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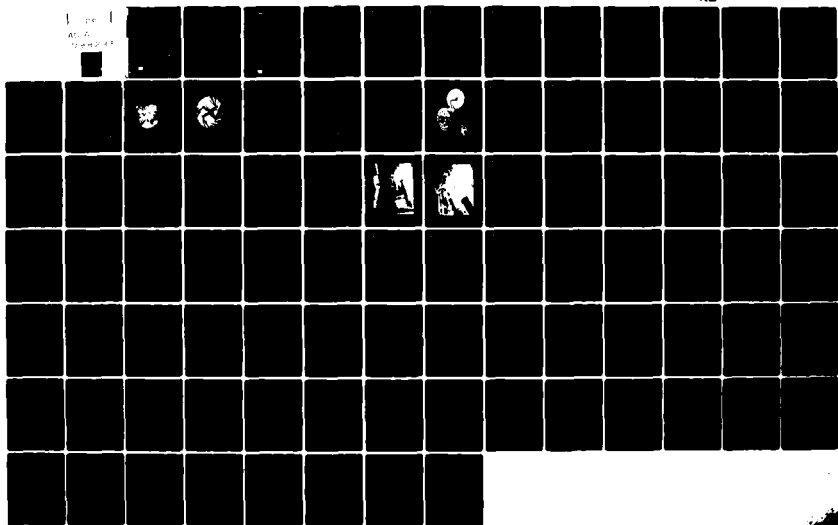
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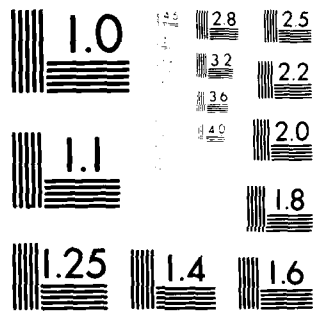
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WR34-8 PERFORMANCE IMPROVEMENT PROGRAM

THE WR34-8 GAS TURBINE COMPRESSOR TEST

CONTRACT NO. DAAK 70-80-C0129

D. BEST AND R. HONN
WILLIAMS RESEARCH CORPORATION
2280 WEST MAPLE ROAD
WALLED LAKE, MICHIGAN 48088

3 APRIL 1981

FINAL REPORT FOR THE COMPRESSOR TEST PHASE

The views, opinions, and/or findings contained in the report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

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FINAL REPORT FOR THE COMPRESSOR TEST PHASE

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PROGRAM MANAGER



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PREFACE

This program was authorized under Contract DAAK 70-80-C-0129. The purpose of the program was to establish the present WR34 engine compressor rig test performance as the first step towards both understanding its performance in the engine and to identifying areas in which engine component performance improvements can be made. The applicable DA Project is for future ground power units.

The authors wish to acknowledge contributions made to this program by the following Williams Research Corporation employees:

J. Colyer, for compressor data reduction and analysis.

S. Herridge and F. Kittredge, for directing the compressor test.

I. King, H. Meloy, and D. McCauley, for instrumenting, assembling, and operating the test rig.

D. Dorer and B. Everett, for engine cycle analysis.

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SUMMARY

This test was conducted to establish the performance level of the present Williams Research Corporation WR34 engine single-stage centrifugal compressor. Specific objectives were to:

- Define the compressor performance map from 40 through 115 percent of the design corrected speed
- Determine the performance of each of the compressor components so that potential improvements could be identified
- Ascertain if the compressor would enable the engine to satisfy a requirement of 27.7 horsepower at an inlet temperature of 107°F at an altitude of 5000 feet.

Compressor rig testing demonstrated a compressor design point stage performance of 74 percent efficiency and 4.25:1 pressure ratio at 0.538 lbm/sec corrected airflow. Test data indicated that the relatively thick impeller blades, which were designed with a state-of-the-art castable thickness distribution, result in higher than anticipated levels of impeller loss and restrict flow range. Cycle analysis using the tested compressor performance showed that the WR34 engine can meet the goal of 27.7 horsepower on a 107°F day at an altitude of 5000 feet.



SECTION 1

INTRODUCTION

This report summarizes the rig testing of the single stage centrifugal compressor that is incorporated in the Williams Research Corporation WR34 Engine. The primary purpose of the compressor rig test was to define the performance of the new Williams designed backswept centrifugal compressor; this design being an improvement over the current WR34 engine radial compressor. This establishes a baseline from which compressor performance improvements can be identified and engine cycle analysis can be conducted. The test rig utilized engine compressor hardware which was representative of production quality to ensure that an accurate assessment of engine compressor performance was made.

The compressor rig test program was conducted in the existing small compressor test cell at WRC. Thorough instrumentation was used to gather data required to establish overall compressor performance and identify the performance of each of the compressor components.

The compressor performance data was used in the WR34 engine simulation computer model. This was done to ascertain whether the engine could satisfy a contractual requirement of 27.7 horsepower on a 107°F day at an altitude of 5000 feet.



SECTION 2

INVESTIGATION

The primary program objective was to conduct a compressor rig test to establish the baseline performance of the present WR34 engine single-stage centrifugal compressor. In addition, it was required that the WR34 engine cycle be evaluated using the compressor rig test data. The program consisted of investigating the areas discussed in Sections 2.1 through 2.4.

2.1 COMPRESSOR DESIGN

The design of the WR34 single-stage centrifugal compressor was done by WRC prior to the inception of this contract. The compressor was designed to be a minimal risk configuration both structurally and aerodynamically. The conservative design approach was taken due to a necessity to minimize development effort. The compressor design was oriented toward low-cost producibility, reliability, and ruggedness as well as towards good performance. This was in keeping with the applications envisioned for the WR34 engine. Figure 1 presents a cross-section of the WR34 engine.

The impeller was designed to be accurately cast consistently using proven state-of-the-art casting techniques. This resulted in relatively thick impeller blades which enhance its ruggedness. The impeller is shown in Figure 2.

The rugged, low-cost theme is also present in the radial diffuser. The vane design is similar to ones that have proven to be easily machined and relatively insensitive to leading edge erosion damage and its effect on engine performance. The diffuser was designed to accept bolts through the vanes that are used for engine assembly. The diffuser is portrayed in Figure 3.

In addition to the structural conservatism, the aerodynamic design also reflected a low risk approach. Impeller splitter blades were not considered. Only proven aerodynamic design parameters were incorporated in the design of the inlet, impeller, and radial vane-island diffuser. Aerodynamic and geometric parameters of note are presented in Table I.

2.2 COMPRESSOR TEST RIG DESIGN

This task resulted in the test rig design shown in Figure 4. The test rig utilized the main housing, impeller, and diffuser from the WR34 engine to form the bulk of the compressor flowpath. Figure 5 portrays the compressor flowpath hardware from the engine. The WR34 engine thrust bearing and a shaft modified to mate with an existing high-speed gearbox were the other engine components incor-



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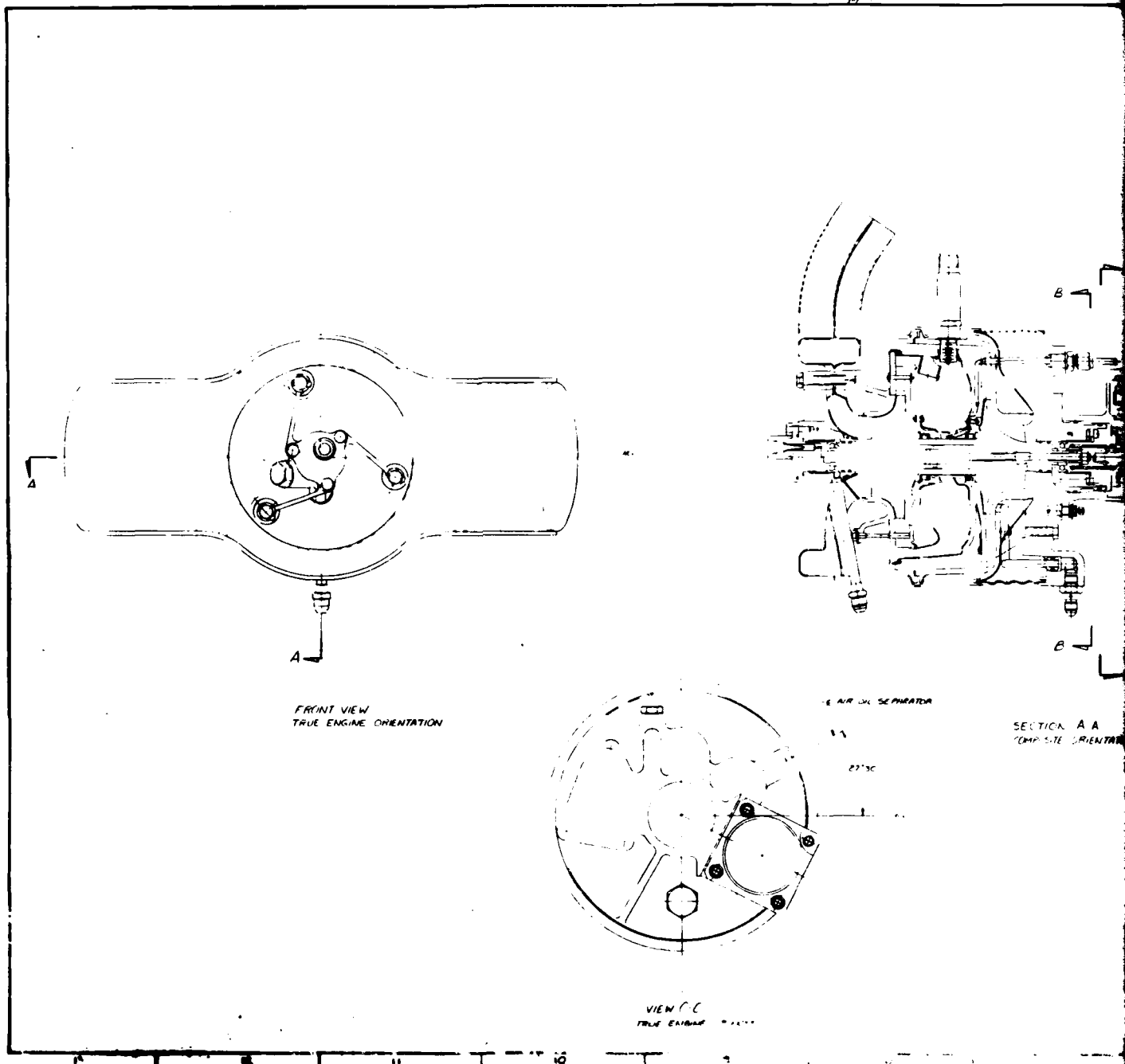
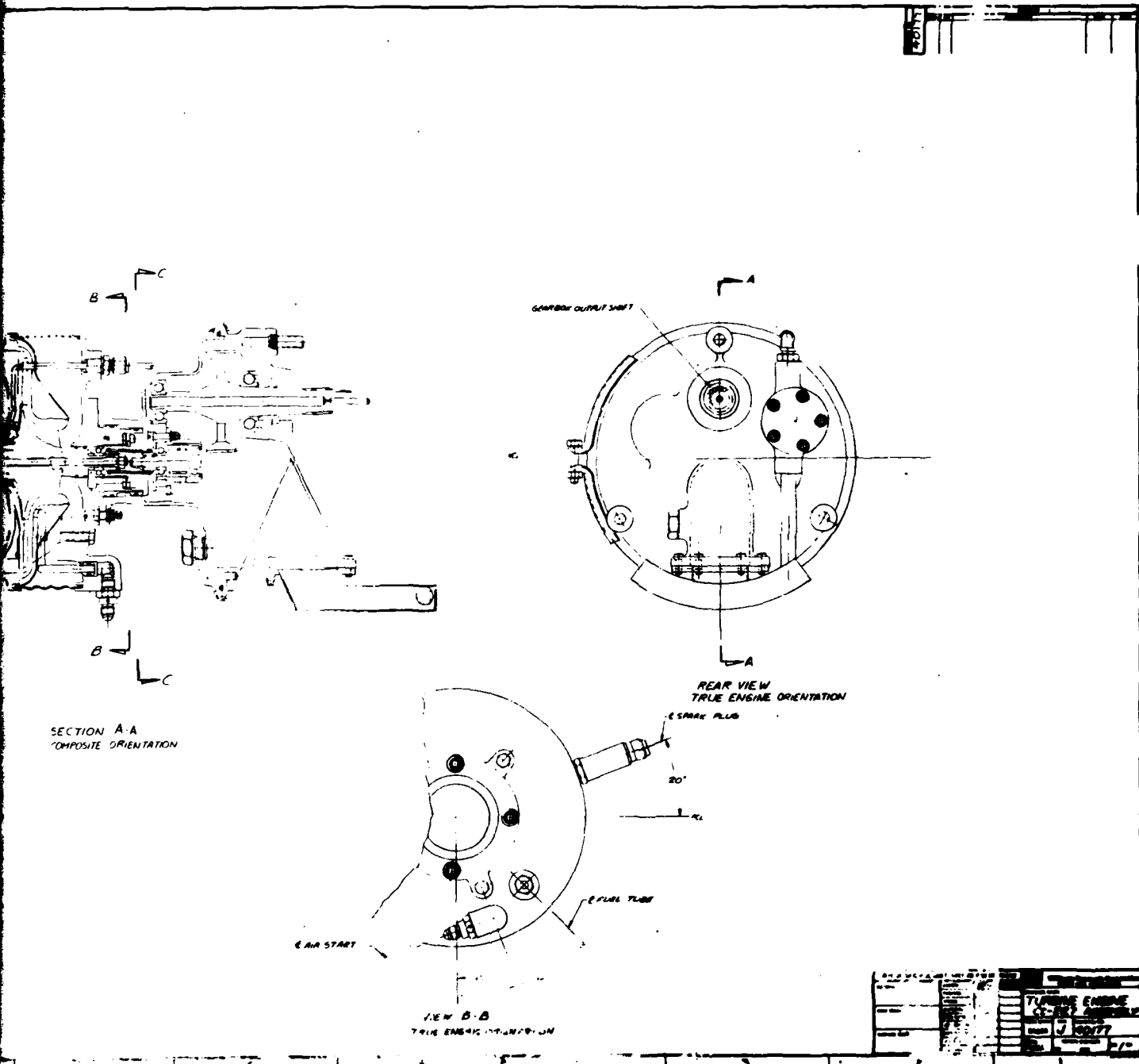


Figure 1. Layout of WR34-15X Engine



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Figure 2. Photograph of Impeller

