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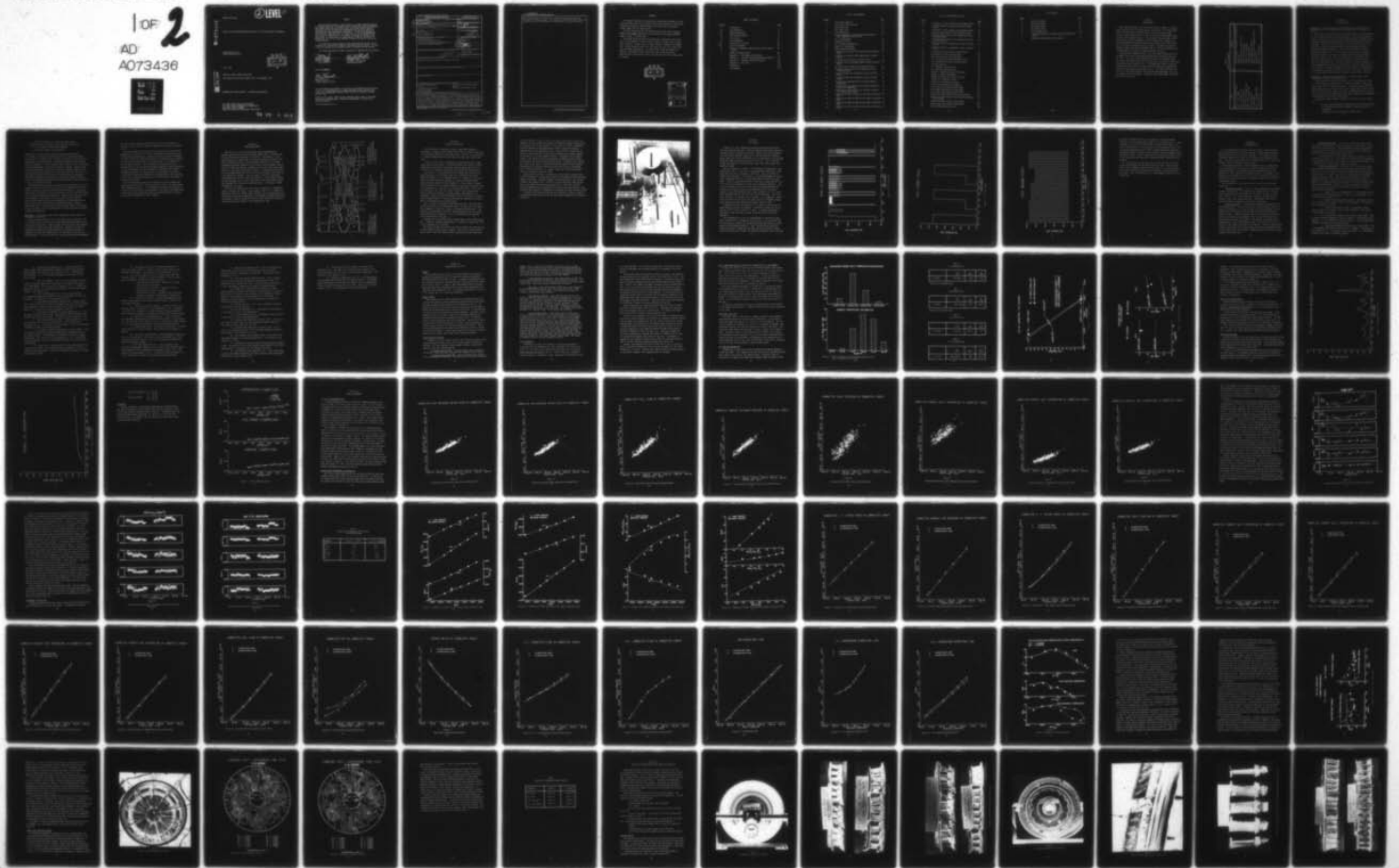
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Build 2 of an Accelerated Mission Test of a TF41 with Block 76 Hardware

Performance Branch  
Turbine Engine Division

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Technical Report AFAPL-TR-79-2063

Final Report for Period 2 August 1978 - 20 September 1978

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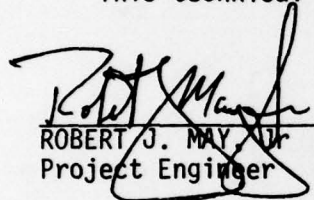
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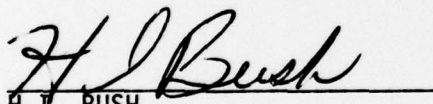
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This technical report has been reviewed and is approved for publication.

  
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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM	
1. REPORT NUMBER AFAPL-TR-79-2063	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER 9	
4. TITLE (and Subtitle) Build 2 of an Accelerated Mission Test of a TF-41 with Block 76 Hardware. A068595	5. TYPE OF REPORT & PERIOD COVERED Final Report 2 Aug - 20 Sep 78		
7. AUTHOR(s) Robert J. May, Jr	8. CONTRACT OR GRANT NUMBER(s) 1716		
9. PERFORMING ORGANIZATION NAME AND ADDRESS Performance Branch Turbine Engine Division /TBA Air Force Aero Propulsion Laboratory ✓	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 16 3066 16 02		
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE 11 Jul 1979		
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12 191 p	13. NUMBER OF PAGES 182		
	15. SECURITY CLASS. (of this report) UNCLASSIFIED		
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE			
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited. 62203F			
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)			
18. SUPPLEMENTARY NOTES			
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Accelerated Mission Test      First Stage High Pressure Turbine TF-41      Failure Performance Deterioration      Exhaust Gas Temperature Survey Sea-Level Testing Block 76 Hardware			
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) An accelerated mission test (AMT) of a TF41 (S/N 142163) was conducted in the Air Force Aero Propulsion Laboratory's "D" Bay Sea-Level Engine Test Facility between 2 August 1978 and 20 September 1978. The primary objective of the test was to evaluate the structural reliability of a series of parts changes known as "Block 76" hardware. A two-hundred-sixty-three hour test program was initially planned but only one-hundred-eighty-nine hours were actually completed due to the failure of a first stage high pressure turbine blade. Post-test teardown showed all of the "Block 76" hardware to be in good condition. Engine perfor-			

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mance deterioration was tracked and an exhaust gas temperature survey was performed and the data analyzed. This report describes the details of the test, including test objectives, approach, instrumentation, facility and results.

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FOREWORD

This report describes an in-house test conducted by personnel of the Turbine Engine Division and Technical Facilities Division, Air Force Aero Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio, under Project 3066, Task 16, Work Unit 02.

The work reported herein was performed during the period 2 August 1978 to 20 September 1978 under the direction of the project engineer, Robert J. May, Jr. (AFAPL/TBA).

The author wishes to thank the technicians involved for their hard work in this program, especially Messrs Richard G. Homer, Paul R. Hagedorn, Jerrold F. Carnes, Leroy P. Sauer, Donald J. Perdsock, and Robert Graf. Special mention goes to Mr. Mark Reitz for his aid in data reduction and report preparation. The author also wishes to express his thanks to the Detroit Diesel Allison Division of General Motors, especially Mr. Darwin Hoose and Mr. Gary Williams for their patience and assistance.

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SECTION I  
INTRODUCTION

This report describes an Accelerated Mission Test (AMT) of a Detroit Diesel Allison TF41-A-1 turbofan engine, S/N 142163. The primary objective of the test was to evaluate the structural reliability under realistic usage conditions of a series of structural improvements known as "Block 76" hardware (Table 1). Two hundred sixty-three hours of AMT testing were initially scheduled for this engine build. However, the test was prematurely terminated after only 189 hours due to the failure of a first stage high pressure turbine blade. The test was conducted between 2 August 1978 and 20 September 1978 in the Air Force Aero Propulsion Laboratory's "D"-Bay sea level engine test facility.

This test was conducted as part of a fleet leader program which also included flight test of this engine configuration by both the Navy and Air Force. This was the second AMT test of this serial number engine. The initial test ended after only 106 hours due to a failure in the second stage high pressure turbine (ref 1). The engine was rebuilt using the turbine section from TF41 S/N 141677 which had previously undergone AMT testing at the Propulsion Laboratory (ref 2). This engine did not have cast first stage high pressure turbine blades and replacement "Block 76" cast blades were not available. Therefore, the forged blades from 141677 were used in this test.

TABLE 1  
 "BLOCK 76" HARDWARE

PART	PURPOSE
HPT #6 cast bearing support HPT - 1 cast blade HPT - 1 bullnose vane #5 bearing rear seal HPC-4-5-6 Eiffel tower vanes HPC - 1 full chord blade 8-9 fuel manifold NL anticipator HPT - 1 lockplate damper Viton Wills ring	Ease of Assembly and Reduced Oil Consumption Reduce cost Obtain 500 hour hot section life Deletes seal requirement Improve fatigue strength Improve surge margin Improve temperature profile Reduce turbine inlet temperature spikes Reduce fretting Reduce oil consumption

## SECTION II TEST OBJECTIVES

OBJECTIVE 1: Establish durability and operability characteristics of a TF41 with "Block 76" hardware modifications under realistic usage conditions.

In the past, several TF41 fixes and modifications were introduced into the fleet without proper testing and evaluation. These hastily adopted fixes, in addition to not solving the problems they were intended to, have resulted in unexpected interactions which have caused failures in other components. By the time these problems surface, the entire fleet has been retrofit and the purging process is time-consuming and causes related non-technical problems. According to the 1975 TF41 Executive Review Group Report (ref 3), "this issue can be resolved by designing proper test programs to prove the improved parts are really improved." The report further states that the consequence of the proposed fixes should be demonstrated in the context of the total engine and under realistic usage conditions. This test objective is aimed at meeting this ERG recommendation by running a production TF41, modified with the proposed "Block 76" hardware, through a test program which is representative of the type of usage that the engine will see in the field. The "Block 76" hardware modifications and their purpose are described in Table 1.

OBJECTIVE 2: Demonstrate the durability of various overhaul repair schemes under realistic usage conditions.

During overhaul of the TF41's at both Air Force and Navy facilities, it is often necessary and desirable to "repair" or "rework" some parts rather than replace them with new ones. In keeping with the 1975 TF41 Executive Review Group's mandate that "there must be very careful testing and verification of the adequacy of repair procedures, especially for the critical hot section of the engine," some rework schemes were incorporated in this engine to verify their reliability.

The specific rework schemes included in the build-up of this engine are:

- 15 first stage low pressure compressor blades with weld repairs.
- 7 first stage low pressure compressor blades with hard coat replacement.
- 5 combustion liners repaired with "L605" rings.

- 10 primary combustor air scoops with weld repairs.

In addition, several "improved" parts were tested including:

- H.P. fuel pump with Viton HMG diaphragm
- viscoelastic wrapped inlet extension

OBJECTIVE 3: Document overall engine performance deterioration.

The 1974 TF41 Executive Review Group (ref 4) listed engine thrust deterioration as a problem area. However, the engines in the field have been seeing less than 200 hours of use before overhaul due to assorted durability problems. In this relatively short amount of time, the engines have not deteriorated to the point of causing a problem. However, many of the CIP objectives, including the "Block 76" hardware modifications, are aimed at improving engine life to the point where the TF41 is a "firm 1000 hour MOT engine with a 500 hour hot section periodic inspection." Under these conditions, deterioration is expected to become a problem. A recent TF41 Management Review Group established engine thrust deterioration as a prime area of concern.

Some deterioration data has been generated by past AEDC tests of TF41s. However, the engines did not have the "Block 76" hardware modifications which may impact the engine's deterioration characteristics. More importantly, due to the nature of the test objectives, most of the AEDC engine's test time was at steady state conditions. However, due to the many transients imposed on the engine in the A7 aircraft, the AEDC engine's deterioration would not be totally representative of the deterioration that an engine would exhibit after an equivalent number of hours in operational usage. The deterioration data from this type of accelerated mission test should be more representative of field usage and its effects on engine deterioration.

OBJECTIVE 4: Investigate burner outlet temperature profile changes as the engine deteriorates.

One of the major causes of first stage turbine nozzle failure in the TF41 has been the high peak burner outlet temperatures encountered transiently and steady state. Several changes have been made in the combustor and control to reduce these peak temperatures. However, the impact of combustor deterioration and deterioration in the upstream compression components on burner peak temperature is an area where little data has been generated. In fact, the 1975 TF41 Executive Review Group recommended

that AMT "testing should include periodic traverse measurements as a function of cycle time to account for combustor performance degradation" (ref 3).

