESTIMATION OF ERRORS

The accuracy of the measurements was estimated by summing the potential root-mean-square errors for each element between (and including) the test apparatus and data reduction system. The root-mean-square error corresponds to 1 standard deviation. Each measurement and its estimated accuracy is listed below:

Pressure, percent of full scale	±0.6
Temperature (based on 65.6° C reference oven), percent:	
At 20° C	±2.0
At 200° C	±0.3
At 1000° C	±0.6
Volumetric airflow, percent	±0.55
Volumetric fuel flow, percent	±0.55
Torque, percent	±0.6
Speed, percent	±0.22

These data acquisition errors have been combined into estimates of the accuracy of the efficiency calculations.

$$\text{Error} = \sqrt{\sum_{m=1}^{n}\left[\left(\frac{\partial\eta}{\partial P_m}\right)(\delta P_m)\right]^2}$$

where

P_m measured parameter in given calculation

δP_m error associated with that measured parameter

n number of independent variables in given calculation

$\partial\eta/\partial P_m$ partial derivative with respect to P_m in given calculation of η

The data were reduced by using a digital computer for accurate simulation of the properties of humid air with combustion products. However, for estimating the error in terms of percentage points, the following approximate equations were used:

$$\eta_{comp} = \frac{h_1 - h_{2,id}}{h_1 - h_2} \approx \frac{T_1\left[\left(\frac{P_{2,T}}{P_{1,T}}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}{T_2 - T_1}$$

where $\gamma = 1.4$.

$$\eta_{ct} = \frac{h_{5.2} - h_6}{h_{5.2} - h_{6,id}}$$

$$= \frac{\mathscr{W}_{comp}\left(\frac{\dot{m}_{in}}{\dot{m}_5}\right) + L_{par}}{\Delta h_{id}}$$

$$h_{5.2} \approx h_6 + \mathscr{W}_{comp}\left(\frac{\dot{m}_{in}}{\dot{m}_5}\right) + L_{par}$$

$$\mathscr{W}_{comp}\left(\frac{\dot{m}_{in}}{\dot{m}_5}\right) = (T_{1.5} - T_{1.1})0.24\left(\frac{\dot{m}_{in}}{\dot{m}_{in} + \dot{m}_f - \dot{m}_{leak}}\right)$$

For lack of more accurate information the parasitic losses and leakages are assumed to be the same as those predicted in table I.

$$h_{6,id} \approx C_p\left(T_{6,T} + \frac{\Delta h}{C_p}\right)\left[1 - \left(\frac{P_{6,T}}{P_{5.2,T}}\right)^{\frac{\gamma-1}{\gamma}}\right]$$

$$\Delta h \approx (T_{1.5} - T_{1.1})0.24\left(\frac{\dot{m}_{in}}{\dot{m}_{in} + \dot{m}_f - \dot{m}_{leak}}\right) + L_{par}$$

$$\eta_{ct} \approx \frac{\Delta h}{C_p\left(T_{6,T} + \frac{\Delta h}{C_p}\right)\left[1 - \left(\frac{P_{6,T}}{P_{5.2,T}}\right)^{\frac{\gamma-1}{\gamma}}\right]}$$

where C_p and γ are evaluated at 900° C and $\gamma = C_p/C_v = 1.324$ and $C_p = 1.174$ kJ/kg K.

$$\eta_{pt} \approx \frac{\mathscr{P}_{net} + \mathscr{P}_{par}}{(\dot{m}_{in} + \dot{m}_f - \dot{m}_{leak})\Delta h_{id}}$$

$$\Delta h_{id} \approx C_p\left(T_{7,T} + \frac{\mathscr{P}_{gross}}{C_p m_6}\right)\left[1 - \left(\frac{P_{7,T}}{P_{6.3,T}}\right)^{\frac{\gamma-1}{\gamma}}\right]$$

Assuming parasitic losses and leakages as predicted in the engine design and constant specific heats gives

$$\eta_{pt} \approx \frac{\mathscr{P}_{net} + \mathscr{P}_{par}}{\dot{m}_6 C_p\left(T_{7,T} + \frac{\mathscr{P}_{gross}}{C_p \dot{m}_6}\right)\left[1 - \left(\frac{P_{7,T}}{P_{6.3,T}}\right)^{\frac{\gamma-1}{\gamma}}\right]}$$

where C_p and γ are evaluated at 780° C and C_p = 1.152 kJ/kg K and γ =1.332.

$$\eta_r = \frac{T_4 - T_3}{T_8 - T_3}$$

From these equations a table can be made of estimated errors as a function of gas generator speed for typical data (table IV). The values given in table IV represent 1 standard deviation of the random error due to inaccuracies in the instrumentation and the data acquisition system. There are also systematic errors that are not accounted for. The arithmetic average temperature or pressure at any station can differ significantly from the true mean value simply because of the spatial variation of temperature and pressure at each station. A compromise was made between the number of probes at each station and blockage.

APPENDIX D

SUMMARY OF DATA

CALCULATED PARAMETERS

IRN	ENGGP PERCENT	ENDC RPM	HPC KW	SFC G/W-HR	WAC KG/SEC	WFC KG/HR	ETAC	ETACT	ETAPT	ETAREG	ETAB	THP DEGREES
104	49.88	1019.	2.53		0.208		0.685	0.775	0.606	0.956		36.2
105	49.96	1019.	2.50		0.207		0.684	0.774	0.600	0.956		36.7
106	49.97	1019.	2.53		0.207		0.677	0.773	0.599	0.957		36.2
107	60.10	1338.	5.75		0.260		0.728	0.788	0.604	0.953		35.1
108	60.00	1337.	5.79		0.260		0.725	0.789	0.610	0.953		35.1
109	69.97	1638.	10.96		0.320		0.743	0.805	0.620	0.948		35.2
110	69.94	1638.	10.90		0.320		0.743	0.804	0.619	0.948		35.7
111	80.10	2038.	18.48		0.391		0.749	0.820	0.648	0.941		35.8
112	80.06	2038.	18.49		0.391		0.744	0.821	0.650	0.942		35.6
154	49.88	599.	2.31		0.208		0.678	0.780	0.497	0.948		35.4
155	49.99	795.	2.56		0.208		0.680	0.778	0.560	0.952		36.1
156	49.96	1010.	2.60		0.207		0.675	0.781	0.606	0.956		36.0
157	49.89	1197.	2.42		0.207		0.675	0.779	0.630	0.957		36.5
158	49.86	1399.	2.02		0.208		0.674	0.780	0.636	0.958		36.3
159	49.90	1400.	2.05		0.208		0.674	0.781	0.641	0.957		36.6
160	49.99	1197.	2.42		0.208		0.675	0.777	0.629	0.957		36.7
161	49.97	1013.	2.56		0.208		0.674	0.780	0.606	0.957		35.7
162	49.98	797.	2.53		0.208		0.674	0.779	0.562	0.955		35.5
163	50.03	600.	2.30		0.208		0.672	0.781	0.498	0.952		36.1
164	59.97	851.	5.20		0.260		0.726	0.791	0.526	0.949		34.8
165	59.98	1105.	5.73		0.259		0.723	0.791	0.576	0.952		34.8
166	59.95	1355.	5.81		0.259		0.718	0.791	0.618	0.955		35.6
167	59.96	1599.	5.47		0.260		0.718	0.791	0.638	0.955		35.5
168	59.91	1897.	4.78		0.259		0.719	0.789	0.639	0.953		35.3
169	59.91	1910.	4.73		0.260		0.717	0.791	0.637	0.953		35.0
170	59.88	1599.	5.44		0.259		0.718	0.789	0.640	0.955		35.2
171	59.86	1351.	5.82		0.258		0.718	0.793	0.617	0.955		35.7
172	59.86	1104.	5.66		0.259		0.720	0.794	0.579	0.954		35.1
173	60.00	853.	5.21		0.260		0.721	0.794	0.527	0.949		35.0
174	70.04	1098.	10.07		0.321		0.762	0.804	0.548	0.942		35.7
175	69.93	1350.	10.68		0.320		0.743	0.806	0.590	0.948		35.7
176	69.91	1637.	10.95		0.319		0.742	0.804	0.622	0.951		35.7
177	69.94	2003.	10.17		0.320		0.741	0.804	0.641	0.949		35.7
178	69.90	2399.	8.72		0.320		0.740	0.801	0.629	0.946		35.7
179	69.91	2397.	8.73		0.320		0.741	0.804	0.630	0.946		35.6
180	69.95	1997.	10.21		0.320		0.742	0.805	0.641	0.950		35.6
181	69.98	1638.	10.92		0.319		0.742	0.805	0.621	0.951		34.9
182	69.93	1351.	10.61		0.319		0.742	0.806	0.589	0.948		35.3
183	69.91	1104.	9.87		0.319		0.739	0.807	0.551	0.944		35.7
184	79.98	1201.	16.00		0.391		0.751	0.823	0.558	0.937		36.3
185	79.91	1647.	17.90		0.389		0.746	0.821	0.617	0.943		35.7
186	80.02	2029.	18.24		0.390		0.746	0.821	0.648	0.946		36.2
187	80.01	2445.	16.96		0.391		0.745	0.821	0.657	0.943		36.7
188	79.96	2897.	14.33		0.391		0.744	0.819	0.626	0.940		36.7
189	79.98	2897.	14.51		0.391		0.746	0.819	0.632	0.940		36.9
190	80.02	2447.	17.00		0.391		0.746	0.823	0.658	0.943		36.9
191	79.96	1986.	18.35		0.389		0.746	0.822	0.643	0.946		36.6
192	79.99	1648.	17.92		0.389		0.745	0.823	0.614	0.944		36.8
193	80.00	1197.	16.10		0.390		0.745	0.826	0.561	0.939		36.6
221	49.94	1025.	2.41	1.111	0.207	2.683	0.676	0.774	0.569	0.955	0.940	36.1
222	49.93	1023.	2.45	1.086	0.207	2.657	0.670	0.776	0.574	0.956	0.932	36.1
223	60.00	1339.	5.77	0.740	0.259	4.271	0.715	0.795	0.602	0.952	0.905	35.0
224	60.01	1341.	5.79	0.728	0.259	4.220	0.714	0.797	0.603	0.953	0.897	35.0
225	69.92	1639.	10.73	0.599	0.319	6.429	0.739	0.809	0.610	0.945	0.930	34.8
226	69.98	1639.	10.70	0.602	0.319	6.434	0.737	0.809	0.609	0.945	0.931	34.7
227	79.97	2044.	18.07	0.514	0.389	9.294	0.744	0.827	0.639	0.935	0.973	36.1
228	79.98	2045.	18.28	0.512	0.389	9.354	0.739	0.827	0.646	0.935	0.968	36.1
243	50.08	1025.	2.50	1.113	0.206	2.777	0.694	0.777	0.594	0.955	0.896	36.1
244	50.09	1028.	2.52	1.090	0.206	2.745	0.692	0.779	0.600	0.956	0.889	36.2
245	60.03	1340.	5.73	0.760	0.257	4.356	0.750	0.788	0.606	0.951	0.886	35.5
246	59.98	1339.	5.69	0.748	0.257	4.260	0.733	0.794	0.605	0.953	0.879	35.6
247	69.93	1635.	10.85	0.598	0.318	6.489	0.750	0.808	0.623	0.946	0.892	35.0
248	69.92	1634.	10.89	0.593	0.318	6.457	0.749	0.809	0.626	0.946	0.896	35.1
249	79.99	2045.	18.69	0.509	0.388	9.512	0.753	0.826	0.653	0.939	0.917	35.7
250	80.02	2045.	18.36	0.514	0.389	9.438	0.750	0.825	0.654	0.939	0.918	36.2
251	70.00	1640.	11.11	0.581	0.317	6.450	0.740	0.813	0.635	0.948	0.884	35.5
252	70.04	1640.	11.05	0.576	0.317	6.358	0.743	0.813	0.632	0.946	0.927	35.5
253	59.87	1342.	5.92	0.696	0.256	4.119	0.719	0.803	0.635	0.955	0.878	35.1
254	59.95	1342.	5.93	0.704	0.256	4.175	0.724	0.802	0.636	0.954	0.865	35.1
255	49.94	1026.	2.63	0.999	0.204	2.625	0.672	0.787	0.621	0.957	0.902	35.7
256	49.91	1025.	2.63	1.004	0.204	2.635	0.674	0.789	0.620	0.958	0.875	35.7
321	50.00	602.	2.28	1.223	0.208	2.789	0.673	0.777	0.515	0.948	0.929	35.7
322	49.93	801.	2.53	1.058	0.207	2.673	0.669	0.779	0.579	0.953	0.928	36.1
323	49.94	999.	2.56	1.039	0.206	2.657	0.668	0.778	0.621	0.955	0.942	36.1
324	49.94	1193.	2.41	1.105	0.206	2.664	0.664	0.778	0.642	0.956	0.945	36.0
325	49.93	1407.	2.03	1.295	0.207	2.629	0.661	0.781	0.653	0.955	0.929	36.6
326	60.00	797.	5.00	0.818	0.260	4.092	0.715	0.792	0.520	0.945	0.932	34.9
327	59.96	1101.	5.62	0.697	0.258	3.916	0.711	0.792	0.591	0.952	0.949	35.0
328	59.97	1301.	5.79	0.705	0.258	4.083	0.710	0.791	0.622	0.953	0.939	35.0
329	59.95	1607.	5.44	0.741	0.259	4.032	0.708	0.792	0.647	0.951	0.947	35.0
330	59.92	1805.	4.99	0.803	0.258	4.008	0.710	0.789	0.653	0.951	0.956	35.2
331	69.95	1104.	9.86	0.647	0.320	6.382	0.741	0.803	0.558	0.940	0.925	35.5

IRN	ENGGP PERCENT	ENDC RPM	HPC KW	SFC G/W-HR	WAC KG/SEC	WFC KG/HR	ETAC	ETACT	ETAPT	ETAREG	ETAB	THP DEGREES
332	69.97	1300.	10.39	0.610	0.319	6.340	0.735	0.805	0.593	0.943	0.917	35.3
333	69.95	1600.	10.82	0.591	0.318	6.391	0.735	0.803	0.626	0.947	0.927	35.0
334	69.97	1802.	10.77	0.580	0.318	6.248	0.732	0.804	0.650	0.945	0.948	35.0
335	69.91	2206.	9.68	0.651	0.319	6.302	0.734	0.803	0.659	0.944	0.932	35.6
336	80.00	1602.	17.75	0.528	0.389	9.371	0.750	0.817	0.623	0.936	0.931	36.1
337	79.99	1904.	17.97	0.517	0.389	9.292	0.742	0.819	0.651	0.940	0.935	36.2
338	79.99	1999.	18.07	0.514	0.388	9.277	0.741	0.819	0.655	0.940	0.943	36.2
339	79.99	2207.	17.89	0.517	0.388	9.256	0.743	0.819	0.663	0.938	0.953	36.2
340	79.93	2407.	17.33	0.536	0.388	9.294	0.742	0.819	0.667	0.939	0.935	36.2
341	89.91	1899.	26.84	0.495	0.468	13.276	0.741	0.839	0.648	0.929	0.933	37.9
342	89.92	2104.	27.22	0.488	0.468	13.294	0.740	0.837	0.663	0.929	0.943	38.2
343	89.87	2198.	27.27	0.490	0.468	13.356	0.740	0.838	0.671	0.930	0.935	38.3
344	89.89	2305.	27.27	0.489	0.468	13.328	0.738	0.838	0.679	0.932	0.940	38.4
345	89.96	2504.	26.50	0.499	0.469	13.232	0.738	0.839	0.693	0.931	0.946	38.6
346	89.90	2808.	25.25	0.524	0.469	13.236	0.739	0.838	0.695	0.930	0.945	38.4
366	94.90	2191.	30.61	0.530	0.513	16.216	0.732	0.845	0.696	0.924	0.902	41.2
437	49.90	995.	2.58	1.054	0.206	2.720	0.681	0.790	0.609	0.952	0.974	35.9
438	80.05	1998.	19.16	0.505	0.387	9.679	0.743	0.833	0.646	0.936	0.952	35.9
439	90.03	2259.	28.64	0.481	0.469	13.783	0.742	0.847	0.678	0.934	0.913	37.9
440	93.39	2258.	31.30	0.501	0.500	15.665	0.730	0.856	0.671	0.931	0.896	38.9
441	94.92	2260.	32.69	0.483	0.512	15.777	0.729	0.859	0.678	0.933	0.910	39.3
442	94.86	2261.	32.76	0.485	0.513	15.895	0.724	0.862	0.679	0.929	0.910	39.9
443	97.16	2259.	34.71	0.491	0.534	17.052	0.726	0.864	0.695	0.928	0.887	40.6
444	97.04	2255.	34.34	0.511	0.533	17.536	0.720	0.863	0.694	0.930	0.852	41.1
445	97.68	2261.	34.44	0.509	0.531	17.544	0.729	0.838	0.680	0.919	1.033	40.8
446	97.06	2257.	34.11	0.513	0.532	17.494	0.721	0.861	0.692	0.928	0.865	41.1
447	97.05	2260.	34.11	0.503	0.532	17.171	0.721	0.863	0.696	0.926	0.882	41.2
448	79.97	2000.	19.16	0.503	0.385	9.634	0.734	0.836	0.649	0.939	0.933	36.3
449	70.09	1605.	11.35	0.569	0.314	6.463	0.713	0.829	0.630	0.947	0.904	35.1
450	59.75	1308.	5.93	0.699	0.253	4.144	0.692	0.810	0.619	0.956	0.891	34.5
451	49.93	1009.	2.61	1.037	0.203	2.712	0.637	0.805	0.612	0.959	0.877	35.1
452	58.21	1304.	5.03	0.825	0.248	4.153	0.728	0.802	0.617	0.954	0.827	35.1
453	58.26	1305.	5.32	0.784	0.245	4.170	0.714	0.803	0.621	0.955	0.842	34.5
468	50.06	1000.	2.35	1.297	0.207	3.053	0.735	0.756	0.585	0.947	0.959	36.5
469	49.99	1000.	2.45	1.145	0.206	2.810	0.697	0.776	0.609	0.951	0.977	36.8
470	60.04	1301.	5.81	0.765	0.257	4.447	0.733	0.797	0.608	0.950	0.925	34.2
471	70.03	1598.	10.94	0.599	0.317	6.553	0.734	0.817	0.625	0.945	0.937	35.0
472	79.92	2000.	18.41	0.517	0.385	9.515	0.742	0.833	0.649	0.937	0.963	35.6
473	89.97	2258.	28.30	0.488	0.466	13.819	0.735	0.853	0.673	0.931	0.953	37.6
474	94.97	2257.	32.00	0.498	0.509	15.931	0.721	0.863	0.678	0.930	0.953	40.6
475	97.49	2255.	33.96	0.508	0.529	17.258	0.718	0.860	0.688	0.928	0.961	41.0
476	97.72	2257.	34.61	0.497	0.534	17.209	0.713	0.867	0.693	0.928	0.955	41.3
477	97.60	2260.	34.26	0.502	0.533	17.194	0.714	0.866	0.692	0.929	0.947	41.3
478	97.32	2257.	33.79	0.508	0.530	17.151	0.712	0.866	0.693	0.931	0.926	41.3
479	94.92	2258.	32.21	0.498	0.509	16.034	0.721	0.864	0.678	0.930	0.952	40.8
480	90.02	2266.	27.73	0.483	0.465	13.381	0.723	0.858	0.674	0.932	0.974	38.7
481	80.04	2006.	18.65	0.504	0.384	9.408	0.728	0.841	0.650	0.939	0.967	36.3
483	69.92	1600.	10.91	0.589	0.313	6.428	0.713	0.826	0.629	0.950	0.922	35.3
484	59.95	1297.	5.73	0.695	0.253	3.985	0.667	0.820	0.621	0.957	0.945	34.8
485	49.85	1008.	2.50	0.987	0.202	2.462	0.598	0.813	0.624	0.960	0.953	35.7
501	89.87	2261.	27.84	0.491	0.468	13.677	0.728	0.842	0.676	0.938	0.916	38.4
502	95.04	2259.	32.38	0.497	0.513	16.107	0.669	0.888	0.668	0.937	0.914	40.2
511	89.94	2261.	27.73	0.508	0.467	14.084	0.735	0.845	0.675	0.936	0.899	38.0

UNCORRECTED TEMPERATURES-(KELVIN)

IRN	T0.5	T1	T1.1T	T1.5T	T1.9T	T2	T3	T4	T5T	T5.2T	T6T	T6.3T	T7T	T8	T9	T5CALC
104	309.5	309.8	309.8	364.4	365.0	364.2	380.6	1016.1		1137.7	1088.1	1085.5	1060.5	1045.5	445.2	1139.9
105	309.5	309.8	309.8	364.4	365.1	364.2	380.7	1016.7		1137.9	1087.6	1085.0	1060.6	1046.2	445.5	1139.4
106	309.2	309.5	309.5	364.2	365.1	364.5	383.3	1019.3		1139.6	1089.0	1086.0	1061.7	1047.7	449.0	1140.8
107	309.1	310.0	309.8	387.5	386.6	385.2	401.0	1012.2		1160.0	1089.6	1087.8	1056.3	1042.5	472.0	1162.6
108	309.2	310.2	310.0	387.6	386.9	385.5	401.6	1013.4		1159.1	1089.2	1087.3	1056.4	1043.2	473.0	1162.2
109	309.0	310.0	309.7	414.5	412.4	410.2	423.2	1010.2		1189.8	1095.7	1094.9	1054.9	1042.3	501.1	1193.3
110	309.1	310.0	309.8	414.4	412.6	410.4	423.8	1010.4		1190.3	1096.7	1096.0	1055.5	1042.4	501.9	1194.3
111	308.9	309.5	309.6	445.4	442.4	439.1	448.6	1006.5		1227.0	1103.3	1104.4	1053.2	1041.3	532.8	1229.1
112	308.9	309.4	309.8	445.6	442.9	439.7	450.2	1006.6		1226.0	1102.8	1103.9	1052.8	1041.0	534.3	1228.7
154	306.9	307.2	307.4	361.1	362.2	361.3	374.6	1006.7		1128.7	1078.7	1076.0	1055.7	1041.1	447.2	1129.9
155	307.3	307.6	307.9	361.8	362.8	361.9	377.6	1008.5		1134.1	1082.2	1078.5	1055.0	1040.5	444.9	1133.7
156	307.5	307.8	308.0	362.1	363.2	362.4	379.2	1011.2		1133.1	1082.1	1079.0	1054.4	1040.3	445.0	1133.9
157	307.8	308.2	308.4	362.3	363.5	362.7	380.1	1010.8		1130.9	1079.9	1076.5	1052.6	1039.1	444.3	1131.3
158	308.1	308.4	308.6	362.6	363.7	363.0	380.8	1007.1		1123.7	1074.5	1071.9	1048.7	1034.7	444.9	1126.0
159	308.2	308.5	308.7	362.8	363.9	363.2	381.2	1006.7		1125.1	1074.8	1071.9	1048.6	1034.8	445.4	1126.4
160	308.4	308.7	308.8	363.1	364.3	363.5	381.8	1009.9		1132.2	1081.4	1078.5	1052.9	1038.2	446.3	1133.2
161	308.4	308.9	308.9	363.2	364.4	363.7	382.3	1012.4		1131.6	1081.2	1078.2	1053.9	1040.6	448.4	1133.0
162	308.6	309.0	309.2	363.4	364.6	363.9	382.8	1011.6		1131.9	1081.0	1078.1	1055.0	1041.3	451.6	1132.7
163	308.6	309.0	309.2	363.6	364.8	364.1	383.6	1010.8		1134.6	1082.0	1079.0	1057.5	1042.7	457.8	1133.9
164	308.9	309.6	309.6	386.6	385.8	384.2	399.7	1010.2		1154.9	1084.3	1081.6	1055.7	1043.2	477.3	1157.0
165	309.1	310.0	309.9	387.1	386.6	385.1	401.0	1017.1		1164.1	1092.9	1090.4	1060.5	1047.9	474.3	1165.9
166	309.4	310.1	310.1	387.3	386.9	385.5	401.7	1016.4		1162.5	1092.3	1089.8	1058.6	1045.1	473.6	1165.4
167	309.3	310.1	310.0	387.3	386.9	385.5	402.0	1012.2		1157.9	1087.3	1084.9	1053.7	1041.0	472.9	1160.3
168	309.5	310.4	310.4	387.3	387.0	385.7	402.2	1011.3		1156.8	1086.8	1084.2	1054.0	1041.5	472.6	1159.5
169	309.8	310.5	310.4	387.6	387.3	385.9	402.5	1011.8		1157.8	1088.0	1085.6	1055.1	1042.1	473.0	1161.1
170	309.9	310.7	310.7	387.8	387.4	386.0	402.8	1013.3		1159.8	1089.4	1086.8	1055.4	1042.3	473.7	1162.2