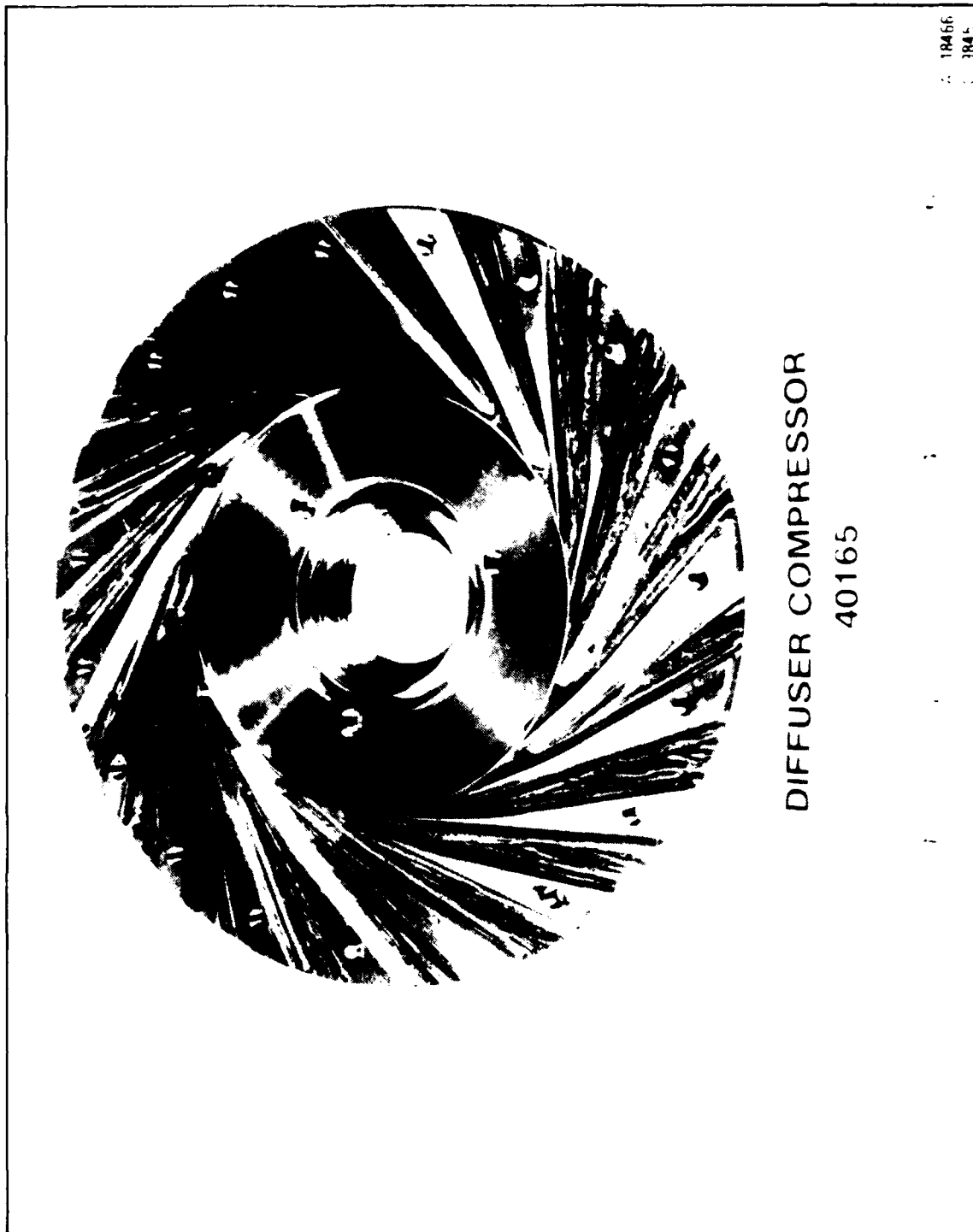


Figure 3. Photograph of Vaned Diffuser

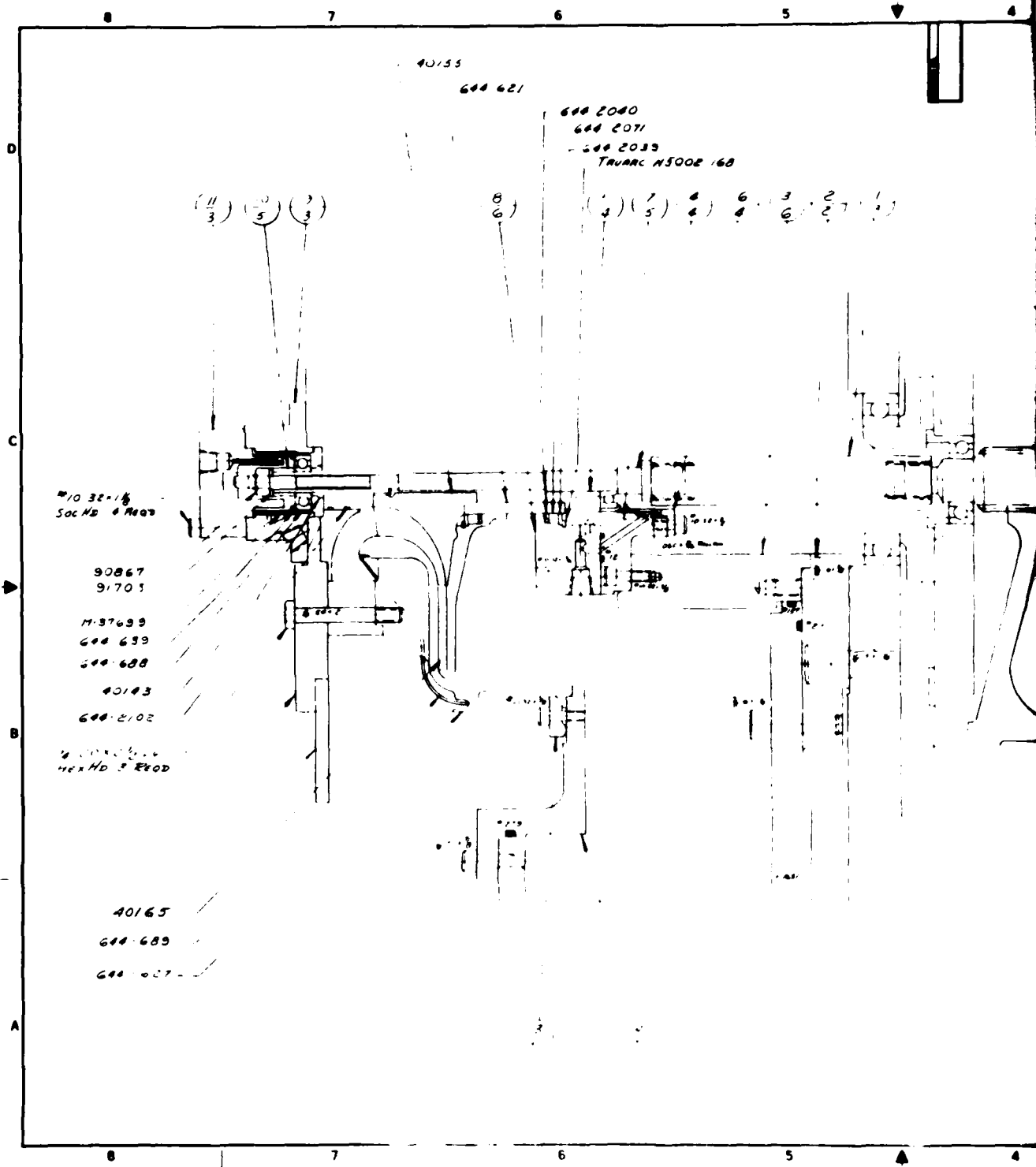
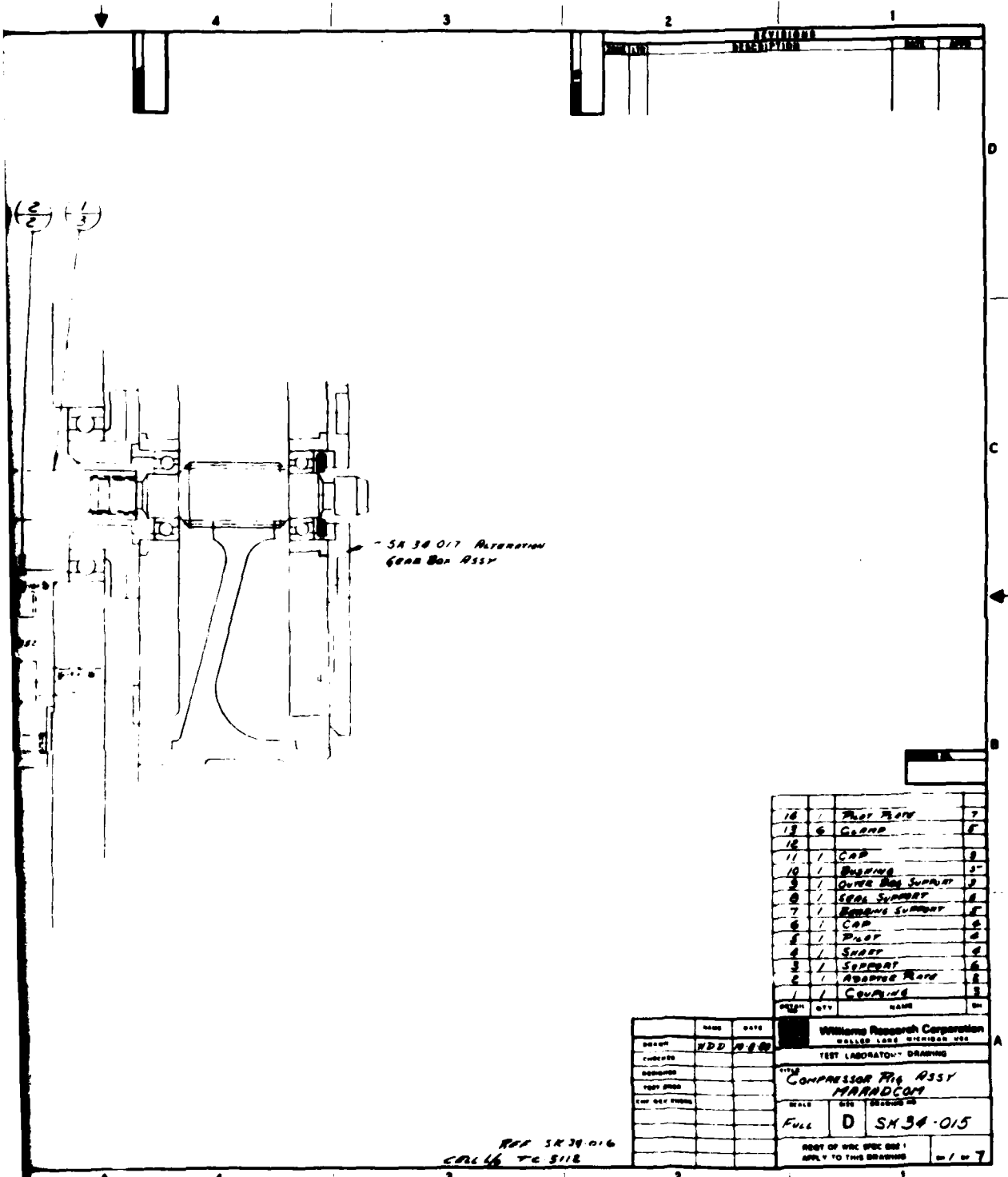


Figure 4. Layout of Test Rig



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TABLE I. WR34 COMPRESSOR DESIGN PARAMETERS

Stage Pressure Ratio (inlet total to stage exit total)	3.862-4.25
Stage Pressure Ratio (inlet total to stage exit static)	3.757-4.15
Stage Efficiency (total-to-total)	0.749-0.740
Stage Efficiency (total-to-static)	0.730-0.721
Stage Temperature Rise ($\Delta T/T$)	0.625
Corrected Flow (lbm/sec)	0.538
Corrected Speed (rpm)	99,050
Number of Impeller Blades	14
Inducer Hub Radius (inches)	0.479
Inducer Edge of Blade Radius (inches)	1.056
Inducer Hub Normal Thickness (inches)	0.051
Inducer Edge of Blade Normal Thickness (inches)	0.020
Impeller Exit Radius (inches)	1.921
Impeller Exit Blade Width (inches)	0.147
Impeller Exit Hub Normal Thickness (inches)	0.081
Impeller Exit Shroud Normal Thickness (inches)	0.020
Impeller Exit Angle (degrees)	37.97
Impeller Rake Angle (degrees)	30.0
Number of Diffuser Vanes	19
Vaned Diffuser Leading Edge Radius (inches)	2.017
Vaned Diffuser Leading Edge Thickness (inches)	0.015
Vaned Diffuser Passage Height (inches)	0.150
Vaned Diffuser Trailing Edge Radius (inches)	3.510
Vaned Diffuser Trailing Edge Thickness (inches)	0.378
Compressor Exit Outer Radius (inches)	3.721
Compressor Exit Inner Radius (inches)	3.571

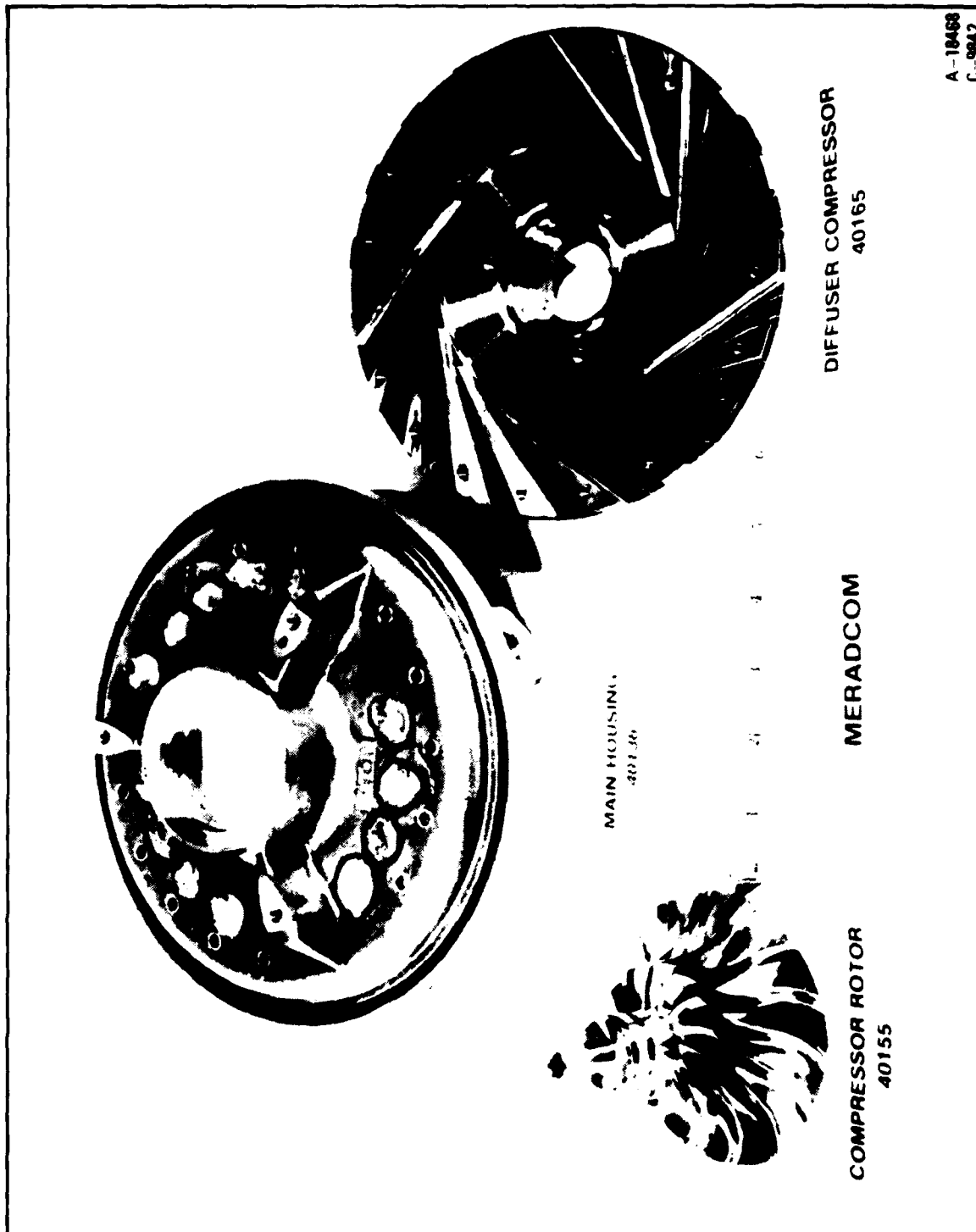


Figure 5. Photograph of Main Housing, Impeller, and Vaned Diffuser



porated into the test rig. This enables the test rig to readily accept and test engine compressor hardware if engine diagnostic testing is required.

An impeller thrust analysis utilizing the WRC centrifugal compressor thrust analysis computer program, which has been correlated against available data including the WRC F107 cruise missile turbofan engine, was used to calculate thrust bearing loads. The thrust bearing was judged to be satisfactory for the projected compressor test duty cycle.

Stress and vibration analysis of both the impeller and diffuser, which were conducted during the design of the compressor, and thus prior to this contract, indicated compressor test rig operation would be satisfactory at all desired speeds. As the analyses were run to satisfy more rigorous conditions than would occur during the compressor rig test, the compressor operation in the rig was considered safe.

2.3 TEST RIG FABRICATION AND ASSEMBLY

2.3.1 Test Rig Fabrication

The test rig was fabricated in accordance with test rig drawings.

2.3.2 Impeller Fabrication

The impeller, though designed to be cast, was fabricated using WRC's in-house impeller machining facility to shorten the hardware schedule. The impeller was machined out of 15-5 Ph stainless steel. The blades were cut on a pantograph machine with the other finish machine work done in the experimental machine shop.

Careful finished machining of the impeller produced a nearly nominal part. This was verified by thorough inspection of the impeller blades on a ten to one optical comparator. The worst blade discrepancy found was 0.001 inches on the suction surface of the blades in the region of the impeller transition from axial to radial.

2.3.3 Impeller Stationery Shroud Fabrication

A WR34 engine main housing casting was machined to form the shroud side inlet contour into the impeller, the impeller stationary shroud, the sealing wall for the vaned diffuser, and the outer wall of the bend downstream of the diffuser vanes. The machining utilized existing WR34 engine detail drawings and tooling. All machining was done at Williams Research. An inspection of the contours on a ten to one optical comparator showed the worst discrepancy to be 0.002 inches which occurred in the inlet.



2.3.4 Vaned Diffuser Fabrication

The vane-island diffuser vanes were cut out of 17-4 PH stainless steel using WRC's pantograph machining facility. All other machining was done in the corporation's experimental shop. No noticeable discrepancies between the vanes and the nominal ten times size vane template were observed during inspection.

2.3.5 Test Rig Static Pressure Tap Machining

All static pressure taps used in the compressor testing were located analytically by WRC's compressor personnel. They were subsequently accurately milled into the WR34 engine main housing. This insured accurate location of all static pressures.

2.3.6 Test Rig Pressure and Temperature Rake Fabrication

All pressure and temperature rakes incorporated into the test rig were designed and built by WRC. Sketches of the inlet total pressure and temperature rakes are shown in Figures 6 and 7 respectively. Exit total pressure and temperature rake sketches are shown in Figures 8 and 9 respectively.

2.3.7 Test Rig Assembly

Instrumentation was first installed in the individual test rig parts. The test rig was then assembled according to the build instructions. The impeller and shaft were dynamically balanced. All critical build dimensions were recorded. The test rig, after assembly, was installed in the test cell.

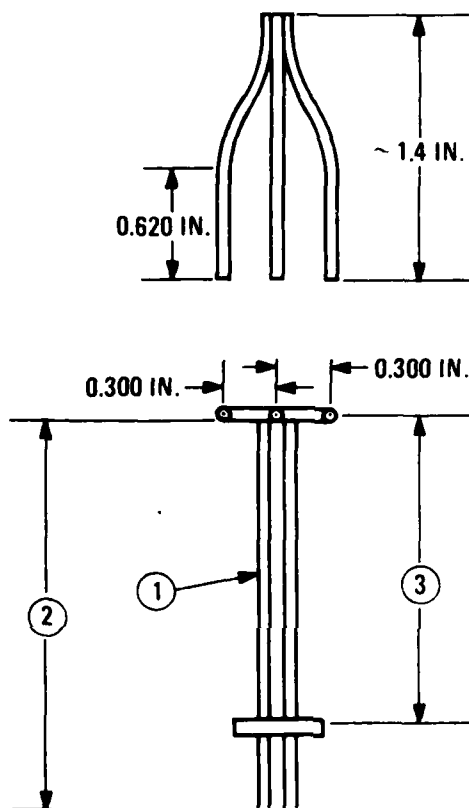
2.4 COMPRESSOR TESTING

2.4.1 Compressor Test Cell Description

The test was run in the existing WRC centrifugal compressor test cell. A sketch of the test set-up is shown in Figure 10. Ambient air is drawn through a roof top mounted air filter into a plenum directly below. The air then enters an ASME bellmouth where inlet total temperature and pressure and static pressure at the nozzle throat are measured. The flow then passes through an uninsulated 9-inch diameter cylindrical duct followed by a right-angle bend of circular cross section. Air exits from the bend through a short section of 8-inch diameter duct to the inlet plenum. Total pressure and temperature are measured at this location. The air then enters the test section, is compressed, and enters a large insulated discharge plenum, where total temperature and pressure and static pressure are measured. The air leaves the discharge plenum through two insulated opposed discharge plenum headers. The flow then merges into one larger duct which guides it to the discharge throttling valves. There are two electrically operated throttling valves--a main valve and a vernier valve. The vernier valve permits



I. TOTAL PRESSURE AT STAGE INLET
(3 RAKES REQUIRED)



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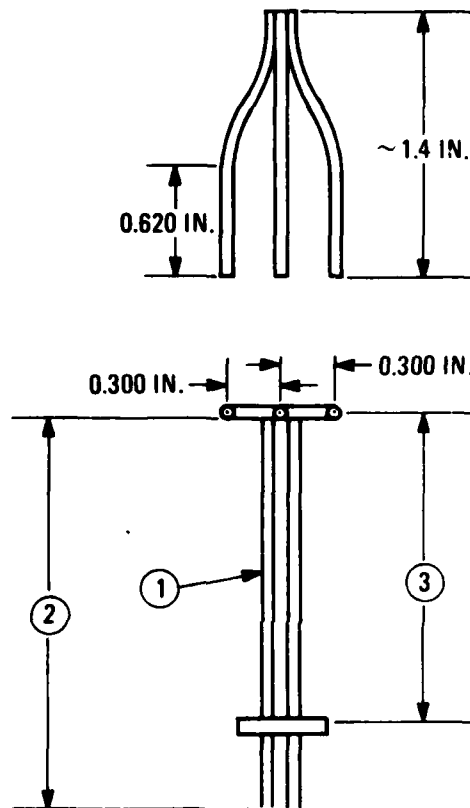
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- ② MAKE THE TUBE LENGTH 4 FEET OR MORE.
- ③ RAKE IMMERSION DEPTH DOWN TO MOUNTING PAD SHOULD BE SUCH THAT RAKES ARE EQUALLY SPACED ACROSS THE PASSAGE WITH RAKES SEPARATED BY 120 DEGREES FROM EACH OTHER. RAKES SHOULD BE MOUNTED ON GEARBOX HOUSING USING EXISTING SCREWS.

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Figure 6. Sketch of Inlet Total Pressure Rake



II. TOTAL TEMPERATURE AT STAGE INLET (3 RAKES REQUIRED)



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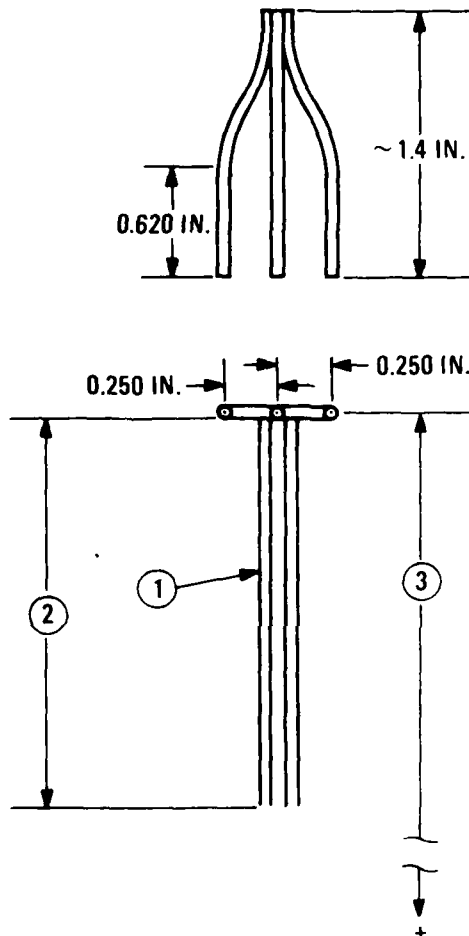
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- ③ RAKE IMMERSION DEPTH DOWN TO MOUNTING PAD SHOULD BE SUCH THAT RAKES ARE EQUALLY SPACED ACROSS THE PASSAGE WITH RAKES SEPARATED BY 120 DEGREES FROM EACH OTHER. RAKES SHOULD BE MOUNTED ON GEARBOX HOUSING USING EXISTING SCREWS.

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Figure 7. Sketch at Inlet Temperature Rake



III. TOTAL PRESSURE AT STAGE EXIT (4 RAKES REQUIRED)



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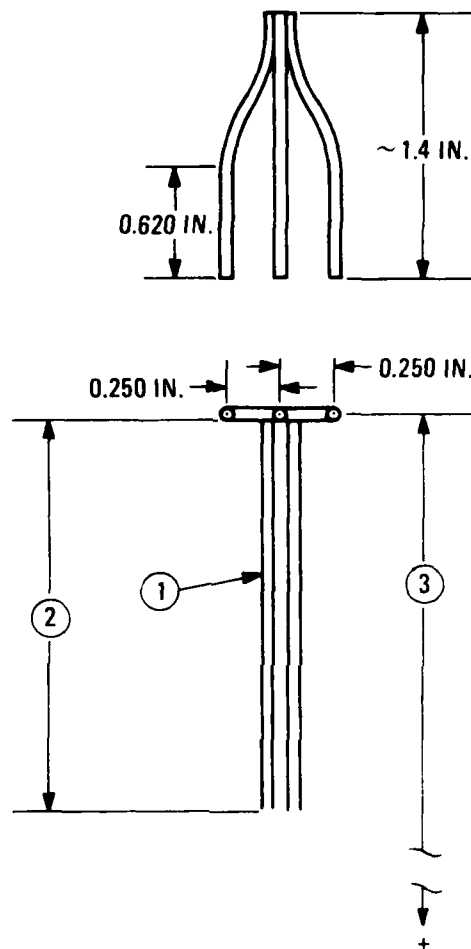
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- ② MAKE THE TUBING LENGTH 4 FEET OR MORE.
- ③ RAKE IMMERSION RADIUS OF 3.647 INCHES IS FROM THE TEST RIG CENTERLINE TO ELEMENT CENTERLINE. THE RADIUS TOLERANCE IS ± 0.005 INCH. NOTE THAT THE RAKE HAS TO BE SET AT 50.557 DEGREES FROM THE RIG CENTERLINE TO MATCH THE PREDICTED FLOW ANGLE.