The best method for accomplishing this objective and the one recommended by the 1975 ERG is to install high pressure turbine nozzle vane leading edge instrumentation. However, discussion with NAPTC personnel at Trenton, where this approach was used in a performance test, revealed that the vane instrumentation is so delicate that it is inappropriate for AMT type of testing. The instrumented vanes would have to be removed while the cyclic testing was being conducted and then reinstalled to take a temperature profile measurement at different time intervals throughout the test; this would result in unacceptable time delays. Also, the Navy's experience showed that continued removal and reinstallation of this instrumentation resulted in an unacceptably large number of thermocouple failures.

An alternate approach would be to measure the turbine exhaust gas temperature profile and at least qualitatively relate it to the turbine inlet temperature profile. A 45 thermocouple rake was fabricated to fit in the TF41 tailpipe which allowed mapping of the exhaust gas temperature profile during the steady state power calibration portions of the test and was easily removable for cyclic testing.

### SECTION III ENGINE DESCRIPTION

The TF41-A-1 is a mixed flow turbofan engine manufactured by Detroit Diesel Allison Division of General Motors and is currently used to power the Air Force and Navy's A7 aircraft. The engine is a twin spool design with a three-stage low pressure compressor driven by a two-stage low pressure turbine. The core engine consists of a two-stage intermediate pressure compressor also driven by the low pressure turbine and an 11-stage high pressure compressor with variable inlet guide vanes driven by a two-stage high pressure turbine. In the production version, first and second stage vanes and the first stage blades of the high pressure turbine are aircooled. The main burner is an axial flow design incorporating ten cannular combustion chambers. The core engine exhaust gas and the bypass air are mixed downstream of the low pressure turbine and exhausted out a fixed area convergent nozzle. The engine is shown schematically in Figure 1.

The TF41 has a design (sea level static, standard day, intermediate power) airflow of 261 lb/sec, a design bypass ratio of .7, a design fan pressure of 2.45 and a design overall pressure ratio of approximately 22. The maximum turbine inlet temperature is estimated at approximately 2625°R. The engine is rated at 14,500 lb of thrust at sea level static standard day conditions with a specific fuel consumption of .654.

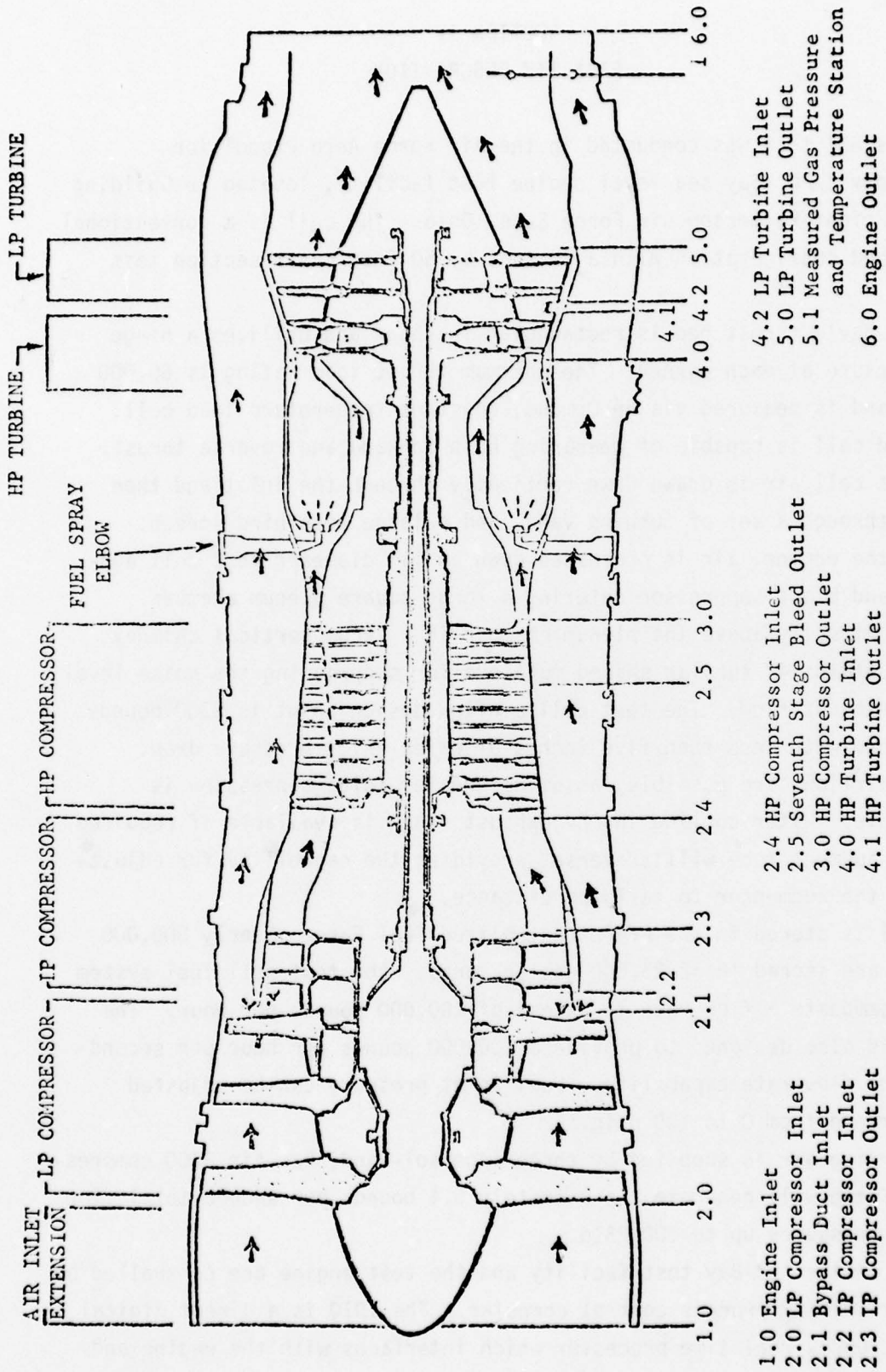


FIGURE 1 - TF41 ENGINE SCHEMATIC

## SECTION IV FACILITY DESCRIPTION

This AMT test was conducted in the Air Force Aero Propulsion Laboratory's "D"-Bay sea level engine test facility, located in Building 71A at Wright-Patterson Air Force Base, Ohio. The cell is a conventional "U" shaped configuration with a 50 foot by 50 foot cross section test area.

"D"-Bay's thrust bed is rectangular in shape and utilizes a hinge type flexure at each corner. The maximum thrust load rating is 60,000 pounds and is measured via an Ormand, constant temperature load cell. The load cell is capable of measuring both forward and reverse thrust.

Test cell air is drawn down vertically through the inlet and then passes through a set of turning vanes and a large mesh bird screen. Behind the engine, air is processed down an 11' diameter test cell augmentor and blast suppressor entering a large square plenum chamber. Located directly above the plenum chamber is a large vertical chimney which contains 42 tubular shaped mufflers for suppressing the noise level of the exhaust flow. The test cell airflow design point is 2300 pounds per second with less than five inches of water inlet pressure drop. Higher airflows are possible, assuming greater inlet depression is acceptable. Water cooling in the exhaust stack is available if required and the augment tube will traverse, providing the capability for adjustment of the augmentor to tailpipe distance.

Fuel is stored in the AFAPL centralized Fuel Farm. Nearly 800,000 gallons are stored in 32-25,000 gallon tanks. The test cell fuel system can accommodate a flow rate in excess of 100,000 pounds per hour. The system is also designed to provide a 100,000 pounds per hour per second transient flow rate capability. Fuel inlet pressure can be adjusted over a range from 0 to 100 psig.

Starting air is supplied by three Ingersol-Rand, Pac-Air 3000 compressors. These will generate approximately 5.4 pounds per second total flow rate at pressures up to 100 PSIG.

The entire "D"-Bay test facility and the test engine are controlled by a Taylor 1010/72 process control computer. The 1010 is a direct digital control (DDC), real time processor which interfaces with the engine and

facility through a series of analog and digital inputs which provide the computer with the information necessary to regulate, control, and optimize all phases of the "D"-Bay operation. The system in "D"-Bay is redundant with two identically configured process control computers connected together with a high speed memory link. A "bus switch" is used to allow the input and output lines to be rapidly switched to the backup computer in the event of a primary computer failure. In addition to the control function, the Taylor 1010 and its peripheral equipment provide "D"-Bay's primary means for acquiring and displaying data. A Modcomp II-26 computer was linked to the Taylor system and provides the means for data storage. Approximately 76 variables (engine and facility) as well as the output from all facility devices (i.e., pumps, valves, etc.) were acquired and stored at the rate of once per second.

Engine throttle control is provided by an ATEC throttle control unit. Throttle actuation is accomplished electrically through a buffer/transmitter-stepper drive motor, receiving commands from the electronic logic package located in the control room. Pre-set or variable actuation rates may be used or the throttle may be manually moved via a "joy stick" actuator. Throttle movements can be made manually or the throttle system can be interfaced with the computer to automatically reproduce any input throttle profile.

A picture of the facility with the TF41 installed is shown in Figure 2. A more detailed description of the facility and the computer can be found in reference 1.

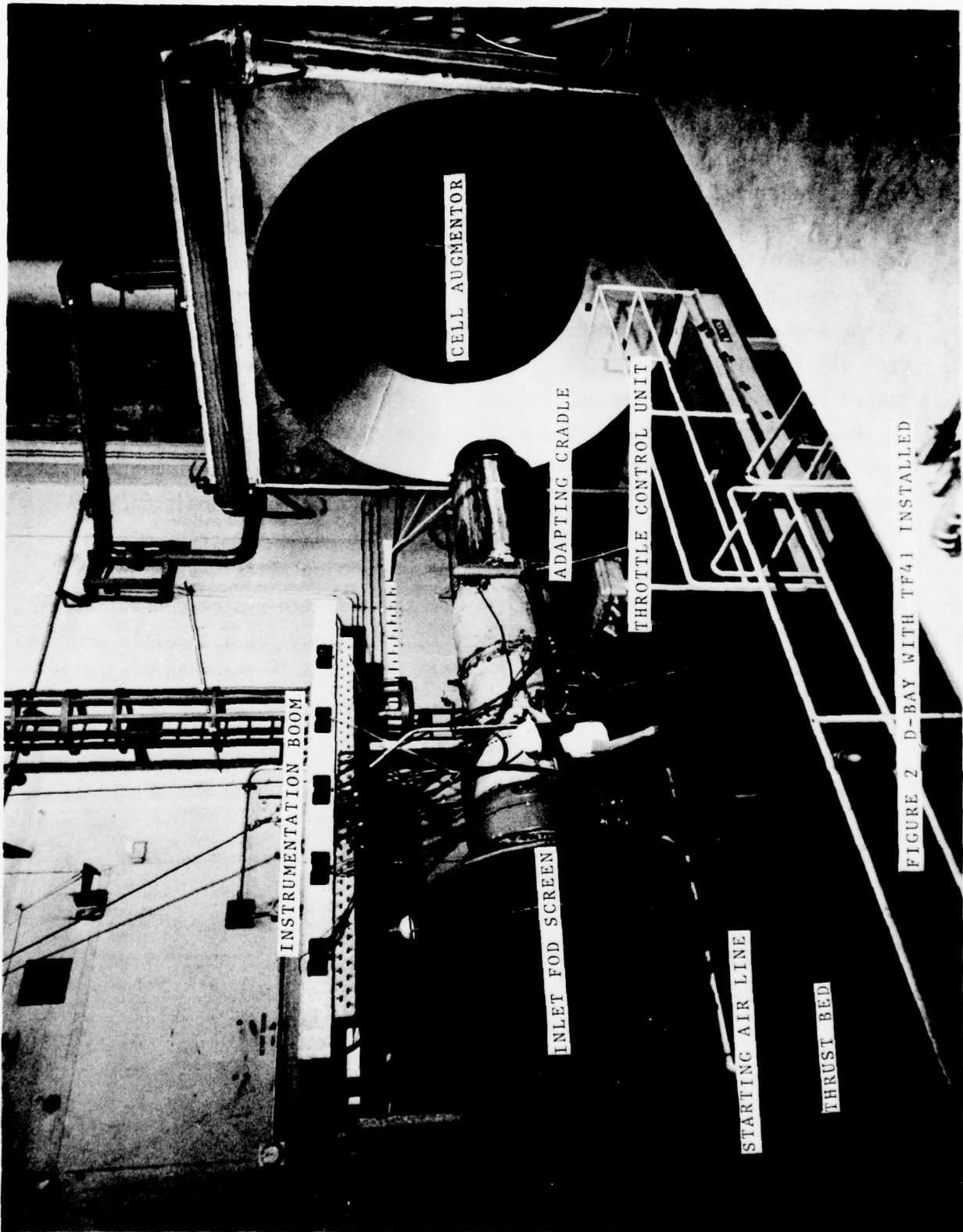


FIGURE 2 D-BAY WITH TF41 INSTALLED

## SECTION V TEST CYCLES

Figures 3, 4, and 5 graphically represent the throttle transient profiles run during the test. Percent of design high pressure compressor rotational speed is plotted versus time. These cycles were programmed into the control computer, making use of the high pressure compressor speed, power lever angle relationship for this engine which was generated during the power calibration portion of this test. This is required because the automatic throttle controls power lever angle rather than compressor speed.