IRN	T0.5	T1	T1.1T	T1.5T	T1.9T	T2	T3	T4	T5T	T5.2T	T6T	T6.3T	T7T	T8	T9	T5CALC
171	310.2	310.9	310.7	388.1	387.8	386.4	403.3	1021.1		1168.0	1097.3	1094.5	1063.1	1050.1	475.2	1170.6
172	310.2	311.2	310.9	388.1	387.8	386.5	403.5	1018.0		1161.6	1091.6	1089.1	1059.9	1047.9	476.9	1164.7
173	310.5	311.3	311.2	388.7	388.3	387.0	404.0	1014.9		1159.5	1089.4	1087.0	1060.2	1047.5	481.7	1162.8
174	310.9	311.5	311.5	415.9	412.9	410.0	421.9	1013.5		1194.1	1098.4	1097.6	1061.5	1050.1	504.3	1196.4
175	311.1	311.8	311.7	416.4	414.5	412.1	425.2	1018.0		1196.4	1100.8	1100.1	1061.7	1050.4	505.2	1199.0
176	311.0	312.0	312.0	416.5	414.7	412.5	426.2	1021.0		1201.0	1105.9	1105.2	1064.1	1051.7	505.0	1204.0
177	311.1	311.9	312.0	416.5	414.8	412.5	426.6	1012.0		1192.5	1097.2	1096.0	1055.4	1043.5	503.9	1195.3
178	311.2	312.0	312.2	416.5	414.8	412.5	426.6	1012.3		1192.1	1097.4	1096.5	1057.4	1045.7	503.4	1195.3
179	311.2	312.1	312.0	416.5	414.7	412.4	426.7	1012.1		1192.3	1097.0	1096.1	1056.9	1045.5	503.6	1195.1
180	311.4	312.3	312.2	416.8	415.0	412.8	427.0	1014.5		1194.7	1100.1	1099.1	1057.9	1045.7	504.3	1198.3
181	311.5	312.5	312.5	417.2	415.4	413.1	427.4	1021.9		1203.0	1107.4	1106.7	1065.2	1052.6	506.2	1205.7
182	311.6	312.7	312.5	417.3	415.5	413.3	427.6	1019.1		1197.6	1102.4	1101.7	1063.0	1051.3	507.7	1200.8
183	311.8	312.6	312.7	417.3	415.7	413.4	427.8	1016.4		1194.0	1098.9	1098.0	1062.4	1051.5	510.4	1197.2
184	311.5	312.0	312.3	447.7	444.5	441.0	450.6	1010.5		1225.4	1100.8	1102.8	1058.1	1048.2	541.6	1227.1
185	311.9	312.4	312.8	448.3	445.6	442.4	453.2	1017.3		1235.7	1110.8	1113.2	1062.3	1051.6	538.8	1237.2
186	312.2	312.8	313.1	449.2	446.4	443.1	454.3	1019.4		1237.7	1112.6	1115.2	1062.5	1051.7	538.1	1239.7
187	312.5	313.0	313.3	449.5	446.9	443.6	455.0	1014.3		1232.7	1108.0	1110.8	1058.4	1048.0	537.9	1235.0
188	312.4	312.9	313.3	449.2	446.7	443.5	455.0	1014.7		1232.0	1107.1	1109.3	1060.6	1050.7	538.0	1233.9
189	312.5	313.2	313.4	449.3	446.7	443.5	455.2	1015.6		1232.2	1107.7	1110.1	1061.3	1051.2	538.6	1234.6
190	312.6	313.2	313.3	449.6	446.9	443.7	455.5	1014.8		1233.2	1108.4	1111.1	1058.9	1048.5	538.7	1235.6
191	313.0	313.5	313.8	450.2	447.6	444.3	456.0	1024.1		1243.7	1118.4	1120.9	1067.6	1056.4	540.5	1245.8
192	313.1	313.7	314.0	450.4	447.7	444.5	456.3	1021.0		1239.0	1113.7	1116.3	1065.4	1054.8	542.2	1241.0
193	313.1	313.7	313.8	450.3	447.7	444.6	456.4	1018.1		1231.7	1107.4	1109.7	1065.0	1054.8	547.9	1234.8
221	297.3	298.1	298.3	350.5	351.4	350.7	367.7	979.9		1097.4	1049.2	1046.1	1021.6	1008.8	433.2	1098.8
222	297.4	297.9	298.5	350.7	351.7	351.1	368.4	981.3		1096.8	1048.8	1045.6	1021.9	1009.6	434.2	1098.5
223	298.0	298.9	299.2	373.8	373.4	372.1	386.6	976.5		1120.6	1052.1	1049.6	1018.4	1006.2	457.5	1122.3
224	297.9	298.9	299.1	373.8	373.5	372.2	387.1	976.9		1117.7	1050.1	1047.5	1017.3	1006.3	458.4	1120.4
225	297.7	298.5	298.9	399.4	397.4	395.2	406.7	972.1		1152.0	1055.4	1055.0	1014.7	1004.8	485.4	1149.3
226	298.0	298.9	299.2	399.9	398.1	396.0	408.2	972.5		1152.6	1056.3	1055.6	1015.2	1005.1	486.7	1150.2
227	298.2	299.0	299.5	430.2	427.5	424.5	433.6	968.4		1191.0	1062.7	1067.5	1012.9	1005.7	517.0	1184.0
228	298.1	298.7	299.5	430.2	427.8	424.8	434.7	968.2		1191.3	1062.6	1067.1	1012.6	1005.4	518.2	1183.9
243	298.6	299.1	298.2	351.2	351.7	351.0	365.5	982.3		1099.6	1052.0	1049.6	1024.4	1011.2	431.0	1102.3
244	298.7	299.0	298.2	351.3	351.9	351.2	366.5	982.6		1097.6	1050.5	1048.0	1023.6	1011.2	432.3	1100.9
245	298.6	299.4	298.5	373.0	371.4	369.8	382.2	976.4		1121.3	1053.3	1051.0	1019.3	1007.2	453.1	1123.4
246	298.9	299.5	298.6	373.5	372.6	371.2	384.7	979.4		1120.2	1053.2	1051.0	1020.4	1008.9	456.2	1123.7
247	299.6	300.3	299.4	400.6	398.6	396.5	407.9	974.6		1150.2	1059.1	1058.0	1018.1	1007.0	485.5	1153.5
248	299.6	300.4	299.4	400.7	398.7	396.7	408.5	974.8		1150.5	1059.4	1058.2	1018.4	1007.0	486.1	1153.8
249	299.5	299.9	299.5	431.0	427.8	424.7	433.3	975.6		1190.9	1071.3	1072.6	1021.0	1010.9	516.6	1193.2
250	299.6	300.1	299.8	431.4	428.5	425.5	435.0	972.5		1186.7	1066.8	1068.1	1017.7	1007.4	518.0	1188.8
251	300.5	301.3	300.5	402.6	401.2	399.4	414.2	980.9		1154.6	1063.5	1062.6	1022.7	1012.1	493.4	1158.7
252	300.4	301.2	300.2	402.4	400.8	398.9	413.5	980.5		1160.2	1064.1	1064.4	1023.0	1013.1	492.5	1159.4
253	299.8	300.5	299.7	375.0	374.8	373.7	390.5	979.5		1116.5	1050.8	1048.4	1018.3	1007.1	461.9	1121.6
254	299.9	300.8	299.8	375.3	374.9	373.8	390.2	979.7		1116.4	1050.0	1047.3	1017.9	1007.9	461.6	1121.0
255	300.0	300.5	299.8	353.3	354.7	354.4	374.8	987.7		1101.0	1054.1	1051.1	1026.9	1015.1	440.5	1104.9
256	300.0	300.5	299.7	353.1	354.4	354.0	374.3	987.7		1098.0	1052.3	1049.2	1025.6	1014.4	440.0	1103.0
321	302.4	302.1	302.9	356.2	356.8	355.9	369.4	984.9		1107.2	1055.7	1052.5	1032.1	1018.8	441.8	1105.9
322	302.3	302.0	302.8	355.9	357.0	356.1	371.2	990.7		1108.4	1058.1	1055.0	1033.0	1021.2	438.9	1108.3
323	302.4	302.2	303.0	356.1	357.0	356.3	371.9	991.9		1110.8	1060.9	1058.3	1034.1	1021.4	436.9	1111.1
324	302.1	301.9	302.7	355.9	357.0	356.3	372.5	991.9		1111.5	1061.2	1058.5	1034.0	1020.5	436.4	1111.5
325	301.5	301.6	302.3	355.5	356.7	356.0	372.8	987.4		1102.9	1053.5	1050.6	1028.0	1016.1	436.7	1103.7
326	302.0	302.3	303.0	378.5	377.8	376.4	390.0	983.3		1126.8	1056.8	1053.9	1029.5	1017.8	468.4	1127.4
327	302.1	302.5	303.2	378.7	378.4	377.2	392.1	989.0		1129.5	1060.1	1057.4	1030.0	1019.2	465.1	1130.7
328	302.2	302.5	303.2	378.9	378.4	377.2	392.1	990.7		1135.6	1065.9	1063.0	1033.0	1020.4	463.7	1136.7
329	301.9	302.2	302.9	378.5	378.2	377.0	392.0	987.7		1131.8	1062.6	1059.8	1029.7	1018.1	462.0	1133.3
330	302.3	302.6	303.4	378.8	378.3	377.2	392.2	987.6		1132.6	1062.6	1060.1	1029.8	1018.4	462.2	1133.2
331	301.9	302.4	303.2	404.8	402.6	400.4	411.4	982.8		1162.1	1066.8	1064.5	1030.1	1019.4	493.3	1161.2
332	302.2	302.9	303.5	405.5	403.7	401.8	413.9	983.2		1160.1	1066.1	1063.4	1027.9	1017.7	494.3	1160.8
333	302.3	302.9	303.6	405.7	404.0	402.0	414.3	989.4		1170.1	1075.1	1072.7	1033.8	1021.7	494.2	1169.9
334	301.9	302.4	303.2	405.3	403.6	401.7	414.3	986.7		1167.3	1072.5	1069.6	1030.9	1019.7	492.7	1167.2
335	301.9	302.7	303.4	405.1	403.4	401.6	414.2	983.5		1162.4	1068.2	1065.5	1027.6	1017.1	492.1	1162.6
336	302.1	302.6	303.6	435.5	432.1	428.8	436.9	980.7		1197.3	1075.0	1073.1	1027.7	1017.8	522.2	1196.6
337	301.9	302.6	303.5	435.6	432.9	430.0	439.8	980.5		1196.1	1074.1	1072.0	1025.9	1015.0	523.4	1195.9
338	302.0	302.6	303.5	435.7	433.0	430.1	440.1	981.5		1199.3	1077.0	1075.3	1027.4	1015.8	523.5	1198.9
339	301.7	302.6	303.4	435.4	432.7	429.9	440.0	982.6		1201.8	1079.4	1076.8	1029.0	1018.6	522.1	1201.2
340	302.0	302.8	303.8	435.7	433.1	430.3	440.5	983.7		1200.3	1079.2	1077.6	1029.3	1019.2	522.8	1200.8
341	301.9	302.4	303.8	469.1	465.3	461.4	467.8	976.3		1230.5	1078.1	1077.6	1022.2	1015.0	556.8	1229.9
342	301.7	302.3	303.7	468.9	465.3	461.6	468.8	978.3		1235.5	1082.3	1081.4	1026.3	1017.1	556.5	1234.0
343	302.2	302.7	303.9	469.4	465.9	462.2	469.8	980.4		1236.9	1084.4	1084.0	1028.9	1019.0	557.6	1236.3
344	301.9	302.2	303.5	469.0	465.5	461.8	469.8	981.0		1238.2	1084.8	1084.6	1029.7	1018.6	556.9	1236.7
345	301.8	302.2	303.5	469.2	465.8	462.1	470.4	976.9		1233.4	1080.1	1079.1	1025.8	1014.3	556.2	1232.0
346	302.0	302.6	303.7	469.3	465.9	462.1	470.4	978.9		1235.4	1082.3	1081.5	1028.2	1017.4	556.0	1234.2
366	289.6	289.5	290.9	468.4	464.7	460.6	464.9	930.4		1195.3	1028.6	1029.2	976.7	968.9	554.3	1190.9
437	302.4	301.9	302.6	356.3	357.0	355.8	364.8	989.8		1116.1	1063.8	1060.3	1036.4	1021.1	430.5	1114.5
438	302.6	302.2	303.3	437.5	435.0	431.8	438.4	984.6		1214.6	1089.7	1089.3	1034.6	1021.9	523.3	1213.2
439	302.8	302.2	303.5	471.3	467.6	463.5	468.6	983.8		1241.3	1092.7	1086.8	1033.9	1020.4	557.0	1246.5
440	302.9	301.6	303.5	484.1	480.5	476.2	481.4	980.4		1249.5	1087.3	1081.8	1027.5	1017.5	570.6	1252.6
441	302.6	301.7	303.1	488.8	485.2	481.1	486.3	980.1		1249.0	1085.4	1082.5	1026.3	1015.6	576.5	1255.4
442	302.8	301.6	303.4	489.8	486.2	482.0	488.2	977.9		1248.8	1083.2	1079.4	1023.6	1015.6	576.9	1253.8
443	302.6	301.7	303.5	498.8	494.5	489.9	495.0	984.6		1255.3	1084.2	1077.2	1028.1	1022.7	586.7	1262.9
444	302.9	301.7	303.5	498.2	494.4	490.1	495.7	982.4		1250.8	1084.4	1080.1	1028.6	1019.3	586.5	1262.5
445	303.2	302.2	303.9	499.0	494.9	490.7	496.4	981.5		1308.3	1117.1	1111.2	1049.5	1024.2	586.5	1295.5
446	303.1	302.2	303.8	498.4	494.8	490.6	496.6	980.6		1253.1	1085.4	1080.8	1028.4	1018.4	586.7	1263.4
447	302.9	301.9	303.5	498.3	494.6	490.4	496.7	979.9		1252.3	1082.5	1076.2	1026.3	1018.4	586.5	1260.8
448	302.6	302.4	303.2	437.7	435.9	433.1	445.7	989.4		1214.7	1092.1	1092.2	1038.1	1024.7	531.2	1215.8
449	302.2	302.4	302.8	407.6	407.5	406.0	422.4	989.8		1169.9	1077.0	1075.2	1035.0	1021.4	503.1	1174.0
450	302.4	303.0	303.5	380.2	381.4	380.5	399.3	997.2		1139.3	1073.8	1068.7	1040.3	1024.8	474.6	1145.6
451	302.3	303.1	303.2	358.1	361.1	361.0	383.2	995.0		1109.7	1062.7	1057.3	1036.0	1021.4	451.3	1114.4
452	302.0	302.4	302.9	374.5	373.6	372.0	389.2	976.2		1111.8	1050.3	1044.7	1019.0	1004.3	460.7	1117.5
453	302.6	303.0	303.4	375.8	375.7	374.3	390.9	992.3		1131.8	1069.4	1063.5	1036.1	1020.6	462.7	1137.2
468	301.3	301.1	301.6	354.1	352.9	351.0	352.6	984.0	1078.2	1121.8	1069.3	1064.0	1039.4	1019.2	417.3	1118.8
469	302.5	302.6	303.0	356.3	356.5	355.2	362.5	987.3	1054.5	1117.7	1065.3	1062.0	1036.6	1019.6	428.0	1115.6
470	302.4	302.7	303.0	379.3	378.1	376.2	385.2	991.4	1078.0	1147.5	1076.1	1072.5	1038.9	1023.6	457.2	1147.4
471	302.4	302.4	303.2	406.5	404.9	402.6	413.2	985.8	1113.5	1174.1	1075.5	1074.6	1031.0	1018.9	491.8	1171.2
472	302.7	302.5	303.5	436.8	434.2	431.1	439.4	983.2	1155.1	1213.3	1083.8	1086.0	1029.0	1019.9	522.4	1206.5
473	302.9	302.2	303.4	471.4	468.1	464.4	471.4	985.1	1180.1	1256.8	1093.8	1103.2	1031.0	1023.3	558.3	1247.8

IRN	T0.5	T1	T1.1T	T1.5T	T1.9T	T2	T3	T4	T5T	T5.2T	T6T	T6.3T	T7T	T8	T9	T5CALC
474	303.0	301.5	303.5	489.9	486.3	482.2	488.7	981.2	1133.4	1267.2	1085.6	1096.1	1023.0	1018.2	576.7	1256.3
475	303.1	301.5	303.7	499.3	495.5	491.2	497.1	984.9	1148.7	1284.7	1093.5	1105.3	1031.1	1022.6	587.1	1272.5
476	302.9	301.0	303.2	500.4	496.4	492.2	498.3	983.6	1147.1	1278.4	1087.5	1097.5	1026.9	1021.4	588.5	1268.0
477	302.7	301.1	303.3	499.7	495.8	491.8	498.2	982.4	1143.6	1274.9	1085.3	1095.3	1025.2	1019.6	588.1	1265.1
478	302.8	300.9	303.3	498.7	495.2	491.2	498.0	982.1	1137.5	1269.2	1083.0	1094.2	1023.6	1018.1	587.5	1261.8
479	303.0	301.6	303.4	490.0	486.4	482.4	490.3	983.0	1135.1	1270.5	1087.3	1098.4	1024.6	1020.0	578.1	1258.1
480	302.7	302.0	303.4	472.0	469.6	466.4	477.3	982.0	1196.1	1251.4	1084.7	1098.6	1024.4	1018.7	563.7	1239.4
481	302.5	302.4	303.3	437.8	436.2	433.7	447.6	989.2	1162.3	1218.0	1085.1	1093.7	1030.9	1024.6	531.7	1209.0
483	302.6	303.0	303.6	407.5	407.3	405.8	423.2	993.2	1108.9	1176.8	1075.8	1078.8	1032.8	1023.0	503.7	1172.0
484	302.3	303.2	303.5	381.2	383.6	383.4	404.3	993.1	1064.0	1138.5	1064.1	1067.1	1029.9	1019.8	478.8	1136.8
485	302.4	303.3	303.7	358.9	363.6	364.3	388.7	995.4	1053.8	1109.6	1056.4	1056.6	1030.5	1020.8	457.3	1108.4
501	302.4	300.9	302.9	470.3	466.7	463.0		983.2		1240.0	1091.1	1090.5	1033.4	1021.3	555.9	1244.5
502	303.1	301.1	303.3	490.4	486.2	482.0		985.8		1261.1	1094.5	1093.5	1034.0	1024.4	576.1	1276.3
511	302.8	301.4	303.3	470.8	466.7	462.8		981.9		1242.3	1090.5	1089.4	1032.9	1020.6	555.3	1243.9

UNCORRECTED PRESSURES-(KPA)

IRN	P1T	P1.1S	P1.9S	P2	P3	P4	P5S	P5.2T	P6T	P6.3T	P7T	P8	P9	PEXH
104	99.7	98.5	148.5	148.9	148.0	146.7		143.8	112.9	111.6	102.0	101.2	99.4	99.3
105	99.8	98.6	148.6	148.8	148.1	146.8		143.9	112.9	111.7	102.0	101.2	99.4	99.3
106	99.8	98.6	148.6	148.9	148.1	146.9		144.0	113.0	111.8	102.0	101.2	99.4	99.3
107	99.6	97.7	176.1	176.5	175.2	173.8		170.0	121.6	119.7	103.0	101.7	99.5	99.3
108	99.5	97.6	175.8	176.2	175.0	173.5		169.7	121.6	119.7	103.0	101.7	99.5	99.3
109	99.3	96.4	211.6	212.2	210.5	209.1		204.2	132.2	129.5	104.4	102.4	99.6	99.3
110	99.3	96.4	211.5	212.2	210.4	209.0		204.1	132.2	129.4	104.4	102.4	99.6	99.3
111	98.9	94.4	258.4	259.4	257.0	255.4		249.4	144.9	140.6	106.6	103.4	99.9	99.4
112	98.9	94.4	258.0	259.0	256.7	255.2		249.2	144.9	140.5	106.6	103.4	99.9	99.4
154	99.9	98.7	148.5	148.7	148.0	146.8		143.7	113.1	111.9	102.3	101.2	99.5	99.4
155	99.8	98.6	148.7	149.0	148.2	146.9		143.9	113.1	111.9	102.1	101.2	99.5	99.4
156	99.8	98.7	148.7	149.0	148.3	147.0		143.9	113.1	111.9	102.1	101.2	99.5	99.4
157	99.8	98.6	148.5	148.7	148.0	146.8		143.6	113.0	111.8	102.2	101.2	99.5	99.4
158	99.8	98.6	148.3	148.6	147.8	146.6		143.5	112.7	111.5	102.4	101.2	99.5	99.4
159	99.8	98.6	148.4	148.7	148.0	146.7		143.5	112.8	111.6	102.4	101.2	99.5	99.4
160	99.8	98.6	148.7	148.9	148.3	146.9		143.9	113.0	111.8	102.2	101.2	99.5	99.4
161	99.8	98.6	148.6	148.9	148.2	146.9		143.8	113.0	111.8	102.1	101.3	99.5	99.4
162	99.8	98.6	148.6	148.9	148.1	146.9		143.8	113.0	111.8	102.1	101.2	99.5	99.4
163	99.8	98.6	148.7	149.0	148.2	146.9		143.8	113.0	111.8	102.3	101.2	99.5	99.4
164	99.6	97.8	175.6	176.0	174.9	173.3		169.3	121.4	119.6	103.4	101.7	99.6	99.4
165	99.6	97.8	175.6	176.1	174.9	173.5		169.4	121.7	119.8	103.1	101.8	99.6	99.4
166	99.6	97.8	175.4	175.9	174.8	173.3		169.3	121.5	119.7	103.1	101.8	99.6	99.4
167	99.6	97.8	175.3	175.8	174.5	173.1		169.2	121.3	119.5	103.4	101.8	99.6	99.4
168	99.6	97.8	175.2	175.7	174.3	173.0		169.0	121.2	119.4	103.7	101.9	99.6	99.4
169	99.7	97.8	175.1	175.6	174.4	173.0		169.0	121.2	119.3	103.8	101.9	99.6	99.4
170	99.6	97.8	175.1	175.6	174.3	172.9		169.0	121.2	119.4	103.4	101.8	99.6	99.4
171	99.6	97.8	175.3	175.8	174.5	173.0		169.1	121.6	119.8	103.2	101.8	99.6	99.4
172	99.7	97.8	175.2	175.7	174.4	173.1		169.1	121.5	119.6	103.1	101.8	99.6	99.4
173	99.6	97.8	175.4	176.1	174.8	173.4		169.4	121.5	119.6	103.4	101.7	99.6	99.4
174	99.4	96.4	212.0	212.7	211.0	209.7		204.3	132.4	129.5	104.9	102.5	99.7	99.4
175	99.4	96.5	211.1	211.9	210.1	208.8		203.6	132.1	129.3	104.4	102.5	99.7	99.4
176	99.4	96.5	211.2	211.9	210.2	208.9		203.6	132.3	129.5	104.5	102.5	99.7	99.4
177	99.4	96.5	210.9	211.7	210.0	208.5		203.4	131.7	128.9	105.0	102.5	99.7	99.4
178	99.4	96.4	210.6	211.4	209.7	208.3		203.1	131.5	128.7	105.7	102.6	99.7	99.4
179	99.4	96.5	210.6	211.4	209.5	208.1		203.1	131.5	128.7	105.7	102.6	99.7	99.4
180	99.4	96.5	210.7	211.5	209.7	208.3		203.2	131.8	129.0	105.0	102.5	99.7	99.4
181	99.4	96.5	211.0	211.9	210.0	208.6		203.5	132.3	129.4	104.6	102.5	99.7	99.4
182	99.4	96.5	210.7	211.6	209.7	208.3		203.3	132.0	129.2	104.4	102.5	99.7	99.4
183	99.4	96.5	210.5	211.3	209.6	208.2		203.1	131.8	129.0	104.8	102.5	99.7	99.4
184	99.0	94.5	256.8	257.9	255.6	254.1		247.7	144.1	139.5	107.0	103.3	99.9	99.4
185	99.0	94.6	256.6	257.8	255.5	253.8		247.5	144.5	140.0	106.4	103.4	99.9	99.4
186	99.0	94.5	257.2	258.4	256.0	254.5		248.1	144.6	140.1	106.6	103.5	99.9	99.4
187	99.0	94.5	256.9	258.1	255.8	254.2		247.9	144.2	139.6	107.2	103.5	99.9	99.4
188	99.0	94.5	256.7	257.9	255.6	253.9		247.6	143.9	139.3	108.0	103.6	99.9	99.4
189	99.0	94.5	256.7	257.9	255.6	254.0		247.7	143.9	139.3	108.1	103.7	99.9	99.4
190	99.0	94.5	257.0	258.2	255.9	254.3		247.9	144.2	139.7	107.3	103.5	99.9	99.4
191	99.0	94.5	257.2	258.4	256.1	254.4		248.1	144.9	140.3	106.5	103.5	99.9	99.4
192	99.0	94.5	257.0	258.2	255.9	254.3		247.8	144.6	140.1	106.3	103.4	99.9	99.4
193	99.0	94.5	257.1	258.3	256.0	254.4		247.9	144.4	139.9	107.3	103.3	99.9	99.4
221	99.4	98.2	148.0	148.0	147.4	146.3		143.2	112.6	111.4	101.5	100.7	99.0	98.9
222	99.4	98.2	148.0	148.0	147.3	146.2		143.2	112.6	111.4	101.5	100.7	99.0	98.9
223	99.2	97.4	175.0	175.2	174.1	172.8		168.7	121.3	119.4	102.6	101.2	99.1	98.9
224	99.2	97.4	175.1	175.3	174.2	173.0		168.7	121.3	119.4	102.6	101.2	99.1	98.9
225	99.0	96.1	210.4	210.8	209.2	207.9		202.5	131.6	128.8	103.9	101.9	99.3	98.9
226	99.0	96.1	210.4	210.8	209.2	208.0		202.5	131.6	128.8	103.9	101.9	99.3	98.9
227	98.6	94.2	256.4	257.0	254.9	253.5		246.6	144.0	139.5	105.8	102.8	99.5	99.0
228	98.6	94.2	256.3	257.0	254.8	253.4		246.5	144.0	139.5	105.8	102.8	99.5	99.0
243	98.8	97.6	147.5	147.6	147.0	145.7		142.7	111.9	110.7	100.9	100.2	98.5	98.3
244	98.8	97.6	147.6	147.7	147.1	145.7		142.7	111.9	110.7	100.9	100.2	98.5	98.3
245	98.6	96.7	174.5	174.7	173.6	172.2		168.1	120.5	118.6	101.9	100.6	98.5	98.3
246	98.6	96.7	174.2	174.4	173.3	171.9		167.9	120.5	118.5	101.9	100.6	98.5	98.3
247	98.4	95.4	209.4	209.8	208.3	206.9		201.7	130.8	128.0	103.3	101.3	98.7	98.3
248	98.4	95.4	209.4	209.8	208.3	206.9		201.7	130.8	128.0	103.3	101.3	98.7	98.3
249	98.0	93.6	255.7	256.3	254.3	252.7		246.5	143.9	139.4	105.3	102.3	98.9	98.4
250	98.0	93.5	255.5	256.1	254.1	252.5		246.2	143.4	138.9	105.4	102.3	98.9	98.4
251	98.4	95.5	209.8	210.3	208.7	207.5		202.2	131.3	128.2	103.4	101.4	98.7	98.4