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Figure 8. Sketch of Exit Total Pressure Rake



IV. TOTAL TEMPERATURE AT STAGE EXIT (5 RAKES REQUIRED)

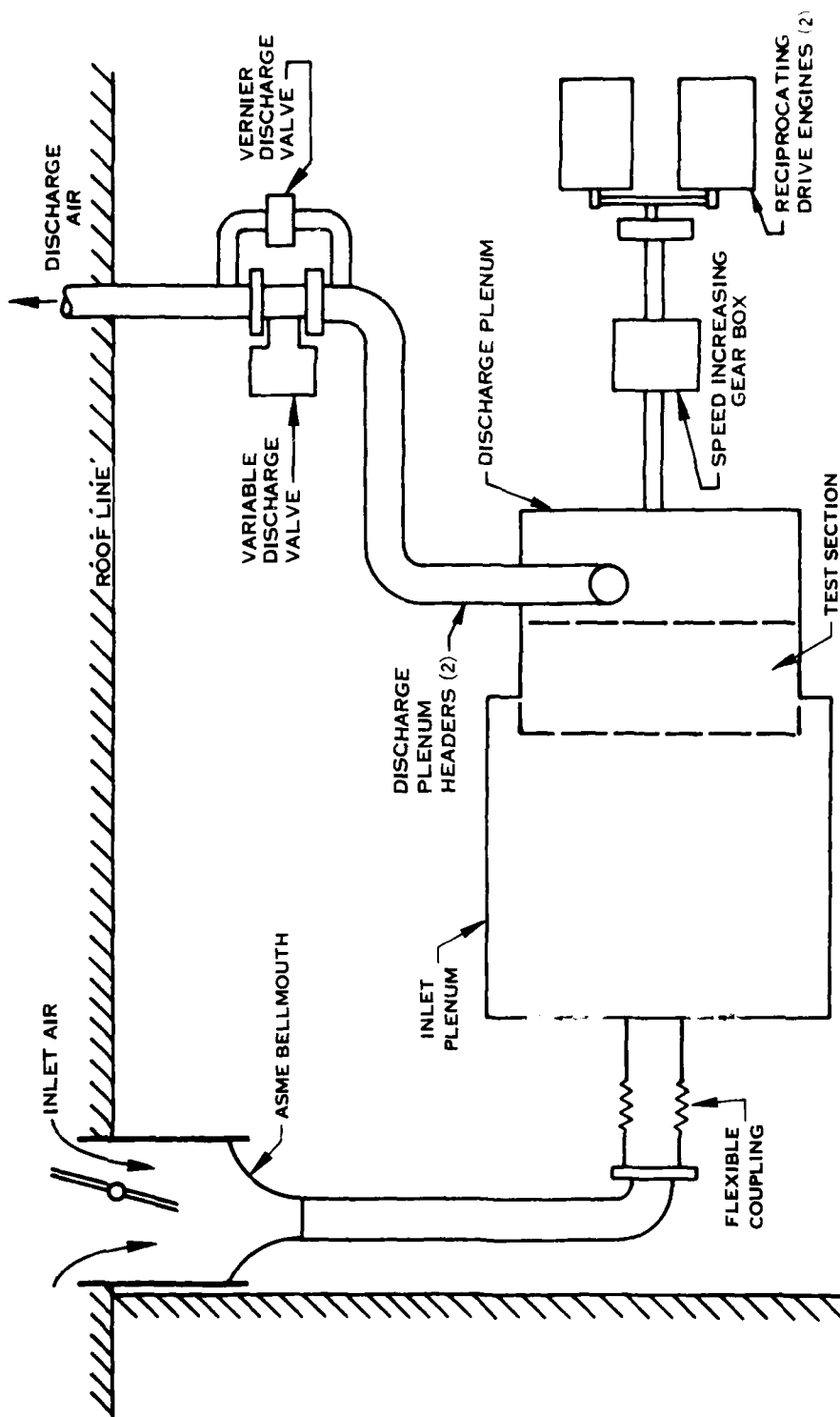


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Figure 9. Sketch of Exit Temperature Rake



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Figure 10. Schematic of WRC Centrifugal Compressor Test Cell (A-1)



the fine adjustments necessary when operating near the compressor surge line. From this point, the flow discharges to the atmosphere.

Compressor drive power is provided by two coupled 413 cubic inch Chrysler industrial engines developing a total of 340 horsepower working through hydraulic clutches and a speed-increasing gearbox. A pressurized labyrinth seal in the gearbox prevents lubricating oil from entering the test section.

2.4.2 Compressor Test Equipment

The equipment used in the compressor rig test is presented in Table II.

2.4.3 Test Data Parameters Recorded

The compressor was instrumented to obtain an overall performance map. In addition, sufficient instrumentation was installed to identify the impeller and vaned diffuser performance characteristics. Compressor performance instrumentation that was installed in the test rig is presented in Table III and portrayed in Figure 11. Bearing temperatures, compressor rotational speed, and other mechanical data, along with the ASME bellmouth temperature and pressure data, were recorded manually. All other performance parameters were recorded on the digital automatic data acquisition system (ADAS).

The ADAS system assigns each parameter a unique channel number and the data is recorded using that identification. The channel number assignments are recognized by the WRC centrifugal compressor data reduction program, which then converts this data into a usable form. A real time display of selected pressure and temperature data was used during the testing which enabled the analyst to quickly check compressor performance.

2.4.4 Test Procedure

After the test rig was partially instrumented, assembled, and installed in the test cell, a mechanical check of the test rig was made (Build 1). Speeds run were at 40, 50, 60, 70, 80, 90 and 100 percent of design corrected speed (99,050). Initially, Regal 20W oil was used in the gearbox lubrication system. Considerable oil foaming occurred preventing proper oil scavenging, resulting in a rapid increase in bearing temperatures and vibrations. The Regal 20W oil was drained and replaced with Texamatic A oil. Also, another oil scavenge pump was connected into the lubrication system. Proper oil circulation throughout the gearbox and compressor test rig resulted. However, a large amount of oil was lost through the discharge plenum chamber and also collected around the inlet to the compressor rotor inside the inlet plenum chamber. Heat transfer from the gearbox and discharge plenum chamber to the compressor main housing was rather high. After approximately 100 minutes



TABLE II. MERADCOM WR34 CENTRIFUGAL COMPRESSOR RIG TEST EQUIPMENT REQUIRED

Inlet ASME Bellmouth

- 4-inch diameter

Plumbing Between the Inlet Bellmouth and Inlet Plenum

Inlet Plenum

Centrifugal Compressor Test Rig Assembly

- Main Housing
- Steel 38° backward curved impeller
- Aluminum impeller stationary shroud
- Steel vane island diffuser

Discharge Plenum

Discharge Plumbing and Valving

Compressor Drive System

- Two Chrysler 413 cubic inch engines
- Speed-increasing gearbox

Test Rig Vibration Meter

Howell Automatic Data Acquisition System (ADAS)

- Digital data acquisition
- 100 pressures available on four scanivalves
- 50 temperatures available

TABLE III. MERADCOM WR34 CENTRIFUGAL COMPRESSOR RIG TEST
SUMMARY OF INSTRUMENTATION

<u>INSTRUMENTATION LOCATION/TYPE</u>	<u>QUANTITY</u>
<u>ASME BELLMOUTH</u>	
Delta Pressure	1
Total Temperature	3
<u>INLET PLENUM</u>	
Total Pressure	4
Total Temperature	4
<u>COMPRESSOR INLET</u>	
Total Pressure Rakes, 3-element	3
Total Temperature Rakes, 3-element	3
Static Pressure, Shroud	4
<u>IMPELLER STATIONARY SHROUD</u>	
Static Pressure	12
Static Pressure, Impeller Exit	6
<u>VANED DIFFUSER</u>	
Static Pressure	18
<u>COMPRESSOR EXIT</u>	
Total Pressure Rakes, 3-element	4
Total Temperature Rakes, 3-element	5
<u>DISCHARGE PLENUM</u>	
Static Pressure	3

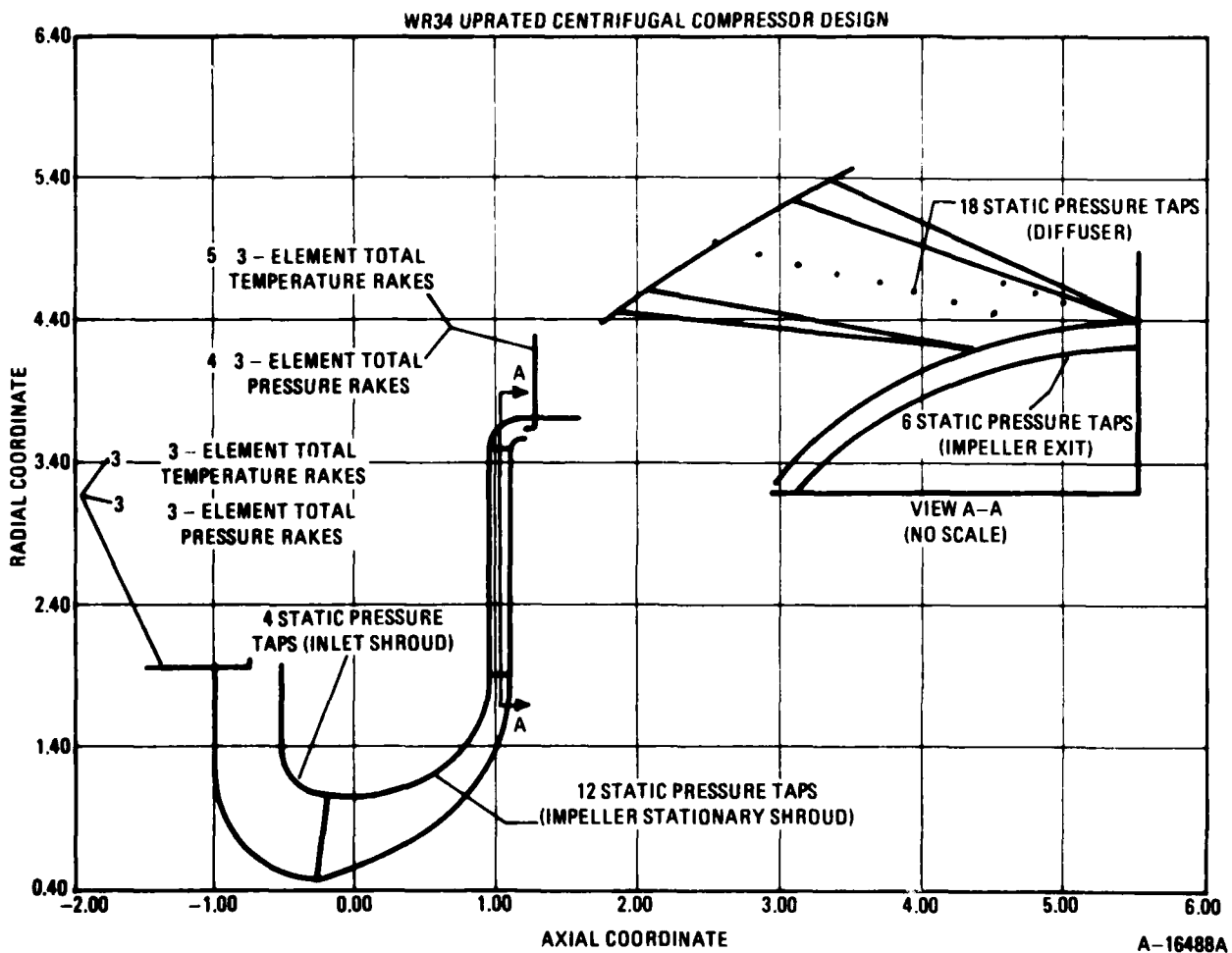


Figure 11. Meradcom WR34 Centrifugal Compressor Instrumentation Locations



running time, the front rig bearing temperature and vibration increased rapidly. Immediate shutdown of the compressor test rig was necessary.

No damage was done to the compressor test rig. The front ball bearing separator had fractured, causing the bearing failure. Compressor rotor front face clearance was determined by measuring the rub tabs installed on the impeller stationery shroud which equalled 0.011 to 0.013 inches.

Prior to Build 2, several alterations were made to the test rig. Provisions were made on the oil seals including a collar separating the diffuser from the rear rig bearing to prevent the oil leakage. The improved oil seals and a supply of 4 to 6 psi guard air pressure to the collar were adequate to prevent the oil leakage. Also, a heat shield was placed on the discharge plenum chamber to prevent heat transfer to the compressor main housing.

All instrumentation was completed for the performance run (Build 2) and installed at the compressor inlet, compressor shroud, and diffuser exit. Also, 0.006 inches was removed from the shim on the compressor rotor stack-up assembly to obtain the required 0.005 to 0.007 inch front face running clearance. A new front rig ball bearing was included on assembly. The compressor test rig was assembled, Build 2, and installed in Cell A-1. Figures 12 and 13 show the test rig installed in the test cell.

On December 19, 1980 the compressor test rig was run at 40, 60 and 80 percent of design corrected speed (99,050 rpm). Wide open, choke, surge, and three points between wide open and surge were recorded. Operation of the compressor test rig was good with no apparent oil leakage or mechanical problems.

On December 20, 1980 the compressor test rig was run beginning at 50 percent of design corrected speed (99,050 rpm). Data points at wide open, choke, surge, and three points in between wide open and surge were recorded. Guard air pressure was maintained at 4 to 6 psi to prevent any major oil leakage. Operation of the compressor test rig continued successfully. The compressor test rig was then accelerated to speeds of 60, 70, 80, 90, 95 and 100 percent of design corrected speed (99,050 rpm). Data for wide open, choke, surge, and three points in between wide open and surge were obtained at all speed lines.

As the compressor test rig was accelerated to 105,000 rpm (105 percent corrected speed), mechanical problems began with the front rig ball bearing. Data at wide open and choke were recorded.

Vibrations began to increase, with an unusual rumbling noise coming from the compressor rig. Therefore, the compressor test rig was immediately shut down.

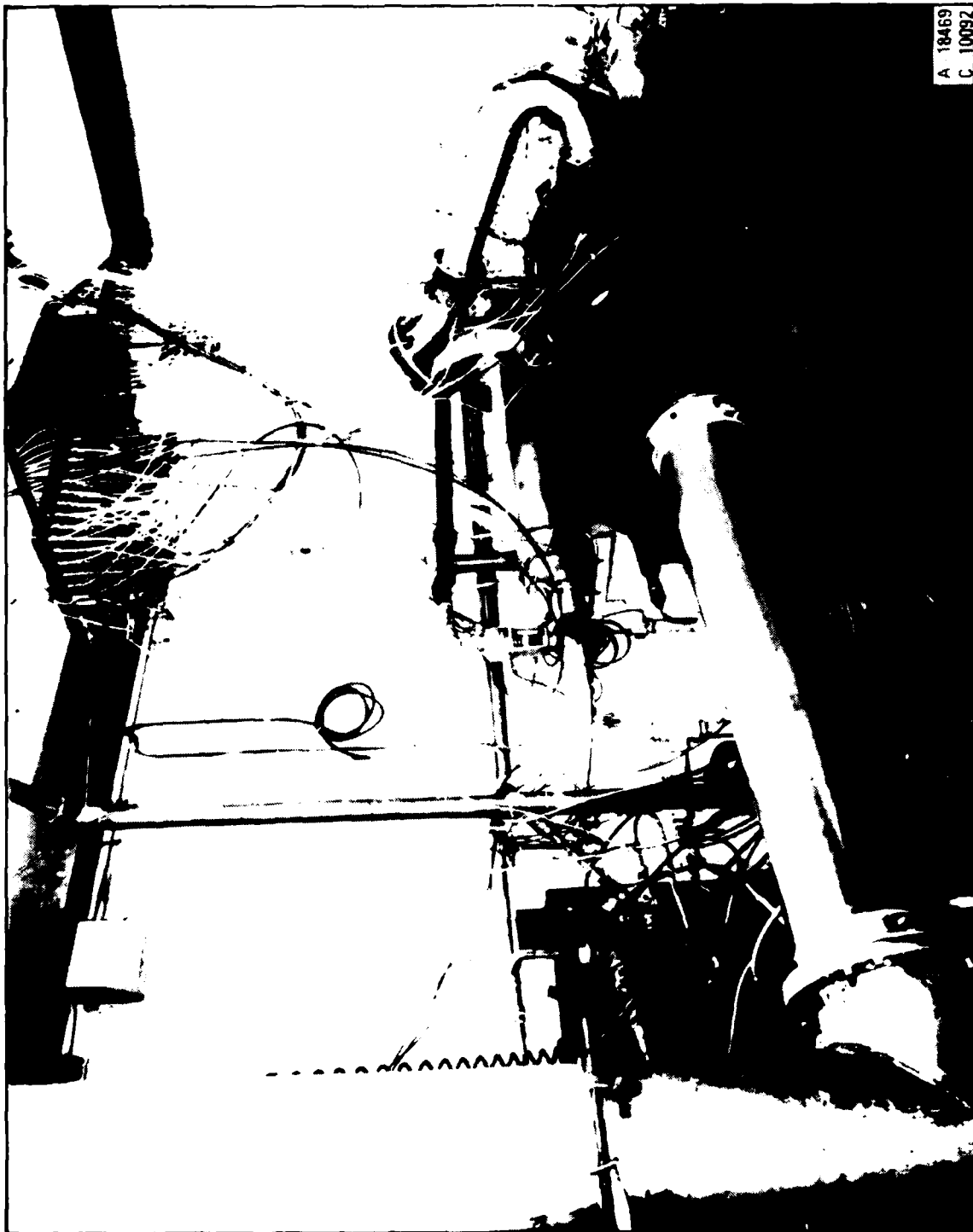


Figure 12. Photograph of Test Cell with Test Rig Installed



Figure 13. Photograph of Test Rig Installed in Test Cell



Vibration pick up #3 had come loose from the gearbox and was re-mounted. The compressor test rig rotated freely and was allowed to cool for 15 minutes, then restarted. All vibrations were checked at various speed lines as the compressor rig was accelerated to 105,000 rpm (105 percent corrected speed).

Data points at wide open and choke were recorded. As surge was attempted the vibrations increased along with a rapid increase in the front rig bearing temperature. Also, a loud whine was audible. Again, the compressor rig was immediately shut down. The run down appeared normal with no unusual sounds or physical problems.

On disassembly of the compressor test rig, it was found that the compressor rotor had slightly rubbed the main housing front face. One of the three rub tabs were lost. Through measuring the other two rub tabs, the final front face clearance was equal to 0.005 + 0.006 inches (design intent).

Examining the front rig ball bearing indicated that the steel ball separator had fractured, almost leading to a complete bearing failure. Other compressor rig hardware including instrumentation was not damaged.

The original intent was to collect data at 105, 110, and 115 percent of design corrected speed in addition to the data that was collected. However, due to funding limitations, the mechanical problem on Build 2 terminated the testing.