The cycle depicted in Figure 3 is designated the Flight cycle (also referred to as an "A" cycle) and is representative of the actual flight usage that the TF41's are seeing in the field. This cycle lasts 43 minutes and 29 seconds. It consists of a considerable number of engine accels and decels as well as a significant amount of time at maximum power. Figure 4, graphically depicts a Start cycle (also referred to as a "B" cycle) representative of flight line maintenance operation. Each "B" cycle includes 10 minutes and 30 seconds of engine operation and contains three engine starts and the remaining time at idle power. Figure 5 is a so-called Ground cycle (also referred to as a "C" cycle) which reproduces typical test cell and trim pad operation. This cycle lasts two hours, six minutes, and 15 seconds. It is composed of several accels from idle to relatively high power settings, followed by steady state operation at this condition, and then a decel to idle.

A complete TF41 AMT test consists of 15+ blocks of testing which is approximately 263 hours of operation. Each block is made up of 20 "A" cycles, four "B" cycles, and one "C" cycle. A complete tabulation of the steps in each cycle may be found at the back of the test plan, Appendix D.

This combination of cycles is representative of the type of usage that a typical TF41 is subjected to in the field. A joint Allison and Air Force project compiled and analyzed data from many sources in order to derive these throttle profiles. Navy "Inflight Engine Condition Monitoring System" (IECMS) Data was used to provide records of engine histories during actual flight. An extensive program of pilot interviews

# TF41 FLIGHT CYCLE

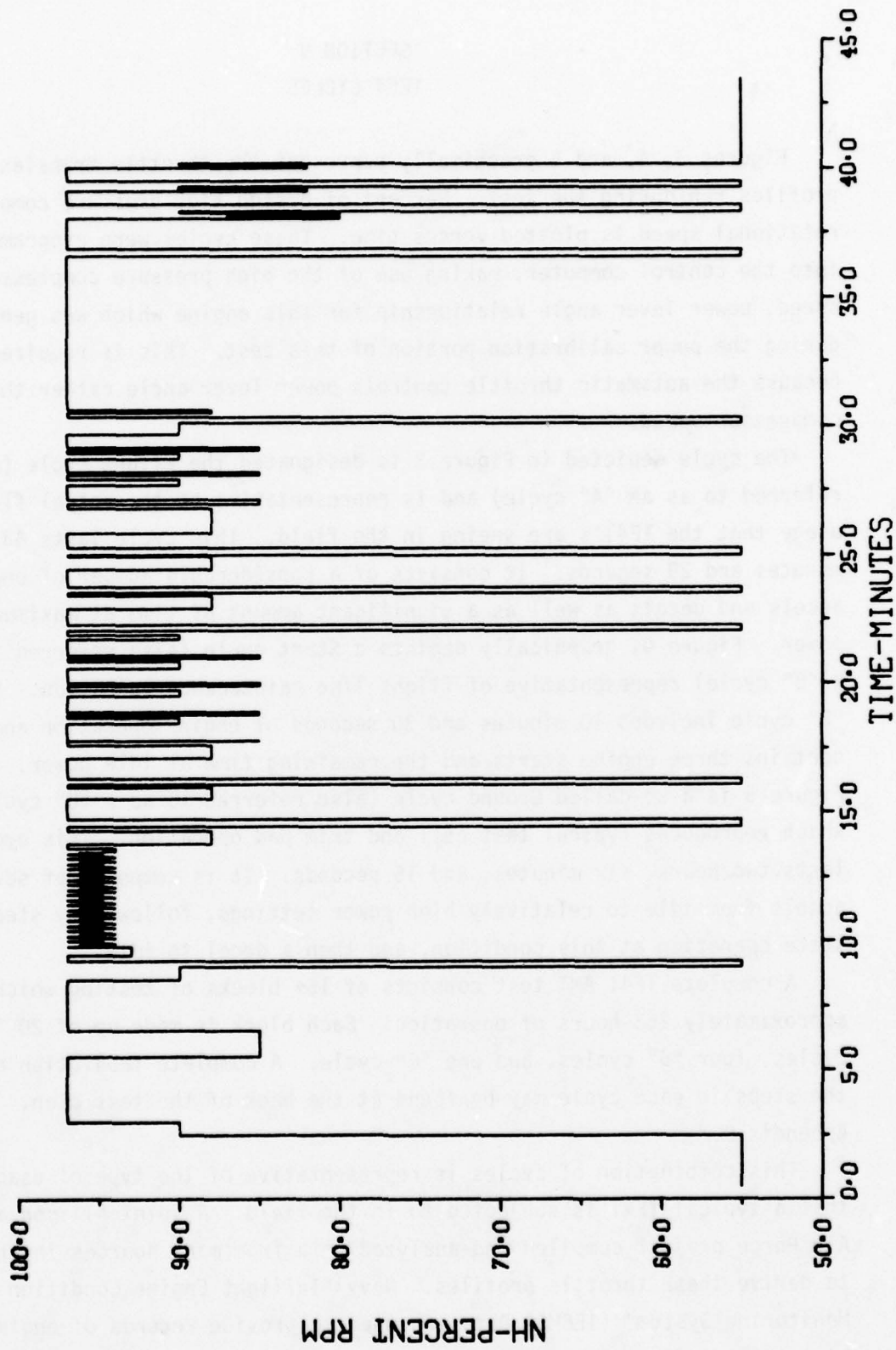


Figure 3 - TF41 Flight Cycle

# TF41 START CYCLE

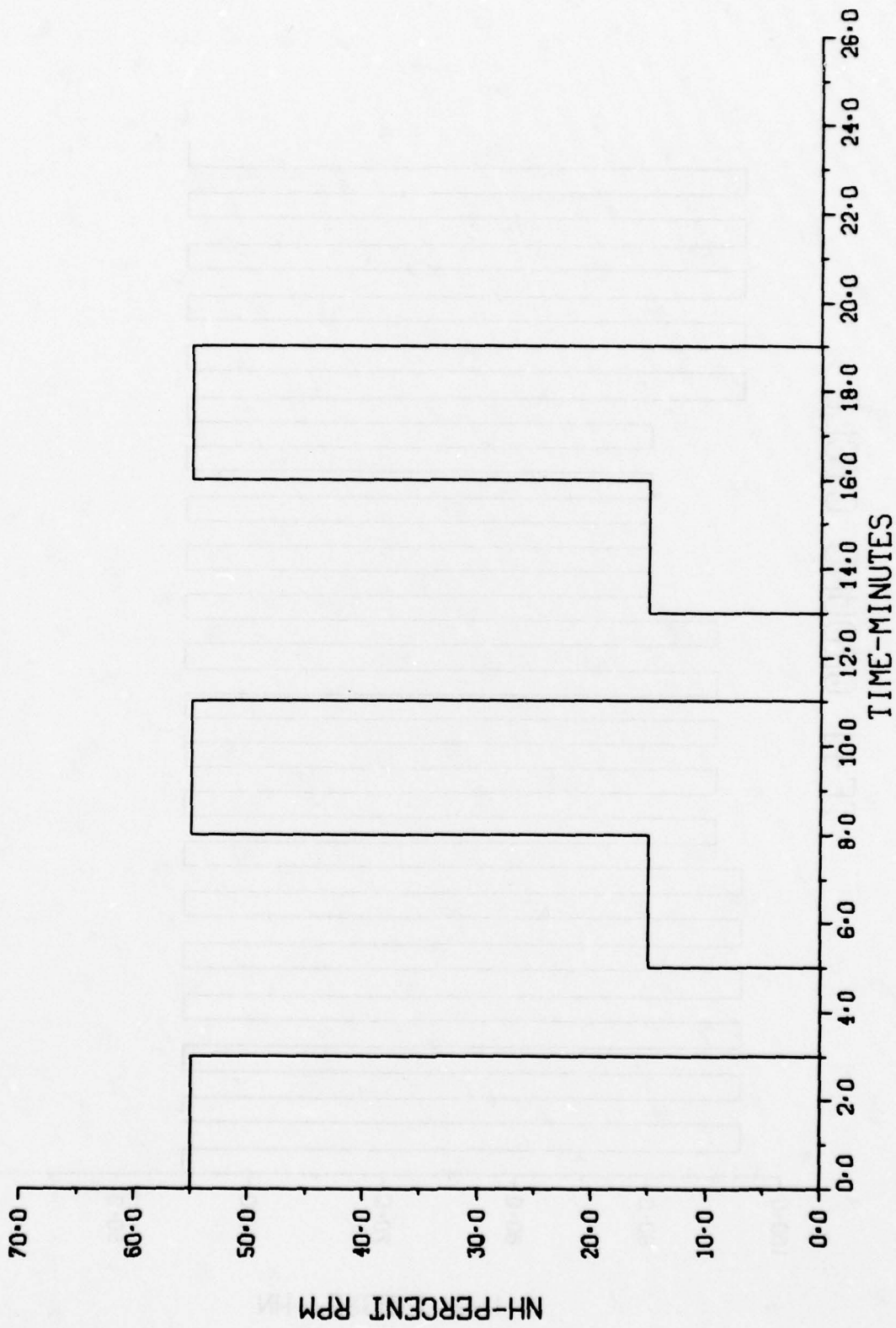


Figure 4 - TF41 Start Cycle

# TF41 GROUND CYCLE

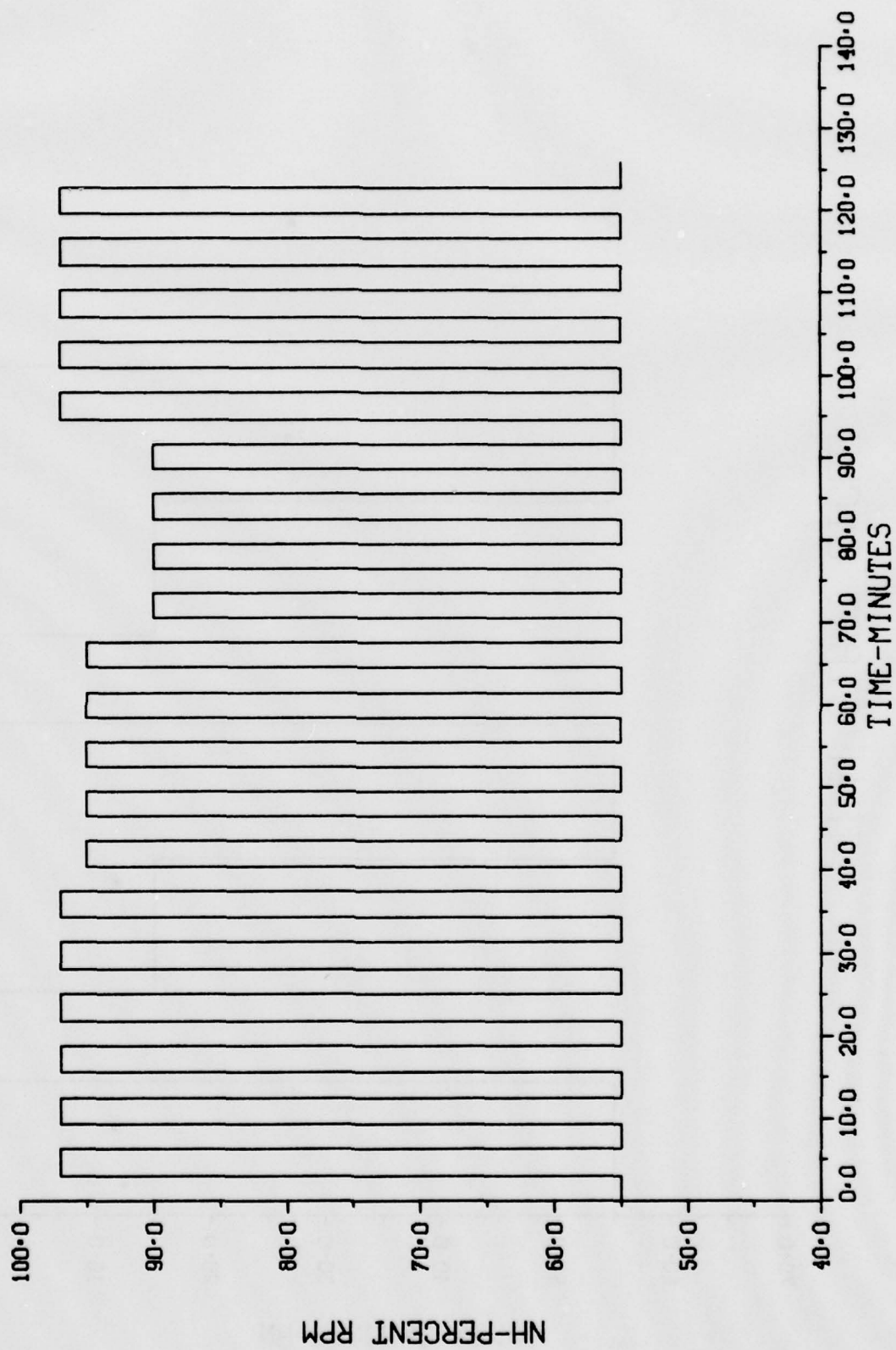


Figure 5 - TF41 Ground Cycle

was used to determine mission mix, estimates of throttle movement frequency, time at maximum power, effects of flight position (i.e., lead or wingman), mission profile definition (altitude, Mach number, time, weight, configuration), and the effects of pilot experience level. Also a flight test program was run at AFFTC, Edwards AFB CA, using specially instrumented engines to define typical ranges of engine parameters during operational flight. Finally, engine data recorded during flight as part of the "Engine/Airframe Structural Integrity Program" (ENSIP/ASIP) was assessed.