IRN	P1T	P1.1S	P1.9S	P2	P3	P4	P5S	P5.2T	P6T	P6.3T	P7T	P8	P9	PEXH
252	98.4	95.5	210.0	210.5	209.0	207.7		202.2	131.3	128.2	103.4	101.4	98.7	98.4
253	98.6	96.8	173.7	174.1	173.1	171.8		167.8	120.6	118.5	102.0	100.7	98.6	98.3
254	98.7	96.8	174.0	174.4	173.4	171.9		168.0	120.6	118.6	102.0	100.7	98.6	98.4
255	98.8	97.7	147.3	147.6	146.9	145.6		142.7	112.2	110.8	101.0	100.2	98.5	98.3
256	98.8	97.7	147.2	147.5	146.9	145.6		142.7	112.2	110.9	101.0	100.2	98.5	98.3
321	99.3	98.1	148.0	148.0	147.2	146.0		142.9	112.2	110.9	101.7	100.6	99.0	98.8
322	99.3	98.1	148.1	148.1	147.3	146.1		142.8	112.2	111.0	101.5	100.6	99.0	98.8
323	99.3	98.1	148.0	147.9	147.1	145.9		142.8	112.2	111.0	101.4	100.7	99.0	98.8
324	99.3	98.1	147.9	147.9	147.0	145.9		142.8	112.3	111.0	101.5	100.6	99.0	98.8
325	99.3	98.1	147.8	147.7	147.1	145.8		142.6	112.1	110.8	101.8	100.7	99.0	98.8
326	99.1	97.2	174.9	174.9	173.8	172.3		168.3	120.6	118.5	102.8	101.1	99.0	98.8
327	99.1	97.2	174.9	174.9	173.8	172.3		168.2	120.7	118.6	102.4	101.2	99.0	98.8
328	99.1	97.2	174.9	175.0	173.8	172.4		168.3	120.8	118.8	102.5	101.1	99.0	98.8
329	99.1	97.2	174.8	174.9	173.8	172.2		168.2	120.7	118.7	102.8	101.2	99.0	98.8
330	99.1	97.2	174.7	174.7	173.6	172.0		168.1	120.6	118.5	103.1	101.2	99.0	98.8
331	98.8	95.9	210.3	210.6	208.9	207.5		202.2	131.1	128.0	104.1	101.8	99.2	98.8
332	98.9	95.9	210.4	210.7	209.0	207.7		202.3	131.0	127.9	103.8	101.8	99.2	98.8
333	98.8	95.9	210.4	210.8	209.0	207.6		202.3	131.4	128.3	103.8	101.8	99.1	98.8
334	98.8	95.9	210.4	210.7	209.0	207.6		202.3	131.3	128.2	104.1	101.8	99.1	98.8
335	98.8	95.9	210.0	210.3	208.6	207.1		201.9	130.9	127.8	104.7	102.0	99.1	98.8
336	98.5	93.9	256.4	256.8	254.7	253.1		246.8	143.5	138.7	105.6	102.6	99.4	98.8
337	98.5	94.0	255.8	256.4	254.2	252.7		246.5	143.3	138.5	105.7	102.7	99.4	98.8
338	98.5	94.0	256.0	256.5	254.2	252.6		246.5	143.6	139.0	105.9	102.7	99.4	98.8
339	98.5	94.0	256.1	256.7	254.4	252.9		246.5	143.8	139.2	106.2	102.8	99.4	98.8
340	98.4	93.9	255.7	256.2	254.0	252.5		246.2	143.7	139.1	106.5	102.8	99.3	98.8
341	97.9	91.1	311.8	312.7	310.0	308.3		300.8	156.6	149.2	107.7	103.7	99.6	98.8
342	97.9	91.1	312.0	312.8	310.0	308.3		300.8	156.8	149.5	107.9	103.7	99.6	98.8
343	97.9	91.1	311.9	312.8	309.7	308.1		300.7	157.0	149.6	108.2	103.8	99.6	98.8
344	97.9	91.1	311.9	312.8	310.0	308.3		300.8	157.1	149.7	108.5	103.9	99.6	98.8
345	97.9	91.1	312.2	313.1	310.1	308.5		301.0	156.7	149.2	109.2	103.9	99.6	98.8
346	97.9	91.1	312.0	312.8	309.8	308.3		300.8	156.7	149.3	110.1	103.9	99.6	98.8
366	97.9	89.5	346.4	347.5	344.3	343.1		333.7	161.9	150.5	109.3	104.7	100.3	99.3
437	100.4	99.3	150.2	150.3	149.4	148.1		144.4	113.7	112.4	102.6	101.7	100.0	99.9
438	99.6	96.2	263.1	263.6	261.3	259.6		251.4	147.6	142.9	107.1	103.8	100.5	100.0
439	99.2	93.9	321.6	322.2	319.3	317.7		307.5	161.0	154.0	110.1	105.1	100.8	100.1
440	99.0	92.9	342.9	343.4	340.5	338.9		328.0	164.9	156.0	110.2	105.5	101.0	100.1
441	98.9	92.4	351.7	352.3	349.0	347.9		337.4	166.5	156.6	110.4	105.7	101.1	100.1
442	98.9	92.4	351.9	352.4	349.4	348.0		337.6	166.6	156.7	110.4	105.7	101.1	100.1
443	98.8	91.7	368.9	369.0	366.6	365.3		353.5	169.3	157.5	111.3	106.1	101.2	100.1
444	98.8	91.7	366.4	366.9	364.0	362.7		351.5	168.6	157.0	111.3	106.1	101.2	100.1
445	98.8	91.8	369.4	371.0	365.8	363.6		353.0	168.6	156.9	111.3	106.1	101.2	100.1
446	98.7	91.7	365.9	366.5	363.4	362.1		351.2	168.3	156.8	111.2	106.1	101.2	100.1
447	98.8	91.7	366.8	367.2	364.2	362.8		351.6	168.3	156.6	111.2	106.1	101.2	100.1
448	99.7	96.2	262.6	263.0	260.8	258.9		250.9	147.7	143.0	107.2	103.9	100.5	100.0
449	100.0	97.7	215.3	215.6	214.0	212.3		205.9	134.4	131.4	105.3	103.0	100.3	100.0
450	100.2	98.7	177.5	177.8	176.5	174.9		170.3	123.0	121.1	103.8	102.3	100.1	99.9
451	100.4	99.4	150.3	150.4	149.6	148.1		144.6	114.0	112.8	102.7	101.8	100.0	99.9
452	100.3	98.8	172.7	173.0	171.8	170.2		165.7	121.0	119.2	103.6	102.2	100.1	99.9
453	100.3	98.8	173.1	173.3	172.2	170.6		166.1	121.6	119.8	103.6	102.2	100.1	99.9
468	99.4	98.3	148.9	149.0	148.3	147.1	142.5	143.4	112.4	111.0	101.6	100.7	99.0	98.9
469	99.4	98.3	148.6	148.7	147.9	146.7	142.3	143.0	112.3	111.0	101.6	100.7	99.0	98.9
470	99.2	97.5	176.3	176.5	175.2	173.9	167.8	168.9	121.7	119.3	102.6	101.2	99.1	98.9
471	98.9	96.5	212.2	212.6	210.9	209.6	201.4	203.1	132.3	128.9	104.0	101.9	99.2	98.9
472	98.6	95.0	258.5	258.9	256.7	255.2	245.0	247.0	145.1	140.1	105.9	102.7	99.4	98.9
473	98.2	92.9	316.8	317.4	314.6	313.1	300.6	303.1	159.6	151.6	108.8	104.0	99.8	99.0
474	97.9	91.3	347.4	348.2	345.0	343.5	329.8	332.1	164.2	153.5	109.2	104.6	100.0	99.0
475	97.7	90.5	363.5	364.5	360.9	359.5	345.4	347.9	166.8	154.4	110.1	105.0	100.1	99.1
476	97.7	90.4	365.1	366.1	362.6	361.1	348.1	350.6	167.6	155.1	110.3	105.1	100.1	99.1
477	97.7	90.4	363.9	364.8	361.4	359.9	346.8	349.5	167.2	154.8	110.2	105.1	100.1	99.1
478	97.8	90.5	362.5	363.5	360.2	359.0	345.0	347.1	166.5	154.2	110.1	105.0	100.1	99.1
479	97.9	91.3	347.3	348.2	345.0	343.5	329.9	332.1	164.5	153.9	109.3	104.6	100.0	99.0
480	98.2	92.7	315.6	316.4	313.5	311.9	299.7	302.1	158.7	150.7	108.6	104.0	99.8	99.0
481	98.6	95.0	258.8	259.4	257.2	255.5	245.4	247.6	145.7	140.5	106.0	102.7	99.4	98.9
483	98.9	96.5	211.3	211.8	210.2	208.7	200.7	202.5	132.4	129.0	104.0	101.8	99.2	98.8
484	99.1	97.5	175.3	175.7	174.5	172.9	167.0	168.4	121.4	119.2	102.6	101.2	99.0	98.8
485	99.3	98.3	147.9	148.1	147.4	146.1	141.7	142.7	112.4	111.1	101.5	100.7	98.9	98.8
501	97.9	92.7	314.4	314.6	312.0	310.4		301.5	157.5	150.4	108.4	103.8	99.5	98.7
502	97.7	91.3	346.9	347.4	344.2	342.8		333.0	163.7	153.7	109.1	104.4	99.8	98.8
511	98.5	93.5	317.4	317.9	314.9	313.4		303.4	158.7	151.4	109.0	104.4	100.1	99.4

EMISSIONS TESTS- CALCULATED PARAMETERS

IRN	ENGGP PERCENT	ENDC RPM	HPC KW	SFC G/W-HR	WAC KG/SEC	TNP DEGREES	FAR	EIHC G/KG	EICO G/KG	EINO G/KG
13	50.04	602.	2.20	1.520	0.211	34.8	0.00440	1.54	67.35	1.27
14	49.95	1000.	2.47	1.372	0.210	35.3	0.00449	0.69	50.89	1.24
15	49.92	1395.	2.01	1.643	0.210	35.3	0.00438	0.53	50.69	1.31
16	49.76	601.	2.00	1.680	0.213	36.5	0.00439	10.78	102.12	1.07
17	49.99	1006.	2.16	1.546	0.214	36.5	0.00435	10.47	104.25	0.98
18	50.00	1398.	1.57	2.086	0.214	36.5	0.00426	8.82	100.61	1.03
19	49.99	1329.	1.28	2.597	0.217	39.6	0.00424	35.89	121.22	1.17
20	49.95	998.	1.80	1.862	0.217	39.6	0.00428	38.69	129.19	1.18
21	49.94	602.	1.84	1.848	0.217	38.6	0.00435	37.99	126.88	1.15
22	59.96	800.	5.00	0.934	0.261	33.4	0.00497	0.30	11.78	1.08

IRN	ENGGP PERCENT	ENDC RPM	HPC KW	SFC G/W-HR	WAC KG/SEC	TMP DEGREES	FAR	EIHC G/KG	EICO G/KG	EINO G/KG
23	59.96	1200.	5.74	0.797	0.261	33.4	0.00488	0.26	8.72	1.14
24	59.96	1402.	5.79	0.815	0.260	33.5	0.00504	0.21	5.26	1.15
25	59.93	1803.	5.07	0.929	0.260	33.9	0.00503	0.18	5.37	1.14
26	69.95	1100.	10.12	0.668	0.320	33.5	0.00586	0.14	0.32	0.82
27	69.92	1603.	11.20	0.609	0.319	33.9	0.00594	0.11	0.35	0.84
28	69.90	2198.	10.22	0.663	0.319	33.9	0.00590	0.11	0.19	0.84
29	79.95	2398.	18.38	0.541	0.389	34.5	0.00710	0.08	0.10	0.59
30	79.99	1996.	19.24	0.514	0.389	35.0	0.00706	0.07	-0.44	0.57
31	80.01	1805.	19.10	0.519	0.389	35.1	0.00708	0.06	0.64	0.59
32	80.05	1199.	16.72	0.583	0.390	35.1	0.00694	0.07	0.65	0.64
33	90.10	1600.	28.04	0.501	0.473	36.6	0.00824	0.05	0.70	0.60
34	90.07	2007.	29.70	0.482	0.472	36.7	0.00841	0.05	0.77	0.54
35	90.01	2198.	29.89	0.470	0.473	37.1	0.00824	0.05	0.67	0.57
36	89.95	2606.	28.53	0.481	0.472	37.2	0.00806	0.05	0.77	0.54
37	90.04	3004.	26.71	0.528	0.473	37.7	0.00826	0.05	0.77	0.53
38	95.03	3209.	30.41	0.530	0.520	39.8	0.00859	0.06	0.79	0.62
39	95.04	2802.	33.06	0.499	0.518	39.8	0.00882	0.07	0.65	0.65
40	95.23	2398.	35.53	0.472	0.519	39.3	0.00895	0.07	0.81	0.74
41	94.98	2003.	34.90	0.469	0.516	38.8	0.00880	0.08	0.77	0.73
42	98.28	2000.	36.75	0.494	0.545	40.4	0.00924	0.15	1.04	25.83
43	98.01	2404.	36.76	0.490	0.543	40.5	0.00921	0.16	1.02	23.99
44	98.60	2792.	34.92	0.519	0.549	41.5	0.00915	0.23	0.63	24.04
45	99.32	2796.	36.17	0.519	0.555	41.5	0.00938	0.28	0.75	25.61
46	98.19	3193.	30.88	0.567	0.546	41.5	0.00890	0.30	0.59	22.00
47	99.97	3196.	16.59	1.029	0.569	51.5	0.00832	0.32	0.52	16.93
48	80.08	2001.	17.47	0.555	0.394	35.6	0.00683	0.33	2.10	5.51
49	80.08	2000.	19.05	0.518	0.389	35.1	0.00704	0.27	2.35	14.97
50	80.07	1801.	19.23	0.530	0.389	35.1	0.00729	0.22	1.72	12.68
51	90.04	2200.	29.67	0.476	0.472	37.1	0.00830	0.16	0.60	5.10
52	90.03	2599.	28.45	0.494	0.472	37.2	0.00826	0.06	0.54	5.97
53	95.02	2404.	34.93	0.472	0.517	38.3	0.00886	0.05	0.50	18.43
54	94.93	2803.	33.01	0.492	0.517	38.8	0.00872	0.05	0.39	8.15
55	99.78	2802.	26.48	0.672	0.566	47.7	0.00872	0.06	0.54	20.18
56	99.76	2392.	28.65	0.612	0.567	47.7	0.00858	0.05	0.44	0.85
57	99.85	1998.	29.00	0.618	0.568	47.7	0.00876	0.05	0.40	0.95
58	99.84	1997.	31.98	0.573	0.566	46.2	0.00898	0.05	0.29	0.98
59	50.06	604.	2.25	1.497	0.210	35.2	0.00446	4.12	42.79	1.44
60	49.79	1000.	2.44	1.364	0.210	35.6	0.00439	3.36	36.45	1.06
61	49.92	1402.	1.91	1.718	0.211	36.1	0.00432	2.34	31.22	1.13
62	59.94	1398.	5.74	0.859	0.262	34.6	0.00523	0.34	5.13	0.90
63	59.91	1800.	4.99	0.972	0.261	35.0	0.00517	0.51	11.42	1.02
64	59.93	1203.	5.75	0.833	0.261	34.5	0.00510	0.56	13.52	0.87
65	59.84	802.	4.98	0.943	0.261	34.5	0.00500	0.60	16.55	0.84
66	69.90	1094.	10.06	0.674	0.322	34.0	0.00585	0.30	7.51	1.36
67	69.91	1601.	11.18	0.621	0.321	34.0	0.00601	0.27	5.60	1.64
68	80.04	1796.	19.14	0.523	0.391	34.5	0.00712	0.19	2.90	1.38
69	80.02	2007.	19.41	0.518	0.389	34.6	0.00717	0.18	2.04	0.59
70	90.04	1597.	27.64	0.508	0.472	37.1	0.00825	0.13	1.29	3.17
71	90.04	1999.	29.63	0.486	0.471	37.2	0.00849	0.15	1.23	7.66
72	89.97	2197.	29.71	0.465	0.471	37.1	0.00814	0.16	1.10	6.04
73	89.99	2607.	28.89	0.490	0.471	37.2	0.00835	0.16	1.10	14.48
74	90.04	3001.	26.24	0.533	0.473	37.7	0.00820	0.17	1.04	5.16
75	94.98	3201.	30.06	0.550	0.517	40.4	0.00887	0.16	0.81	22.12
76	95.10	2807.	33.02	0.497	0.517	40.4	0.00880	0.17	0.86	21.43
77	95.09	2395.	34.80	0.477	0.517	39.9	0.00892	0.16	0.67	24.25
78	95.12	2001.	34.48	0.483	0.516	39.4	0.00896	0.16	0.76	24.10
79	100.04	1999.	37.51	0.509	0.561	42.6	0.00944	0.16	0.74	27.17
80	100.00	2400.	38.71	0.494	0.560	42.6	0.00947	0.16	0.83	27.88
81	99.98	2796.	35.99	0.523	0.561	43.1	0.00930	0.16	0.83	26.04
82	99.90	3199.	31.44	0.585	0.562	43.7	0.00908	0.17	0.72	25.51
83	100.02	2408.	30.34	0.595	0.566	47.3	0.00884	0.18	0.73	19.32

	UNCORRECTED TEMPERATURES-(KELVIN)					PRESSURES-(KPA)				EMISSIONS-(PPM)		
IRN	T1	T2	T6	T8	TEX	P1	P2	P6	P8	HC	CO	NOX
13	302.	357.	1063.	1023.	425.	98.0	146.7	111.7	103.3	14.0	305.6	3.5
14	303.	357.	1068.	1022.	415.	98.0	146.8	111.9	103.3	6.3	235.5	3.5
15	303.	358.	1070.	1023.	412.	98.0	146.6	111.9	103.3	4.8	228.6	3.6
16	303.	357.	1027.	991.	429.	98.0	145.6	110.6	103.3	97.6	462.3	2.9
17	303.	357.	1027.	989.	417.	98.0	146.1	110.8	103.3	93.9	467.5	2.7
18	303.	357.	1028.	989.	413.	98.0	146.2	110.8	103.3	77.5	441.7	2.7
19	303.	357.	988.	954.	411.	98.0	145.8	109.8	103.3	313.4	529.2	3.1
20	303.	357.	988.	954.	413.	98.0	145.8	109.8	103.3	341.7	570.4	3.2
21	302.	357.	989.	957.	426.	98.0	145.7	109.9	103.2	340.5	568.6	3.1
22	303.	378.	1068.	1021.	447.	98.0	173.6	120.6	103.7	3.1	60.2	3.3
23	303.	378.	1072.	1022.	440.	98.0	173.6	120.7	103.7	2.6	43.8	3.5
24	303.	378.	1078.	1024.	438.	98.0	173.6	120.9	103.7	2.2	27.3	3.6
25	303.	378.	1076.	1022.	434.	98.0	173.4	120.8	103.7	1.8	27.8	3.6
26	303.	402.	1080.	1022.	467.	97.9	209.4	132.0	104.2	1.6	1.9	3.0
27	303.	403.	1086.	1022.	462.	97.9	209.3	132.2	104.3	1.4	2.1	3.1
28	303.	403.	1086.	1023.	461.	97.9	209.2	132.1	104.3	1.3	1.2	3.1
29	303.	430.	1098.	1022.	486.	97.9	256.1	145.7	105.1	1.2	0.7	2.6
30	302.	431.	1100.	1022.	493.	97.9	256.1	145.9	105.0	1.1	-3.2	2.5