SECTION 3

DISCUSSION OF TEST RESULTS

3.1 COMPRESSOR TEST RESULTS AND DISCUSSION

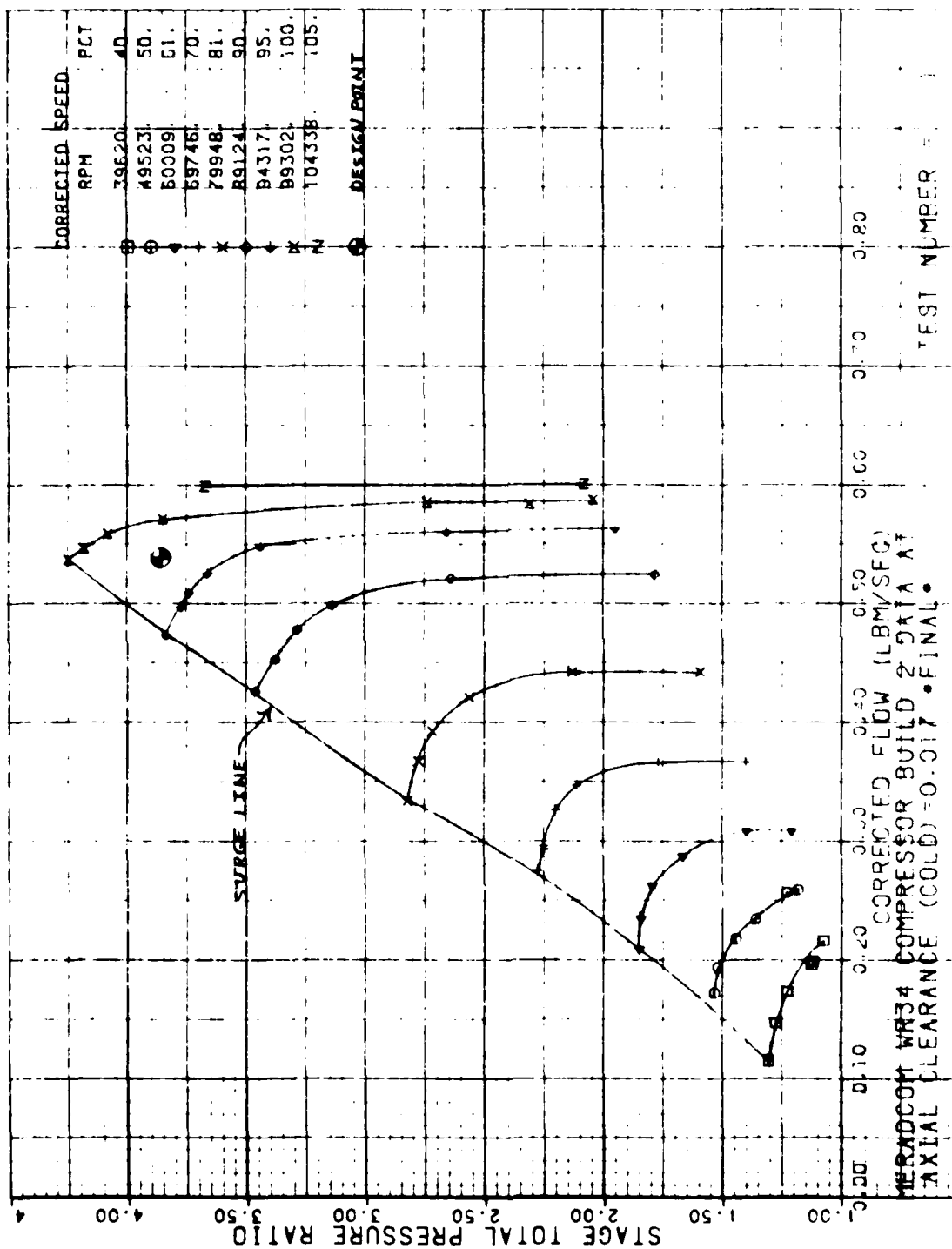
The raw data was reduced using the WRC centrifugal compressor data reduction computer program. Appendix A contains the test log pages, manually recorded data sheets, data reduction program output at the design point, and a summary sheet from the data reduction program presenting compressor parameters of note for all significant data gathered during rig testing.

The overall stage performance, consisting of total pressure ratio, total-to-total efficiency, and temperature rise, is shown in Figures 14, 15 and 16 respectively. The design point goals are shown on each plot as a point of reference. Stage performance was calculated based on total temperature and pressure at the inlet and total temperature and pressure at the bend exit prior to dumping into the discharge plenum. As the inlet measuring station was upstream of the start of the radial inflow inlet, all inlet loss is charged to the compressor. In the same vein, the stage exit measuring station accounted for all losses in the compressor including those in the exit bend. All efficiencies were calculated using enthalpy tables which ensured that an accurate assessment of compressor performance was made.

Table IV presents a comparison of selected compressor parameters at the design point between the projected values and the test data. As is shown in Table IV, impeller axial and radial clearances at the design point for the test data were in agreement with the design intent. Therefore, clearance was not a factor in the differences between projected and tested parameter values.

As is readily observable from Table IV, the compressor pressure ratio and temperature rise are noticeably different than the design intent. Compressor temperature rise is 10 percent higher than the design intent. Compressor pressure ratio (total-to-total) is 9.6 percent above the design intent. The net result of this unexpectedly high energy addition is a 0.9 point lower efficiency than projected. The reason(s) for the larger than expected energy addition are unclear from the data gathered to date. Basically, two temperature anomalies were observed when the data was reduced.

The primary anomaly, the 10 percent high temperature rise, is not explainable at this time. Figure 17 presents the impeller slip



A-18478

Figure 14. Stage Total Pressure Ratio versus Corrected Airflow

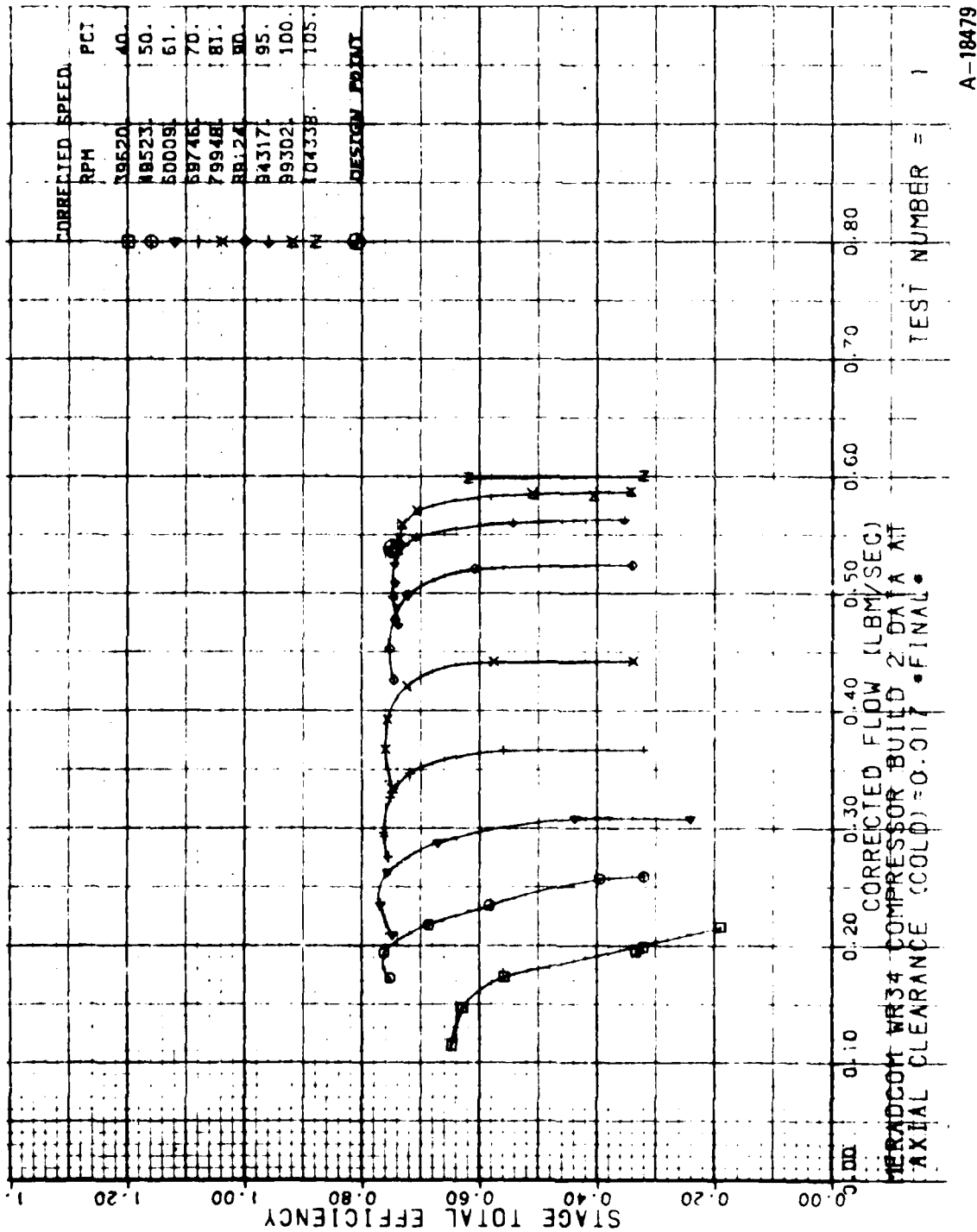
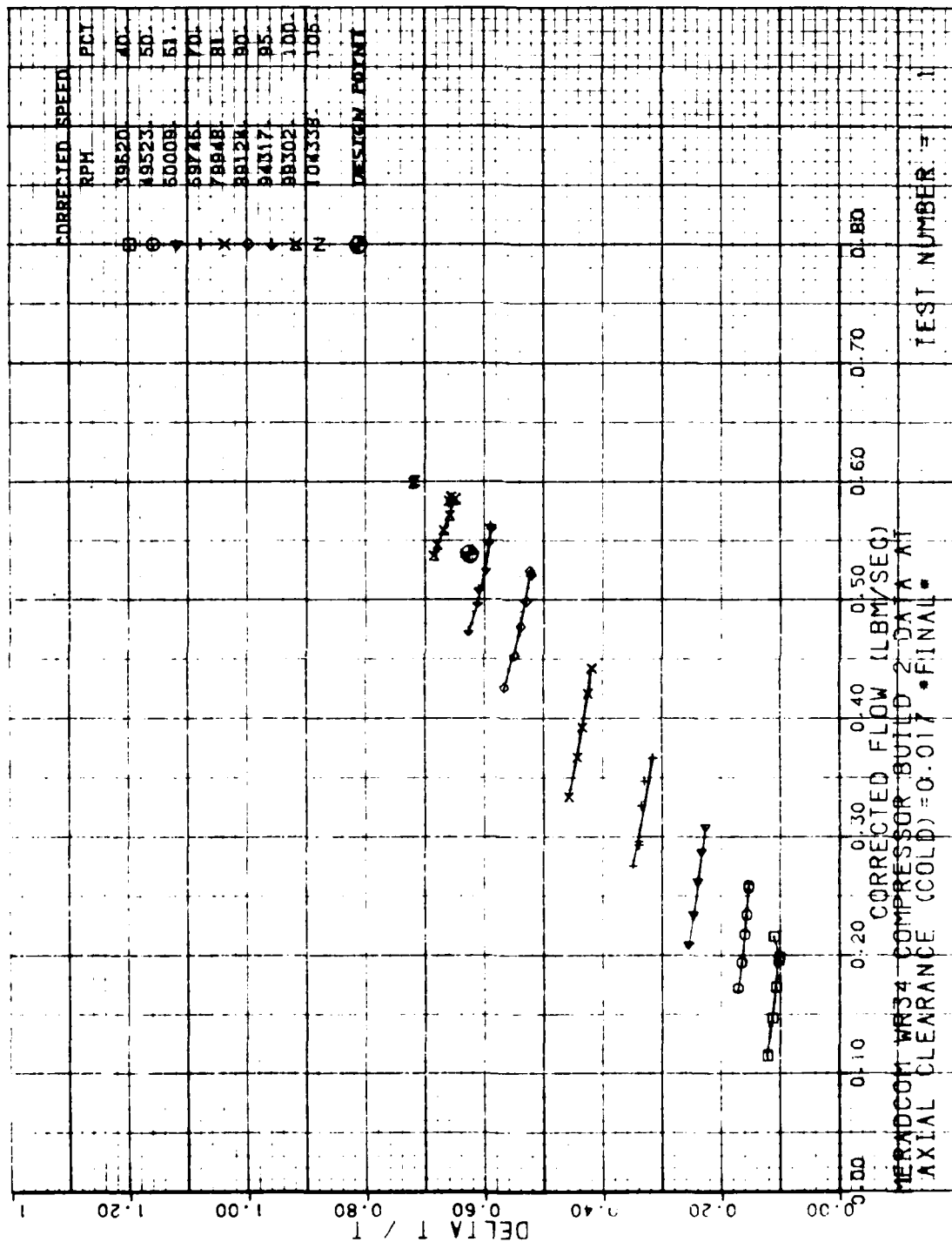


Figure 15. Stage Total-to-Total Efficiency versus Corrected Airflow

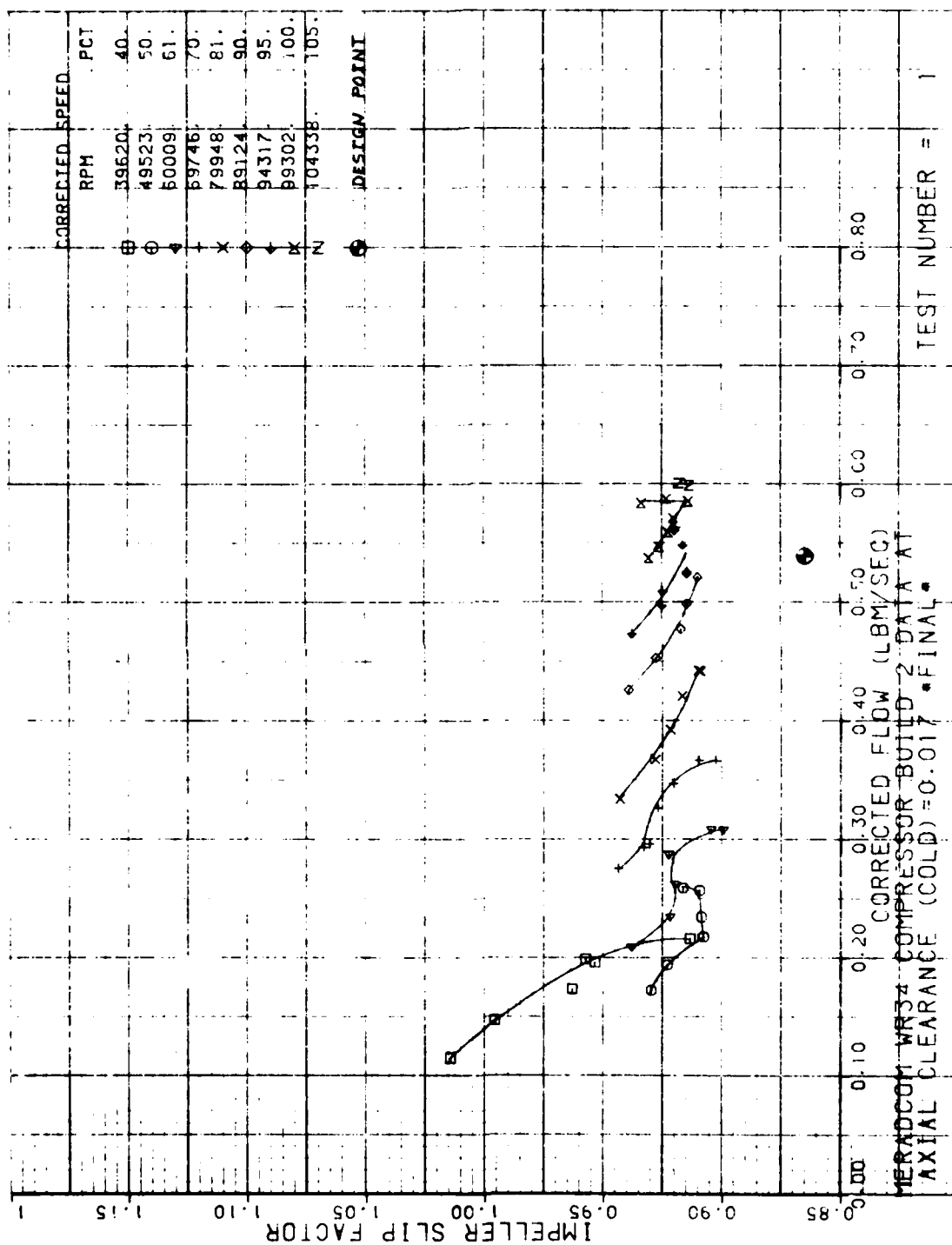


A-18480

Figure 16. Stage Temperature Rise versus Corrected Airflow

TABLE IV. MERADCOM WR34 COMPRESSOR DESIGN POINT COMPARISON
OF PREDICTED VERSUS RIG TEST DATA

	<u>PROGRAM GOAL</u>	<u>DATA</u>
Corrected Airflow (lbm/sec)	0.538	0.538
Corrected Speed (rpm)	99,050	98,999
Pressure Ratio (inlet total to stage exit total)	3.862	4.252
Efficiency (inlet total to stage exit total), percent	74.9	74.0
Pressure Ratio (inlet total to stage exit static)	3.757	4.119
Efficiency (inlet total to stage exit static), percent	73.0	72.0
Temperature Rise ($\Delta T/T$)	0.625	0.688
Stage Exit Mach Number	0.200	0.215
Axial Running Clearance (inches)	0.005	0.0055
Radial Running Clearance (inches)	0.007	0.007



A-18481

Figure 17. Impeller Slip Factor versus Corrected Airflow



factor calculated at all test data points. Note the substantially higher values than would be expected from correlations. Several possible hypotheses could explain the higher than expected slip factor. One explanation is that compressor discharge air was getting past a carbon seal and leaking into the impeller back cavity, thus inserting previously compressed air at the impeller exit. An alternate explanation is that low momentum fluid at the impeller exit was recirculating back into the impeller, thus increasing its temperature level.

The secondary temperature anomaly was also of concern. From the data presented in Appendix A at the compressor design point, it was observed that a temperature spread of 14.29°F exists on the compressor exit thermocouples. It would be expected that they would read much more uniformly. Possibly the close proximity of the main housing, which was aluminum and therefore conducted heat readily from the gearbox, to the thermocouples at the compressor exit caused the temperature spread. The close proximity of the thermocouples to the main housing was caused by the very small passage height at the stage exit. Although the temperature problems are unexplained at this time, some very positive results did come from the testing.

Both the impeller and diffuser performance were only slightly short of their performance goal at the design point. As this was the first rig test of the compressor, the results are very encouraging and portend improved compressor performance with further compressor development. The impeller performance was synthesized from measured airflow, measured speed, measured stage inlet and exit temperatures, measured impeller exit static pressures, and an effective area at the impeller exit. Diffuser static pressure recovery was then calculated based on the synthesized impeller performance and the measured stage exit static pressure. Impeller performance, which is presented in Figures 18 and 19. The impeller design point measured static pressure distribution along the stationery shroud, shown in Figure 20, compares reasonably well with the prediction. Diffuser recovery also compares closely to the prediction.

The diffuser static pressure recovery, calculated from the test data at the compressor design point, is 68.7 percent. Figure 21 presents the diffuser static pressure recovery for all valid test data points.