All this data was analyzed and used to define the three real time cycles and the proper mix that would directly relate to real engine usage. The non-damaging portions of the cycles (i.e., low power operation and small throttle changes) were eliminated in order to compress the cycles. Thus, one AMT test hour is approximately equivalent to 1.9 flight hours.

## SECTION VI INSTRUMENTATION

All instrumentation located in the test facility, either engine or facility related, passes its signal through a signal conditioning room before being routed to the control computers. This provides a common interface location for all patching, calibrating, and adjusting activities. The signal conditioning room is provided with its own interactive terminal link to the digital control system.

On the engine test deck a signal distribution bus, or engine boom, is cantilevered from the cell wall to provide a hook-up point for all engine data signals. A completely enclosed transducer cabinet also provides for local conversion of pressure signals to 0-5V output. This engine boom is permanently wired into the signal conditioning room and provided with various connectors for pressure, hydraulic, electrical, or thermocouple signals.

The following is a brief description of the current data channel capability:

Temperature Channels. Ninety-six (96), temperature (thermocouple) channels are provided. These channels are complete with all necessary signal conditioning and distributed into 40 Type K, 40 Type J, and 16 Type T couples. An ice point reference junction is provided for each channel in the signal conditioning room. Thermocouple jack panels on the engine boom are provided to facilitate installation.

Pressure Channels. The engine boom contains 68 pressure taps of two different types. Sixty of the taps are fitted with Tomco quick disconnect fittings and are limited to 500 psig (by the disconnect) and the other eight are fitted with ordinary pipe fittings for high pressure hydraulic lines. A heated, enclosed cabinet is positioned on the engine deck for the mounting of transducers, thus limiting the distance the actual pressure signal must traverse. Each channel of pressure must be equipped with a signal conditioner/transducer to provide a 0-5V output linear over the range of pressure to be measured. Cables to support these signals are provided from the engine deck to the signal conditioning room. A signal patch panel then provides a permanent path to the digital control system in the control room.

Undesignated Channels. There are 32, 0-5V input channels which are currently undesignated. These are provided with a Mil-Std, five pin connector at the engine boom. These connectors are then provided with a signal cabling to the signal conditioning room and can be connected to the digital control system through a patch panel.

These channels are used to support signals from speeds, vibratic , flow-rates, positions, etc. The software which stipulates the parameters of the measured variable allows a change to be made in the designation via a keyboard entry from the control system, CRT terminal.

Engine Instrumentation. The following is a list of the primary engine related instrumentation which was available and operative during this test of TF41 S/N 142163. All the instrumentation was displayed as a digital output on a cathode ray tube (CRT) display which was updated continuously once per second. Hard copy data was recorded, as required, automatically using a line printer at the rate of once per minute. In addition, all engine parameters were stored on disk (at a once per second rate) using the Modcomp II computer. Finally, 16 channels of oscillograph recorder were available to continuously record some of the more important engine parameters.

1. Engine inlet total temperature ( $^{\circ}$ F) - the average of three iron-constantan thermocouples located in the air inlet bellmouth. The accuracy of this reading is  $\pm 1^{\circ}$ F.

2. Engine inlet total pressure (PSIA) - the average of three total pressure probes located in the air inlet bellmouth. The accuracy of this reading is  $\pm .01$  PSIA.

3. Inlet static pressure (PSIA) - the average of three static pressure taps located in the air inlet bellmouth. The accuracy of this reading is  $\pm .01$  PSIA.

4. Low pressure compressor rotor speed (% Design RPM) - from an engine furnished tachometer on the L.P. gearbox. The accuracy of this reading is  $\pm .2\%$ . In addition to the CRT display, it is also continuously recorded on an Offner oscillograph recorder.

5. High pressure compressor rotor speed (% Design RPM) - from a test equipment tachometer mounted on the H.P. gearbox. The accuracy of this reading is  $\pm .1\%$ . In addition to the CRT display, it is continuously recorded on an Offner oscillograph recorder.

6. Turbine outlet temperature ( $^{\circ}\text{F}$ ) - from nine engine furnished chromel-alumel thermocouples connected in parallel and electronically averaged. The accuracy of this reading is  $\pm 4^{\circ}\text{F}$ . In addition to the CRT display, it is also recorded continuously on an Offner oscillograph recorder.

7. Fuel flow ( $\text{LB}_\text{M}/\text{HR}$ ) - from a test cell furnished flow meter located in the fuel supply line to the engine. The range of this meter is 0-11,000  $\text{LB}_\text{M}/\text{HR}$ . The accuracy of this reading is  $\pm 5\%$ . In addition to the the CRT display, it is continuously recorded on an Offner oscillograph recorder in the control room.

8. Fuel inlet temperature ( $^{\circ}\text{F}$ ) - from a closed-tip type iron-constantan thermocouple located in the test stand fuel line near the flow meter. The accuracy of this measurement is  $\pm 1^{\circ}\text{F}$ .

9. High pressure compressor discharge static pressure (PSIG) from a static pressure tap located on the number nine strut in the diffuser. The measurement is from an engine furnished fitting on the fuel control sense line. The accuracy of this measurement is  $\pm 0.05$  PSI.

10. High pressure compressor discharge temperature ( $^{\circ}\text{F}$ ) - from two engine furnished chromel-alumel thermocouples located in numbers three and nine fuel nozzles and averaged. The accuracy of this reading is  $\pm 1^{\circ}\text{F}$ .

11. Fuel manifold pressure (PSIG) - from a pressure tap on the fuel manifold on the left side of the engine. The accuracy of this measurement is  $\pm 1\%$ . In addition to the CRT display, it was also continuously recorded on an Offner oscillograph recorder.

12. Low pressure turbine discharge total pressure (PSIG) - from nine engine furnished total pressure probes spaced circumferentially in the turbine exhaust. The measurement is picked up from the P5.1 pressure manifold tap. The accuracy of this measurement is  $\pm 1$  PSI. In addition to the CRT display it was also continuously recorded on an Offner oscillograph recorder.

13. Engine main oil pressure (PSIG) - from a high pressure fitting on the oil filter. The accuracy of this measurement is  $\pm 5$  PSI. In addition to the CRT display, it was also continuously recorded on an Offner oscillograph recorder.

14. Low pressure cooling air discharge temperature ( $^{\circ}\text{F}$ ) - taken at the jack on the L.P. cooling air duct fitting using an iron-constantan thermocouple. The accuracy of this measurement is  $\pm 1^{\circ}\text{F}$ .

15. Engine vibrations (mils) - measured using type "106" vibration pickups. In addition to the CRT display, it was also continuously recorded on an Offner oscillograph recorder.

- Front compressor (vertical) - mounted on the front flange on top of the engine.
- Rear compressor (vertical) - mounted on the fuel manifold boss on top of the engine.
- Turbine (near vertical) - mounted on the low pressure turbine oil tube boss on the bottom of the engine.

16. IGV position (degrees) - an angle probe mounted on the engine airflow regulator and measures regulator travel in terms of HP inlet guide vane angle.

17. Power lever position (degrees) - measures the total cam-box lever travel. The accuracy of this measurement is  $\pm 1^{\circ}$ . In addition to the CRT, this parameter is a digital display on the auto-throttle control panel and continuously recorded on an Offner oscillograph recorder.

18. Engine oil inlet temperature ( $^{\circ}\text{F}$ ) - from a closed tip iron-constantan thermocouple located in the tube to the L.P. turbine bearing. The accuracy of this reading is  $\pm 1^{\circ}\text{F}$ . In addition to the CRT display, it is also continuously recorded on an Offner oscillograph recorder.

19. Engine thrust (LBF) - from load cell deflection. The range of the load cell is -60 to +60 KLBS. The accuracy of this reading is  $\pm 100$  LBS.

20. Fuel inlet pressure (PSIG) - from a measurement taken near the L.P. fuel pump inlet. The accuracy of this measurement is  $\pm 1$  PSIG. In addition to the CRT display, it is also continuously recorded on an Offner oscillograph recorder.

21. Oil tank temperature ( $^{\circ}\text{F}$ ) - from a closed tip iron-constantan thermocouple mounted in place of the oil tank drain plug which senses engine oil outlet temperature as measured at the oil tank. The accuracy of the measurement is  $\pm 1^{\circ}\text{F}$ . In addition to the CRT display, it is also continuously recorded on an Offner oscillograph recorder.

22. Junction box temperature ( $^{\circ}\text{F}$ ) - from an iron-constantan thermocouple installed on the small mounting lug for the ballast resistor in the T5.1 thermocouple junction box. The accuracy of this measurement is  $\pm 1^{\circ}\text{F}$ .

23. Pilot fuel manifold pressure (PSIG) - from a pressure tap on the pilot manifold near the main manifold pressure tap. The accuracy of this reading is  $\pm 25$  PSIG. In addition to the CRT display, it is also continuously recorded on an Offner oscillograph recorder.

24. Temperature limiter amplifier current (Milliamps) - measures current to the main fuel control limiting solenoid. Taken from pins 12 and 13 of amplifier test connector on the temperature limiter amplifier. The accuracy of this measurement is  $\pm 5$  milliamps. In addition to the CRT display, it was also continuously recorded on an Offner oscillograph recorder.

25. Ambient pressure (in HG) - from a barometer located on the outside wall of the test cell.

26. Wet bulb temperature ( $^{\circ}\text{F}$ ) - measurement made periodically in the test cell using a sling psychrometer.

27. Dry bulb temperature ( $^{\circ}\text{F}$ ) - measurement made periodically in the test cell using a sling psychrometer.

28. Eleventh stage bleed total pressure (PSIA) - from a pressure probe located in the 11th stage compressor customer bleed port. The accuracy of this reading is  $\pm 1$  PSIA.

29. Eleventh stage bleed static pressure (PSIA) - from a static tap on the probe located in the 11th stage compressor bleed port. The accuracy of this reading is  $\pm 1$  PSIA.

30. Fan discharge total pressure (PSIG) - from a dual pressure probe located in the forward borescope port. The accuracy of this reading is  $\pm 1$  PSIG.

31. Intermediate pressure compressor discharge total pressure (PSIG) - the other half of the dual pressure probe located in the forward borescope port. The accuracy of this reading is  $\pm 1$  PSIG.

32. Fan discharge total temperature ( $^{\circ}\text{F}$ ) - from a dual probe located in the forward borescope port using a chromel-alumel thermocouple. The accuracy of this reading is  $\pm 4^{\circ}\text{F}$ .

33. Intermediate pressure compressor discharge total temperature ( $^{\circ}\text{F}$ ) - the other half of the dual probe located in the forward borescope port also using a chromel-alumel thermocouple. The accuracy of this reading is  $\pm 4^{\circ}\text{F}$ .

34. Exhaust gas temperature rake ( $^{\circ}\text{F}$ ) - a 45 thermocouple rake located directly behind the last stage of turbine. The chromel-alumel thermocouples are mounted on an adapter that fits between the engine case and the tailpipe (see Figure 45). The accuracy of these readings is  $\pm 4^{\circ}\text{F}$ . Each thermocouple is read individually.

SECTION VII  
DISCUSSION OF THE TEST

SUMMARY

An accelerated mission test of a TF41 (S/N 142163) with "Block 76" hardware was conducted at the Air Force Aero Propulsion Laboratory's sea level engine test facility, "D"-Bay. A complete accelerated mission test normally consists of 263 endurance hours, made up of 305 "A" cycles, 60 "B" cycles, and 15 "C" cycles. Only 189 endurance hours (214 total operating hours) were completed before a first stage high pressure turbine blade failure ended the test. Two hundred twenty-three "A" cycles, 27 "B" cycles, and 11 "C" cycles were completed.