IRN	T1	T2	T6	T8	TEX	P1	P2	P6	P8	HC	CO	NOX
31	302.	431.	1098.	1021.	495.	97.9	256.3	145.9	105.0	0.9	4.6	2.6
32	302.	431.	1090.	1021.	502.	97.9	256.3	145.5	105.0	1.0	4.6	2.8
33	302.	463.	1100.	1020.	530.	97.9	315.6	160.8	106.0	0.9	5.9	3.1
34	302.	463.	1104.	1020.	529.	97.9	315.1	161.0	106.0	0.9	6.6	2.8
35	302.	463.	1105.	1021.	528.	97.9	314.9	160.8	106.1	0.9	5.7	2.9
36	302.	463.	1099.	1019.	525.	97.9	314.2	160.1	106.1	0.8	6.4	2.7
37	302.	463.	1100.	1021.	524.	97.9	314.5	160.2	106.2	0.9	6.6	2.7
38	302.	480.	1096.	1019.	540.	97.8	347.3	166.1	106.8	1.1	6.9	3.3
39	302.	480.	1101.	1018.	541.	97.9	347.4	166.8	106.7	1.2	5.9	3.6
40	302.	481.	1110.	1021.	545.	97.8	349.4	168.2	106.7	1.4	7.5	4.1
41	302.	480.	1111.	1022.	548.	97.8	347.5	168.0	106.6	1.5	7.0	4.0
42	302.	493.	1110.	1019.	559.	97.8	371.2	170.4	107.0	2.8	9.9	148.8
43	302.	492.	1108.	1019.	559.	97.8	368.8	169.7	107.0	2.9	9.7	137.7
44	302.	494.	1101.	1017.	558.	97.8	372.5	169.2	107.2	4.3	5.9	137.2
45	302.	495.	1109.	1020.	558.	97.8	378.1	171.0	107.3	5.3	7.2	149.8
46	302.	493.	1095.	1018.	556.	97.8	369.0	167.8	107.2	5.4	5.4	122.1
47	302.	497.	1041.	992.	555.	97.9	378.2	159.9	107.3	5.5	4.5	87.9
48	302.	431.	1049.	988.	491.	97.9	255.0	143.1	105.0	4.6	14.7	23.5
49	302.	431.	1087.	1019.	495.	97.9	255.8	145.7	105.0	3.9	17.0	65.8
50	302.	432.	1093.	1023.	497.	97.9	256.1	146.3	105.0	3.3	12.9	57.7
51	302.	463.	1099.	1023.	527.	97.9	314.7	160.8	106.1	2.8	5.1	26.4
52	302.	463.	1094.	1021.	525.	97.9	314.2	160.2	106.1	1.1	4.6	30.7
53	302.	480.	1104.	1021.	543.	97.9	348.4	167.5	106.7	1.0	4.6	101.9
54	302.	480.	1096.	1019.	542.	97.9	346.5	166.5	106.7	0.9	3.5	44.3
55	302.	496.	1051.	988.	553.	97.9	378.3	163.1	107.4	1.0	4.8	109.7
56	302.	497.	1041.	980.	556.	97.8	376.7	163.4	107.2	0.9	3.9	4.5
57	302.	497.	1038.	976.	559.	97.9	377.0	163.2	107.1	0.8	3.6	5.2
58	302.	498.	1056.	987.	561.	97.9	378.1	166.2	107.1	0.9	2.7	5.5
59	303.	359.	1069.	1024.	441.	98.0	146.2	111.9	103.3	37.8	196.5	4.0
60	303.	359.	1062.	1021.	428.	98.0	145.6	111.6	103.4	30.4	164.8	2.9
61	303.	358.	1067.	1023.	423.	98.0	145.9	111.6	103.4	20.8	138.9	3.0
62	303.	375.	1078.	1025.	439.	98.0	172.9	120.8	103.8	3.6	27.6	2.9
63	303.	378.	1075.	1024.	438.	98.0	172.4	120.6	103.8	5.5	60.8	3.3
64	303.	378.	1075.	1025.	444.	98.0	172.6	120.7	103.8	5.9	71.0	2.8
65	303.	378.	1068.	1023.	450.	98.0	172.3	120.5	103.7	6.2	85.2	2.6
66	303.	401.	1076.	1021.	470.	98.0	208.3	131.7	104.3	3.6	45.3	5.0
67	303.	402.	1083.	1022.	466.	98.0	208.3	132.0	104.3	3.3	34.6	6.1
68	302.	429.	1090.	1020.	492.	98.0	255.8	145.8	105.0	2.8	21.2	6.1
69	302.	431.	1094.	1021.	494.	98.0	255.5	146.2	105.0	2.6	15.0	2.6
70	302.	463.	1092.	1016.	530.	97.9	314.2	160.3	106.0	2.2	11.0	16.3
71	302.	463.	1106.	1022.	529.	97.9	314.8	160.9	106.0	2.6	10.7	40.6
72	302.	463.	1100.	1020.	528.	97.9	313.7	160.5	106.1	2.7	9.2	30.7
73	302.	463.	1107.	1023.	526.	97.9	314.4	160.2	106.1	2.8	9.4	75.4
74	302.	463.	1096.	1020.	523.	97.9	313.9	159.8	106.1	2.9	8.8	26.4
75	302.	479.	1106.	1022.	538.	97.9	347.6	166.3	106.8	3.0	7.4	122.3
76	302.	480.	1105.	1018.	541.	97.9	348.3	166.6	106.7	3.1	7.8	117.7
77	302.	481.	1111.	1019.	545.	97.9	348.4	167.3	106.6	3.0	6.1	134.9
78	302.	481.	1111.	1020.	548.	97.9	348.9	167.5	106.6	3.0	7.0	134.6
79	302.	498.	1106.	1019.	563.	97.9	382.7	171.8	107.2	3.0	7.1	159.9
80	302.	499.	1113.	1023.	564.	97.8	382.9	172.5	107.4	3.1	8.0	164.5
81	302.	499.	1105.	1019.	563.	97.9	382.2	171.1	107.4	3.1	7.9	150.9
82	302.	498.	1096.	1020.	560.	97.9	381.1	169.6	107.4	3.1	6.7	144.4
83	302.	498.	1061.	989.	561.	97.9	379.5	164.7	107.3	3.3	6.6	106.6

REFERENCES

1. Ball, G. A.; Gumaer, J. I.; and Sebestyen, T. M.: The ERDA/Chrysler Upgraded Gas Turbine Engine Objectives and Design. SAE Paper 760279, 1976.

2. Schmidt, F. W.; and Wagner, C. E.: Baseline Gas Turbine Development Program. COO-2749-18, Dept. of Energy, 1977.

3. Warren, E. L.: Lewis Research Center Support of Chrysler Upgraded Engine Program. Highway Vehicle Systems, CONF-771037, Dept. of Energy, pp. 143-149.

4. Miller, Robert L.: Escort: A Data Acquisition and Display System to Support Research Testing. NASA TM-78909, 1978.

5. Johnsen, Roy L.: Performance Sensitivity Analysis of DOE/Chrysler Upgraded Automotive Gas Turbine Engine S/N 5-4. NASA TM-79242, DOE/NASA/1040-79/9, 1979.

6. Wong, Robert Y.: Compressor Development for Upgraded Engine. Highway Vehicle Systems, CONF-761028, Dept. of Energy, 1976, Section VI-C, pp. 212-230.

7. McLallin, Kerry L.; and Kofskey, Milton G.: Investigation of the Interstage Duct and Its Effect on Power Turbine Performance. Highway Vehicle Systems, CONF-791082, Dept. of Energy, 1979, Section IV-B, pp. 183-189.

8. Schmidt, Fred W.; and Wagner, Charles E.: Baseline Gas Turbine Development Program. COO-2749-19, Dept. of Energy, 1977.

9. Japikse, D.; and Pampreen, R.: Annular Diffuser Performance for an Automotive Gas Turbine. ASME Paper 78-GT-147, Apr. 1978.

10. Winter, Jerry; Nussle, Ralph; and Miller, Thomas J.: Preliminary Data from Lewis Research Center Testing of Chrysler Gas Turbine Regenerator. Highway Vehicle Systems, CONF-7805102, Dept. of Energy, 1978, Section II-H, pp. 111-133.

11. Juhasz, Albert J.: Comparative Emission Characteristics of a Diffusion Flame and Premixed Prevaporized Combustor. Highway Vehicle Systems, CONF-791082, Dept. of Energy, 1979, Section IV-A, pp. 177-182.

12. Roelke, Richard J.; and McLallin, Kerry L.: The Aerodynamic Design of a Compressor-Drive Turbine for Use in a 75 kW Automotive Engine. NASA TM X-71717, 1975.

13. Kofskey, Milton G.; Katsanis, Theodore; and Schumann, Lawrence F.: Aerodynamic Design of Free Power Turbine for a 75 kW Gas Turbine Automotive Engine. NASA TM X-71714, 1975.

TABLE I. - UPGRADED ENGINE CHARACTERIZATION[a]

[Inlet air temperature, 29.4° C (85° F); 1.013 bar (14.696 psia).]

(a) SI units

	Gas generator speed, rpm						
	29 250	35 100	40 950	46 800	52 650	55 575	58 500
	Gas generator speed, percent of design						
	50	60	70	80	90	95	100
Power turbine speed, rpm	26 000	34 000	40 600	44 500	50 000	52 000	50 000
Compressor pressure ratio	1.498	1.788	2.177	2.700	3.383	3.770	4.185
Component efficiency:							
Compressor, 1-2[b]	0.769	0.784	0.798	0.804	0.804	0.797	0.785
Compressor turbine, 5-6	0.832	0.836	0.841	0.843	0.846	0.847	0.846
Power turbine, 6-8	0.719	0.719	0.741	0.755	0.764	0.765	0.762
Combustor	0.998	0.998	0.999	0.999	0.999	0.999	0.999
Regenerator	0.957	0.948	0.939	0.928	0.916	0.911	0.905
Parasitic loss, kW:							
Gas generator	0.63	0.90	1.23	1.61	2.03	2.26	2.51
Power turbine	1.46	2.15	3.12	3.90	5.15	5.73	5.57
Output power (net), kW	4.86	10.69	20.71	36.25	56.71	67.49	77.83
Fuel flow (diesel), kg/hr	2.41	4.02	6.44	10.07	15.01	17.85	20.83
Specific fuel consumption, g/W-hr	0.496	0.376	0.311	0.278	0.265	0.265	0.268
Gas flow, kg/sec:							
Station 1	0.196	0.256	0.323	0.408	0.503	0.555	0.606
Station 3	0.191	0.249	0.315	0.397	0.489	0.538	0.587
Station 4	0.191	0.249	0.314	0.396	0.488	0.537	0.586
Station 5	0.192	0.250	0.315	0.397	0.489	0.539	0.588
Station 6	0.194	0.253	0.320	0.403	0.497	0.548	0.598
Station 8	0.196	0.255	0.322	0.407	0.502	0.554	0.604
Station 9	0.197	0.256	0.324	0.410	0.506	0.558	0.610
Pressure, kPa:							
Station 1	101.17	101.05	100.89	100.64	100.28	100.05	99.80
Station 2=3	151.55	180.68	219.64	271.71	339.23	377.19	417.69
Station 4	150.40	179.38	218.23	270.20	337.66	375.60	416.08
Station 5	147.95	175.90	213.67	264.35	330.56	367.86	407.76
Station 6	120.41	132.10	147.31	165.41	186.19	195.61	203.37
Station 8	103.30	104.13	105.20	106.76	108.84	110.10	111.48
Station 9	101.59	101.79	102.12	102.68	103.54	104.11	104.77
Temperature, °C:							
Station 1	29.4	29.4	29.4	29.4	29.4	29.4	20.4
Station 2	77.7	99.2	123.8	152.6	185.4	203.4	222.7
Station 3	86.2	105.4	128.2	155.8	187.6	205.2	224.3
Station 4	705.1	703.5	701.7	699.0	696.0	695.3	694.4
Station 5	829.4	864.6	907.3	954.6	1005.5	1029.5	1051.7
Station 6	776.1	792.1	812.6	834.1	855.5	863.4	868.5
Station 7.5	747.8	747.8	747.8	747.8	747.8	747.8	747.8
Station 8	741.3	742.3	743.0	743.6	744.1	744.3	744.5
Station 9	131.1	155.1	182.3	214.7	250.9	269.5	289.6
Flow leaks (stations i to j), kg/kg of compressor airflow:							
ij = 20	0.00242	0.00251	0.00257	0.00266	0.00280	0.00285	0.00286
25	0.00431	0.00360	0.00308	0.00270	0.00242	0.00230	0.00218
34	0.00251	0.00220	0.00199	0.00170	0.00152	0.00143	0.00135
36	0.00910	0.00942	0.00971	0.01011	0.01068	0.01093	0.01104
38	0.00345	0.00360	0.00371	0.00384	0.00399	0.00404	0.00402
39	0.00478	0.00546	0.00616	0.00696	0.00785	0.00826	0.00852
46	0.00539	0.00577	0.00616	0.00667	0.00735	0.00768	0.00792
48	0.00133	0.00186	0.00245	0.00312	0.00386	0.00422	0.00450
68	0.00236	0.00245	0.00247	0.00245	0.00239	0.00232	0.00218
Heat leaks, J/kg of compressor airflow:							
ij = 30	609	712	722	795	812	812	788
40	2998	2349	1854	1468	1196	1084	996
43	6178	4654	3503	2624	2010	1761	1582
50	2468	2058	1737	1463	1263	1175	1096
60	495	402	328	267	226	207	191
63	788	619	488	381	305	272	249
80	2821	2231	1777	1416	1163	1056	970
83	2089	1593	1219	926	721	635	574

[a]From refs. 1 and 2.
[b]Numbers refer to station notation (fig. 3).

TABLE I. - Concluded.

(b) U.S. customary units.

	Gas generator speed, rpm						
	29 250	35 100	40 950	46 800	52 650	55 575	58 500
	Gas generator speed, percent of design						
	50	60	70	80	90	95	100
Power turbine speed, rpm	26 000	34 000	40 600	44 500	50 000	52 000	50 000
Compressor pressure ratio	1.498	1.788	2.177	2.700	3.383	3.770	4.185
Component efficiency:							
Compressor, 1-2[b]	0.769	0.784	0.798	0.804	0.804	0.797	0.785
Compressor turbine, 5-6	0.832	0.836	0.841	0.843	0.846	0.847	0.846
Power turbine, 6-8	0.719	0.719	0.741	0.755	0.764	0.765	0.762
Combustor	0.998	0.998	0.999	0.999	0.999	0.999	0.999
Regenerator	0.957	0.948	0.939	0.928	0.916	0.911	0.905
Parasitic loss, hp:							
Gas generator	0.84	1.21	1.65	2.15	2.72	3.04	3.37
Power turbine	1.95	2.89	4.19	5.22	6.90	7.68	7.46
Output power (net), hp	6.52	14.33	27.76	48.59	76.02	90.47	104.32
Fuel flow (diesel), lb/hr	5.32	8.86	14.19	22.20	33.09	39.36	45.93
Specific fuel consumption, lb/hp-hr	0.815	0.618	0.511	0.457	0.435	0.435	0.440
Gas flow, lb/sec:							
Station 1	0.433	0.564	0.713	0.900	1.110	1.223	1.335
Station 3	0.421	0.549	0.694	0.875	1.078	1.186	1.295
Station 4	0.421	0.548	0.693	0.874	1.076	1.185	1.293
Station 5	0.423	0.550	0.695	0.876	1.079	1.187	1.296
Station 6	0.428	0.558	0.704	0.889	1.096	1.207	1.318
Station 8	0.431	0.562	0.711	0.898	1.107	1.220	1.332
Station 9	0.433	0.565	0.715	0.904	1.116	1.230	1.344
Pressure, psia:							
Station 1	14.673	14.657	14.633	14.596	14.544	14.511	14.476
Station 2=3	21.980	26.206	31.856	39.409	49.201	54.706	60.580
Station 4	21.814	26.017	31.651	39.190	48.974	54.476	60.348
Station 5	21.458	25.513	30.990	38.341	47.944	53.353	59.141
Station 6	17.463	19.159	21.365	23.990	27.004	28.370	29.495
Station 8	14.983	15.102	15.258	15.484	15.785	15.968	16.169
Station 9	14.734	14.764	14.811	14.893	15.018	15.100	15.196
Temperature, °F:							
Station 1	85.0	85.0	85.0	85.0	85.0	85.0	85.0
Station 2	171.9	210.6	254.8	306.8	365.8	398.1	432.8
Station 3	187.1	221.6	262.8	312.4	369.8	401.4	435.7
Station 4	1301.2	1298.3	1295.0	1290.1	1284.8	1283.6	1281.9
Station 5	1524.9	1588.4	1665.1	1750.3	1841.9	1885.2	1925.0
Station 6	1429.0	1457.5	1494.6	1533.4	1571.9	1586.2	1595.2
Station 7.5	1378.0	1378.0	1378.0	1378.0	1378.0	1378.0	1378.0
Station 8	1366.4	1368.1	1369.4	1370.5	1371.3	1371.7	1372.1
Station 9	268.0	311.3	360.2	418.4	483.6	517.1	553.3
Flow leaks (stations i to j), lb/lb of compressor airflow:							
ij = 20	0.00242	0.00251	0.00257	0.00266	0.00280	0.00285	0.00286
25	0.00431	0.00360	0.00308	0.00270	0.00242	0.00230	0.00218
34	0.00251	0.00220	0.00199	0.00170	0.00152	0.00143	0.00135
36	0.00910	0.00942	0.00971	0.01011	0.01068	0.01093	0.01104
38	0.00345	0.00360	0.00371	0.00384	0.00399	0.00404	0.00402
39	0.00478	0.00546	0.00616	0.00696	0.00785	0.00826	0.00852
46	0.00539	0.00577	0.00616	0.00667	0.00735	0.00768	0.00792
48	0.00133	0.00186	0.00245	0.00312	0.00386	0.00422	0.00450
68	0.00236	0.00245	0.00247	0.00245	0.00239	0.00232	0.00218
Heat leaks, Btu/lb of compressor airflow:							
ij = 30	0.262	0.306	0.332	0.342	0.349	0.349	0.339
40	1.289	1.010	0.797	0.631	0.514	0.466	0.428
43	2.656	2.001	1.506	1.128	0.864	0.757	0.680
50	1.061	0.885	0.747	0.629	0.543	0.505	0.471
60	0.213	0.173	0.141	0.115	0.097	0.089	0.082
63	0.339	0.266	0.210	0.164	0.131	0.117	0.107
80	1.213	0.959	0.764	0.609	0.500	0.454	0.417
83	0.898	0.685	0.524	0.398	0.310	0.273	0.247

[a]From refs. 1 and 2.
[b]Numbers refer to station notation (fig. 3).

TABLE II. - COMPARISON OF MAXIMUM-POWER OPERATING POINT TO DESIGN GOAL

Engine operating conditions	Design	Peformance data[a]
Gas generator speed	58 500 rpm	100 percent of design
Output shaft speed, rpm	3358	2400
Power turbine speed, rpm	50 000	35 736
Compressor pressure ratio	4.185	3.91
Net output power, kW	77.8	38.7
Fuel flow, kg/hr	20.8	19.1
Specific fuel consumption, g/W-hr	0.268	0.494
Engine inlet airflow, kg/sec	0.606	0.560

[a]Corrected to reference conditions (302.6 K; 101.3 kPa).

TABLE III. - DESCRIPTION OF UPGRADED ENGINE[a]

General	
Type	Regenerative gas turbine
Rated output power (at 3280-rpm output shaft speed)[b], kW (hp)	92 (123)
Rated output torque (at zero output shaft speed)[b], N-m (lb-ft)	480 (355)
Augmentation	Variable inlet guide vanes (VIGV) and water injection
Weight, kg (lb)	180 (400)
Engine configuration	Free rotor (designed for compact-vehicle installation
Maximum gas generator acceleration (idle to full speed), sec	1.1
Fuels	Unleaded gasoline, diesel fuel, kerosene, JP-4, etc.
Components	
Compressor	Backward-curved centrifugal with VIGV
Compressor turbine	Axial
Power turbine	Axial; variable-geometry stator
Regenerator	One rotating ceramic disk
Combustor	Fixed geometry
Design-point characteristics	
Maximum gas generator shaft speed, rpm	58 500
Maximum power turbine speed, rpm	70 000
Maximum output speed (after reduction gears), rpm	4 700
Maximum regenerator speed, rpm	31
Compressor pressure ratio:	
Design	4.2
Augmented	4.9
Compressor airflow, kg/sec (lb/sec):	
Design	0.61 (1.34)
Augmented	0.69 (1.52)
Compressor turbine inlet temperature (design), °C (°F)	1052 (1925)
Power turbine outlet temperature, °C (°F)	748 (1378)

[a]From ref. 1.
[b]Ambient conditions: temperature, 29° C (85° F); pressure, 101.3 kPa (14.696 psia).

TABLE IV. - ESTIMATED ERROR

Corrected gas generator speed, percent of design	Compressor	Compressor turbine	Power turbine	Regenerator
	Estimated error			
50	0.022	0.055	0.042	0.002
60	.014	.035	.027	↓
70	.011	.023	.018	
80	.006	.015	.014	
90	.005	.011	.012	
95	.004	.008	.010	

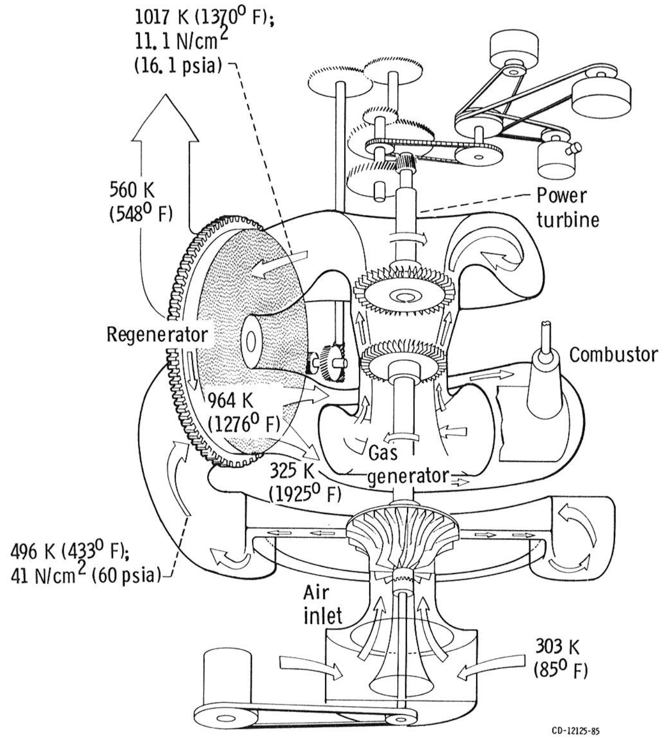


Figure 1. - Schematic of Chrysler upgraded engine.

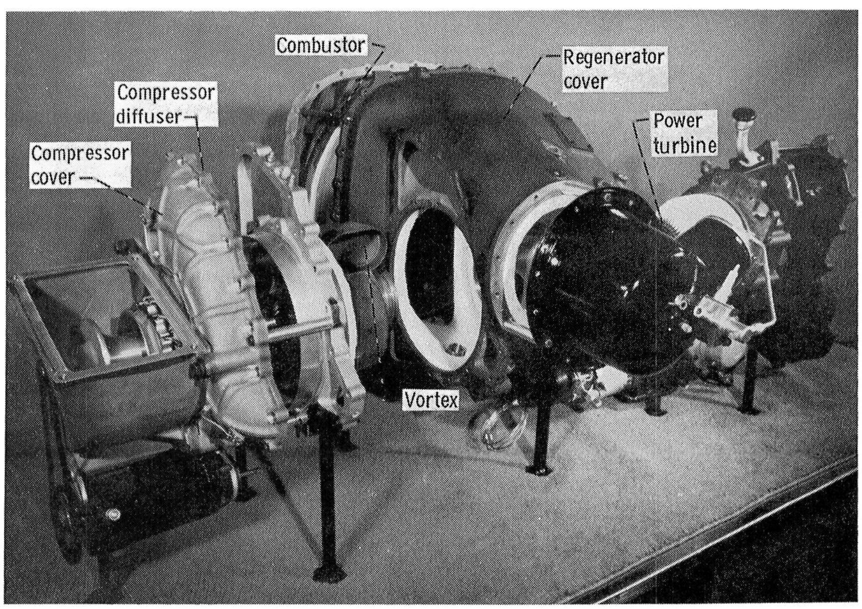


Figure 2. - Expanded display of Chrysler upgraded engine.