Figure 22 presents the calculated impeller exit absolute flow angle variation with corrected airflow and speed for all valid test data points. It is an output of the impeller calculation. Note the relatively constant value of swirl angle at compressor choke (minimum value of angle along each speed line). This, coupled with the absence of a sharp compressor temperature rise

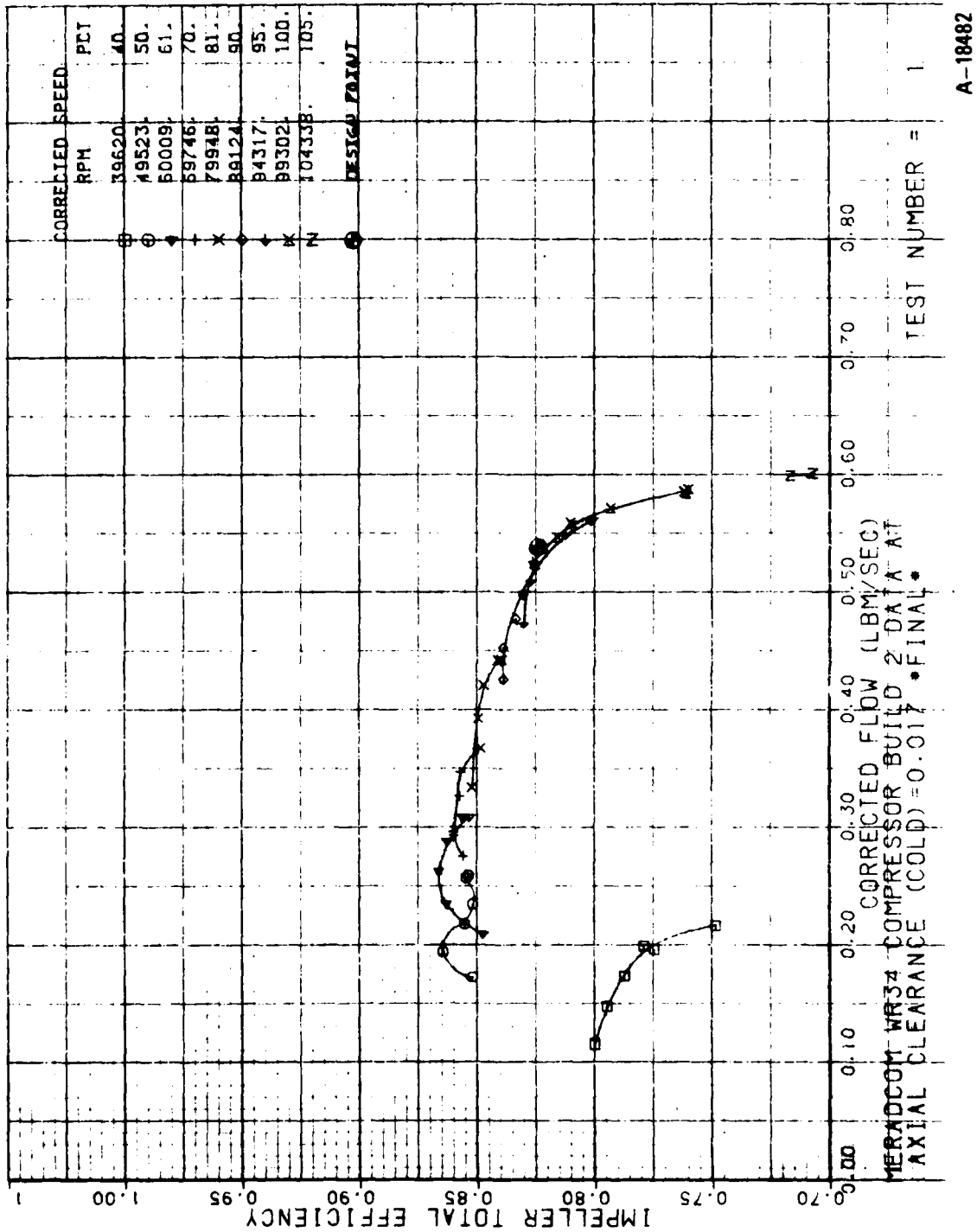


Figure 18. Impeller Total-to-Total Efficiency versus Corrected Airflow

A-18482

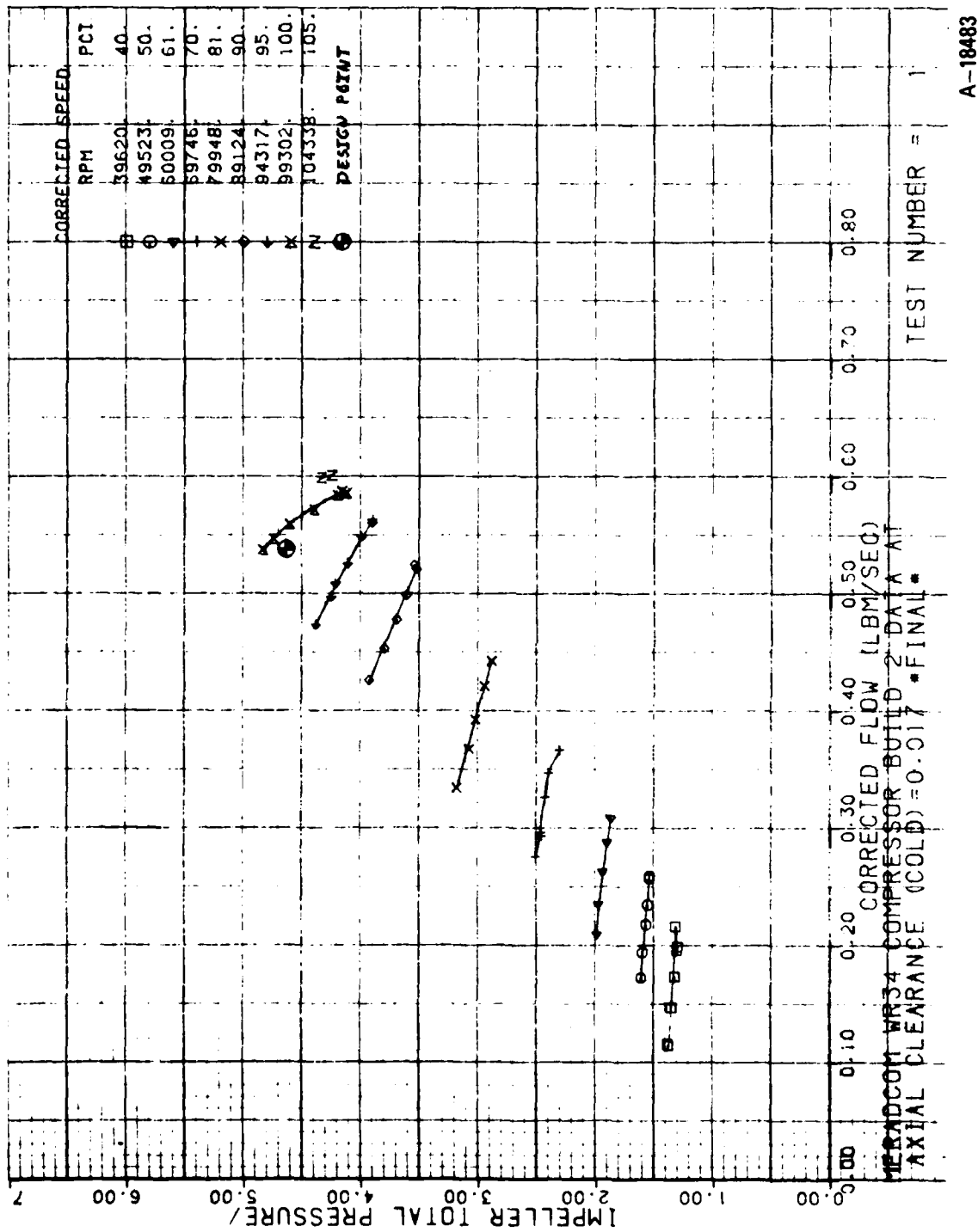


Figure 19. Impeller Total-to-Total Pressure Ratio versus Corrected Airflow

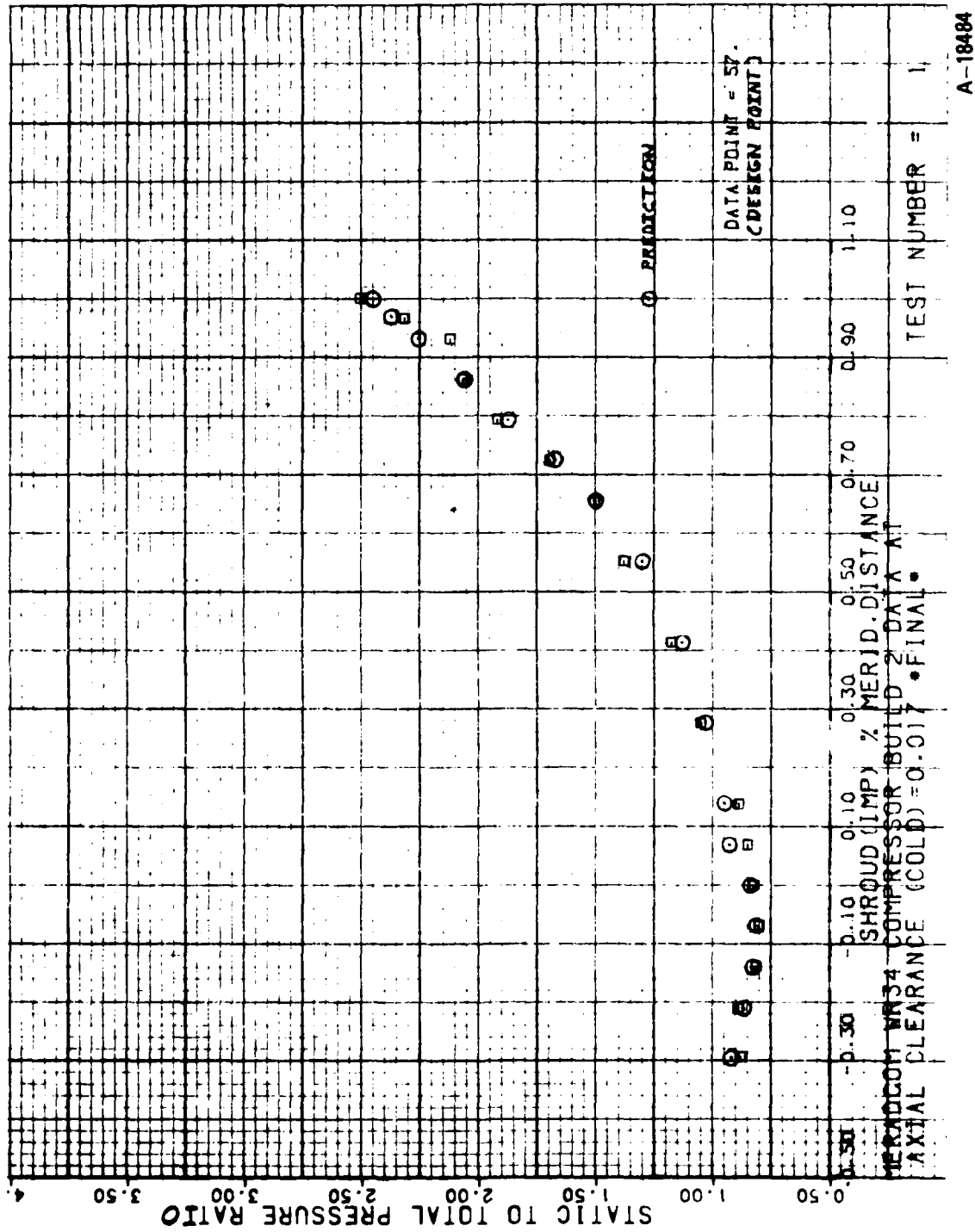


Figure 20. Impeller Shroud Static Pressure Distribution at the Design Point

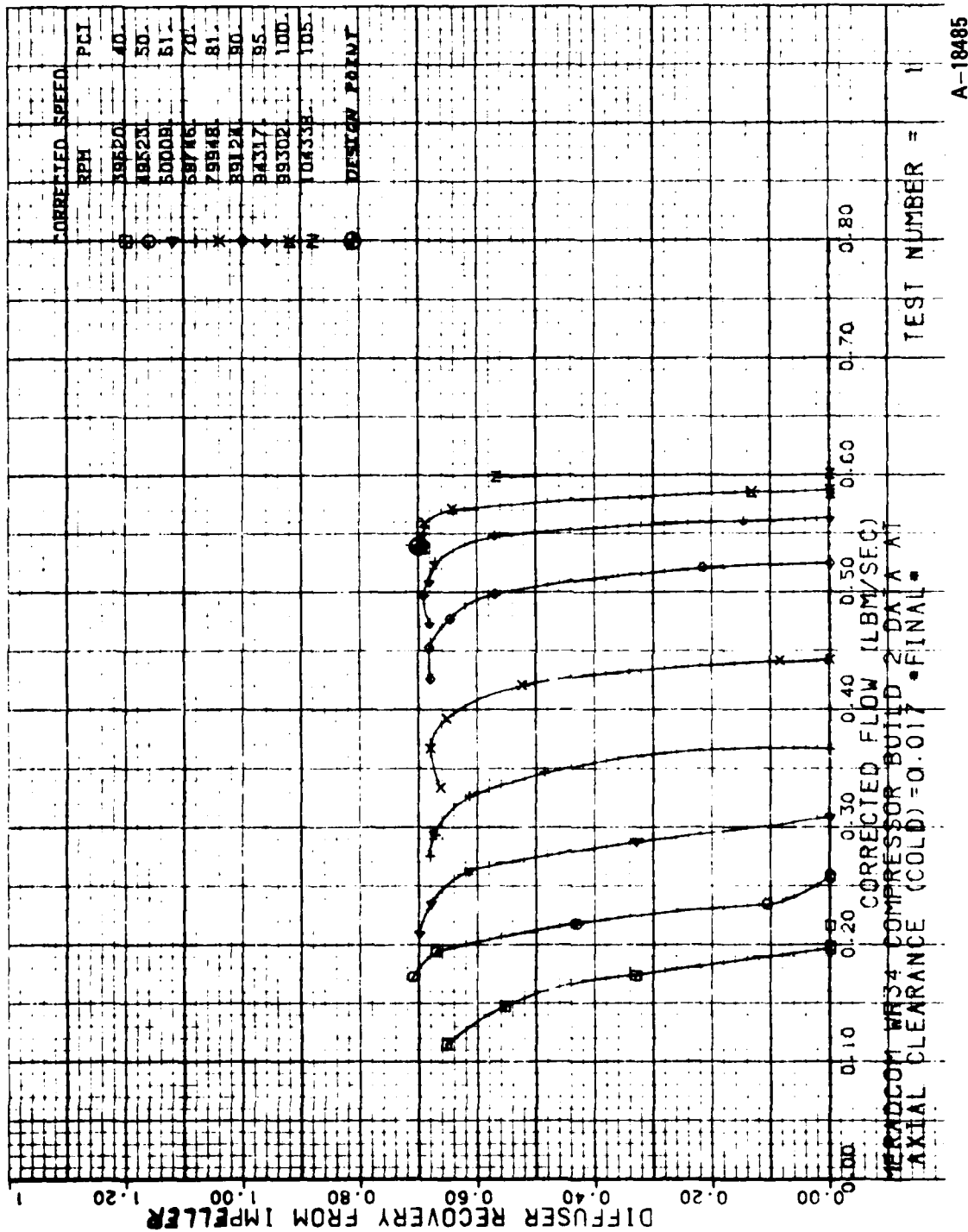


Figure 21. Diffuser Static Pressure Recovery Coefficient from the Impeller

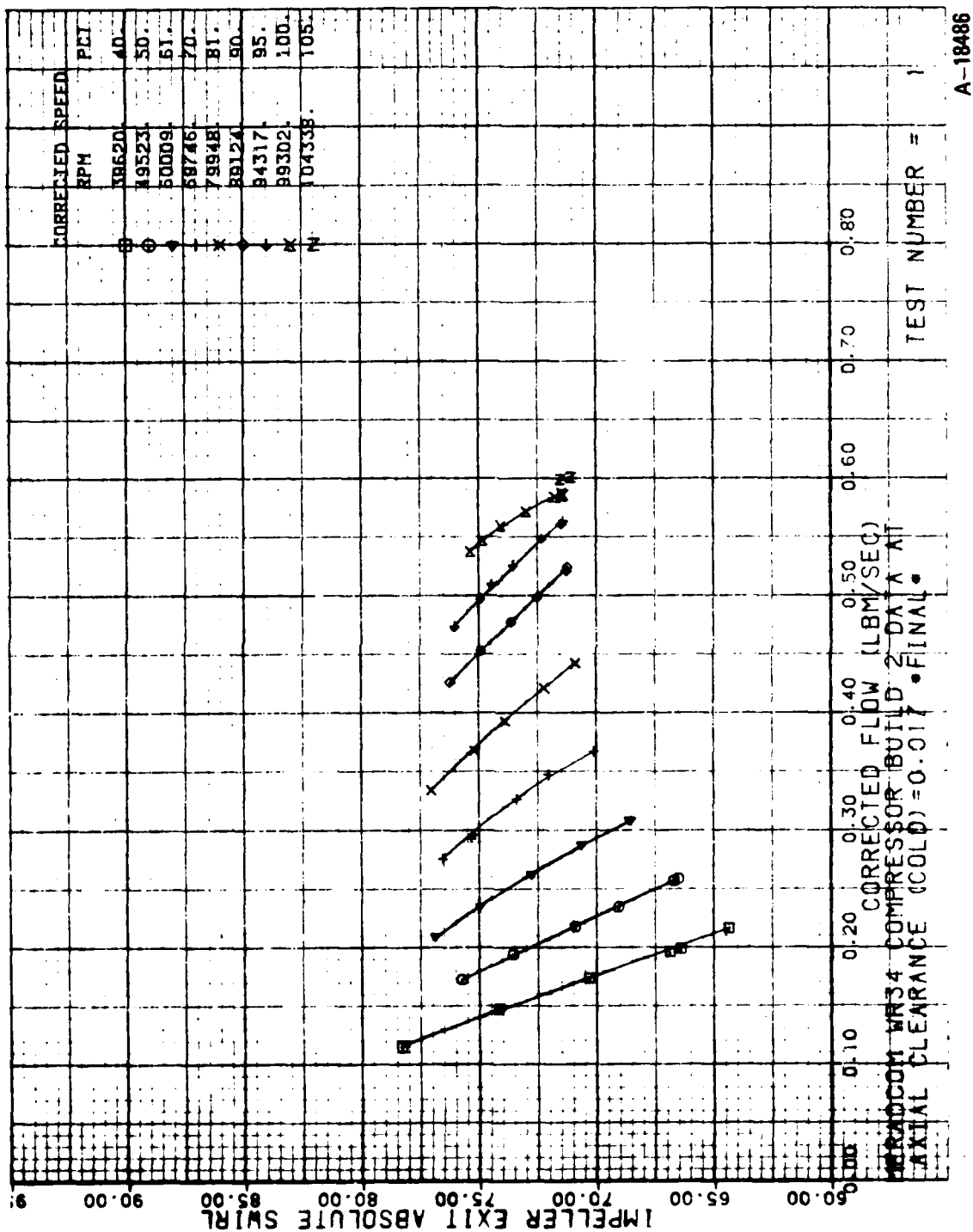


Figure 22. Impeller Exit Absolute Swirl Angle versus Corrected Airflow



reduction at compressor choke from Figure 16, indicates the diffuser controlled choke at corrected speeds above 80 percent of design corrected speed. However, the varying swirl angle at surge (maximum value of angle along each speedline) indicates that the impeller may control surge. A possible explanation for this phenomena is that, at the surge value of impeller incidence, the relatively thick impeller blades form a shock structure that triggers impeller surge. Further testing is required to verify which component, the impeller or diffuser, controls surge.

3.2 CYCLE ANALYSIS RESULTS

The true test of the adequacy of the tested WR34 compressor performance was whether it properly matched with the remainder of the engine. Therefore, the unaltered WR34 test data was input to the WR34 engine computer simulation. The engine achieved the desired output of 35 horsepower with a turbine inlet temperature of 1868°F and a specific fuel consumption of 1.14. In addition, the contract requirement of 27.7 horsepower on a 107°F day at an altitude of 5000 feet was also satisfactorily demonstrated. However, it should be noted that if the horsepower requirement were reduced to approximately 20.1 (approximately 15 KVA), with the same temperature and altitude conditions, turbine life should increase by more than 1,000 hours. Although higher compressor efficiency is desirable, the tested compressor is more than adequate to operate the WR34 engine. Table V presents a summary of the engine cycle.



TABLE V. ENGINE PERFORMANCE CYCLE WR34-8

		ENGINE (WR34-8)	ENGINE (WR34-8)
	$T_{AMB} - ^\circ F$	59	107
	$P_{AMB} - PSIA$	14.696	12.22
	HP_{OUT}	35.0	27.7
	$SFC - LB/(HP \cdot HR)$	1.097	1.135
	$TIT - ^\circ F$	1710	1868
	$N - RPM$	100000	100000
	$W_N - LB/SEC$	0.550	0.407
INLET	$(\Delta P/P_T)_{INLET}$	0.01	0.010
	ΔT_{INLET}	10	10
COMP.	$W_{\theta/\delta} - LB/SEC$	0.555	0.5157
	$N/\theta - RPM$	99050.	94838.
	P_R	3.921	3.631
	ΔT	353.3	353.4
	η	0.710	0.717
BURNER	$(W/T_T/P_T)_{IN}$	0.2835	0.2794
	$(\Delta P/P_T)$	0.030	0.030
	f/a	0.0196	0.0217
	η	0.995	0.995
	F.H.V. - BTU/LB	18400	18400
TURB	$(W/T_T/P_T)_{IN}$	0.4674	0.4657
	P_R	3.72	3.454
	$\eta_{TOTAL-STATIC}$	0.788	0.79
	$(N/T_T)_{IN}$	2146	2072
EXH	$(\Delta P/P_T)_{STATIC - AMB.}$	0.01	0.010
PAR. LOSSES	BEARING FRI-HP	1.05	1.05
	η_{GB}	0.97	0.97
	% LEAKAGE	1.00	1.0

A-155048



SECTION 4

CONCLUSIONS

The WR34 compressor, which was designed to withstand army ground power engine operating environment, has shown to perform adequately in combination with the other existing engine components based on the compressor rig test data. The compressor features a relatively thick bladed impeller design that enables it to be reliably cast using state-of-the-art techniques. The diffuser uses the proven vane-island design machined from 304 stainless steel which is inexpensive to fabricate and resistant to erosion effects on the diffuser performance. The goal of this compressor and diffuser design choice was to keep the WR34 engine fabrication inexpensive without compromises to performance and engine life.