ENGINE HISTORY

The original build of 142163 underwent an accelerated mission test in D-Bay and suffered a second stage high pressure turbine blade failure and heavy secondary turbine damage after 106 AMT hours (ref 1). The engine was rebuilt for this test using the forward section from engine 142163 and the burner and turbine sections from 141677. No refurbishment was done on any of the compression system components. During the initial checkout and trim at Allison, several seal related problems were discovered and the engine was disassembled several times. In addition, nearly 27 engine operating hours were accumulated. During initial check-out runs after initial installation in "D"-Bay, a facility-caused low pressure turbine cooling air discharge problem was discovered. Nearly 13 more engine operating hours were accumulated while trying to isolate and solve this problem. In other words, more than 40 hours of operation were put on this engine build before actual AMT testing began.

ENGINE RELATED INCIDENTS

In general, up to the turbine failure, the TF41 engine tested in this program operated extremely well, with a minimum number of mechanical problems. The more important engine related incidents that occurred during the test are summarized below:

- Oscillation in NH ( $\pm 2\%$ ) - occurred during initial running of the engine. Stable operation returned after bleeding the fuel system.
- Failed Ignition Exciter Box - During an engine start for the initial performance calibrations, the engine did not light-off immediately.

However, once a light-off was achieved, the raw fuel which had been dumped in the tailpipe was also ignited and flame was observed out the nozzle. The engine was shutdown and inspected. No damage was observed. The problem was traced to a faulty ignition exciter box which was only firing the left side ignitor plug. This box was replaced with one from the Propulsion Laboratory's prototype YTF41 (S/N 141003).

- Failed Ignition Exciter Box - after approximately 19 AMT hours at the start of the 27th "A" cycle, the engine failed to light-off. The problem was traced to the ignition exciter box which was not firing either ignitor plug. The exciter box was replaced with a new one.

- Fuel Leak - after approximately 65 AMT hours visual inspection of the engine revealed external fuel leaks around the #8 and #9 fuel nozzles. These nozzles were removed. One pinched and one split "O" ring were discovered and were replaced.

- High Turbine Vibration - after approximately 108 AMT hours during a slow accel from idle to intermediate subsequent to a T5.1 pull-down check, a high turbine vibration alarm was encountered (>5.0 mils). The engine was immediately returned to idle power where another high turbine vibration alarm was triggered so it was shut down. A very thorough inspection did not reveal any apparent damage so the engine was motored on the starter. Coastdowns, etc., all appeared normal and the engine was started and run at idle power. Performance and vibration parameters all appeared normal so AMT testing was continued.

- Turbine Blade Failure - after approximately 189 AMT hours, during a snap accel from idle to intermediate power at 23 minutes and 47 seconds into the 223rd "A" cycle, turbine vibration levels showed a marked increase from 1.3 mils to 4.0 mils. This is still below tech order and computer alarm limits to 5.0 mils. Neither the compressor vibrations nor the mid-frame vibrations showed any significant change. This "A" cycle was completed without further incident, although turbine vibrations behaved erratically. Early in the next "A" cycle turbine vibrations reached nearly 6.5 mils during the first engine acceleration from idle to 90% speed and the control computer returned the engine to idle and eventually shut it down. Visual inspection revealed light damage to the second stage low pressure turbine vanes and one tailpipe bolt was sheared off. The engine was prepared for borescoping and this inspection revealed a failed high pressure turbine blade. The engine was removed from the cell and returned to Allison.

#### TEST PROCEDURES

Throughout this entire test program, the engine was operated in accordance with the procedures and limits contained in Air Force Tech Order, T.O. 2J-TF41-6 (ref 5) and Allison Publication Nr 1F2, TF41-A-1 Engine Operation and Service (ref 6). Prior to each day's running, a pre-test checklist, including a visual inspection of the engine and test

cell were completed. Oil level was checked several times during the day and rotor coastdowns were recorded upon the last shutdown of each test period.

A functional check of the engine's limiters, governors, and schedules was performed before the endurance portion of the test and a similar check was planned after every 100 AMT hours of testing. A pre-test steady-state power calibration, between 50% power and maximum power was also carried out. Actually, two steady state power calibrations were performed back to back. Due to an installation problem, the left side forward borescope port was not accessible so the fan/IP discharge pressure and temperature instrumentation could not be run simultaneously. An additional series of steady-state points were run to define the high pressure compressor rotor speed/power level angle relationship needed to input the test cycles into the automatic throttle controller. Additional calibrations were scheduled in 100 AMT hour intervals and after completion of the test.

Engine maintenance and inspections were planned at 50 hour intervals according to Allison publication 1F2 (ref 6). Borescoping of the engine was to be performed after every 100 AMT hours. Oil samples were taken after approximately 25 hours of engine operating time.

During the test operation, all facility and engine instrumentation was monitored by the test operator and the test cell observer using CRT displays. Hard copy data was recorded using the line printer during the six minute constant power level operation at intermediate power (referred to as the "Intermediate Power Flat") which occurs near the end of every "A" cycle and was processed by a data reduction computer program (using methods outlined in Appendix A) after each day's run. Seventy-six engine and facility parameters were recorded and stored on a computer disk at a one per second rate throughout the duration of the test. In addition, 16 channels of oscillograph recorder were available to continuously record some of the more important engine parameters (See Section VI).

Normally, the endurance portion of an AMT test is run in a series of blocks, each block consisting of 20 "A" cycles, followed by 4 "B" cycles, followed by 1 "C" cycle. However, due to the difficulty in changing cycles in the control computer, this sequencing was not followed.

#### INLET TEMPERATURE/TURBINE STATOR INLET TEMPERATURE (T4) TIME SUMMARY

Previous TF41 AMT tests were run with controlled engine inlet temperature. Forty-one percent of the test was run at  $70^{\circ}\text{F} \pm 5^{\circ}\text{F}$ , 38% was run at  $90^{\circ}\text{F} \pm 5^{\circ}\text{F}$ , 9% was run at  $110^{\circ}\text{F} \pm 5^{\circ}\text{F}$ , and the remaining 12% (the "C" cycles) were run at various inlet temperatures. It was not possible to match this distribution since "D"-Bay does not have any means for controlling the inlet air temperatures. The ambient temperature distribution that was run during this test is presented in Figure 6.

One of the important parameters in an AMT test is the turbine stator inlet temperature (T4) time history. Enough data is recorded during the six minute intermediate power "flat" near the end of each "A" cycle to allow calculation of a turbine stator inlet temperature (see Appendix A). Figure 6 is a histogram plot of this T4 data for the AMT test of TF41 S/N 142163. This distribution compares favorably with those from other TF41 AMT tests.

It should be noted that this data only represents the T4 distribution at one steady-state condition. It does not reflect any transient conditions or part power.

#### FUNCTIONAL CHECK DATA

Functional checks of the engine's limiters, governors, and schedules were performed before the test and after 100 AMT hours. The following checks were made according to T.O. 2J-TF41-6 (ref 5) procedures: IGV ram closing schedule, NL governor, P3 limiter, T5.1 pulldown, NH governor, and acceleration control unit (ACU) and deceleration control unit (DCU). The results of these checks are contained in Tables 2 through 5 and Figures 7 and 8. Note that several of the parameters were slightly out of limits but adjustments were not made due to a lack of the proper adjustment tools. Discussions with Allison engineers confirmed that these apparent out-of-limit conditions, even if real, were not important to the overall objectives of this test nor did they present an engine safety hazard.

#### OIL SAMPLING/CONSUMPTION

The AMT test of this TF41 was used to evaluate the foaming tendencies of two lubricants. MIL-L-23699 oil was used for the first 125 AMT hours and MIL-L-7808 oil was used for the remaining hours. Because of this oil evaluation, oil samples were taken more frequently than the normal 25 hour

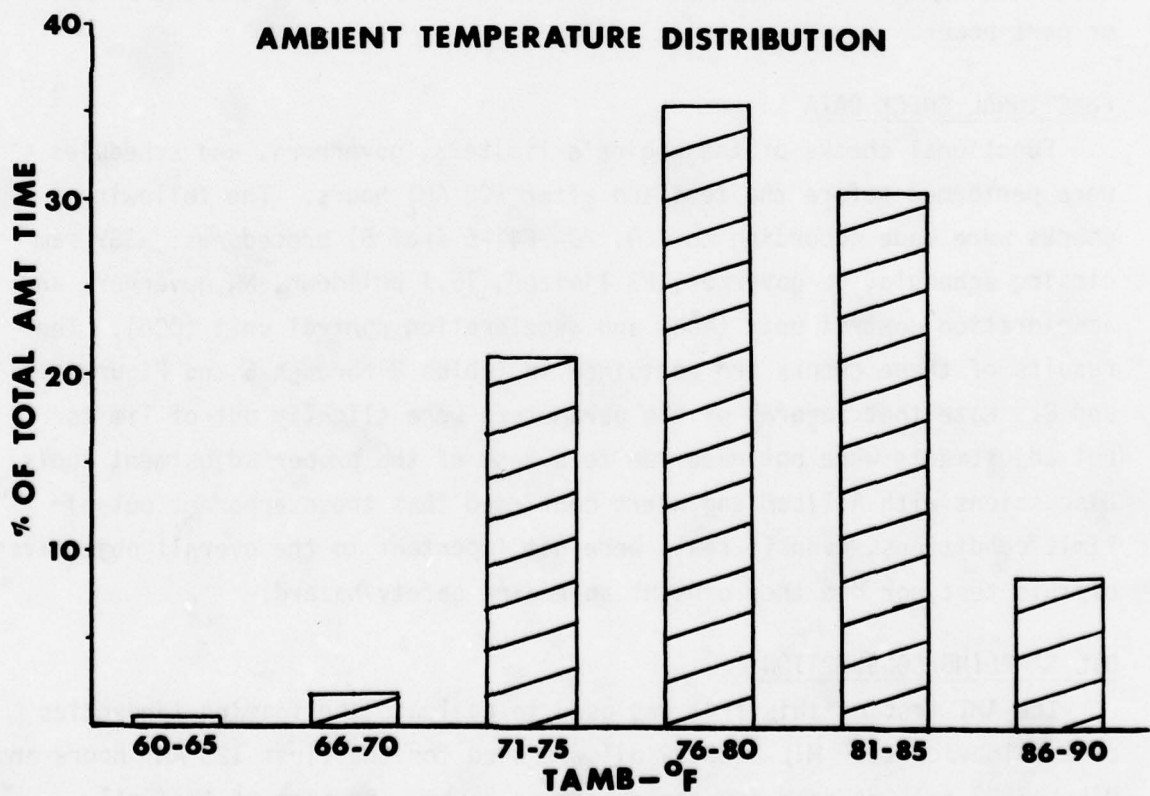
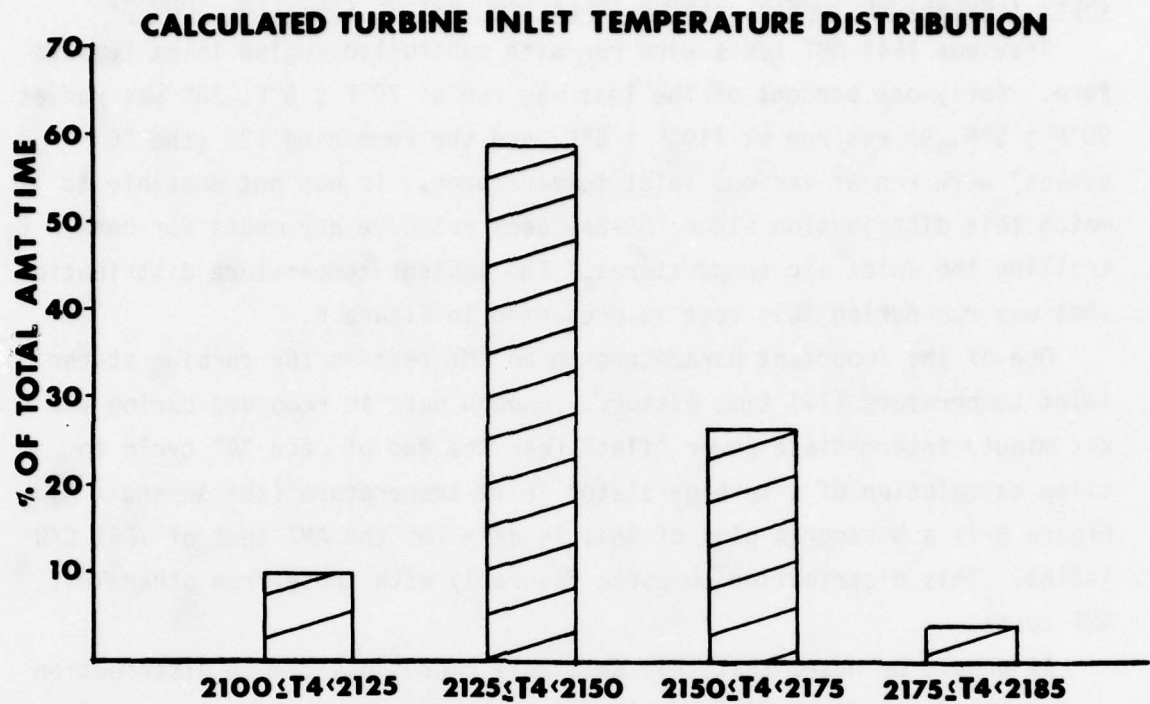