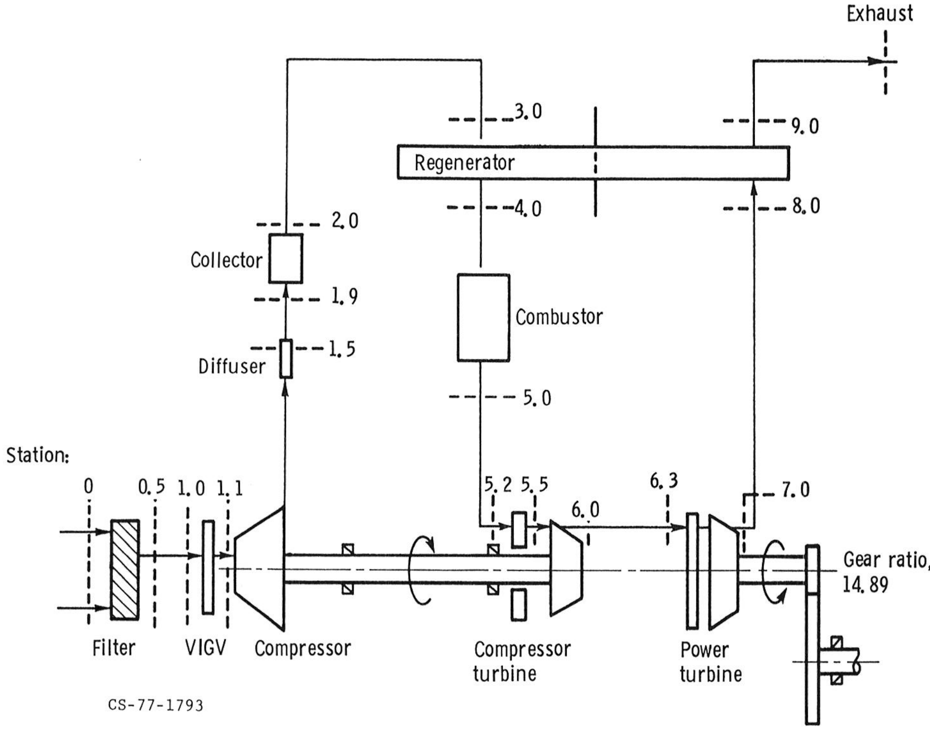


Figure 3. - Station positions.

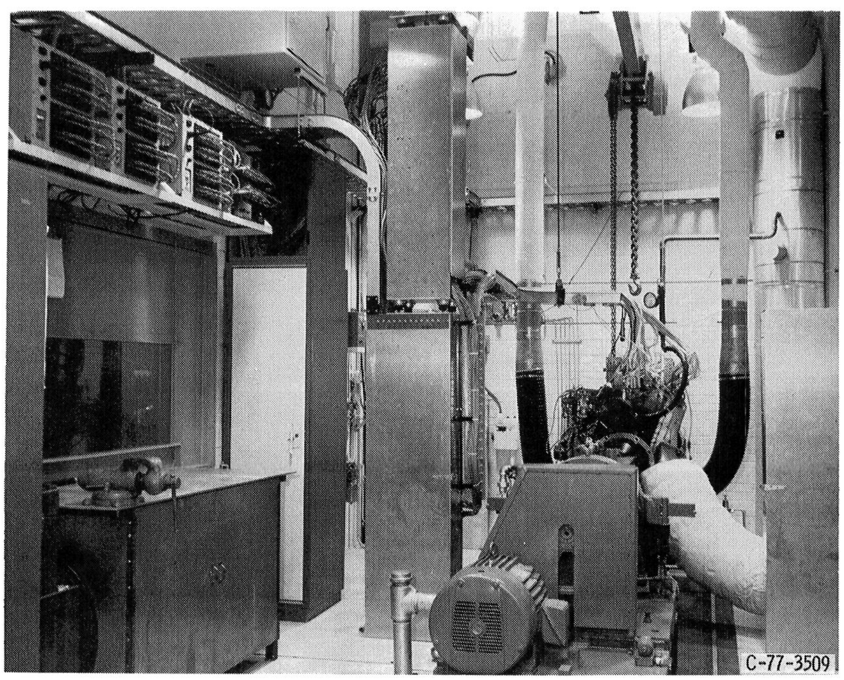


Figure 4. - Lewis test facility.

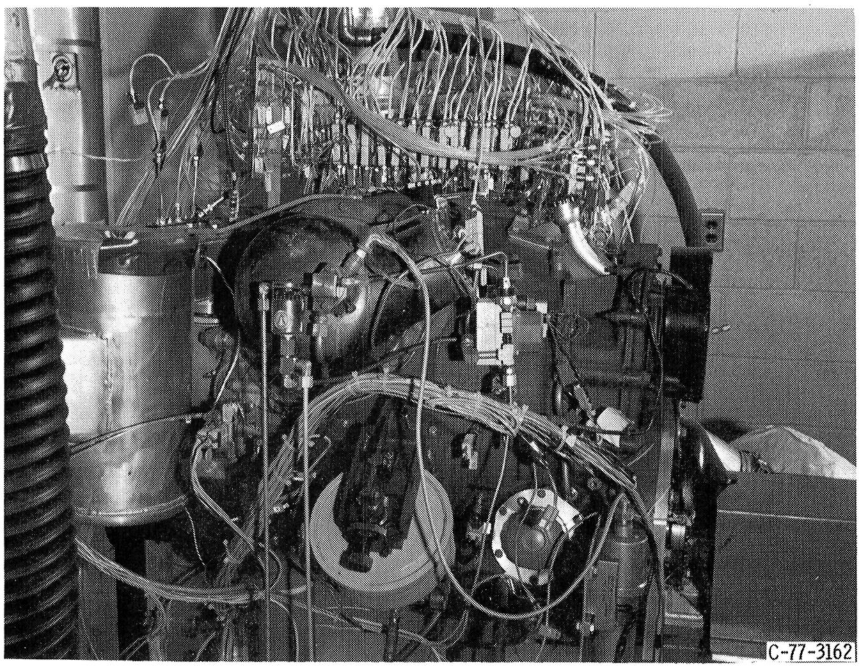


Figure 5. - Chrysler upgraded engine installed in Lewis test cell.

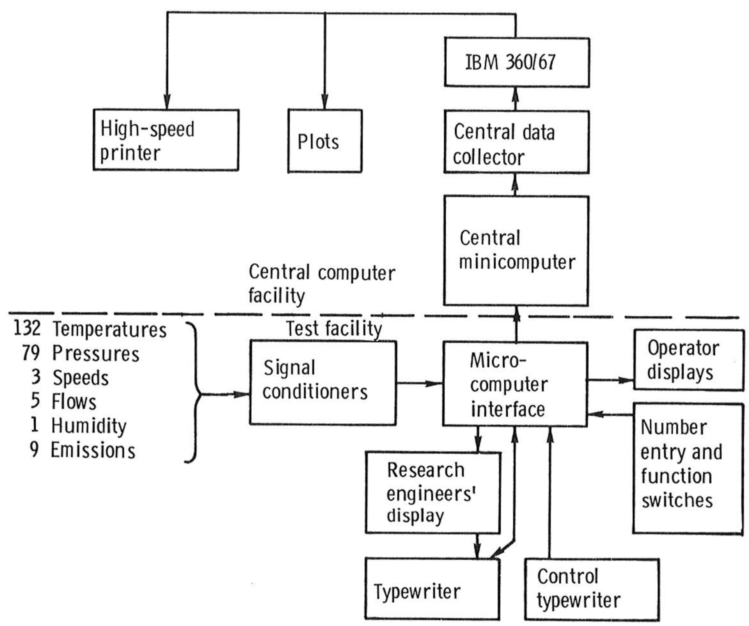


Figure 6. - Schematic diagram of data system.

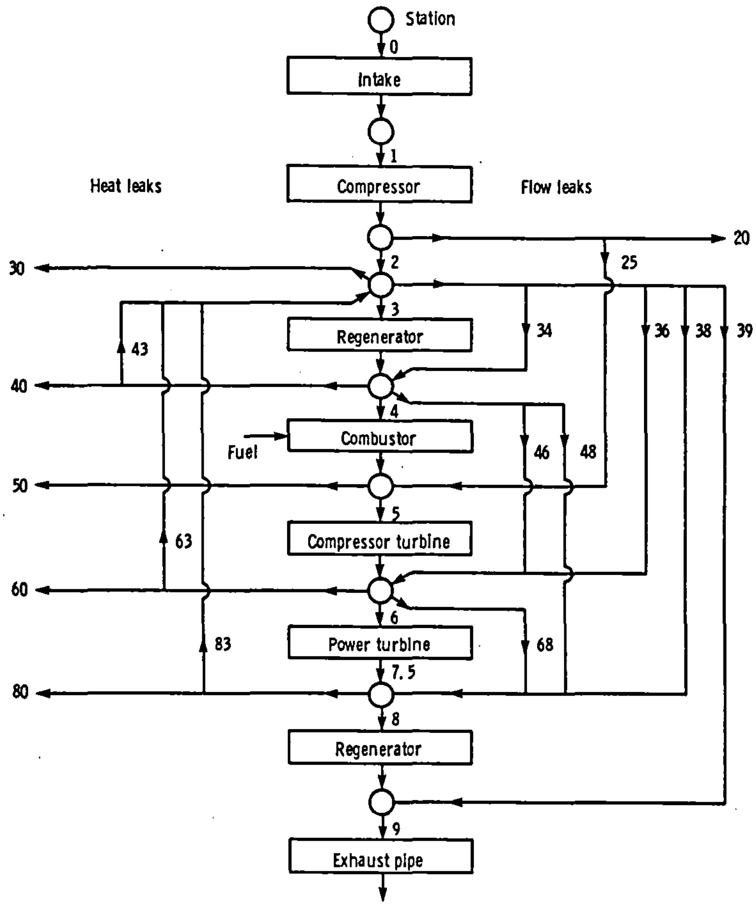


Figure 7. - Characterization schematic of Chrysler upgraded engine.

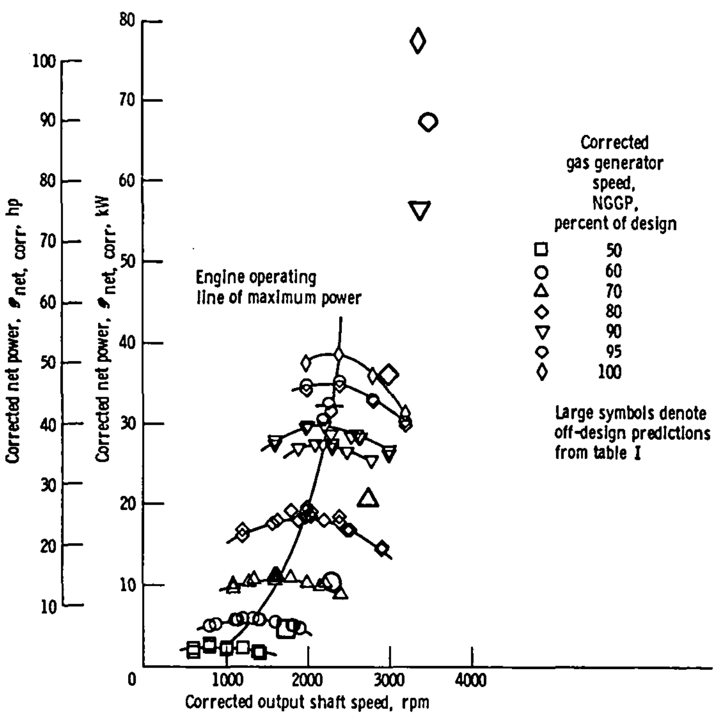


Figure 8. - Engine map - corrected power as a function of corrected speed. Design speed, 58 500 rpm.

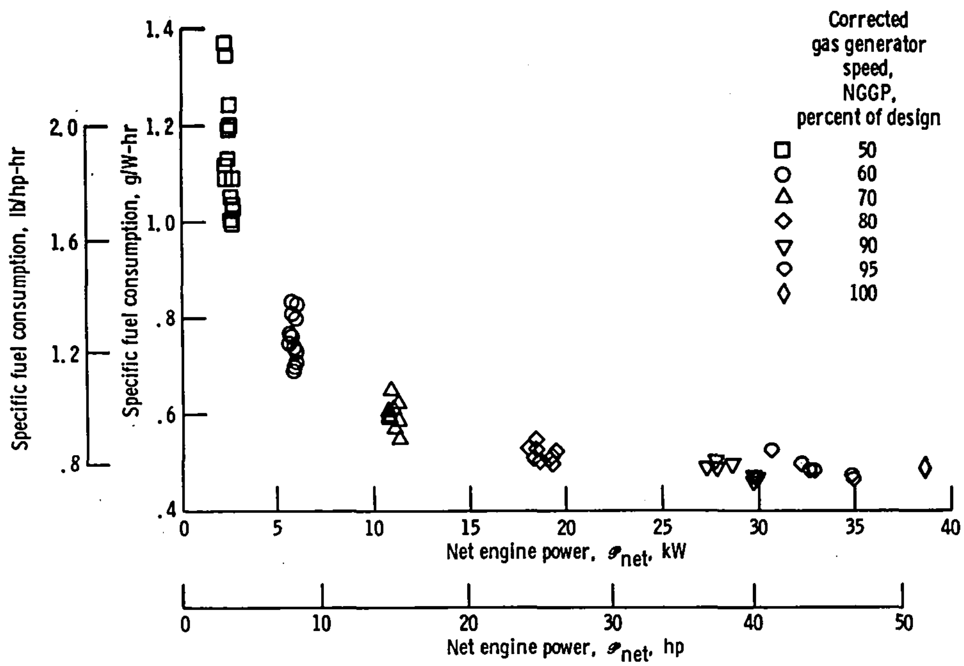


Figure 9. - Engine operating line - specific fuel consumption as a function of characteristic power. Design speed, 58 500 rpm.

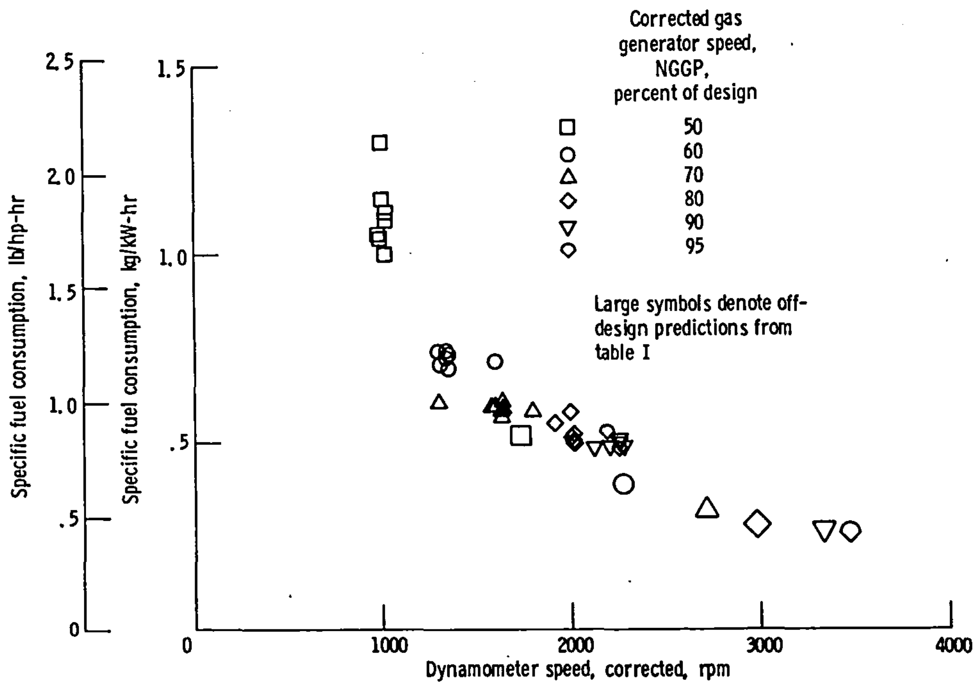


Figure 10. - Engine operating line - specific fuel consumption as a function of dynamometer speed.

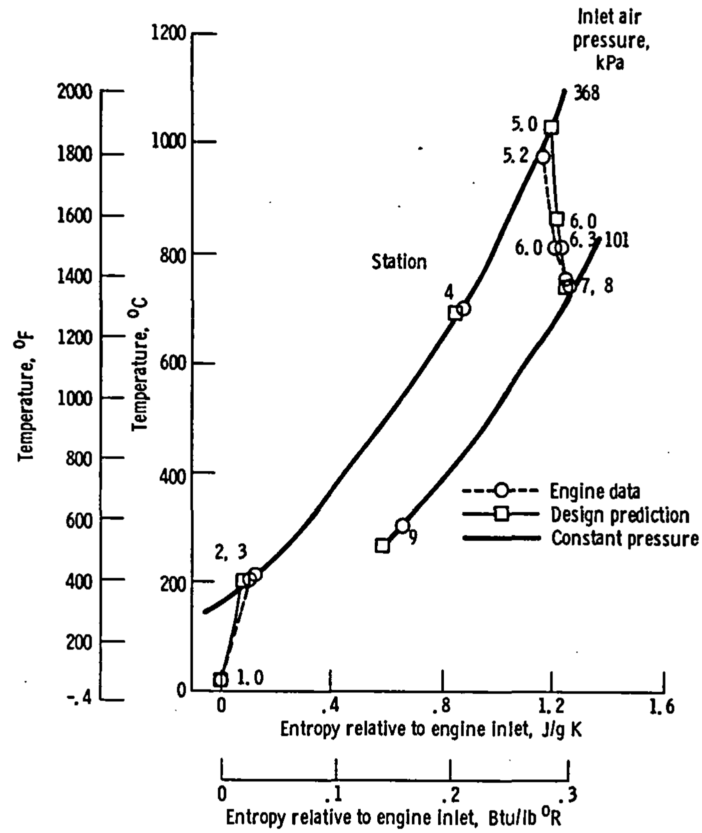


Figure 11. - Temperature-entropy diagram - engine. Gas generator speed, 95 percent of design.

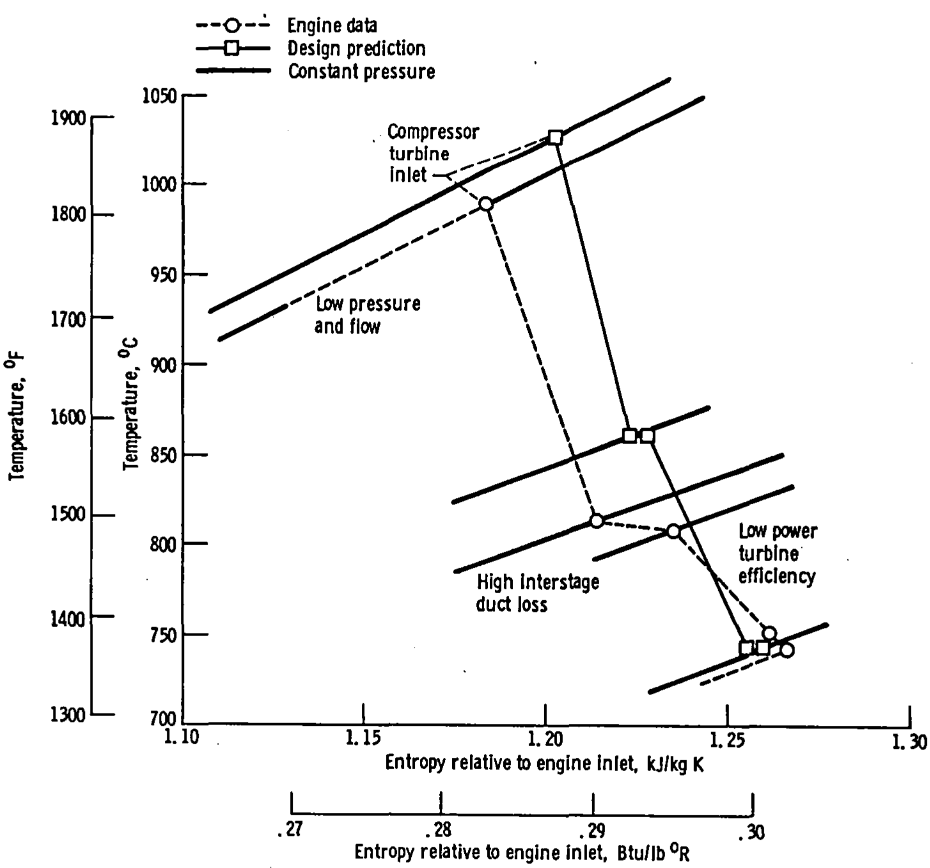


Figure 12. - Temperature-entropy diagram - turbine stages. Gas generator speed, 95 percent of design.

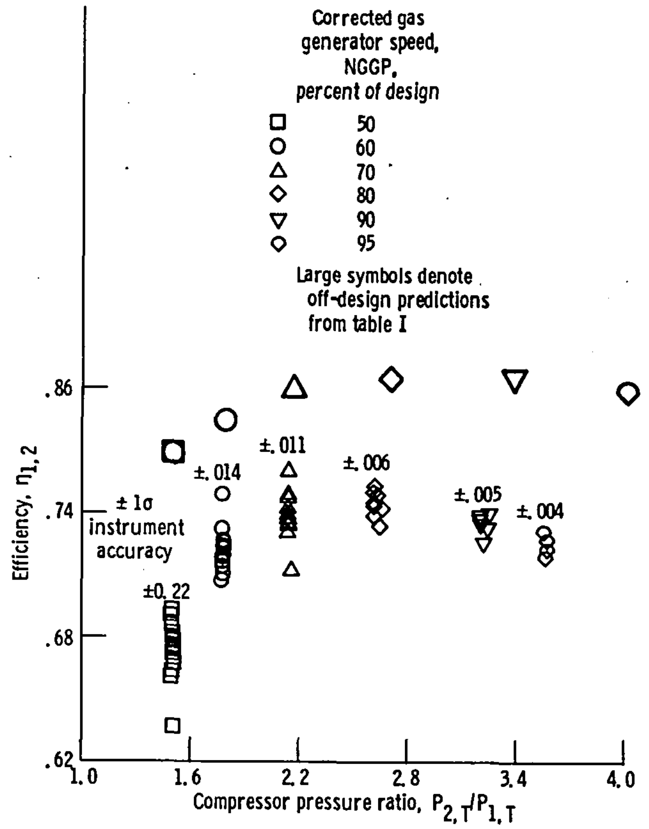


Figure 13. - Compressor efficiency as a function of pressure ratio - engine tests. Efficiency = $T_1\left[\left(\frac{P_2}{P_1}\right)^{(\gamma-1)/\gamma} - 1\right] \Big/ T_2 - T_1$

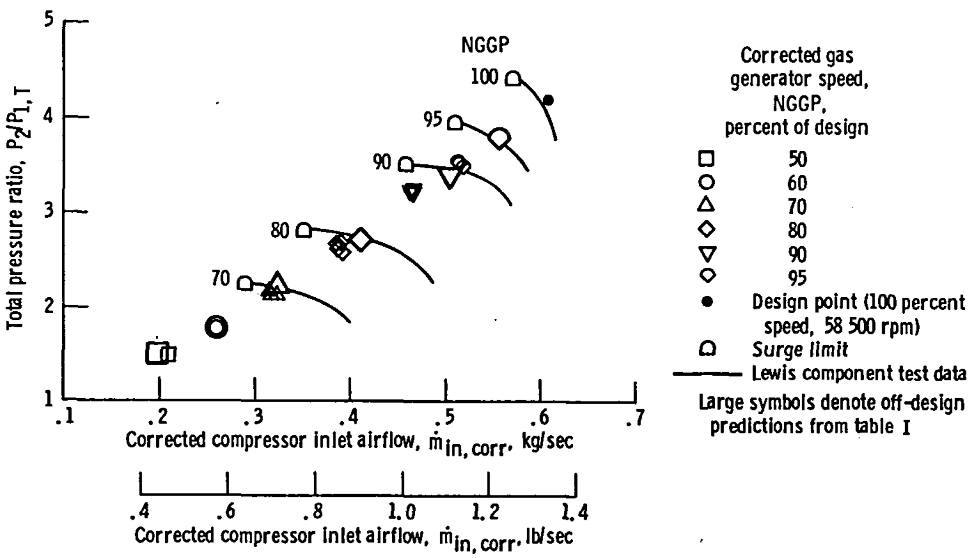


Figure 14. - Compressor pressure ratio and mass flow characteristic - component tests. (Component data were interpolated from data in ref. 12 and corrected for a scale factor of 1.259 reference inlet temperature.)