From the data obtained during the initial rig test of the WR34 compressor it is apparent that, while further testing could result in a more detailed understanding of the compressor, the existing results are more than adequate for the WR34 engine.

Cycle analysis using the compressor rig test data, has verified that the engine can meet the contract specification of 27.7 horsepower on a 107°F day at an altitude of 5,000 feet. As previously noted the reduction of the horsepower to 20.1 will add over 1,000 hours to the life of the turbine. The combined rugged design and excellent performance demonstrated during compressor rig tests indicates the next logical step would be the operating evaluation. Thus, keeping to the WR34 Performance Improvement Program Schedule, Proposal 8125L.



SECTION 5

RECOMMENDATIONS

To verify that the tested compressor performance is consistent with its operation in the engine, and to ensure that the engine computer simulation is a correct representation of engine performance, it is recommended that a WR34 engine be thoroughly instrumented and tested. Instrumentation on the compressor would be a representative sample of what was used during rig testing to allow a direct comparison between engine and rig performance. This testing would be conducted using existing WR34 engine testing facilities at Williams Research. Test data to verify the predicted performance of all the engine components would be obtained and would provide insight into any possible differences between test rig and engine compressor performance.

Rig and engine data on the compressor would then be compared to determine if any change to the compressor is needed to better satisfy engine operation. At this point, the WR34 compressor could be rig tested again and a determination of why it was 10 percent high on temperature rise made. This would be done by running the impeller without the diffuser being present (vaneless space only test) to establish the impeller flow range and temperature rise. If the impeller surges where the stage test did at compressor design speed, a flow stability problem in the impeller would exist and a recontour of the present impeller in the exit region (material off the impeller shroud side) to reduce impeller internal velocity diffusion would be conducted. The main housing would then be metal sprayed and recontoured to match the impeller. The recontoured impeller would then be tested in the vaneless space test configuration. Based on the results of this rig testing, further modifications to the impeller would be identified. Assuming that the impeller operates properly, a new vaned diffuser design and fabrication would be undertaken and a full compressor stage rig test would be conducted. This recommended course of action would result in an effective compressor development program.

Based on the results of the engine testing, modifications to components other than the compressor would also be identified. Improvements could then confidently be made to the WR34 engine.



APPENDIX A
COMPRESSOR RIG TEST DATA



EVENTS AND COMMENTS (continuation)

P2 2

4090 (6-79)

ENGINE MODEL	WIP 34	496	ENGINEER	S. Herdige
SERIAL NO	MERADCOM		COMPLETION DATE	
TEST NO			MECHANIC	
CHANGE NO			INSTRUCTOR	
STARTING DATE	12-6-80		ENGINEER APPROVAL	
TEST OBJECTIVE				
MERADCOM Mechanical Check Run				
Compressor Test Rig				

D.P. #5 8:34 N = 80750 RPM record data
 Oil Scavenge temps front $\approx$ 100°F ; rear 220°F
 decelerate rig { change ASME exhaust
 nozzle ~~pl. to large size~~ water to ~~200~~ 400
 deceleration sounds good no mechanical
 problems

Idle at N = 28000 RPM let
 front & rear rig Brgs cool

8:43 Shut rig down run down sounds good
 Slight oil leakage from rig $\rightarrow$ vent 6/R
 Change H.b #2 sensitivity to 20.6
 CONVERT ASME NOZZLE MANOMETER TO
 50" U TUBE with ~~100~~ H₂O
 Run time = 39 minutes
 Note heat transfer from c/R to Discharge Plenum
 appears to affecting Rig Rear Brg Temp

9:26 Start Rig gradually accelerate
 up to N = 80000 RPM repeat D.P. #5
 Note H.b #1 begins ~~run~~ @ 2.00 s/s than
 tapers off as N increases. Idle @
 33000 RPM add oil to rig

9:31 accelerate rig to 80% N continued
 operation sounds good - no mechanical problems



EVENTS AND COMMENTS (continuation)

pg 3

MODEL	NR 34	99%	TESTER	Steve Herridge
TEST NO.	NERBDCOM		TEST LOCATION	
TEST NO.	1		TEST DATE	
TEST DATE	12-6-80		ENGINEER APPROVAL	
OBJECTIVE				
Mechanical Check Run				
Compressor Test Rig				

TIME	EVENTS AND COMMENTS
9:36	D.P. #6 N = 80760 RPM record data no mechanical → physical problems sig sounds good accelerate to 90% N
9:42	D.P. #7 N = 90350 RPM record data Vib #1 = 4.3 slight loss in oil (oil vapor) accel to 100% N
9:47	D.P. #8 N = 100,012 RPM Vib #1 6.5 → 7.8 6's
9:49	loosing oil out exhaust stack Decelerate Rig Vib's begin to decrease with speed. Oil pressure to rig hold at 4.9 psi As oil temp @ Front & Rear Rig Brgs increased so did Vib Front 6.5 → 8.0 6's Rear 3.8 → 4.5 6's
9:52	Disengage clutch shut shut rig down Run down sounds good no apparent problems Mechanical Check good except for oil leakage problem Run time = 26 minutes
	Add oil 1 qt +
10:03	Start Rig decelerate gradually ^{steadily} to 100% N. Oil pressure to rig 4.9 psi Over head temp Front 100°F ; Rear 180°F Accelerate steadily to N = 100000 RPM



EVENTS AND COMMENTS (continuation)

p25

ADDP (6-78)

ENGINE MODEL	TEST	ENGINEER
TEST NO.		COMPLETION DATE
TEST NO.		MECHANIC
CHANGE NO.		INSPECTOR
STARTING DATE		ENGINEER APPROVAL
TEST DURATION		

13:20	Start rig accelerate to 35000 RPM idle for warm-up. accelerate to 100000 RPM. stabilize at 100000 RPM
13:30	D.P. #9 N = 100090 RPM record data Hib #1 3.5 → 4.5 G's Close exhaust valve to obtain partial choke conditions
13:33	D.P. #10 N = 100020 RPM record data sudden increase in Hib #1 3.5 → 8.0 G's high squeal sound from rig
13:35	Disclutch shut rig down for inspection run down sounds good. Much Oil vapor found in cell. Disassemble Rig
	Oil found inside Inlet Pleum Chamber Excess heat build-up around Discharge Pleum Shaft coupling bottomed out on spline drive Outer ring on Brg - slight rotation Front Rig Brg - Ball Separator came apart causing non-uniform spacing of balls
	Comp Rotor - not damage Main Hsg - not damage Front free C.L.R. = 0.011 → 0.01310
	Total Run Time = 111 minutes Total Starts = 7



COMMENTS: *Compressor Test*

Hand Data Hook-Up

TEST NO. 496

PAGE 2 OF 3

DATA SHEET 1A

DATE 6 12 80
DAY MO.

A-1
Boom Pos

Run #		1	2	3	4	5	6	
N ₁ [RPM]	(high speed)	#1	40680	50130	59760	70400	80850	90740
N ₂ [RPM]	(CLC interval)	#2	40760	50450	60110	70200	80050	90100
Start Time			8:06					9:26
Stop Time							8:43	
Total Run Time							37 min	
G's	Vib #1 front rig	1	1.3	0.8	1.1	1.0	1.5	1.5
G's	Vib #2 rear rig	2	0.4	0.5	0.6	1.0	2.3	1.0
G's	Vib #3	3	0.0	0.0	0.0	0.2	0.1	0.0
CE [°F]	T front Rig Box	overhead ①	92	100	100	110	100	100
CE [°F]	T front Rig Box	4	104	113	120.3	125.9	133.2	131.7
CE [°F]	T rear Rig Box	overhead ②	90	100	150	195	220	210
CE [°F]	T rear Rig Box							
CE [°F]	T front High speed rig							
CE [°F]	T oil return → Rig	3	75.3	81.6	87.0	92.7	96.7	92.7
CC [°F]	T ASME Nozzle	5	48.9	46.6	45.2	45.2	45.5	47.1
CC [°F]	T Inlet Pipe	6	56.4	54.5	55.8	54.0	52.0	52.1
CC [°F]	T Inlet Pipe	7	51.8	50.7	53.6	46.1	46.8	46.9
[in H ₂ O]	P ASME Nozzle	WALL	3.55	5.5	7.13	10.75	15.5	5.8
[psi]	P oil Press to Comp Rig	PANIC ①	42	42	42	42	42	43
Initial Face CLR			0.020					
Final Face CLR			0.011 // 0.001					

* A O A S

TITLE: MERANCOM CH #1TEST NO. 416COMMENTS: Compressor TestPAGE 2 OF 3Hand Data Check - UpDATA SHEET 7 BDATE 12 10 81
DAY MONTH YR.

		A-1 Boom Pos	7	8	9	10
W1 (C/L)	(in. - yd)	#1	90.910	100.300	100.670	100.280
W2 (R/L)	(in. - yd)	#2	90.920	100.400	100.70	100.200
Start Time					13:30	
Stop Time				9:52		13:35
Total Run Time				26 min		5 min
G's	Vib #1	1	4.3	6.5	3.5	3.5
G's	Vib #2	2	1.4	3.8	1.5	1.5
G's	Vib #3	3	0.2	1.2	0.5	0.5
CR [F]	T front Rig Reg	overhead ①	100	140		
CR [F]	T front Rig Reg	4	143.4	162.0	174.6	
CR [F]	T over Rig Reg	overhead ②	280	300		
CR [F]	T C/L High Speed Rig	—				
CR [F]	T C/L High Speed Rig	—				
CR [F]	T Oil Return → Rig	3	103.8	115.1	100.7	
CR [F]	T ASME Nozzle	5	46.2	46.3	46.4	
CR [F]	T Inlet Pipe	6	47.0	47.0	45.9	
CR [F]	T Inlet Pipe	7	48.0	47.1	45.1	
U.P.S.	P ASME Nozzle	U tube	20.4	25.8	25.2	24.8
PR	T C/L Press to Comp. Rig	Penetral	44	44	44	44
Initial Error %						
Final Error %						

ADAS read-out



WRC0129-TR-81-1

TITLE: MERRACOM B/d #1

TEST NO. 496

PAGE 3 OF 3

COMMENTS: *Compressor Test*

DATA SHEET 2A

Hand Data Hook-Up

DATE 6 12 80
DAY MO. YR.

A-1
Bottom Pos.

		1	2	3	4	5	6																																
Start Time																																							
Stop Time																																							
Total Run Time																																							
Eng #1																																							
Eng #2	<table border="1"> <thead> <tr> <th></th> <th>2</th> <th>169</th> <th>160</th> <th>168</th> <th>168</th> <th>165</th> <th>165</th> </tr> </thead> <tbody> <tr> <td>Water Temp [°F]</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Gen Amps</td> <td></td> <td></td> <td>6</td> <td>4</td> <td>4</td> <td>4</td> <td>4</td> </tr> <tr> <td>Oil Press</td> <td></td> <td></td> <td>42</td> <td>48</td> <td>48</td> <td>50</td> <td>55</td> </tr> </tbody> </table>		2	169	160	168	168	165	165	Water Temp [°F]								Gen Amps			6	4	4	4	4	Oil Press			42	48	48	50	55						
	2	169	160	168	168	165	165																																
Water Temp [°F]																																							
Gen Amps			6	4	4	4	4																																
Oil Press			42	48	48	50	55																																
[°F]	Amb Temp	74.0	74.0																																				
[in Hg]	vac motor	29.26	29.26																																				
	% Rel Humidity																																						



TITLE: MERADCOM Bid # 1

COMMENTS: *Compressor Test*

Hand Data Hook-Up

TEST NO. 49'

PAGE 2 OF 3

DATA SHEET 2B

DATE DAY 12 80
MO. YR.

A-1
Boom Pos.

A-10



EVENTS AND COMMENTS (continuation)

P21

4000 (8-79)

ENGINE MODEL	<u>HERADCOM</u>	TEST	ENGINEER	<u>S. H. R. F. H. K. R.</u>
SERIAL NO.	<u>2</u>	<u>RID # 2</u>	COMPLETION DATE	<u>12-20-80</u>
BUILD NO.	<u>2</u>		MECHANIC	
CHARGE NO.	<u>12-19-80</u>		INSPECTOR	
STARTING DATE	<u>12-19-80</u>		ENGINEER APPROVAL	
TEST OBJECTIVE <u>Compressor Test</u>				

LAST READ	EVENTS AND COMMENTS
15:00	START ENGINE - WARM UP
15:34	PIG ENGAGED
15:38	ACCEL TO 40 K R.P.M.
15:42	DATA PT. #1
15:45	SET TO CHOKE
15:58	DATA PT. #2
16:00	SET TO SURGE
16:04	DATA PT. 3
16:05	SET TO S+1
16:09	DATA #4
16:11	SET TO S+2
16:11	DATA #5
16:13	SET TO S+3
16:15	DATA #6
16:18	ACCEL TO 60 K
16:19	DATA PT 7 W.O.
16:21	SET TO CHOKE
16:22	DATA PT. 8
16:24	SET TO SURGE
16:30	DATA PT. #9
16:32	SET TO S+1
16:33	DATA PT. #10
16:35	SET TO S+2
16:36	DATA PT. 11
16:37	SET TO S+3
16:38	DATA-PT. #12
16:40	ACCEL TO 20 K
16:42	DATA PT. #13
16:44	SET TO CHOKE
16:46	DATA PT. #14
16:49	SHUT DOWN run time = 75 min



EVENTS AND COMMENTS (continuation)

P22

4000 (6-78)

ENGINE MODEL	NERADCOM	TEST	ENGINEER	G. Herdige
SERIAL NO			COMPLETION DATE	12-50-80
BUILD NO	2		MECHANIC	
CHARGE NO			INSPECTOR	
STARTING DATE	12-19-80		ENGINEER APPROVAL	
TEST OBJECTIVE				
COMP. TEST				

LAST READ	EVENTS AND COMMENTS
	Starts
	Engine 11:00
	engine stall 11:20 restart
	Rig Start 11:20 accelerate to $N = 50000$ RPM
	but temp stabilize: ASME Nozzle temp
	do not stabilize accelerate to 70000 RPM
	10°F spread over temp range still remains.
	decelerate to 50000 RPM; 48600 RPM mechanical
	D.P. #17 W.D. 10:45
D.P. #18	11:49 choke $N = 48860$ RPM
D.P. #19	11:55 surge $N = 48730$ RPM
D.P. #20	12:00 S+1 $\Delta P = 3.0$ $N = 48700$ RPM
D.P. #21	12:04 S+2 $\Delta P = 3.8$ $N = 48600$ RPM
D.P. #22	12:06 S+3 $\Delta P = 4.4$ $N = 48600$ RPM
	Decelerate to 60000 RPM; 58500 RPM mechanical
D.P. #23	12:09 W.D. $\Delta P = 7.6$ $N = 58800$ RPM
D.P. #24	12:11 choke $\Delta P = 7.6$ $N = 58500$ RPM
D.P. #25	12:17 surge $\Delta P = 3.5$ $N = 58600$ RPM
D.P. #26	12:19 S+1 $\Delta P = 4.4$ $N = 58600$ RPM
D.P. #27	12:22 S+2 $\Delta P = 5.5$ $N = 58700$ RPM
D.P. #28	12:27 S+3 $\Delta P = 6.6$ $N = 58600$ RPM
	Decelerate to 70000 RPM; 68400 RPM mechanical
D.P. #29	12:32 W.D. $\Delta P = 10.7$ $N = 68400$ RPM
D.P. #30	12:36 choke $\Delta P = 10.6$ $N = 68500$ RPM
D.P. #31	12:44 surge $\Delta P = 6.0$ $N = 68700$ RPM
D.P. #32	12:48 Surge +1 $\Delta P = 6.8$ $N = 68700$ RPM
* D.P. #33	12:50 Surge +2 $\Delta P = 6.8$ $N = 68700$ RPM
D.P. #34	12:55 Surge +2 $\Delta P = 8.4$ $N = 68400$ RPM
D.P. #35	12:58 Surge +3 $\Delta P = 7.5$ $N = 68500$ RPM

* note: increase Guard Air 4→6 psi



EVENTS AND COMMENTS

P2 3

2

LINE NO.	DATE	TIME	TESTER	ENGINEER APPROVAL
1	12-19-80	12:15	2	S. Herdige
2	12-19-80	12:15	2	S. Herdige
3	12-19-80	12:15	2	S. Herdige
4	12-19-80	12:15	2	S. Herdige
5	12-19-80	12:15	2	S. Herdige
6	12-19-80	12:15	2	S. Herdige
7	12-19-80	12:15	2	S. Herdige
8	12-19-80	12:15	2	S. Herdige
9	12-19-80	12:15	2	S. Herdige
10	12-19-80	12:15	2	S. Herdige
11	12-19-80	12:15	2	S. Herdige
12	12-19-80	12:15	2	S. Herdige
13	12-19-80	12:15	2	S. Herdige
14	12-19-80	12:15	2	S. Herdige
15	12-19-80	12:15	2	S. Herdige
16	12-19-80	12:15	2	S. Herdige
17	12-19-80	12:15	2	S. Herdige
18	12-19-80	12:15	2	S. Herdige
19	12-19-80	12:15	2	S. Herdige
20	12-19-80	12:15	2	S. Herdige
21	12-19-80	12:15	2	S. Herdige
22	12-19-80	12:15	2	S. Herdige
23	12-19-80	12:15	2	S. Herdige
24	12-19-80	12:15	2	S. Herdige
25	12-19-80	12:15	2	S. Herdige
26	12-19-80	12:15	2	S. Herdige
27	12-19-80	12:15	2	S. Herdige
28	12-19-80	12:15	2	S. Herdige
29	12-19-80	12:15	2	S. Herdige
30	12-19-80	12:15	2	S. Herdige
31	12-19-80	12:15	2	S. Herdige
32	12-19-80	12:15	2	S. Herdige
33	12-19-80	12:15	2	S. Herdige
34	12-19-80	12:15	2	S. Herdige
35	12-19-80	12:15	2	S. Herdige
36	12-19-80	12:15	2	S. Herdige
37	12-19-80	12:15	2	S. Herdige
38	12-19-80	12:15	2	S. Herdige
39	12-19-80	12:15	2	S. Herdige
40	12-19-80	12:15	2	S. Herdige
41	12-19-80	12:15	2	S. Herdige
42	12-19-80	12:15	2	S. Herdige
43	12-19-80	12:15	2	S. Herdige
44	12-19-80	12:15	2	S. Herdige
45	12-19-80	12:15	2	S. Herdige
46	12-19-80	12:15	2	S. Herdige
47	12-19-80	12:15	2	S. Herdige
48	12-19-80	12:15	2	S. Herdige
49	12-19-80	12:15	2	S. Herdige
50	12-19-80	12:15	2	S. Herdige
51	12-19-80	12:15	2	S. Herdige
52	12-19-80	12:15	2	S. Herdige
53	12-19-80	12:15	2	S. Herdige
54	12-19-80	12:15	2	S. Herdige
55	12-19-80	12:15	2	S. Herdige
56	12-19-80	12:15	2	S. Herdige
57	12-19-80	12:15	2	S. Herdige
58	12-19-80	12:15	2	S. Herdige
59	12-19-80	12:15	2	S. Herdige
60	12-19-80	12:15	2	S. Herdige
61	12-19-80	12:15	2	S. Herdige
62	12-19-80	12:15	2	S. Herdige
63	12-19-80	12:15	2	S. Herdige
64	12-19-80	12:15	2	S. Herdige
65	12-19-80	12:15	2	S. Herdige
66	12-19-80	12:15	2	S. Herdige
67	12-19-80	12:15	2	S. Herdige
68	12-19-80	12:15	2	S. Herdige
69	12-19-80	12:15	2	S. Herdige
70	12-19-80	12:15	2	S. Herdige
71	12-19-80	12:15	2	S. Herdige
72	12-19-80	12:15	2	S. Herdige
73	12-19-80	12:15	2	S. Herdige
74	12-19-80	12:15	2	S. Herdige
75	12-19-80	12:15	2	S. Herdige
76	12-19-80	12:15	2	S. Herdige
77	12-19-80	12:15	2	S. Herdige
78	12-19-80	12:15	2	S. Herdige
79	12-19-80	12:15	2	S. Herdige
80	12-19-80	12:15	2	S. Herdige
81	12-19-80	12:15	2	S. Herdige
82	12-19-80	12:15	2	S. Herdige
83	12-19-80	12:15	2	S. Herdige
84	12-19-80	12:15	2	S. Herdige
85	12-19-80	12:15	2	S. Herdige
86	12-19-80	12:15	2	S. Herdige
87	12-19-80	12:15	2	S. Herdige
88	12-19-80	12:15	2	S. Herdige
89	12-19-80	12:15	2	S. Herdige
90	12-19-80	12:15	2	S. Herdige
91	12-19-80	12:15	2	S. Herdige
92	12-19-80	12:15	2	S. Herdige
93	12-19-80	12:15	2	S. Herdige
94	12-19-80	12:15	2	S. Herdige
95	12-19-80	12:15	2	S. Herdige
96	12-19-80	12:15	2	S. Herdige
97	12-19-80	12:15	2	S. Herdige
98	12-19-80	12:15	2	S. Herdige
99	12-19-80	12:15	2	S. Herdige
100	12-19-80	12:15	2	S. Herdige



EVENTS AND COMMENTS (continuation)

P24

3

ENGINE MODEL		TEST		ENGINEER	
MERRACOM				S. Herdige	
SERIAL NO.				COMPLETION DATE	
2				12-20-80	
CHANGE NO.				MECHANIC	
STARTING DATE				INSPECTOR	
12-19-80				ENGINEER APPROVAL	
TEST OBJECTIVE					
Compressor Test					
EVENTS AND COMMENTS					
Accelerate to 100000 96500 RPM mechanical					
P.P. 55	14:30	W.O.	$\Delta P = 26.5$	$N = 96600 \text{ RPM}$	
P.P. 56	14:32	choke	$\Delta P = 26.3$	$N = 96500 \text{ RPM}$	
P.P. 57	14:40	Surge	$\Delta P = 22.1$	$N = 96600 \text{ RPM}$	
P.P. 58	14:42	Surge +1	$\Delta P = 23.0$	$N = 96600 \text{ RPM}$	
P.P. 59	14:45	Surge +2	$\Delta P = 24.0$	$N = 96900 \text{ RPM}$	
P.P. 60	14:47	Surge +3	$\Delta P = 25.0$	$N = 96500 \text{ RPM}$	
P.P. 61	14:50	Surge +4	$\Delta P = 26.1$	$N = 96500 \text{ RPM}$	
Accelerate to 105% N 101300 RPM mech.					
P.P. 62	14:54	W.O.	$\Delta P = 27.6$	$N = 101900 \text{ RPM}$	
		choke	$\Delta P =$	$N = 101300 \text{ RPM}$	
Disclutch 14:57 shut down due to unusual noise. #1b #3 was loose from G/B. Hsg. Clutch on #1 Eng was slightly warm. Remount #1b #3 by bolting to G/B.					
15:50 Restart Engine					
P.P. #63 Zero Point					
16:00 Engage Clutch start compressor Rig					
Check Vib pickups at various speed lines					



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EVENT 1: 2004 National Security Strategy

pg 5

4

TIME		EVENTS AND COMMENTS	
DP 64	16:10	W.D.	DP = 27.7 N = 10/250 RPM
DP 65	16:14	choke	DP = 27.5 N = 10/250 RPM
16:15 declutch shut-down: loud whine; #1 increased to 5.8 G's 6/B High Speed shaft Brg Temp increased rapidly to 250°F. Also oil return to rig increased in temp. Front rig Brg temp increased rapidly.			