Figure 6 - Ambient Temperature and Calculated Turbine Stator Inlet Temperature Time History

TABLE 2  
NL GOVERNOR CHECK

	T.O. Limit	0 Hours	121 Hours
NL (RPM)	7947-8002	7965	7930*

\*Low but no adjustment made

TABLE 3  
NH GOVERNOR CHECK

	T.O. Limit	0 Hours	121 Hours
NH (RPM)	13000-13070	13017	12991*

\*Low but no adjustment made

TABLE 4  
P3 LIMITER CHECK

	T.O. Limit	0 Hours	121 Hours
P3 (PSIG)	145-155	152.4	151

TABLE 5  
T5.1 PULLDOWN CHECK

	T.O. Limit	0 Hours	121 Hours
T5.1 (°F)	884.5-888.5	888	887.9

HP IGV SCHEDULING TF41 S/N142163

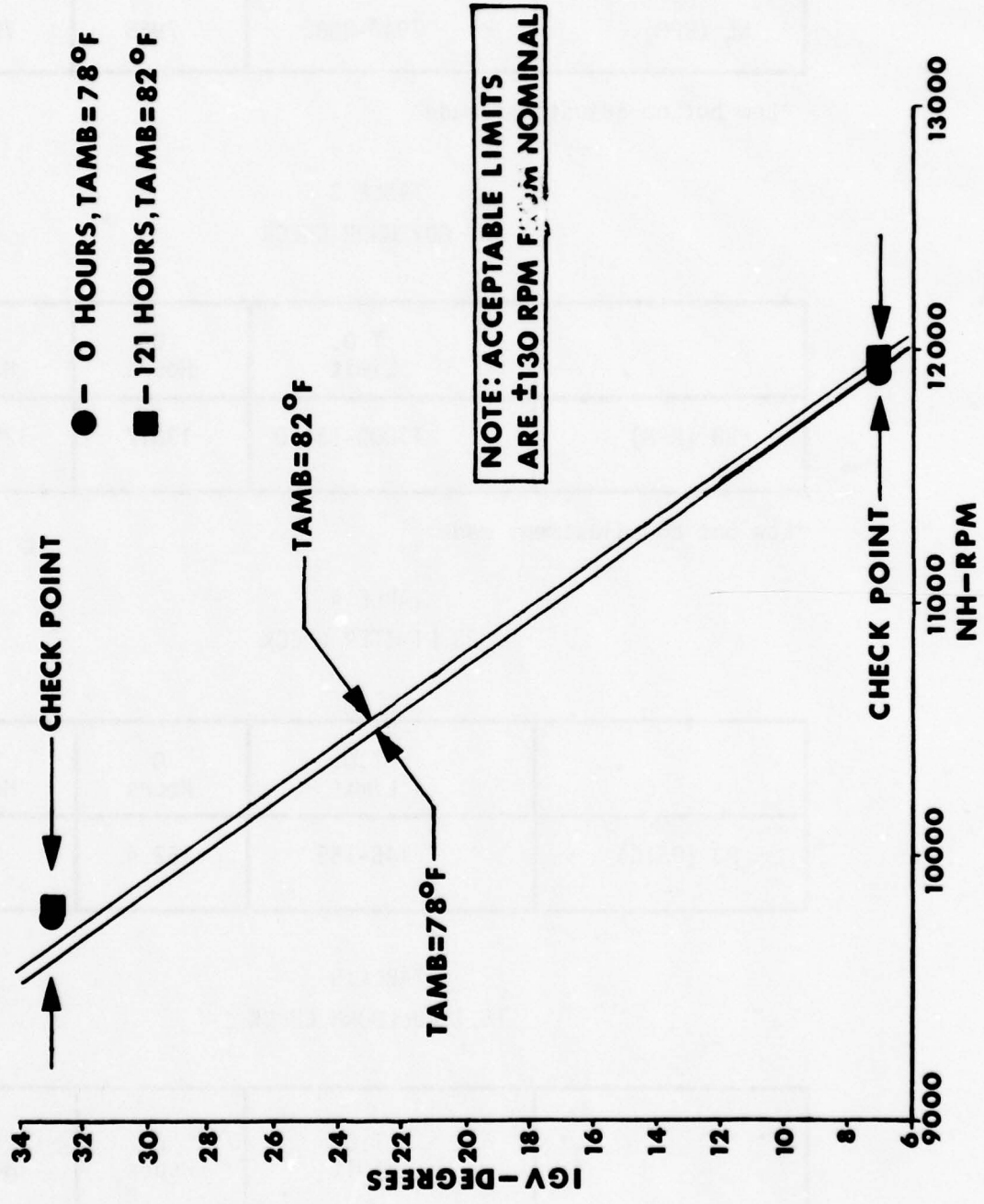


Figure 7 - H.P. IGV Scheduling

ACU/DCU TIME CHECK  
TF41 S/N142623

● - 0 HOURS

■ - 121 HOURS

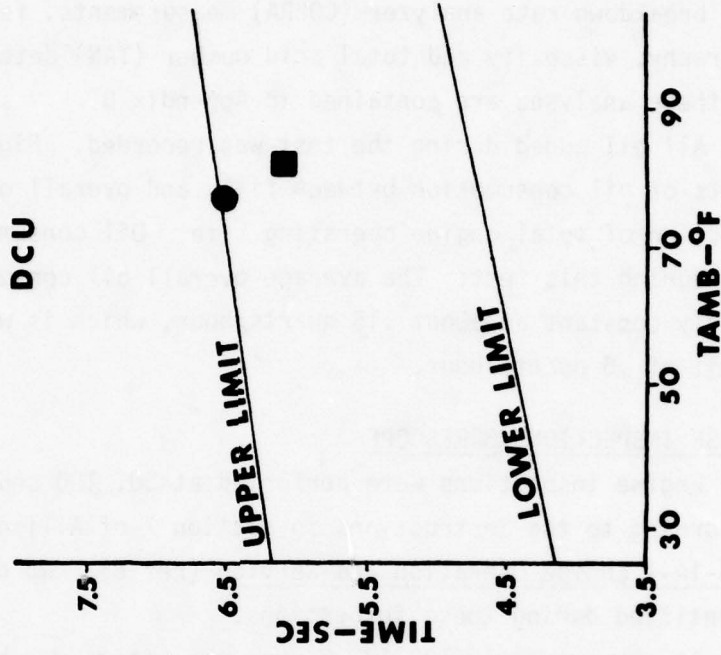
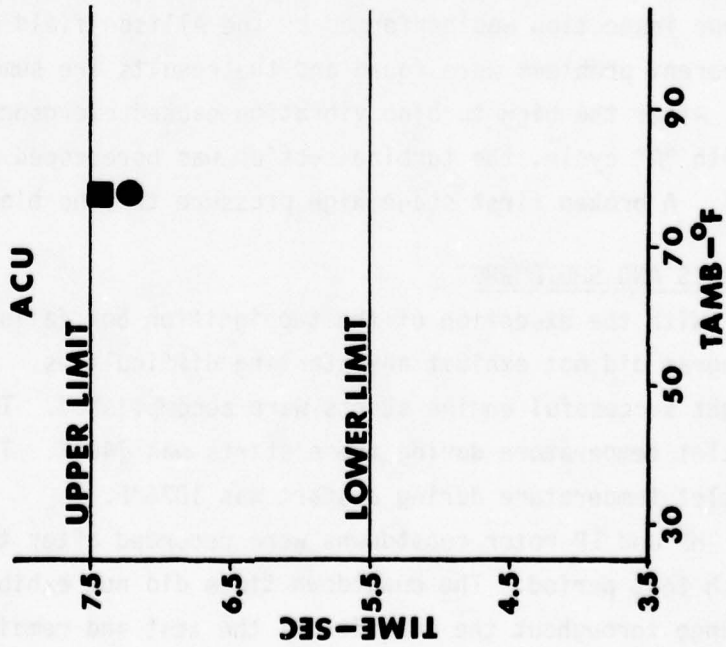


Figure 3 - ACU/DCU Time Checks

intervals. The samples were sent to the Air Force Aero Propulsion Laboratory's Fuels and Lubrications Division for analysis. The tests performed included foaming, spectrometric oil analysis (SOAP), complete oil breakdown rate analyzer (COBRA) measurements, ferrography, gas chromatography, viscosity and total acid number (TAN) determinations. Results of these analyses are contained in Appendix B.

All oil added during the test was recorded. Figures 9 and 10 are plots of oil consumption between fills and overall oil consumption, as a function of total engine operating time. Oil consumption was not a problem during this test. The average overall oil consumption remained fairly constant at about .15 quarts/hour, which is well below the T.O. limit of .5 quarts/hour.

#### PHASE INSPECTIONS/BORESCOPE

Engine inspections were performed at 50, 100 and 150 AMT hours according to the instructions in section 7 of Allison publication No. 1F2, TF4-1A-1 Engine Operation and Service (ref 6). No discrepancies were identified during these inspections.

At approximately 100 AMT hours, the engine was borescoped. It was prepared for borescoping by AFAPL personnel. All fuel nozzles, HPT-2 borescope port plug and intermediate case plugs were removed. The borescope inspection was performed by the Allison field service group. No apparent problems were found and the results are summarized in Appendix B.

After the high turbine vibration caused emergency shutdown during the 224th "A" cycle, the turbine section was borescoped by Laboratory personnel. A broken first stage high pressure turbine blade was discovered.

#### STARTS AND SHUTDOWNS

With the exception of the two ignition box failures, the engine in this program did not exhibit any starting difficulties. Three hundred sixty-eight successful engine starts were accomplished. The average peak turbine outlet temperature during these starts was 740°F. The maximum observed peak outlet temperature during a start was 1036°F.

HP and LP rotor coastdowns were recorded after the final shutdown of each test period. The coastdown times did not exhibit any significant change throughout the duration of the test and remained well above the T.O. minimums of 60 sec for the LP and 20 sec for the HP.