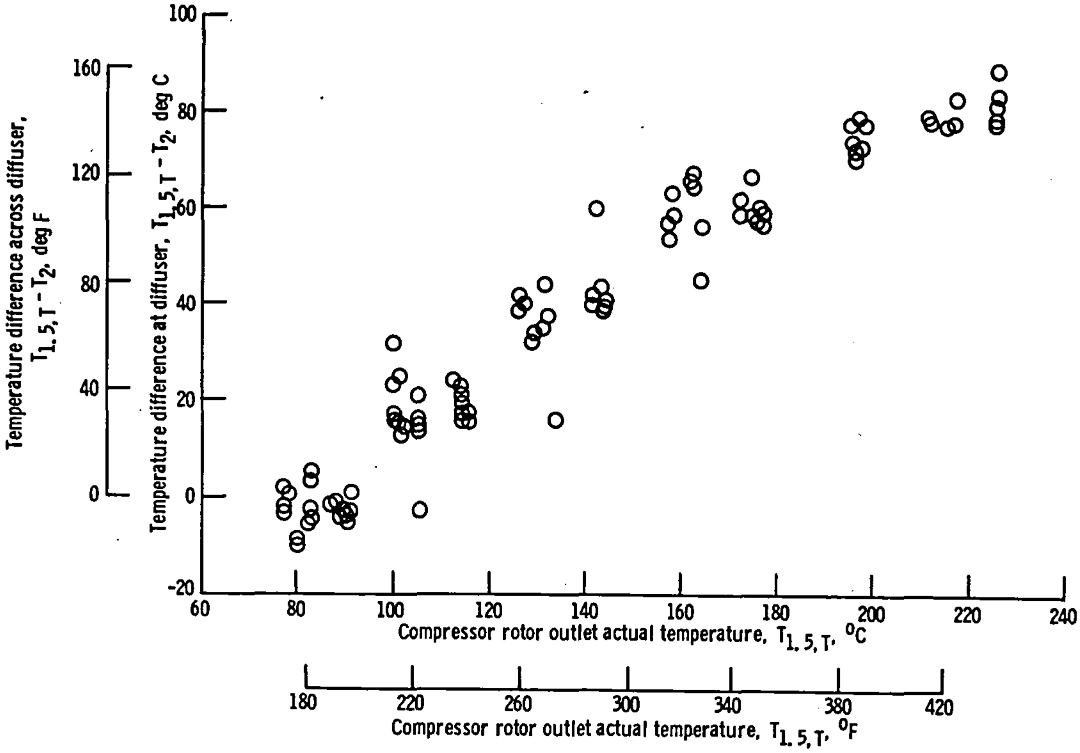


Figure 15. - Compressor air heat loss in diffuser and collector.

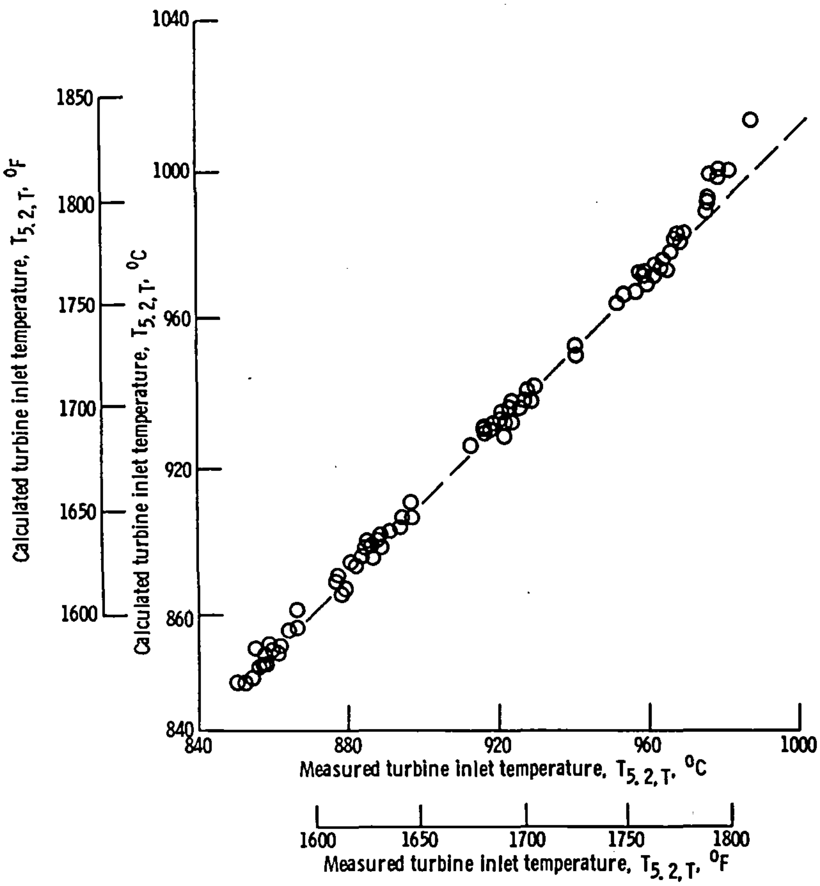


Figure 16. - Comparison of measured and calculated turbine inlet temperature.

$$T_{5.2,\,calc} = T_{6,T} + \frac{(h_{1.5} - h_{1.1})\left(\dfrac{\dot{m}_{in}}{\dot{m}_{in} + \dot{m}_f - \dot{m}_{leak}}\right) + \Delta h_{par}}{C_p}$$

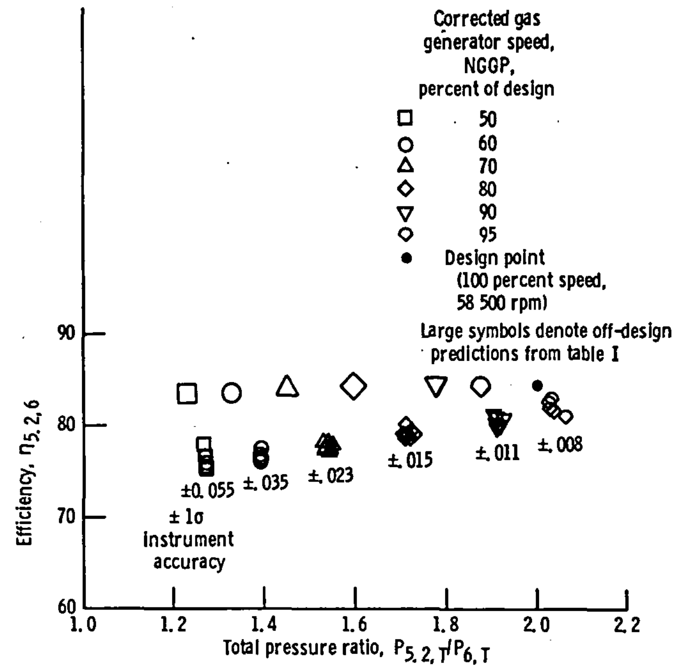


Figure 17. - Compressor turbine efficiency (based on compressor work and predicted parasitic losses and leakage).

$$\eta_{ct} = \frac{\mathcal{W}_{comp} + L_{par,des}}{\Delta h_{id}(\dot{m}_{in} + \dot{m}_f - \dot{m}_{leak})}$$

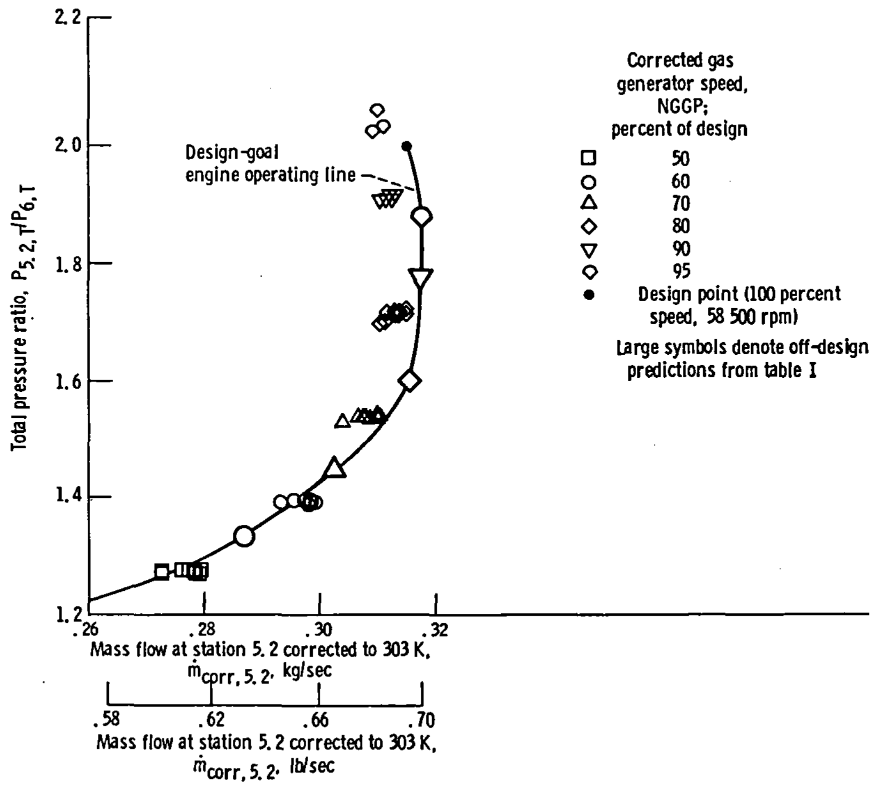


Figure 18. - Compressor turbine pressure ratio and mass flow characteristic.

$$\dot{m}_{corr} = \frac{\left(\dot{m}_{in} + \dot{m}_f - \dot{m}_{leak}\right)\sqrt{\frac{T_{5.2,T}}{303\ K}}\ \varepsilon}{\frac{P_{5.2,T}}{101\ kPa}}.$$

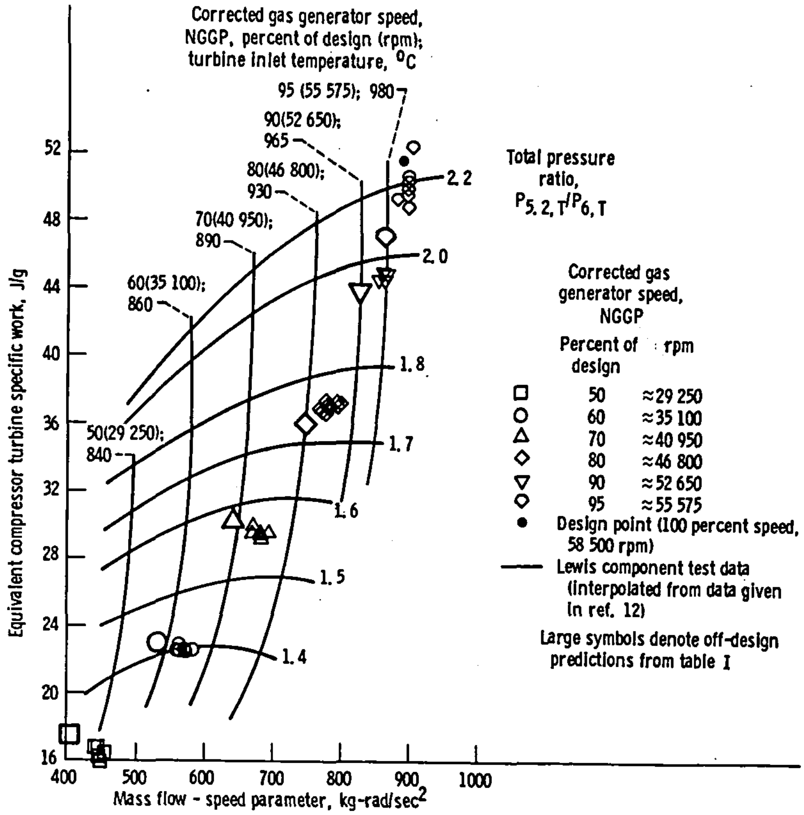


Figure 19. - Compressor turbine map - component tests.

$$\text{Mass flow - speed parameter} = \frac{(585.0)\ \text{NGGP}\ (\dot{m}_{in} + \dot{m}_f - \dot{m}_{leak})\ \frac{2\pi}{60}}{\frac{P_{5.2,T}}{101.3\ \text{kPa}}};$$

$$\text{Equivalent compressor turbine specific work} = \frac{(h_{1.5} - h_{1.1})\ \dot{m}_{in} + \mathcal{P}_{par}}{(\dot{m}_{in} + \dot{m}_f - \dot{m}_{leak})\ \theta_{cr}}$$

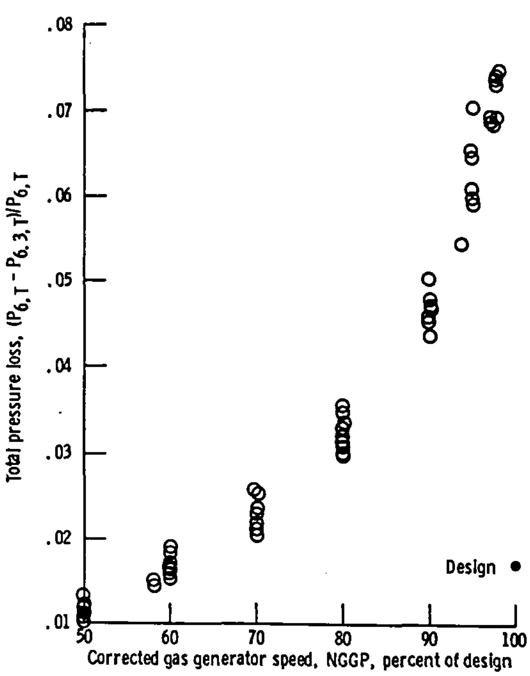


Figure 20. - Interstage duct pressure loss.

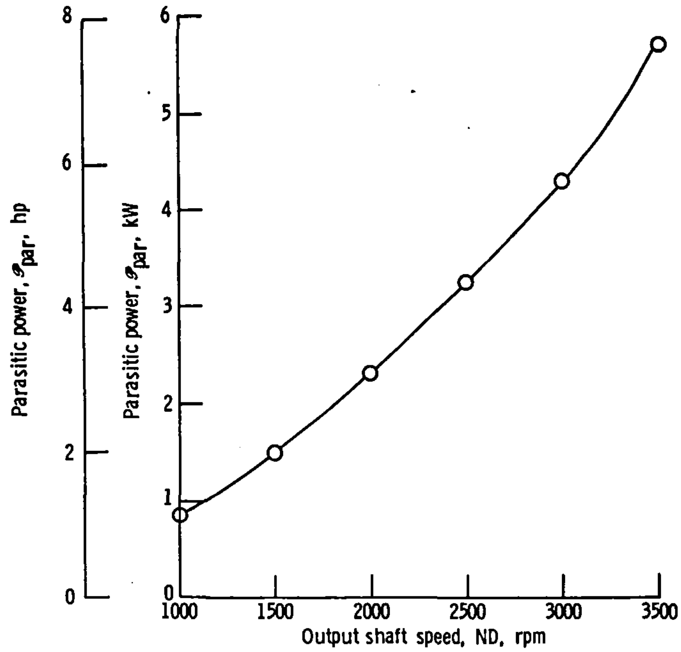


Figure 21. - Power turbine shaft parasitic losses. Dummy power turbine shaft; gas generator and regenerator installed; oil inlet temperature, 66° C; gas generator speed, NGG, 80 percent of design; low-pressure-side regenerator inlet temperature, T_8, 749° C.

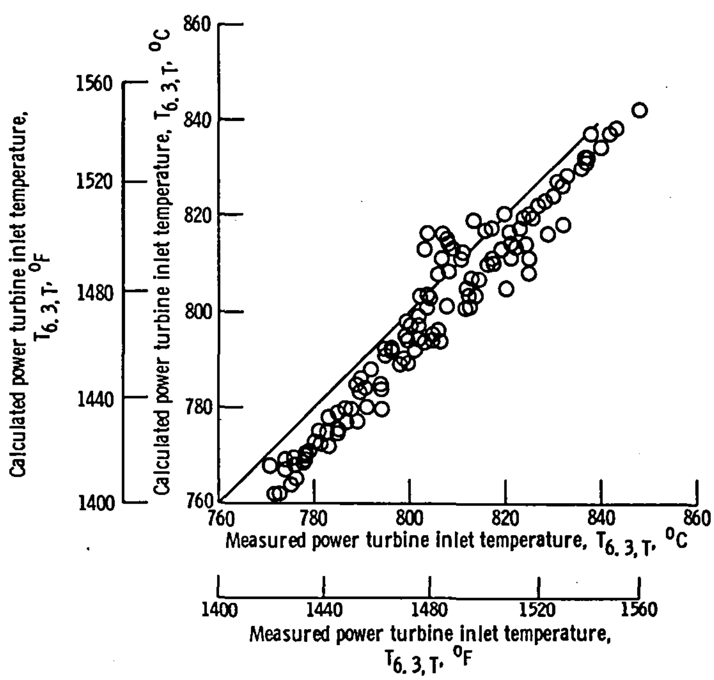


Figure 22. - Comparison of measured and calculated power turbine inlet temperature.

$$T_{6.3,T,calc} = T_{7,T} + \frac{\mathscr{P}_{net} + \mathscr{P}_{par}}{(\dot{m}_{in} + \dot{m}_f - \dot{m}_{leak})\, C_p}$$

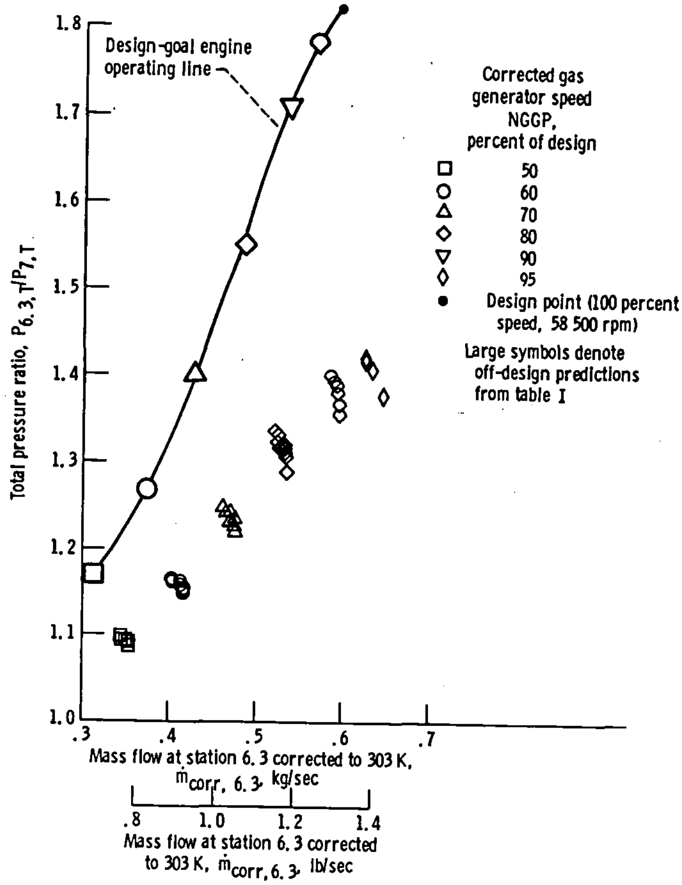


Figure 23. - Power turbine pressure ratio and mass flow characteristic.

$$\dot{m}_{corr} = \frac{(\dot{m}_{in} + \dot{m}_f - \dot{m}_{leak}) \sqrt{\frac{T_{6.3,T}}{303\ K}}\ \varepsilon}{\frac{P_{6.3,T}}{101\ kPa}}$$

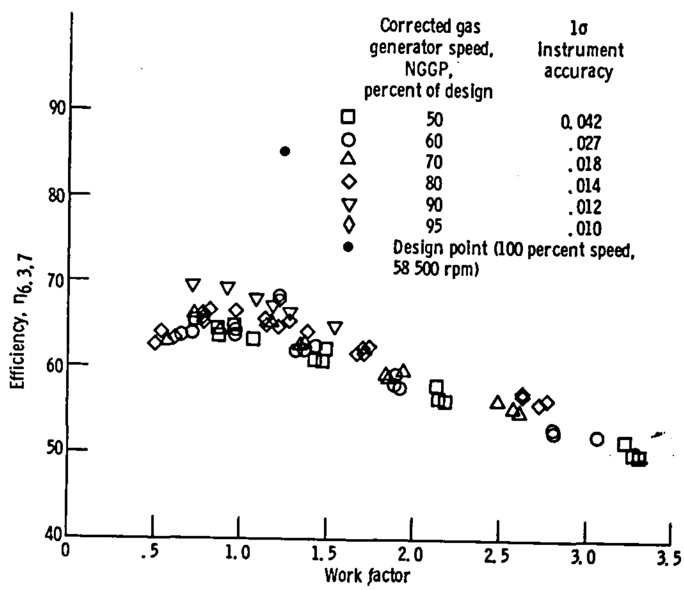


Figure 24. - Power turbine efficiency (based on dynamometer).

$$\text{Efficiency} = \frac{\mathcal{P}_{net} + \mathcal{P}_{par}}{(\dot{m}_{in} + \dot{m}_f - \dot{m}_{leak}) \times \Delta h_{id}}$$

$$\text{Work factor} = \frac{\mathcal{P}_{net} + \mathcal{P}_{par}}{(\dot{m}_{in} + \dot{m}_f - \dot{m}_{leak}) \times U^2}$$

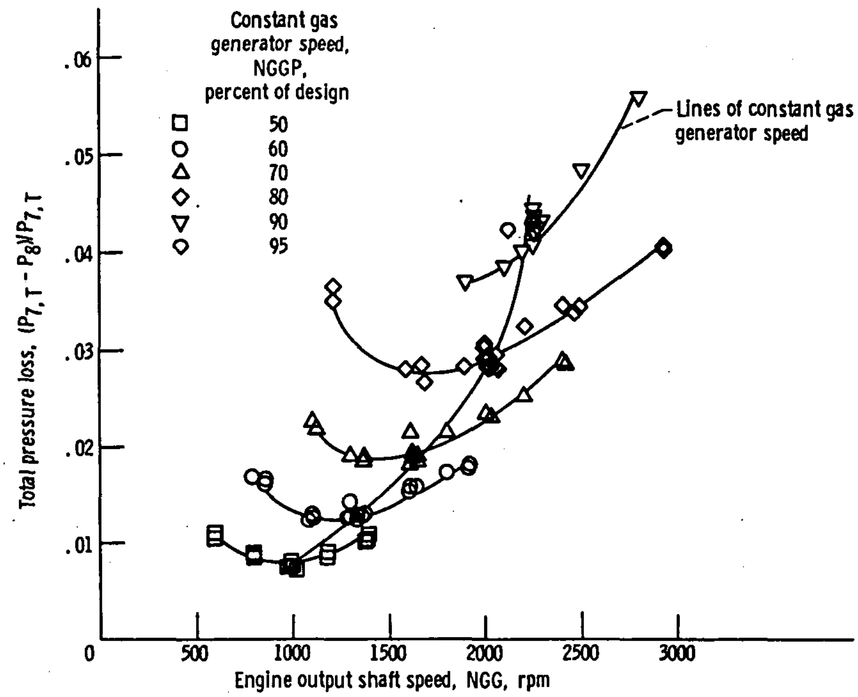


Figure 25. - Power turbine diffuser pressure loss. Design speed, 58 500 rpm.