TITLE: <u>MERADCOM Bid # 2</u>		TEST NO. <u>496</u>						
COMMENTS: <u>Compressor Test</u>		PAGE <u>1</u> OF <u>12</u>						
<u>Hand Data Hook - Up</u>		DATA SHEET <u>A</u>						
		DATE <u>12</u> <u>80</u> <u>PC</u>						
		DAY MO. YR.						
1		Data Pt.						
		PROBE NO	1	2	3	4	5	6
			W.O	CHORE	SURGE	S+1	S+2	
N ₁ [RPM] high speed			39970	38400	38300	38500	38600	38400
N ₂ [RPM] 61R internal			40000	38200	38400	38200	38600	38700
Start Time			15:34					
Stop Time								
Data Pt. Time			15:43	15:53	16:04	16:09	16:11	16:13
Total Run Time								
G's Vib #1 front rig brg			1.0	0.5	0.6	0.6	0.6	0.5
G's Vib #2 Rear rig brg			0.5	0.5	0.5	0.5	0.5	0.5
G's Vib #3 61R surface			2.0	2.5	2.6	2.3	2.8	2.5
CC [°F] T front rig brg		overhead	100	100	100	100	100	95
CC [°F] T rear rig brg		overhead	80	85	85	85	85	95
CC [°F] T oil return → rig		3	75.3	81.5	78	78.8	79.3	79.7
CC [°F] T front rig brg		4	80.0	82	84.6	91	87	90.1
CC [°F] T ASME Nozzle		5	15.3	16	15.3	14.6	14.1	14.4
CC [°F] T ASME Nozzle		6	14.2	14	14.2	13.6	13.5	13.4
CC [°F] 61A Brg Temp front		7	121.3	130	130.6	131	131.1	131.2
CC [°F] 61R Brg Temp rear		8	109.8	122	122	122.7	123.1	123.5
Fin H ₂ O P P ASME Nozzle		well	3.9	3.3	1.1	1.8	2.5	3.2
[psi] P oil press →		UTG	44	44	44	44	44	44
Camp Rig		gauge						
Initial Face CLR								
Final Face CLR								

TITLE: ALFA ROMEO 501 - 11TEST NO. 1961COMMENTS: Compressor Test
Hand Data Hook-UpPAGE 3 OF 12DATA SHEET ADATE 19 12 80
DAY MO. YP.

3

		Data Pt.				
	PRIME NO.	13	14	15	16	17
N ₁ [C/M] high spec		76.29	76.0			
N ₂ [C/M] high spec		76.3	76.0			
Start Time						
Stop Time						
Time 1 to 2		16:42	16:			
Time 1 to 3						
Y ₁ #1 on 1		1.0	0.7			
Y ₁ #2 rear sig key		0.6	0.6			
Y ₁ #3 w/c rollers		2.1	1.7			
[E] T front sig key	overhead	200	200			
[E] T rear sig key	overhead	200	190			
[E] T oil return sig	3	94.7	95.2			
[E] T front sig key	4	167.3	167.2			
[E] T ASME Nozzle	5	14.6	12.6			
[E] T ASME Nozzle	6	13.2	12.9			
[E] G/LR sig Temp	7	206.5	208.2			
[E] G/LR sig Temp	8	188.9	190.3			
CC [E] ASME Nozzle	9					
[E] ASME Nozzle		12.2	14.0			
[E] ASME Nozzle		44	45			
Time 1 to 2						
Time 1 to 3						



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TLST NO. 476'

PAGE 4 OF 12

DATA SHEET **A**

DATE 20 12 80
DAY MONTH YEAR

Hand Data Hick - Up

DATA PT. 16

50%

A-19



6

7090

20 12 80

		N.O 29	CHOKE 30	S 31	S+1 32	S+2 33	S+2 34
1. Inlet Temp	12	68600	68800	68750	68680	68750	68390
2. Inlet Temp	12	68590	68790	68810	68650	68710	68400
3. Inlet Temp	12						
4. Inlet Temp	12						
5. Inlet Temp	12						
6. Inlet Temp	12						
7. Inlet Temp	12	12:32	12:37	12:44	12:47	12:51	12:55
8. Inlet Temp	12						
9. Inlet Temp	12	0.8	0.8	0.7	0.5	0.5	0.5
10. Inlet Temp	12	0.4	0.4	0.7	0.6	0.6	0.6
11. Inlet Temp	12	0	0	0	0	0	0
12. Inlet Temp	12	0	135	135	140	130	140
13. Inlet Temp	12	0	190	190	200	205	205
14. Inlet Temp	12	3	93.9	94.4	92.4	98.3	99.8
15. Inlet Temp	12	4	118.6	118.6	123.5	1240	127.8
16. Inlet Temp	12	5	30.9	28.9	29.2	29.6	24.6
17. Inlet Temp	12	6	44.9	39.0	35.9	40.5	23.2
18. Inlet Temp	12	7	193.4	192.7	199.6	200.2	195.2
19. Inlet Temp	12	8	178.1	179.8	181.6	182.1	182.1
20. Inlet Temp	12	9	33.5	30.5	33.6	32.1	23.9
21. Inlet Temp	12	10.7	10.6	6.0	6.8	6.2	8.4
22. Inlet Temp	12	45	45	45	45	45	45
23. Inlet Temp	12						
24. Inlet Temp	12						
25. Inlet Temp	12						
26. Inlet Temp	12						
27. Inlet Temp	12						
28. Inlet Temp	12						
29. Inlet Temp	12						
30. Inlet Temp	12						
31. Inlet Temp	12						
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33. Inlet Temp	12						
34. Inlet Temp	12						
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64. Inlet Temp	12						
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66. Inlet Temp	12						
67. Inlet Temp	12						
68. Inlet Temp	12						
69. Inlet Temp	12						
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74. Inlet Temp	12						
75. Inlet Temp	12						
76. Inlet Temp	12						
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78. Inlet Temp	12						
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80. Inlet Temp	12						
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91. Inlet Temp	12						
92. Inlet Temp	12						
93. Inlet Temp	12						
94. Inlet Temp	12						
95. Inlet Temp	12						
96. Inlet Temp	12						
97. Inlet Temp	12						
98. Inlet Temp	12						
99. Inlet Temp	12						
100. Inlet Temp	12						



7 12						
A						
20 12 80						
70%						
S+3	W.O.	CHARGE	STAGE	S+1	S+2	
35	36	37	38	39	40	
67500	77770	77650	77600	77710	77650	
68495	77775	77590	77580	77670	77640	
80%						
12:58	13:03	13:09	13:15	13:24	13:29	
0.5	0.6	0.6	0.6	0.6	0.6	
0.6	0.6	0.4	0.5	0.5	0.5	
0	0	0	0	0	0	
130	140	140	150	150	150	
180	210	210	210	230	230	
3	101.4	103.2	101.8	103.0	105.8	107.1
4	121.8	125.0	124.5	129.0	130.2	130.5
5	23.8	25.1	21.5	23.1	23.0	23.5
6	22.5	24.2	21.1	21.7	22.0	21.9
7	196.4	214.7	217.1	217.8	219.4	220.1
8	183.1	198.3	201.7	202.4	203.8	203.1
9	22.6	23.0	21.0	21.9	22.1	22.2
9.5	15.4	15.3	8.8	10.6	12.1	
45	45	46	46	46	46	
T A S M E NOZZLE						
E.C.						
A.C.						

				8	12	



10

9590 →

10 12
20 12 80
10090

	S+3 53	S+4 54	W.O. 55	CHOKE 56	5	57	S+1 58
Net L ₁ -L ₄ in.	91700	91710	96610	96570	96610	96650	
T ₁ -T ₂ in.	91600	91700	96600	96560	96600	96600	
Stroke Time							
Time							
Time							
Time	14:22	14:25	14:29	14:32	14:39	14:43	
Time							
Time							
Time	1.8	1.8	2.1	2.3	2.0	2.0	
Time	0.6	0.6	1.0	1.1	1.3	1.8	
Time	0	0	0.1	0.1	0.1	0.1	
Time	0	160	150	160	160	170	160
Time	0	380	300	320	320	340	340
Time	3	117.4	117.9	120.8	122.9	125.8	124.8
Time	4	143.0	141.5	146.6	145.0	149.6	150.0
Time	5	212.4	211.6	20.7	20.8	21.2	22.2
Time	6	21.1	21.2	20.8	20.9	20.6	22.4
Time	7	254.6	255.0	265.2	267.6	268.0	268.8
Time	8	236.0	236.2	246.6	247.9	249.3	249.8
(C) T A S M E NOZZLE	9	21.0	20.2	20.6	20.8	20.1	21.0
		21.3	23.2	26.5	26.3	22.2	23.0
		48	48	48	48	48	48



					11	12	
					A		
					20	12	80
					10.5%		
					W.O	CHOKE	C
					62	62	63
					96410	96310	96450
					10154	101	
					96400	96300	96390
					10150	101	
					14.57		
					14.46	14.48	14.50
					14.54	14.55	14.56
					2.0	2.2	2.4
					3.1		
					0.9	0.5	1.0
					1.9		
					0.1	0.1	0.2
					0.3		
					0	160	160
					160	160	160
					335	330	325
					340		
					3	122.9	122.2
					122.0	124.0	
					4	147.5	147.4
					147.8	149.6	
					5	20.8	21.1
					21.0	20.5	
					6	20.9	20.9
					20.9	20.3	
					7	267.0	266.9
					266.6	274.9	
					8	248.8	248.4
					248.2	253.7	
					9	20.2	21.2
					20.5	19.7	
					24.0	25.0	26.1
					27.6	28.0	
					48	48	48
					48	48	48

(C) T A S M E NOZZLE

SHUT DOWN TO CHECK RIG

ZERO POINT



WRC0129-TR-81-1

12

12 12

A

20 12 80

10570
W.O. CHOKE
64 65

101350 101520

101 300 10.1 532

16:00

16:15

16:11

16:14

2.2

2.2

14

1.8

5.8

•

T60

1

一、

280

2

3

112.9

419.8.

4

142.7

210

5

20.

6

20.

..

263.

268.6

2

263

cc (OF) T A S M E NOZZLE

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WRC0129-TR-81-1

TEST NO. 496

PAGE 1 OF 2

DATA SHEET *B*

DATE 19 12 80
DAY MO. YR.

Eng #



WRC0129-TR-81-1

TITLE: MERADCOM Bid # 2

COMMENTS: Compressor Test

Final Data Check-Up

TEST NO. 446

PAGE 2 OF 2

DATA SHEET 8

DATE 20 12 80
DAY MO. YR.

	DP 36	DP 42	DP 48	DP 55	DP 62	DP 64
PROBE NO	W.O.	W.O.	W.O.	W.O.	W.O.	W.O.
N ₁ [REM] (high sp.)	77500		916200	96500	101300	101300
N ₁ [REM] (Kinter)	77600		917500	96500	101500	101300
Start Time						
Stop Time						
Total Run Time						
Water Temp [°F]	161.5	171.6	169.3	170.3	171.1	168.0
Gen Amps	3	2	2	3	3	3
Oil Press	50	50	50	50	52	52
Probe Temp						
Barometer						
Rel Humidity						



••WILLIAMS RESEARCH CORPORATION CENTRIFUGAL COMPRESSOR TEST RIG DATA REDUCTION••

WERADCOM WP34 COMPRESSOR THIPD RUN AT AXIAL CLEARANCE (COLD)=0.017 FOR DATA
TEST DATE 12 20 80 TEST NO 1
DATE RUN : 02/15/81
TIME RUN : 15.2505

CONSTANTS USED INSIDE THE PROGRAM INCLUDING INPUT VALUES AND STORED CONSTANTS

COMPRESSOR GEOMETRIC PARAMETERS IN INCHES

INDUCER HUB RADIUS =0.4790
INDUCER EDGE OF BLADE RADIUS =1.0560
IMPELLER EXIT RADIUS =1.9205
IMPELLER EXIT PASSAGE HEIGHT =0.1540
VANED DIFFUSER LEADING EDGE RADIUS =2.0170
VANED DIFFUSER LEADING EDGE PASSAGE HEIGHT =0.1500
VANED DIFFUSER THROAT WIDTH =0.2043
VANED DIFFUSER THROAT PASSAGE HEIGHT =0.1500
VANED DIFFUSER EXIT RADIUS =1.5100
VANED DIFFUSER EXIT PASSAGE HEIGHT =0.1500
OUTSIDE RADIUS AT DESWIRL VANE LEADING EDGE =0.
INSIDE RADIUS AT DESWIRL VANE LEADING EDGE =0.
OUTSIDE RADIUS AT DESWIRL VANE TRAILING EDGE =0.
INSIDE RADIUS AT DESWIRL VANE TRAILING EDGE =0.
OUTSIDE RADIUS AT STAGE EXIT =3.7210
INSIDE RADIUS AT STAGE EXIT =3.5710
NUMBER OF BLADES AT THE IMPELLER LEADING EDGE = 14
NUMBER OF BLADES AT THE IMPELLER EXIT = 14
IMPELLER BACKWARD CURVATURE ANGLE =37.973
NUMBER OF VANES AT VANED DIFFUSER LEADING EDGE = 19
NUMBER OF VANES AT VANED DIFFUSER TRAILING EDGE = 19

COMPRESSOR AERODYNAMIC PARAMETERS

COMPRESSOR INLET EFFECTIVE AREA (PERCENT) =0.9800
IMPELLER INDUCER EFFECTIVE AREA (PERCENT) =0.9800
IMPELLER EXIT EFFECTIVE AREA (PERCENT) =0.9000
VANED DIFFUSER LEADING EFFECTIVE AREA (PERCENT) =0.9600
VANED DIFFUSER THROAT EFFECTIVE AREA (PERCENT) =0.9600
VANED DIFFUSER EXIT EFFECTIVE AREA (PERCENT) =0.9000
DESWIRL VANE LEADING EDGE EFFECTIVE AREA (PERCENT) =0.9000
DESWIRL VANE TRAILING EDGE EFFECTIVE AREA (PERCENT) =0.9000
COMPRESSOR EXIT EFFECTIVE AREA (PERCENT) =0.9000

CONSTANTS AND CONVERSION FACTORS

COMPRESSOR DESIGN CORRECTED SPEED = 99050.0
SPEED COUNT CONVERSION FACTOR = 1.00000
BELLMOUTH DIAMETER = 2.0125
BELLMOUTH EFFECTIVE AREA COEFFICIENT (PERCENT) = 0.9900
GAS CONSTANT = 53.3450
GRAVITATIONAL CONSTANT = 32.1740
CONVERSION FROM INCHES OF MERCURY TO PSI = 0.4911600
CONVERSION FROM INCHES OF MERCURY 295 TO MERCURY = 0.2169110
CONVERSION FROM INCHES OF WATER TO MERCURY = 0.0355200



WILLIAMS RESEARCH CORPORATION CENTRIFUGAL COMPRESSOR TEST RIG DATA REDUCTION

MILACOM W33L COMPRESSOR THIRD RUN AT AXIAL CLEARANCE (COLD)=0.017 FOR DATA
TEST DATE: 12 20 80DATE RUN : 02/15/81
TIME RUN : 15.2505

TEST NO. 1

PROGRAM OPTIONS UTILIZED

COMPRESSOR INLET CALCULATION = YES
INDUCER LEADING EDGE CALCULATION = YES
INDUCER TOTAL TEMPERATURE DATA = NO
INDUCER ANGLE DATA INPUT = NO
INDUCER PSOUTER INPUT ONLY = YES
IMPELLER SHROUD AND EXIT CALCULATION = YES
VANELESS SPACE CALCULATION = NO
VANED DIFFUSER CALCULATION = YES
BEND CALCULATION = NO
DESWIRL VANE CALCULATION = NO
STAGE EXIT CALCULATION = YES
EFFICIENCY BASED ON ENTHALPY = YES
WORK FACTOR IS INPUT = NO
PERFORMANCE CORRECTED FOR HUMIDITY = NO
PERFORMANCE CORRECTED FOR REYNOLDS NO. = YES
ROTOR ONLY TEST = NO

SUMMARY OF NUMBER OF INPUT TEMPERATURE AND PRESSURE PARAMETERS

NUMBER OF INLET BELLMOUTH TEMPERATURE ELEMENTS = 3
NUMBER OF INLET PIPE OR TANK TOTAL PRESSURE ELEMENTS = 4
NUMBER OF INLET PIPE OR TANK TOTAL TEMPERATURE ELEMENTS = 4
NUMBER OF TOTAL PRESSURE ELEMENTS AT OR NEAR THE START OF THE COMPRESSOR INLET = 9
NUMBER OF TOTAL TEMPERATURE ELEMENTS AT OR NEAR THE START OF THE COMPRESSOR INLET = 9
NUMBER OF STATIC PRESSURES ON THE OUTSIDE WALL AT OR NEAR THE START OF THE COMPRESSOR INLET = 4
NUMBER OF STATIC PRESSURES ON THE INSIDE WALL AT OR NEAR THE START OF THE COMPRESSOR INLET = 0
NUMBER OF TOTAL PRESSURE ELEMENTS AT OR NEAR THE IMPELLER INDUCER LEADING EDGE = 0
NUMBER OF TOTAL TEMPERATURE ELEMENTS AT OR NEAR THE IMPELLER INDUCER LEADING EDGE = 0
NUMBER OF STATIC PRESSURES ON THE OUTSIDE WALL AT OR NEAR THE IMPELLER INDUCER LEADING EDGE = 1
NUMBER OF STATIC PRESSURES ON THE INSIDE WALL AT OR NEAR THE IMPELLER INDUCER LEADING EDGE = 0
NUMBER OF SINGLE TAP STATIC PRESSURE LOCATIONS ON THE IMPELLER SHROUD = 16
NUMBER OF MULTIPLE TAP STATIC PRESSURE LOCATIONS ON THE IMPELLER SHROUD = 1
NUMBER OF IMPELLER BACK CAVITY TOTAL TEMPERATURE ELEMENTS = 0
NUMBER OF STATIC PRESSURE TAPS IN THE VANELESS SPACE BETWEEN THE IMPELLER AND DIFFUSER = 0
NUMBER OF STATIC PRESSURE TAPS AT THE VANED DIFFUSER THROAT = 4
NUMBER OF TOTAL PRESSURE ELEMENTS AT THE VANED DIFFUSER LEADING EDGE = 0
NUMBER OF STATIC PRESSURE TAPS AT THE VANED DIFFUSER THROAT = 0
NUMBER OF STATIC PRESSURE TAPS AT THE VANED DIFFUSER EXIT = 3
NUMBER OF VANED DIFFUSER STATIC PRESSURES TO BE PLOTTED ON THE VANE LAYOUT = 3
NUMBER OF STATIC PRESSURE TAPS IN THE BEND DOWNSTREAM OF THE VANED DIFFUSER = 18
NUMBER OF STATIC PRESSURE TAPS AT THE DESWIRL VANE LEADING EDGE = 0
NUMBER OF STATIC PRESSURE TAPS AT THE DESWIRL VANE TRAILING EDGE = 0
NUMBER OF TOTAL PRESSURE ELEMENTS AT THE STAGE EXIT = 12
NUMBER OF TOTAL TEMPERATURE ELEMENTS AT THE STAGE EXIT = 15
NUMBER OF STATIC PRESSURE TAPS AT THE STAGE EXIT = 0
NUMBER OF STATIC PRESSURE TAPS IN THE COMPRESSOR DISCHARGE PLenum = 3