# OIL CONSUMPTION BETWEEN FILLS

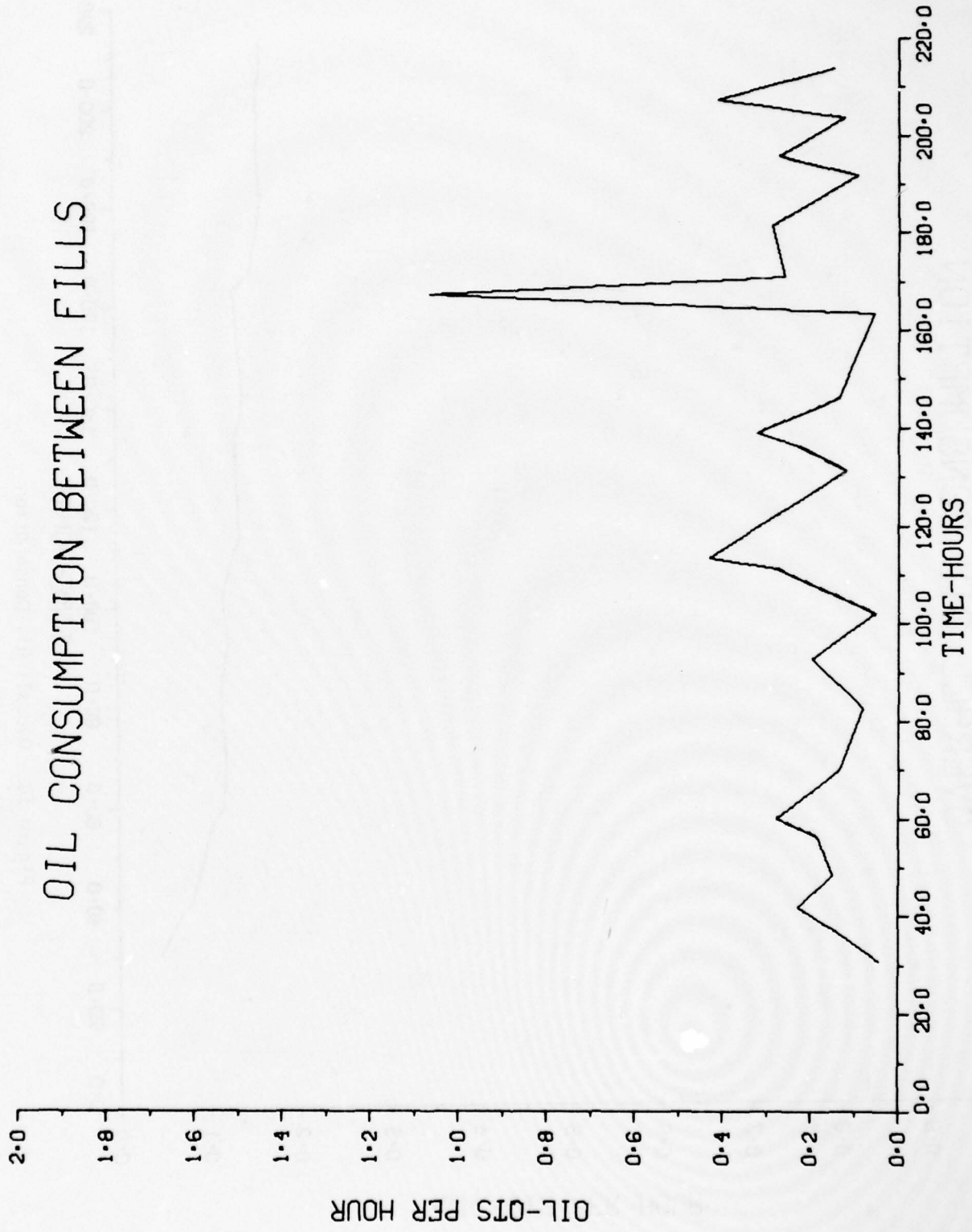


Figure 9 - Oil Consumption Between Fills

# OVERALL OIL CONSUMPTION

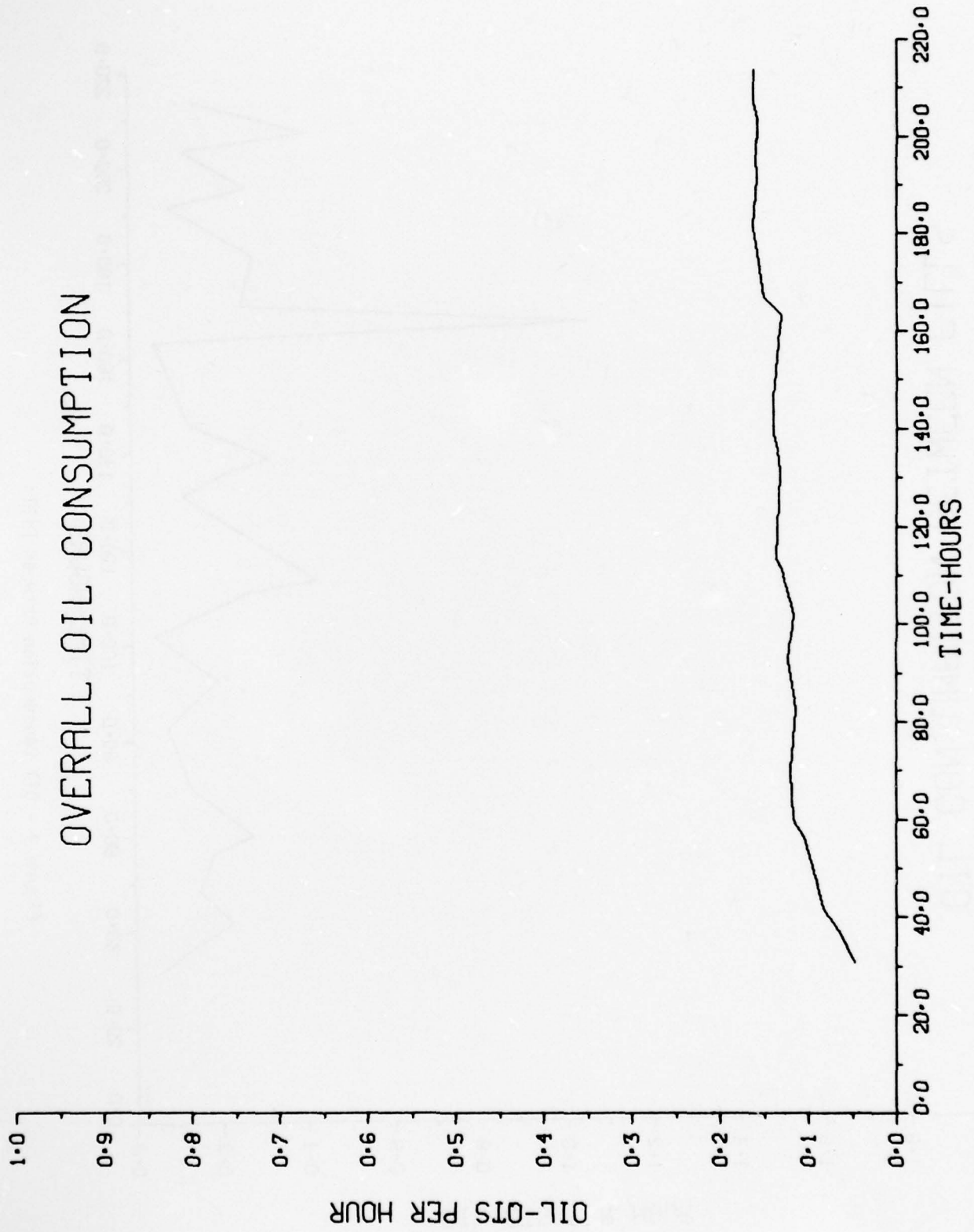
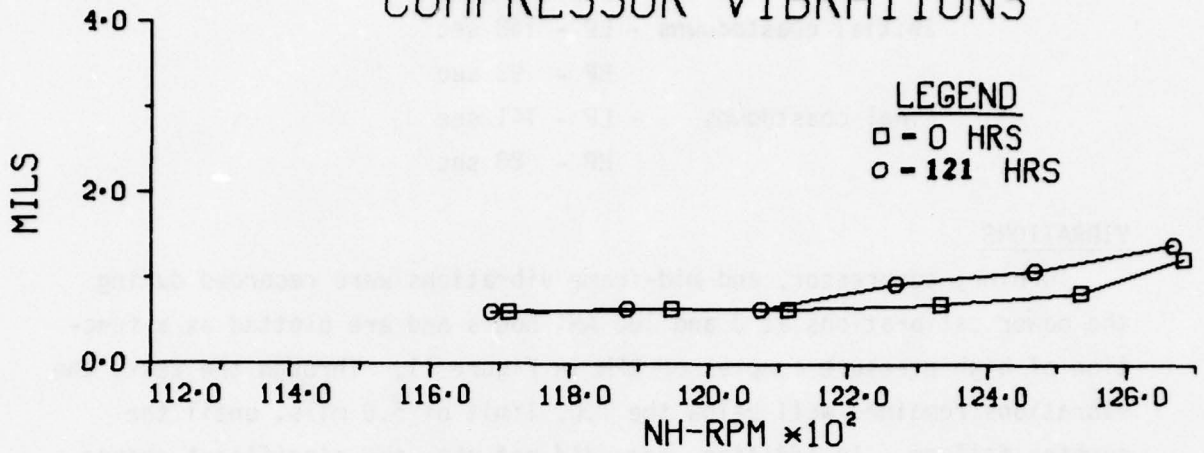


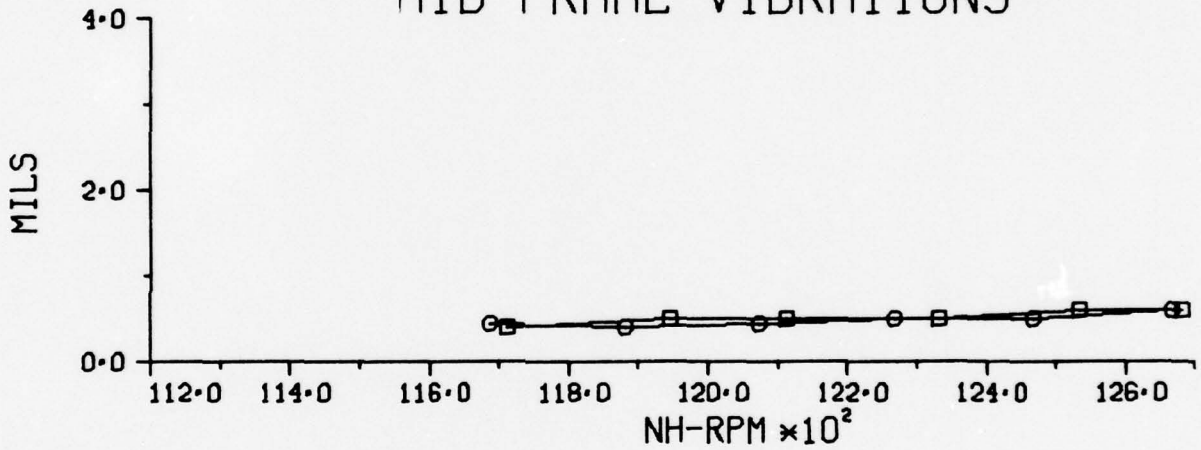
Figure 10 - Overall Oil Consumption



# COMPRESSOR VIBRATIONS



# MID-FRAME VIBRATIONS



# TURBINE VIBRATIONS

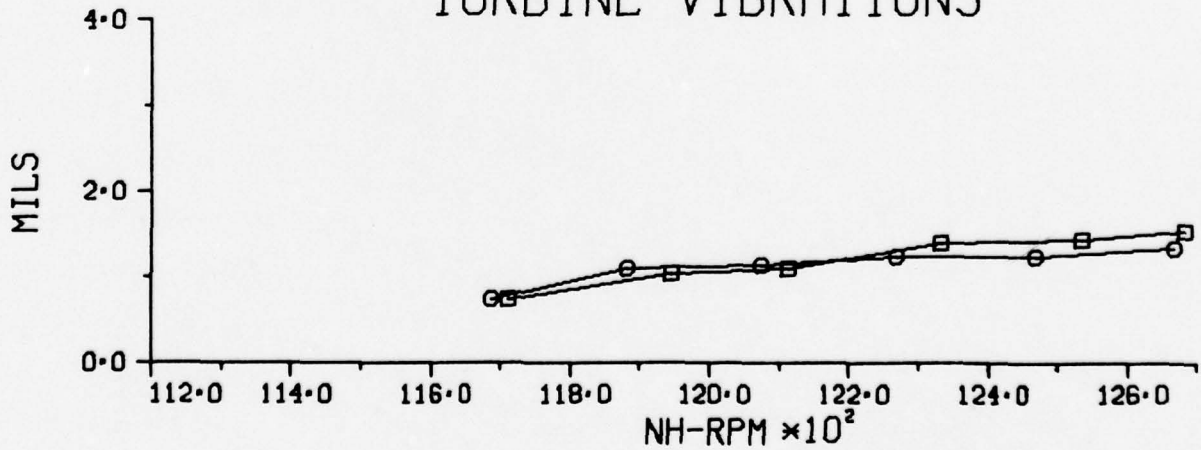


Figure 11 - Engine Vibration History

## SECTION VIII ENGINE PERFORMANCE

### "A" CYCLE PERFORMANCE DATA

A steady-state data point was recorded at intermediate power during the six minute "flat" near the end of each "A" cycle. The raw data was processed through a data reduction computer program based on the equations in Appendix A. Plots of corrected high pressure rotor speed (NHC1), corrected low pressure rotor speed (NLC1), corrected fuel flow (WFC59), corrected turbine discharge pressure (P51C), corrected airflow (W2C1), turbine inlet temperature corrected to 77°F (T4C77), and trimmed turbine exhaust gas temperature corrected to 77°F (T51TC7) and corrected to 59°F (T51TC5) versus thrust corrected to 59°F (FGC59) or 77°F (FGC77) are presented in Figures 12 through 19.

Even though all the data points plotted are at intermediate power, there is a variation in corrected thrust due to the varying engine inlet temperature and engine deterioration. The relatively large amount of scatter in the data is the result of several factors. The control computer, which acquires the instrumentation signal, processes it, displays it on the CRT, and records it on the line printer, introduces a certain amount of random scatter due to the limited word storage size which limits the number of significant figures available. This problem appears to be most pronounced with thermocouple readings where a  $\pm 6^\circ\text{F}$  "bounce" is introduced and the measured thrust which can only be read to  $\pm 100$  lb. An obvious solution to this problem would be to take many readings over a given time span and average them. However, this is not feasible since data can only be recorded at a once per minute rate and the engine takes nearly five of the six available minutes to stabilize. Even with the scatter, the trends shown by these plots are typical of a TF41, and confirm that the engine was operating properly throughout the test until failure.