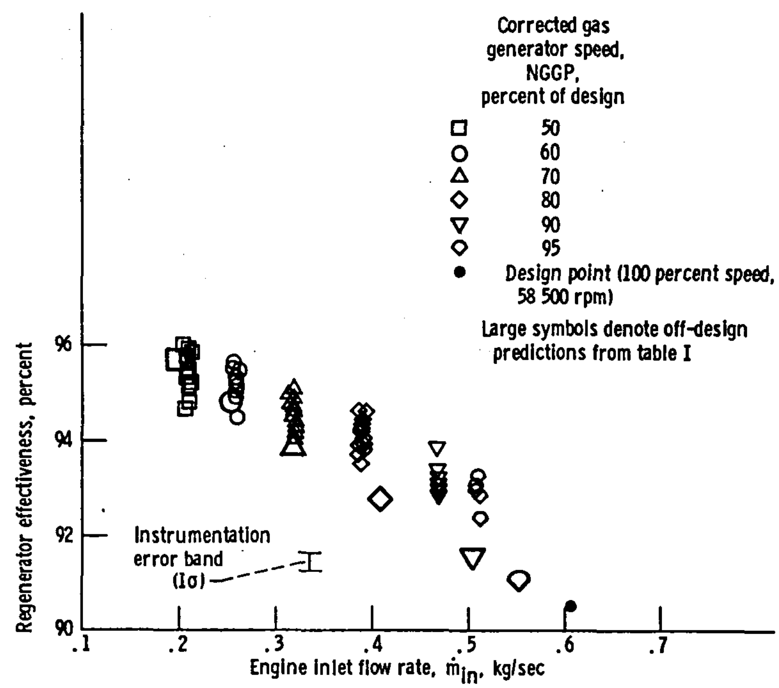


Figure 26. - Regenerator performance. Effectiveness = $\frac{T_4 - T_3}{T_8 - T_3}$

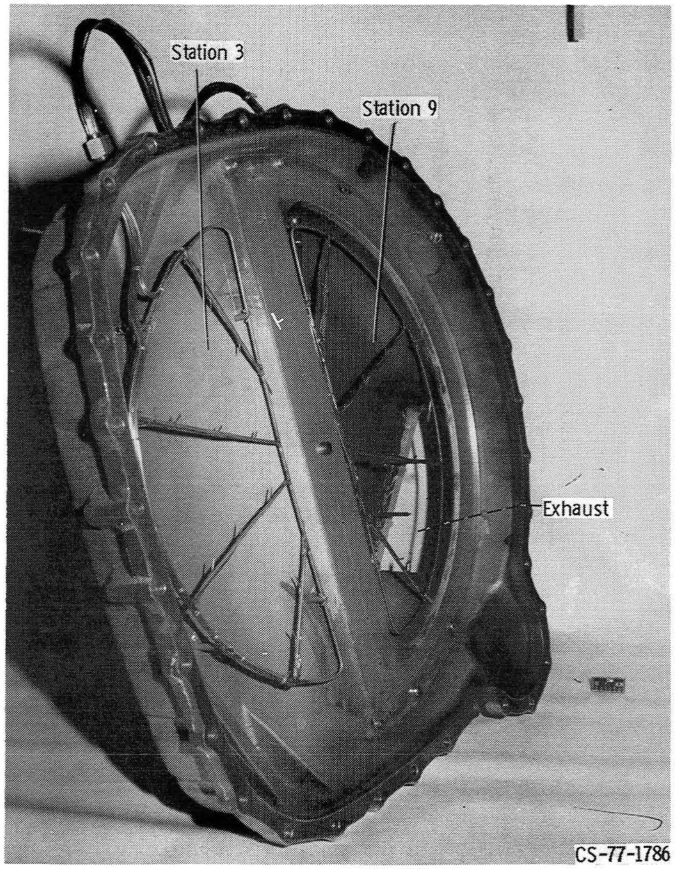


Figure 27. - Regenerator instrumentation - a view of inside of regenerator cover showing thermocouple grid.

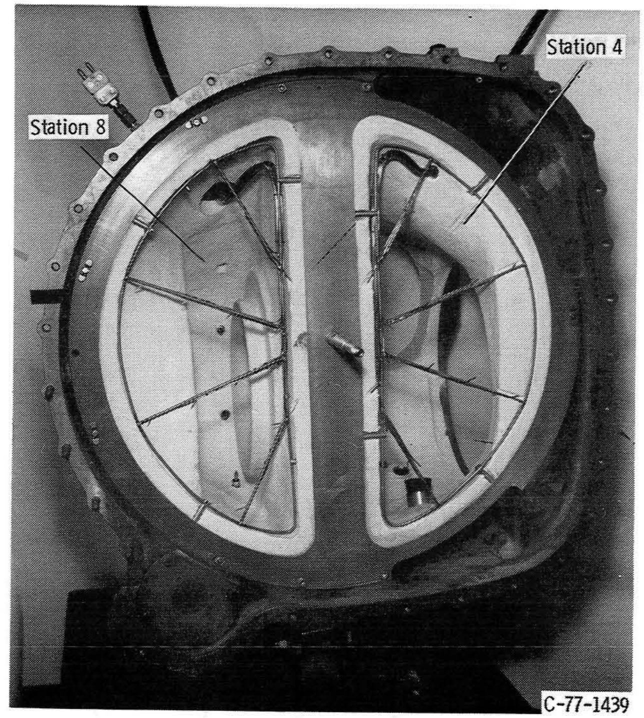


Figure 28. - Regenerator instrumentation - view into engine housing with regenerator disk and turbine shafting removed.

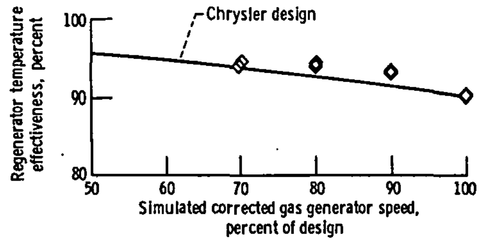


Figure 29. - Test facility regenerator performance. (From ref. 10.)

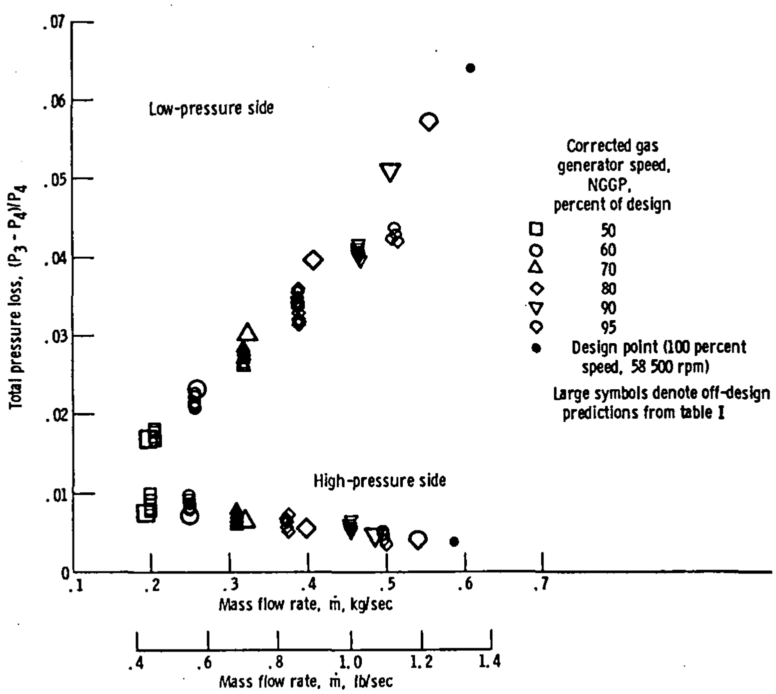


Figure 30. - Regenerator pressure loss.

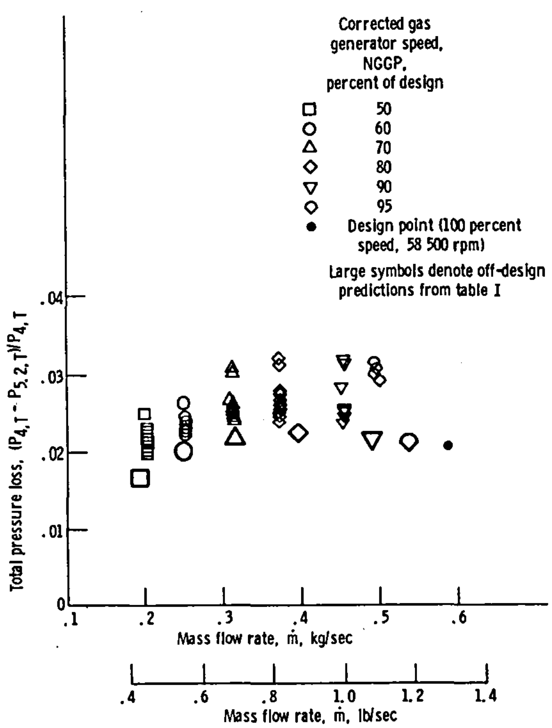


Figure 31. - Combustor-vortex pressure loss (noninstrumented combustor).

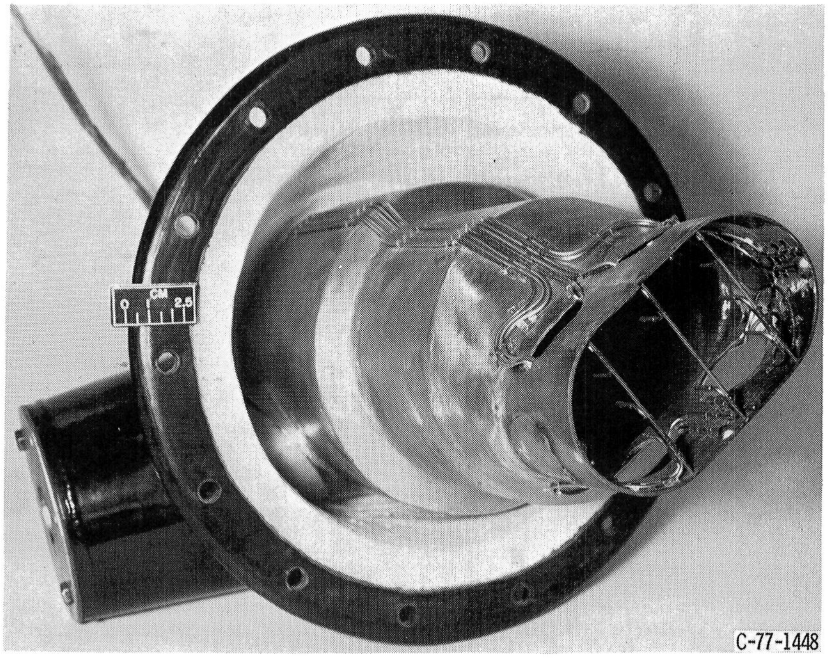


Figure 32. - Instrumented combustor.

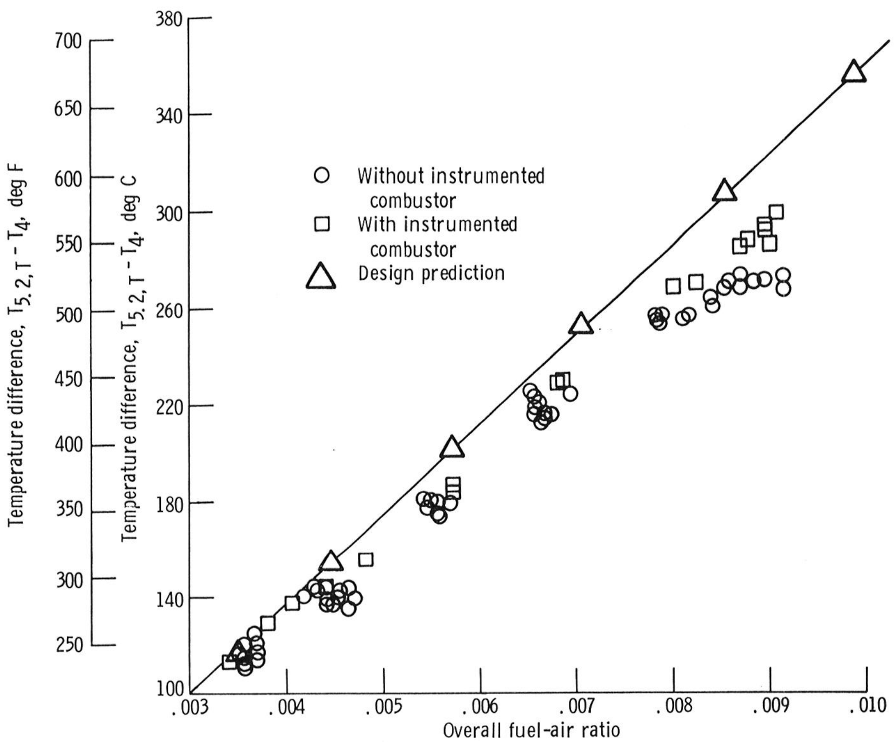


Figure 33. - Increase in temperature difference between high-pressure regenerator outlet and compressor turbine nozzle inlet.

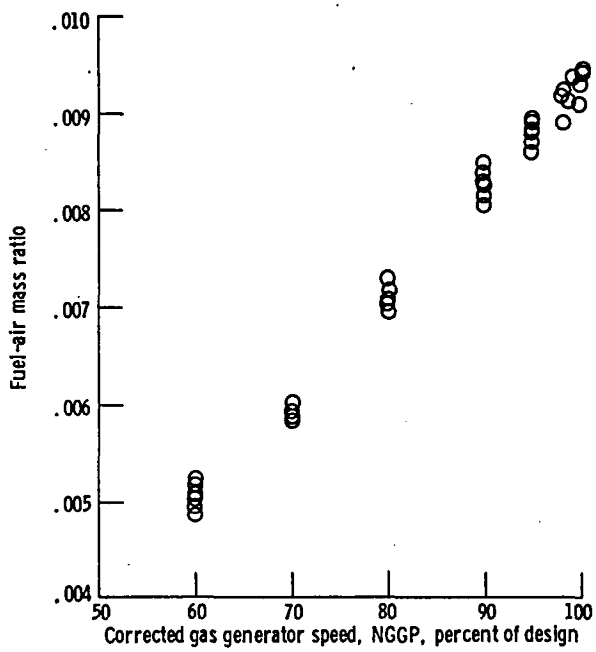


Figure 34. - Relationship between fuel-air mass ratio and gas generator speed.

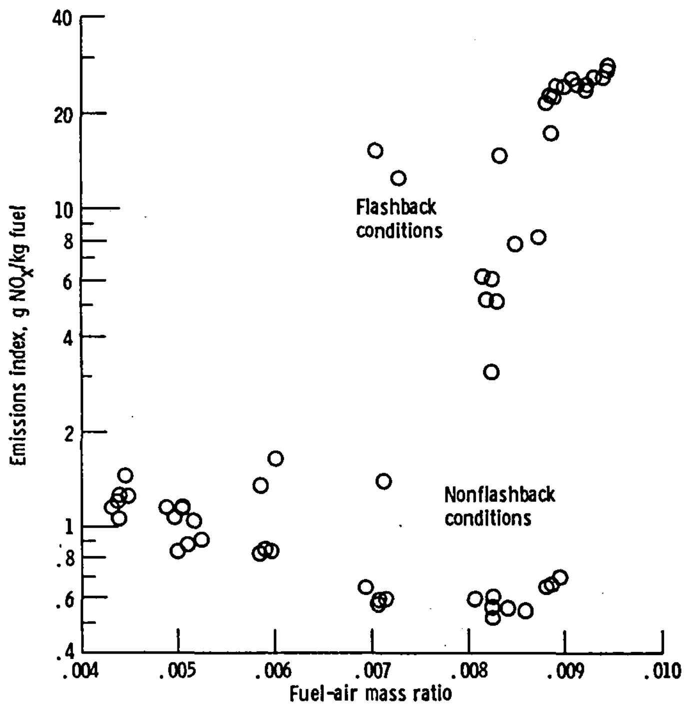


Figure 35. - Relationship between oxides-of-nitrogen emission index and fuel-air mass ratio. Low-pressure-side regenerator inlet temperature, T_8, 748° C; high-pressure-side regenerator outlet temperature, T_4, 715° C.

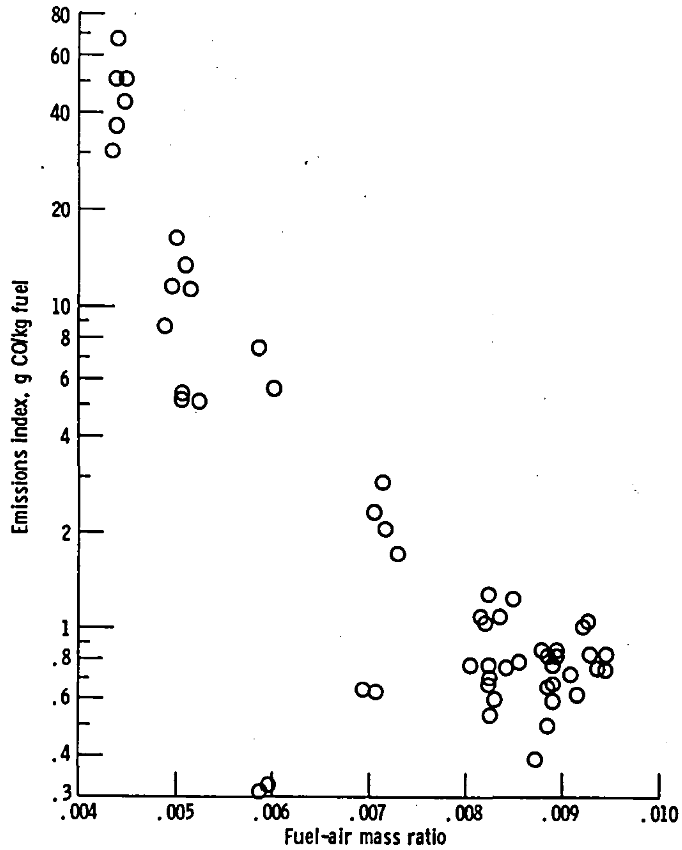


Figure 36. - Relationship between carbon monoxide emissions index and fuel-air mass ratio. Low-pressure-side regenerator inlet temperature, T_8, 748° C; high-pressure-side regenerator outlet temperature, T_4, 715° C.

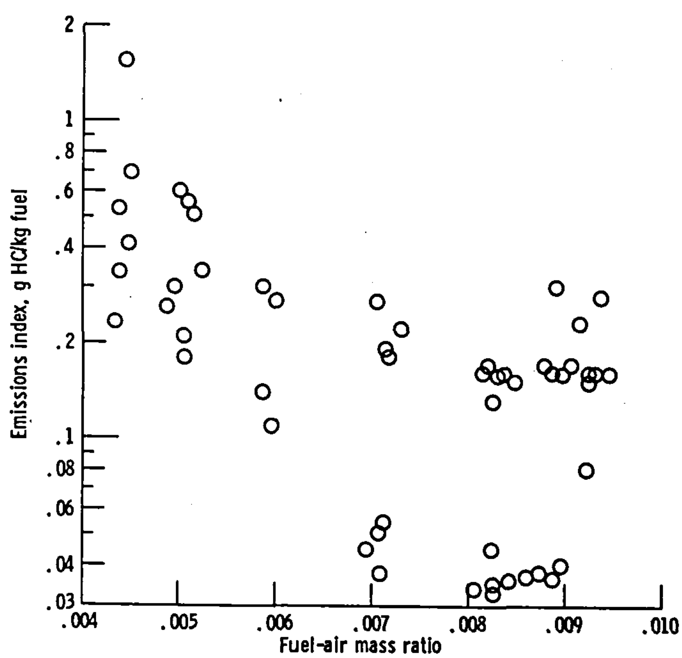


Figure 37. - Relationship between hydrocarbon emissions index and fuel-air ratio. Low-pressure-side regenerator inlet temperature, T_8, 748° C; high-pressure-side regenerator outlet temperature, T_4, 715° C.

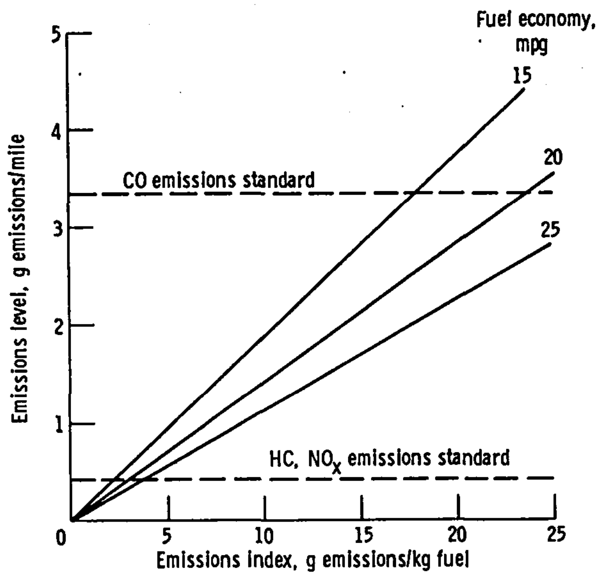


Figure 38. - Emissions level related to emissions index and fuel economy. Fuel density, 744 kg/m^3.

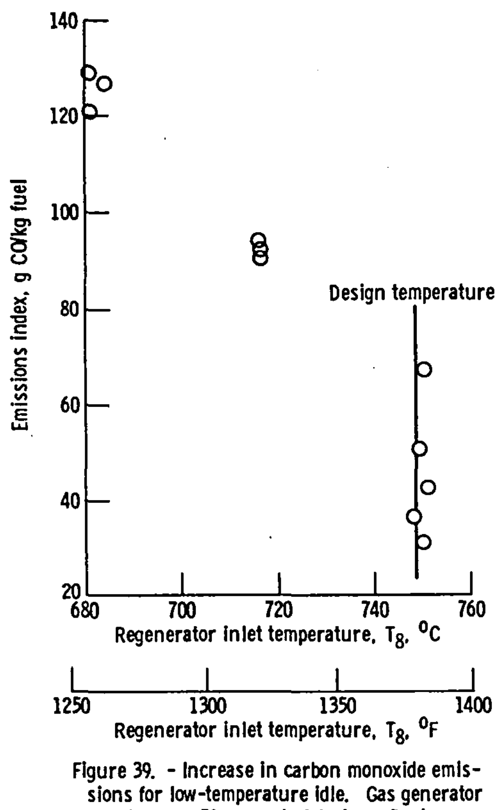


Figure 39. - Increase in carbon monoxide emissions for low-temperature idle. Gas generator speed, NGG, 50 percent of design. Design speed, 58 500 rpm.

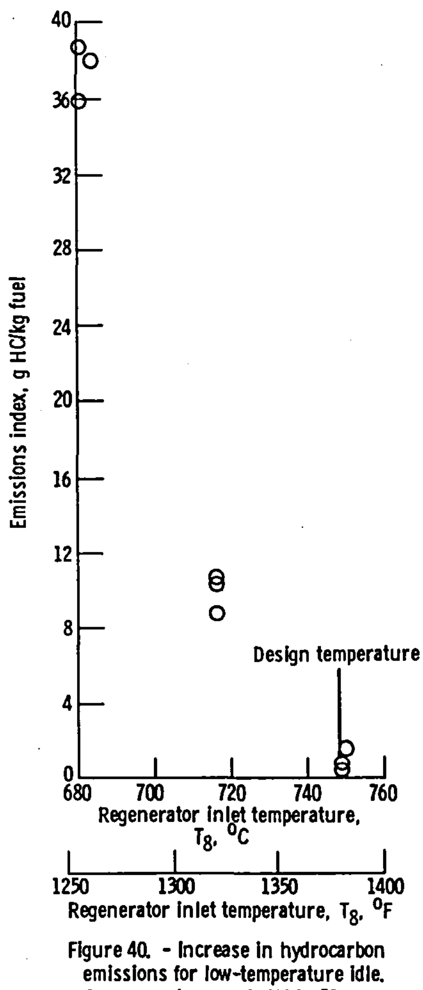


Figure 40. - Increase in hydrocarbon emissions for low-temperature idle. Gas generator speed, NGG, 50 percent of design. Design speed, 58 500 rpm.

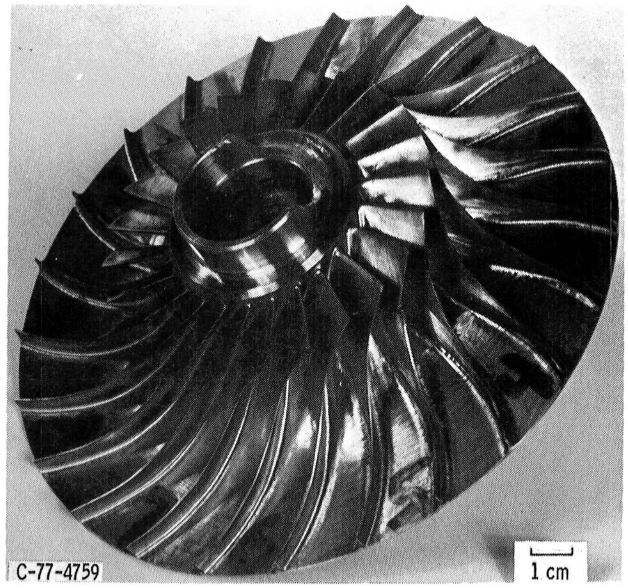


Figure 41. - Compressor rotor with inducer.