DATE RUN : 02/15/81
TIME RUN : 15.2505

... NAME RECORD: COORDINATION CENTRIFUGAL COMPRESSOR TEST RIG DATA REDUCTION*

MPRADCOM WPT4 COMPRESSOR THIRD RUN AT AXIAL CLEARANCE (COLD)=0.017 FOR DATA
TEST DATE 12 20 80 TEST NO 1

MEASURING FLUID USED FOR PRESSURE PARAMETERS

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INLET PIPE OR TANK MEASUREMENT      =PS1G
COMPRESSOR INLET MEASUREMENT        =PS1G
OUTSIDE WALL STATIC PRESSURE AT COMPRESSOR INLET MEASUREMENT =PS1G
INSIDE WALL STATIC PRESSURE AT COMPRESSOR INLET MEASUREMENT   =PS1G
TOTAL PRESSURE AT INDUCER INLET MEASUREMENT                   =PS1G
OUTSIDE WALL STATIC PRESSURE AT IMPELLER INDUCER LEADING EDGE MEASUREMENT =PS1G
INSIDE WALL STATIC PRESSURE AT IMPELLER INDUCER LEADING EDGE MEASUREMENT =PS1G
IMPELLER SHROUD SINGLE STATIC TAP LOCATION MEASUREMENT       =PS1G
IMPELLER SHROUD MULTIPLE STATIC TAP LOCATION MEASUREMENT     =PS1G
WANELESS SPACE STATIC PRESSURE MEASUREMENT                    =PS1G
ADVANCED DIFFUSER LEADING EDGE STATIC PRESSURE MEASUREMENT    =PS1G
VANED DIFFUSER THROAT TOTAL PRESSURE MEASUREMENT              =PS1G
VANED DIFFUSER THROAT STATIC PRESSURE MEASUREMENT             =PS1G
VANED DIFFUSER EXIT STATIC PRESSURE MEASUREMENT               =PS1G
VANED DIFFUSER EXIT STATIC PRESSURES THAT ARE PLOTTED MEASUREMENT =PS1G
ADVANCED DIFFUSER STATIC PRESSURE MEASUREMENT                 =PS1G
REND DOWNSTREAM OF VANED DIFFUSER STATIC PRESSURE MEASUREMENT =PS1G
DESIGN VANE LEADING EDGE STATIC PRESSURE MEASUREMENT          =PS1G
DESIGN VANE TRAILING EDGE STATIC PRESSURE MEASUREMENT         =PS1G
STAGE EXIT TOTAL PRESSURE MEASUREMENT                          =PS1G
STAGE EXIT STATIC PRESSURE MEASUREMENT                         =PS1G
COMPRESSOR DISCHARGE PLenum STATIC PRESSURE MEASUREMENT      =PS1G

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FOR THE USE OF THE INLET TOTAL PRESSURE IN CALCULATIONS (PTINL)

NOTE: COMPRESSOR INLET TOTAL TEMPERATURE WILL BE USED AS THE INLET TOTAL TEMPERATURE IN CALCULATIONS (TTINL)

WARNING.....EXIT TOTAL PRESURE TO BE USED IN CALCULATIONS IS NOT SPECIFIED. PTSTGE WILL BE DEFAULTED TO

EXIT STATIC PRESQURE TO BE USED IN CALCULATIONS IS NOT SPECIFIED. PSQLEN WILL BE DEFAULTED TO 0.000000.

WARNING.....FVIT TOTAL TEMPERATURE TO BE USED IN CALCULATIONS IS NOT SPECIFIED. TSTGTE WILL BE DEFAULTED TO



DATE RUN : 02/15/81
TIME RUN : 15.2505

••WILLIAMS RESEARCH CORPORATION CENTRIFUGAL COMPRESSOR TEST RIG DATA REDUCTION••

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MPRDCOM MPZ COMPRESSOR THIRD RUN AT AXIAL CLEARANCE (COLD)=D.017 FOR DATA
DATA POINT 57 TEST DATE 12 20 80 TEST NO

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TEMPERATURES AS INPUT IN DEGREES FARENHEIT WITH AVERAGES IN DEGREES RANKINE

ASME	TANK OR	COMPRESSOR	INDUCER	STAGE	IMPELLER
NOZZLE (ITRELL)	INLET PIPE (TTANK)	INLET (TITNL)	LEADING EDGE (TTIND)	EXIT (TTSIG)	BACK CAVITY (ITBACK)
21-200	38.703	32.266	0.	369.631	0.
20-600	0.	32.376	0.	369.192	0.
20-1000	35.750	32.820	0.	365.674	0.
0.	36.448	34.483	0.	365.456	0.
0.	0.	35.038	0.	370.730	0.
0.	0.	0.	0.	373.149	0.
	0.	35.925	0.	375.128	
	0.	34.927	0.	379.744	
	0.	35.481	0.	374.468	
	0.	0.	0.	0.	
	0.	0.	0.	382.822	
	0.	0.	0.	377.326	
				377.986	
				378.645	
				373.149	
				0.	
				--0-	
				0.	
				0.	
				0.	
				0.	
				0.	
				0.	
200.321	406.655	603.852	0.	833.481	



WRC0129-TR-81-1

DATE RUN : 02/15/81
TIME RUN : 15.2505

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WERADCOM WR34 COMPRESSOR THIRD RUN AT AXIAL CLEARANCE (COLD)=0.017 FOR DATA
DATA POINT 57 TEST DATE 12 20 80          - - - - - TEST NO

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POSSIBLE AS INPUT IN INCHES OF WATER, MERRIAM 205 FLUID, MERCURY AND PSIG WITH AVERAGES IN PSIA

TANK OR PIPE	COMP.	INLET OD	INLET STATIC (PSODINL)	INLET ID	INDUCER L.E.	INDUCER TOTAL (PTIND)	INDUCER OD (PSODIND)	INDUCER L.E.	INDUCER ID (PSIDIND)	SHROUD STATIC (PSS)	SHROUD SINGLE TAP (PSS)	SHROUD MULTI TAP (PSM)	SMROUD MULTI TAP (PSM)	SMROUD STATIC (PSM)	WAVELESS SPACE STATIC (PSWLS)
(PTANK)	(PTNL)														
-0.580	-0.584	-2.229	0.	0.	0.	0.	-2.865	0.	0.	-2.229	12.247	23.534	0.	0.	0.
-0.593	-0.594	-2.083	0.	0.	0.	0.	0.	0.	0.	-2.083	14.323	18.849	0.	0.	0.
-0.593	-0.594	-3.134	0.	0.	0.	0.	0.	0.	0.	-3.134	15.081	19.833	0.	0.	0.
-0.593	-0.593	-3.299	0.	0.	0.	0.	0.	0.	0.	-3.299	17.780	17.744	0.	0.	0.
-0.593	-0.593	0.	0.	0.	0.	0.	0.	0.	0.	-2.965	0.	18.544	0.	0.	0.
-0.593	-0.593	0.	0.	0.	0.	0.	0.	0.	0.	-2.608	0.	24.102	0.	0.	0.
-0.593	-0.593	0.	0.	0.	0.	0.	0.	0.	0.	-2.076	0.	0.	0.	0.	0.
-0.593	-0.593	0.	0.	0.	0.	0.	0.	0.	0.	0.182	0.	0.	0.	0.	0.
-0.593	-0.593	0.	0.	0.	0.	0.	0.	0.	0.	1.896	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	4.710	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	6.495	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9.167	0.	0.	0.	0.	0.

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113	2114	2115	2116	2117	2118	2119	2120	2121	2122	2123	2124	2125	2126	2127	2128	2129	2130	2131	2132	2133	2134	2135	2136	2137	2138	2139	2140	2141	2142	2143	2144	2145	2146	2147	2148	2149	2150	2151	2152	2153	2154	2155	2156	2157	2158	2159	2160	2161	2162	2163	2164	2165	2166	2167	2168	2169	2170	2171	2172	2173	2174	2175	2176	2177	2178	2179	2180	2181	2182	2183	2184	2185	2186	2187	2188	2189	2190	2191	2192	2193	2194	2195	2196	2197	2198	2199	2200	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214	2215	2216	2217	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239	2240	2241	2242	2243	2244	2245	2246	2247	2248	2249	2250	2251	2252	2253	2254	2255	2256	2257	2258	2259	2260	2261	2262	2263	2264	2265	2266	2267	2268	2269	2270	2271	2272	2273	2274	2275	2276	2277	2278	2279	2280	2281	2282	2283	2284	2285	2286	2287	2288	2289	2290	2291	2292	2293	2294	2295	2296	2297	2298	2299	2300	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350	2351	2352	2353	2354	2355	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413	2414	2415	2416	2417	2418	2419	2
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REFERENCE PRESSURES

[illegible][illegible]

20.636 67.902 57.692

REFERENCE PRESSURES

[illegible]



WILLIAMS RESEARCH CORPORATION CENTRIFUGAL COMPRESSOR TEST RIG DATA REDUCTION

DATE RUN : 02/15/81
TIME RUN : 15.2505MERADCOM WR34 COMPRESSOR THIRD RUN AT AXIAL CLEARANCE (COLD)=0.017 FOR DATA
DATA POINT 57 TEST DATE 12 20 80 TEST NO 1

PERFORMANCE OUTPUT DATA

UNCORRECTED BAROMETER (IN. HG) = 29.690
CORRECTED AMBIENT PRESSURE (PSIA) = 14.522
AMBIENT TEMPERATURE (FAHRENHEIT) = 74.000
DELTA P NOZZLE (IN. H₂O) = 22.200
NOZZLE AREA (INCHES ** 2) = 3.149
RPM COUNTS = 96600.00

MEASURED STAGE OVERALL PERFORMANCE

CORRECTED SPEED (RPM)	PERCENT DESIGN SPEED	CORRECTED FLOW (LBM/SEC)	FLOW SORT THETA	Q INLET FLOW (LBM/SEC)	STATIC/TOTAL PRESSURE RATIO (PSPLEN/PTINL)	TOTAL/TOTAL PRESSURE RATIO (PTSTGE/PTINL)
98999.19	99.9	0.5377	0.97577	0.94781	4.1189	4.2522
DELTA T / T (TTSTGE-TTINL/TTINL)	WORK FACTOR	STATIC/TOTAL EFFICIENCY	TOTAL/TOTAL EFFICIENCY	EXIT MACH NUMBER		
0.68771	0.78270	0.7200	0.7398	0.2145		

STAGE OVERALL PERFORMANCE CORRECTED FOR REYNOLDS NUMBER

NOTE.....TEST DATA REYNOLDS NUMBER IS BASED ON THE AVERAGE PRESSURE AND TEMPERATURE AT THE INDUCER LEADING EDGE (PTIND AND TTIND)

REYNOLDS NUMBER BASED ON TEST DATA
STANDARD DAY
0.362E 07
0.339E 07

CORRECTED SPEED (RPM)	PERCENT DESIGN SPEED	CORRECTED FLOW (LBM/SEC)	FLOW SORT THETA	Q INLET FLOW (LBM/SEC)	STATIC/TOTAL PRESSURE RATIO (PSPLEN/PTINL)	TOTAL/TOTAL PRESSURE RATIO (PTSTGE/PTINL)
98999.19	99.9	0.5177	0.97577	0.94781	4.1165	4.2499
DELTA T / T (TTSTGE-TTINL/TTINL)	WORK FACTOR	STATIC/TOTAL EFFICIENCY	TOTAL/TOTAL EFFICIENCY	EXIT MACH NUMBER		
0.68771	0.78270	0.7196	0.7394	0.2147		



WILLIAMS RESEARCH CORPORATION, CENTRIFUGAL COMPRESSOR TEST RIG DATA REDUCTION

WRC0129-TR-81-1
DATA POINT 57 TEST DATE 12 20 80
DATE RUN : 02/15/81
TIME RUN : 15.2505

- TEST NO 1

COMPRESSOR INLET CALCULATION

NOTE-----AVERAGE TOTAL PRESSURE USED IN THE CALCULATION IS FROM THE COMPRESSOR INLET STATION (PTINL)

NOTE-----AVERAGE TOTAL TEMPERATURE USED IN THE CALCULATION IS FROM THE COMPRESSOR INLET STATION (TTINL)

INPUT PARAMETERS FOR THE COMPRESSOR INLET CALCULATION

NUMBER OF TOTAL PRESSURE RAKES = 3
NUMBER OF TOTAL TEMPERATURE RAKES = 3
OUTER (SHROUD) WALL RADIUS (INCHES) = 1.400
OUTER (SHROUD) WALL AXIAL COORDINATE(Z) (INCHES) = -0.533
INNER (HUB) WALL RADIUS (INCHES) = 1.400
INNER (HUB) WALL AXIAL COORDINATE (INCHES) = -1.004

RAKE ELEMENT DATA AVERAGED AT EACH AXIAL IMMERSION

Z (INCHES)	TOTAL PRESSURE (PSIA)	Z (INCHES)	TOTAL TEMPERATURE (DEGREES RANKINE)
-1.004	13.928	-1.004	492.175
-0.769	13.930	-0.769	494.448
-0.533	13.928	-0.533	495.132

RMS PERIODICAL VELOCITY AND MACH NUMBER FROM FLOW FUNCTION USING INPUT AERODYNAMIC BLOCKAGE FACTOR = 0.980

PERIODICAL VELOCITY
(FEET / SECOND)
249.912

MERIDIONAL MACH NUMBER
0.2306

OUTER WALL VELOCITY AND MACH NUMBER FROM MEASURED STATIC PRESSURE, MEASURED TOTAL PRESSURE, AND MEASURED TOTAL TEMPERATURE

STATIC NUMBER	STATIC PRESSURE (PSIA)	STATIC PRESSURE/ TOTAL PRESSURE	MERIDIONAL VELOCITY (FT/SEC)	PERIODICAL MACH NUMBER
1	12.292	0.8924	452.126	0.4265
2	12.432	0.8928	435.486	0.4057
3	11.988	0.8174	577.083	0.5444
4	11.723	0.8055	597.034	0.5644



WILLIAMS RESEARCH CORPORATION CENTRIFUGAL COMPRESSOR TEST RIG DATA REDUCTION

DATE RUN : 02/15/81
TIME RUN : 15.2505MACHINERY DATA (COMPRESSOR) THIS RUN AT AXIAL CLEARANCE (COLD)=0.017 FOR DATA
DATA POINT 57 TEST DATE 12 20 80 TEST NO 1-----
IMPELLER INDUCER LEADING EDGE CALCULATION

NOTE.....AVERAGE TOTAL PRESSURE USED IN THE CALCULATION IS FROM THE COMPRESSOR INLET STATION (PTINL)

NOTE.....AVERAGE TOTAL TEMPERATURE USED IN THE CALCULATION IS FROM THE COMPRESSOR INLET STATION (TTINL)

INPUT PARAMETERS FOR THE IMPELLER INDUCER LEADING EDGE CALCULATION

NUMBER OF TOTAL PRESSURE RAKES = 0
NUMBER OF TOTAL TEMPERATURE RAKES = 0
NUMBER OF INPUT AIR ANGLES = 0
OUTER (SHROUD) WALL RADIUS (INCHES) = 1.056
INNER (HUB) WALL RADIUS (INCHES) = 0.479

RMS MERIDIONAL VELOCITY AND MACH NUMBER FROM FLOW FUNCTION USING INPUT AERODYNAMIC BLOCKAGE FACTOR =0.980

MERIDIONAL VELOCITY
(FEET / SECOND)
196.114
MERIDIONAL MACH NUMBER
0.3589

OUTER WALL VELOCITY AND MACH NUMBER FROM MEASURED STATIC PRESSURE, AVERAGE TOTAL PRESSURE, AND AVERAGE TOTAL TEMPERATURE

STATIC PRESSURE (PSIA) 11.557
TOTAL PRESSURE 0.8295
MERIDIONAL VELOCITY (FT/SEC) 556.179
MACH NUMBER 0.5236

CALCULATED PARAMETERS AT THE IMPELLER INDUCER LEADING EDGE

RMS				OUTER WALL				INNER WALL			
RELATIVE VELOCITY (FT/SEC)	RELATIVE AIR ANGLE (DEGREES)	RELATIVE MACH NUMBER	RELATIVE MACH RATIO TO RMS	RELATIVE VELOCITY (FT/SEC)	RELATIVE AIR ANGLE (DEGREES)	RELATIVE MACH NUMBER	RELATIVE MACH RATIO TO RMS	RELATIVE VELOCITY (FT/SEC)	RELATIVE AIR ANGLE (DEGREES)	RELATIVE MACH NUMBER	RELATIVE MACH RATIO TO RMS
207.231	60.8115	0.2359		1049.663	58.0037	0.9881	1.4405	0.	0.	0.	0.



WRC0129-TR-81-1

DATE RUN : 02/15/81
TIME RUN : 15.2505

WILLIAMS RESEARCH CORPORATION CENTRIFUGAL COMPRESSOR TEST RIG DATA REDUCTION.

WATERGAS 4074 COMPRESSOR T1100 RUN AT AXIAL CLEARANCE (COLP)=0.017 FOR DATA 1
DATA POINT 57 TEST DATE 12 20 80 TEST NO 1

IMPELLER SHROUD AND EXIT PARAMETERS

NOTE:.....COMPRESSOR INLET TOTAL PRESSURE WILL BE USED AS THE INLET TOTAL PRESSURE IN CALCULATIONS (PTINL)

IMPELLER SHROUD STATIC / TOTAL PRESSURE RATIO VERSUS PERCENT MERIDIONAL DISTANCE

LOCATION NUMBER	PERCENT MERIDIONAL DISTANCE	STATIC/ INLET TOTAL PRESSURE/	LOCATION NUMBER	PERCENT MERIDIONAL DISTANCE	STATIC/ INLET TOTAL PRESSURE/	LOCATION NUMBER	PERCENT MERIDIONAL DISTANCE	STATIC/ INLET TOTAL PRESSURE/
1	-0.293	0.887	10	0.552	1.381	19	0.	0.
2	-0.209	0.893	11	0.655	1.509	20	0.	0.
3	-0.139	0.818	12	0.724	1.701	21	0.	0.
4	-0.068	0.806	13	0.793	1.922	22	0.	0.
5	0.	0.830	14	0.862	2.071	23	0.	0.
6	0.069	0.855	15	0.931	2.125	24	0.	0.
7	0.138	0.894	16	0.966	2.319	25	0.	0.
8	0.276	1.056	17	1.000	2.510	26	0.	0.
9	0.414	1.179	18	C.	0.	27	0.	0.

IMPELLER EXIT PERFORMANCE USING STAGE FEXIT MEASURED TEMPERATURE

[illegible]



DATE RUN : 02/15/81
TIME RUN : 15.2505

MEMORANDUM FOR THE DIRECTOR, ARMY RESEARCH OFFICE (DARO)
SUBJECT: CENTRIFUGAL COMPRESSOR TEST RIG DATA REDUCTION SUMMARY
DATE: 10/1/54
BY: DR. WILLIAMS RESEARCH CORPORATION

[illegible]