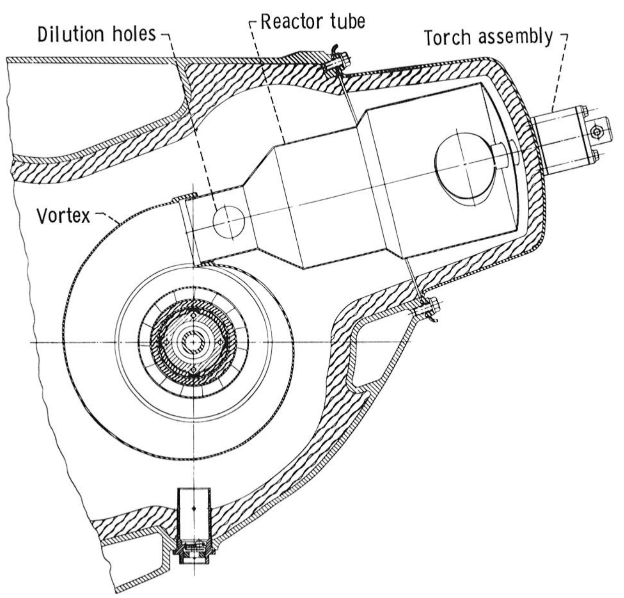
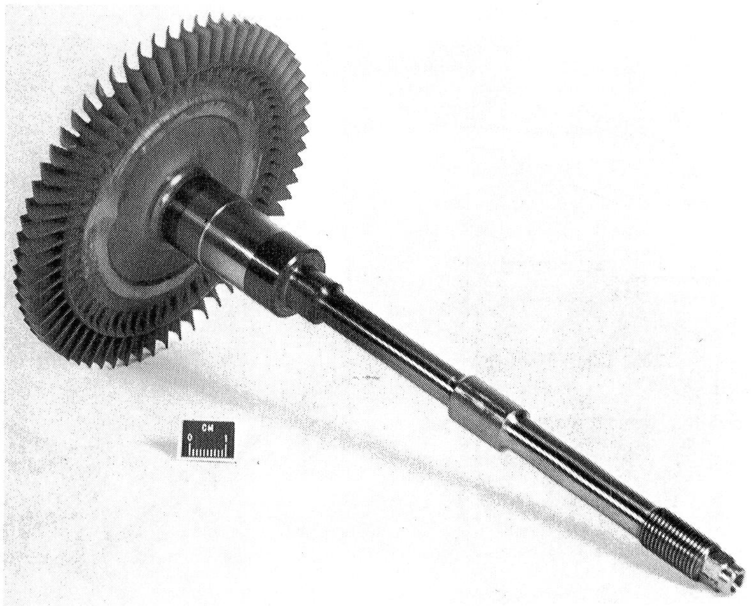


Figure 42. - Combustor and vortex.



C-77-4758

Figure 43. - Compressor turbine rotor with gas generator shaft.

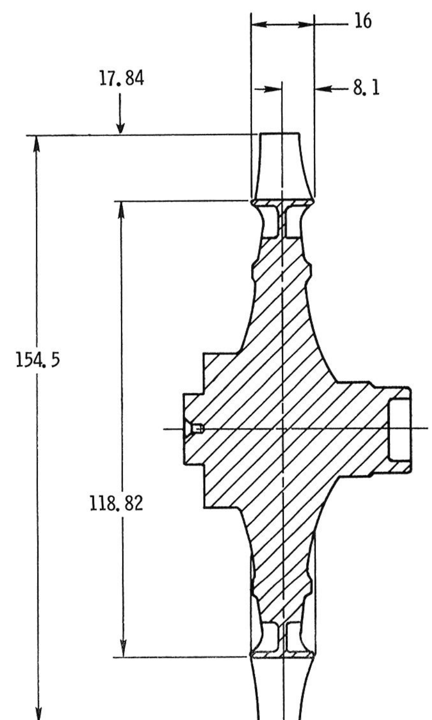


Figure 44. - Power turbine wheel.

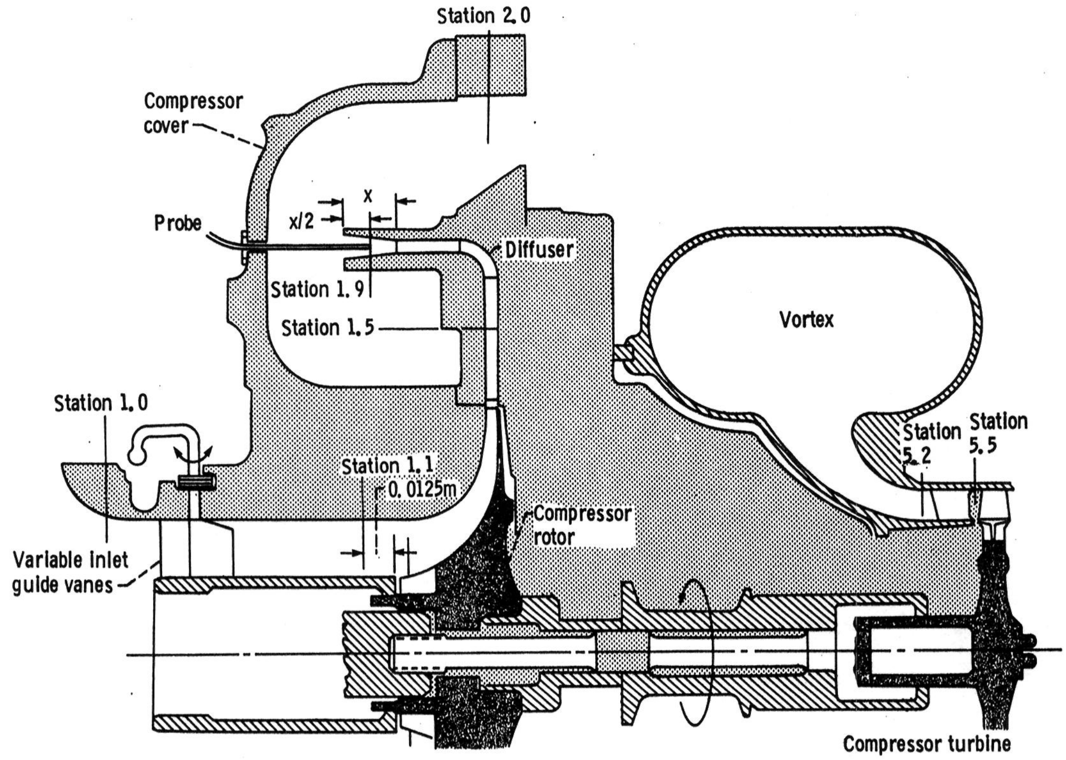


Figure 45. - Gas generator instrumentation station locations.

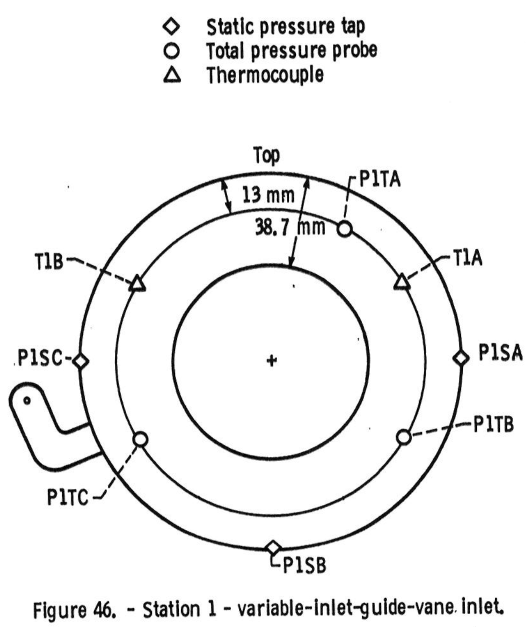


Figure 46. - Station 1 - variable-inlet-guide-vane inlet.

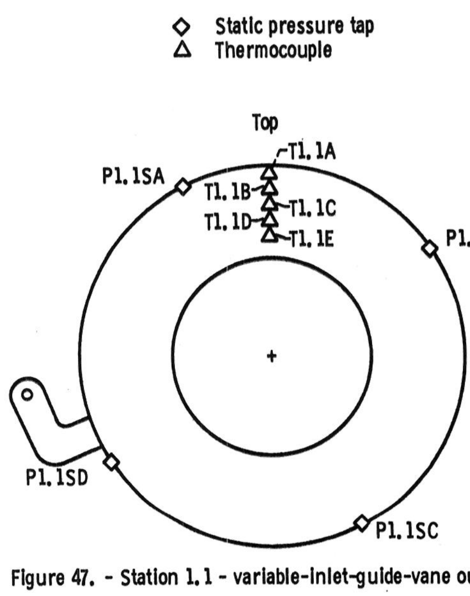


Figure 47. - Station 1.1 - variable-inlet-guide-vane outlet.

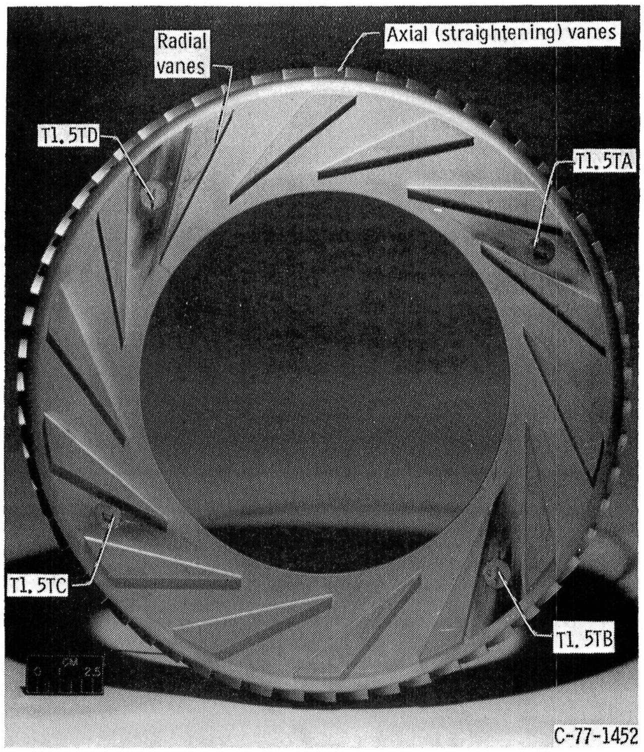


Figure 48. - Station 1.5 - compressor diffuser and straightening vanes.

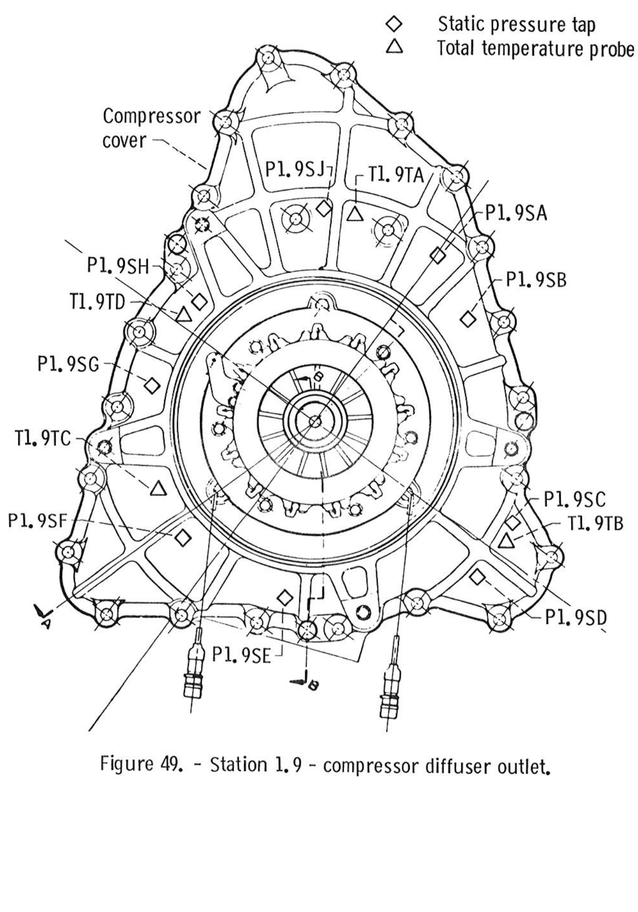


Figure 49. - Station 1.9 - compressor diffuser outlet.

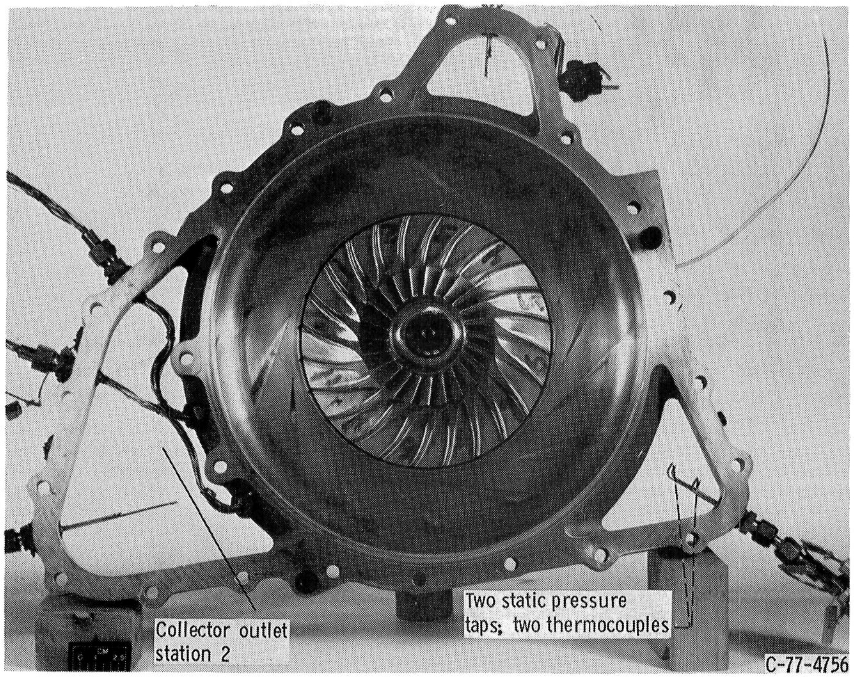


Figure 50. - Compressor collector outlets.

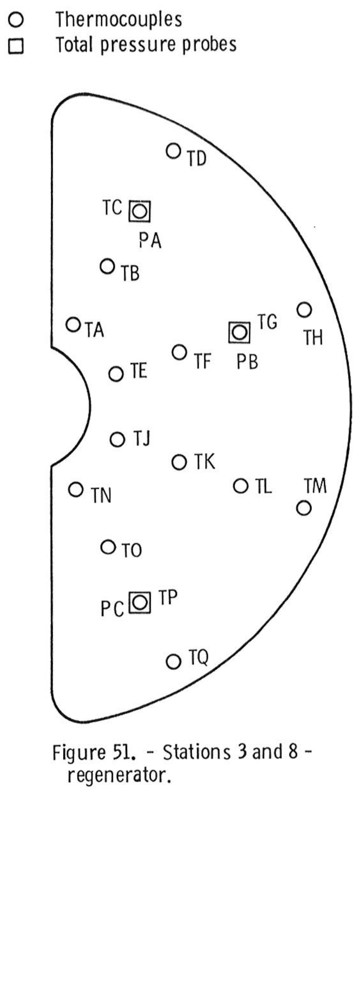


Figure 51. - Stations 3 and 8 - regenerator.

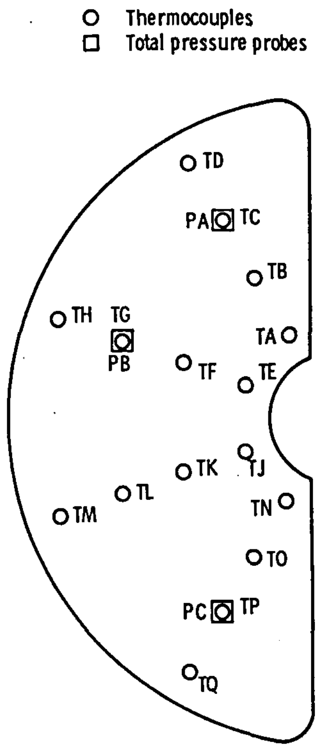


Figure 52. - Stations 4 and 9 - regenerator.

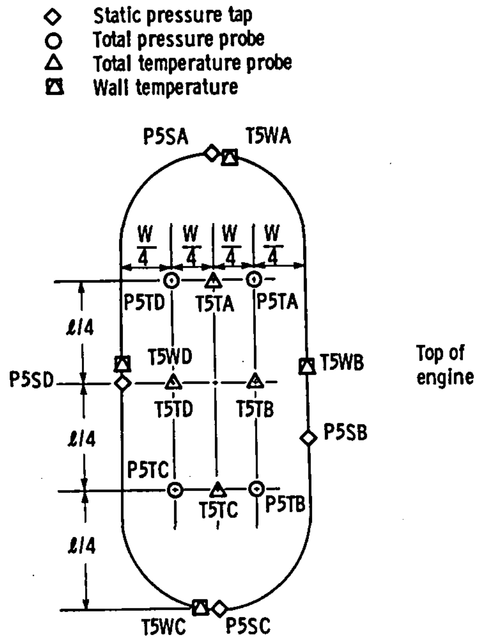


Figure 53. - Station 5 - view into combustor exit.

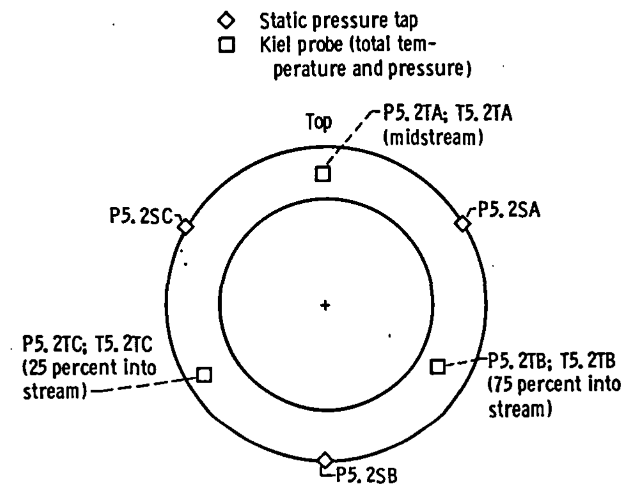


Figure 54. - Station 5.2 - compressor turbine stator inlet.

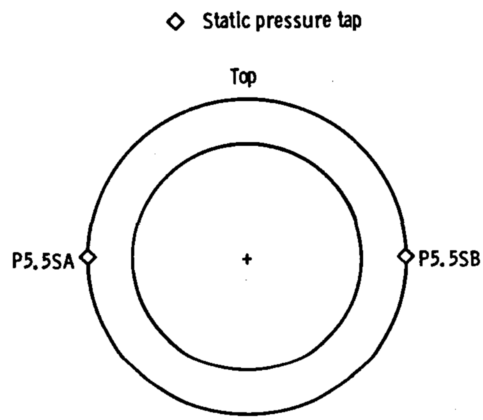


Figure 55. - Station 5.5 - compressor turbine stator outlet.

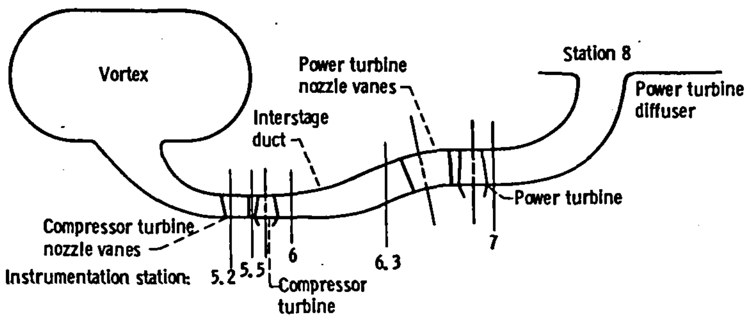


Figure 56. - Instrumentation station locations in turbine region.

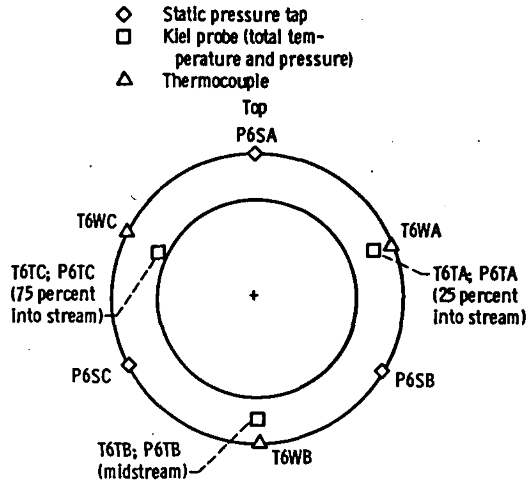


Figure 57. - Station 6 - compressor turbine rotor outlet.

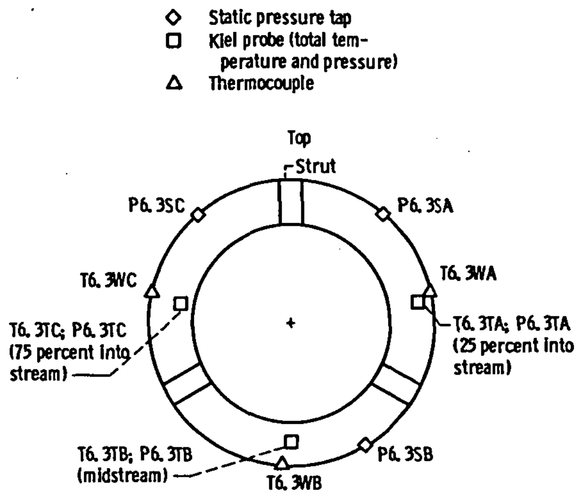


Figure 58. - Station 6.3 - power turbine stator inlet.

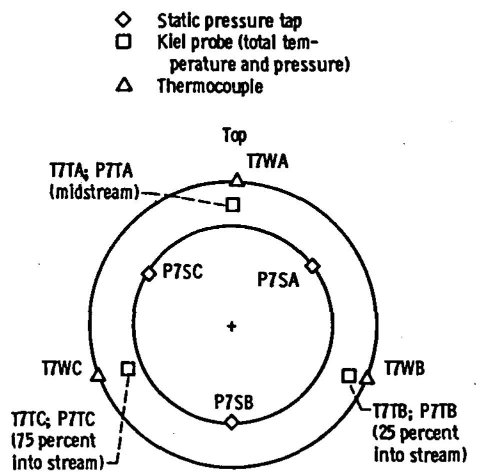


Figure 59. - Station 7 - power turbine rotor outlet.

1. Report No. NASA TM-81660	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle TEST RESULTS OF THE CHRYSLER UPGRADED AUTOMOTIVE GAS TURBINE ENGINE - INITIAL DESIGN		5. Report Date July 1981
		6. Performing Organization Code 778-32-01
7. Author(s) David Horvath, Guy H. Ribble, Jr., Edward Warren, and James C. Wood		8. Performing Organization Report No. E-676
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Energy Office of Vehicle and Engine R&D Washington, D.C. 20545		13. Type of Report and Period Covered Technical Memorandum
		14. Sponsoring Agency ~~Code~~ Report No. DOE/NASA/51040-22

15. Supplementary Notes

Final report. Prepared under Interagency Agreement DE-AI01-77CS51040.

16. Abstract

The Chrysler upgraded automotive gas turbine engine as built to the original design was deficient in power and had excessive specific fuel consumption. As part of a corrective action program under the Department of Energy Heat Engine project, NASA tested a highly instrumented version of the engine at the Lewis Research Center to identify the sources of the engine problems. Analysis of the data shows the major problems to be low compressor and power turbine efficiency and excessive interstage duct losses. In addition, high HC and CO emissions were measured at idle, and high NO_x emissions at high engine speeds.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Gas turbine engine Automotive engine Fuel economy Vehicle emissions	Unclassified - unlimited STAR Category 44 DOE Category UC-96

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified		

* For sale by the National Technical Information Service, Springfield, Virginia 22161