### MAXIMUM POWER PERFORMANCE DETERIORATION

One of the primary objectives of this test was to quantify engine performance deterioration under realistic usage conditions. In past tests, one approach has been to track maximum power thrust (recorded during the six minute "flat" of each A cycle) as a function of engine operating time.

# CORRECTED HIGH PRESSURE ROTOR SPEED VS CORRECTED THRUST

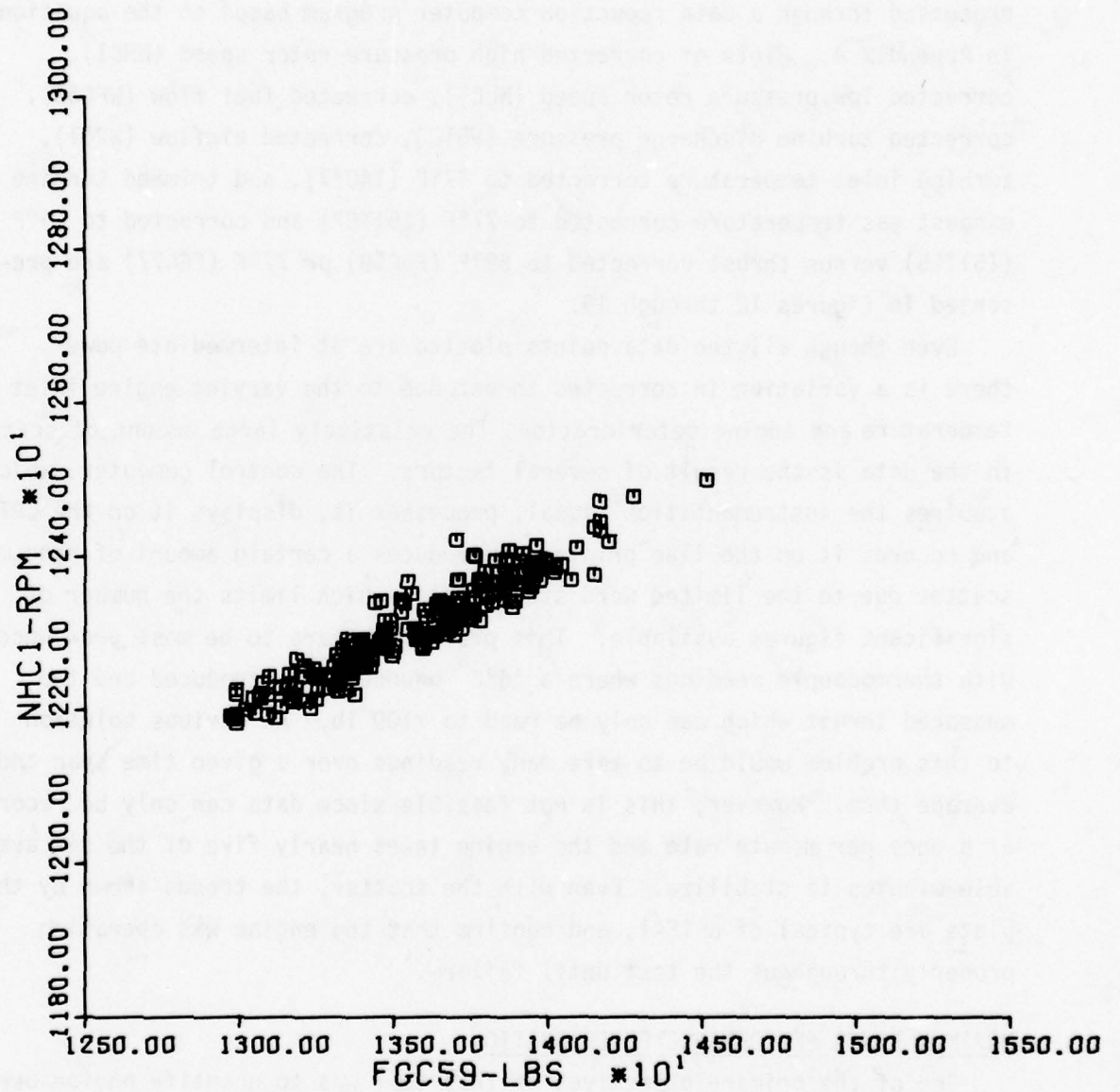


Figure 12

Corrected High Pressure Rotor Speed versus Corrected Thrust

CORRECTED FUEL FLOW VS CORRECTED THRUST

CORRECTED LOW PRESSURE ROTOR SPEED VS CORRECTED THRUST

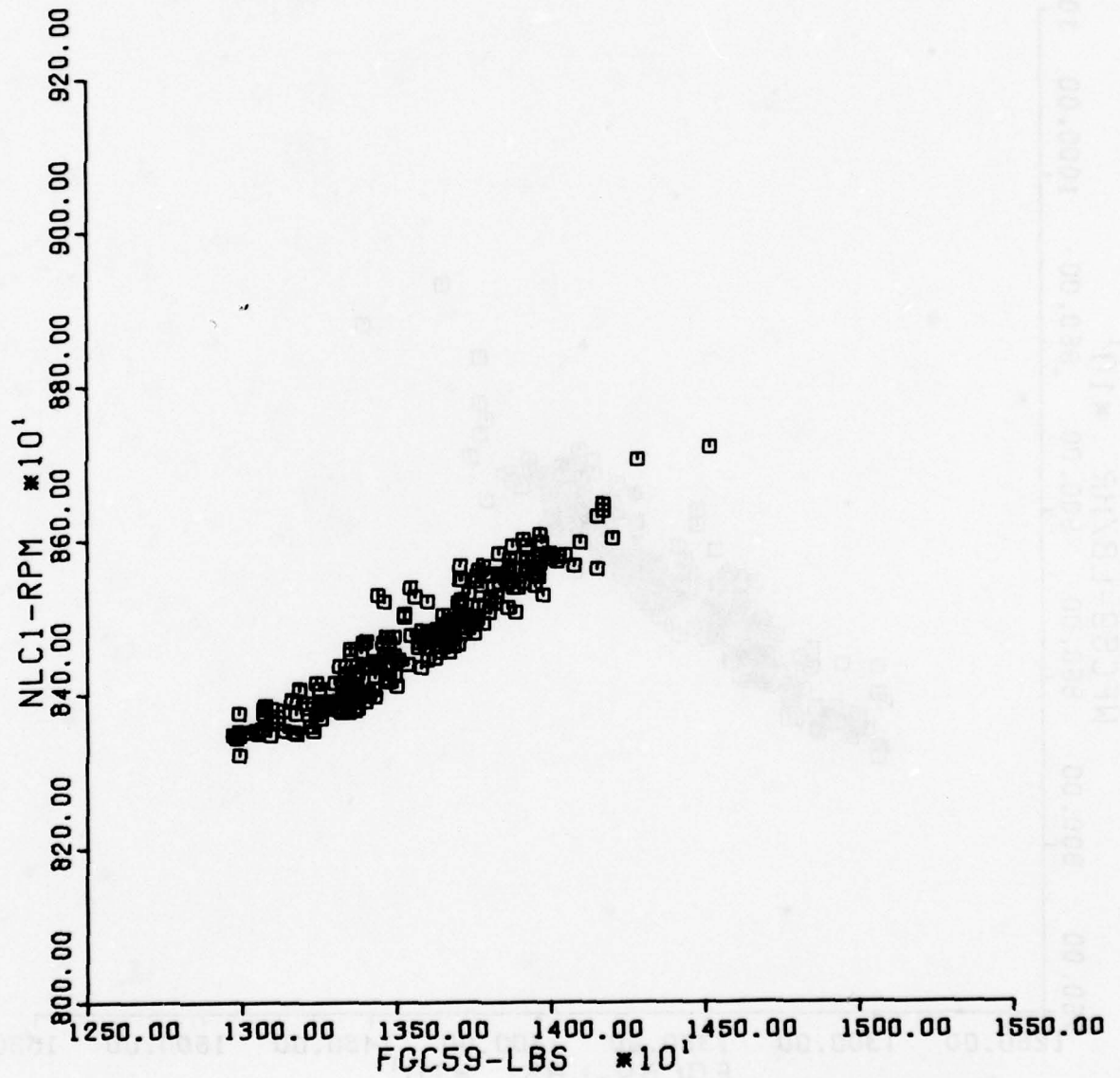


Figure 13

Corrected Low Pressure Rotor Speed versus Corrected Thrust

# CORRECTED FUEL FLOW VS CORRECTED THRUST

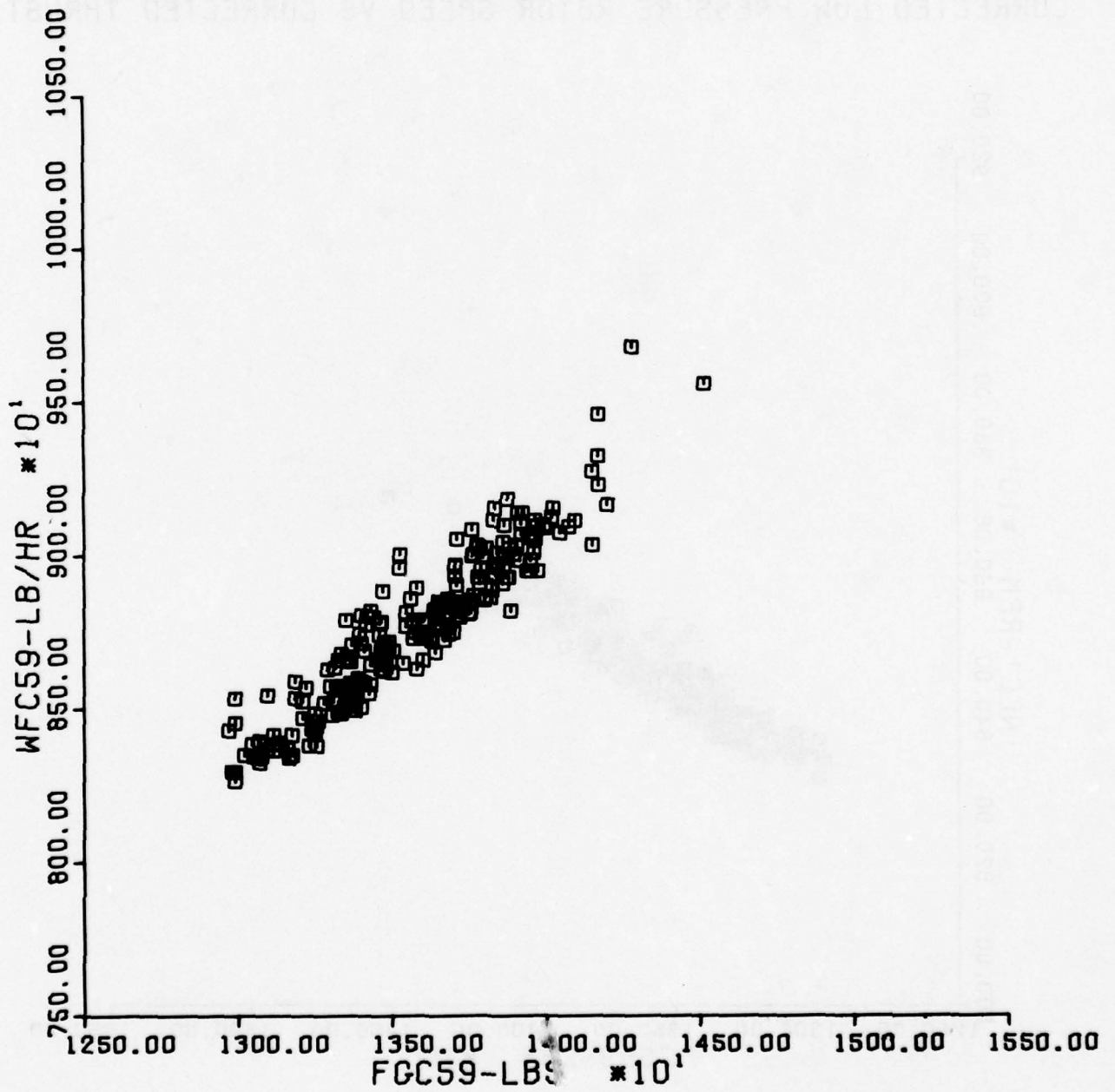


Figure 14 - Corrected Fuel Flow versus Corrected Thrust

CORRECTED TURBINE DISCHARGE PRESSURE VS CORRECTED THRUST

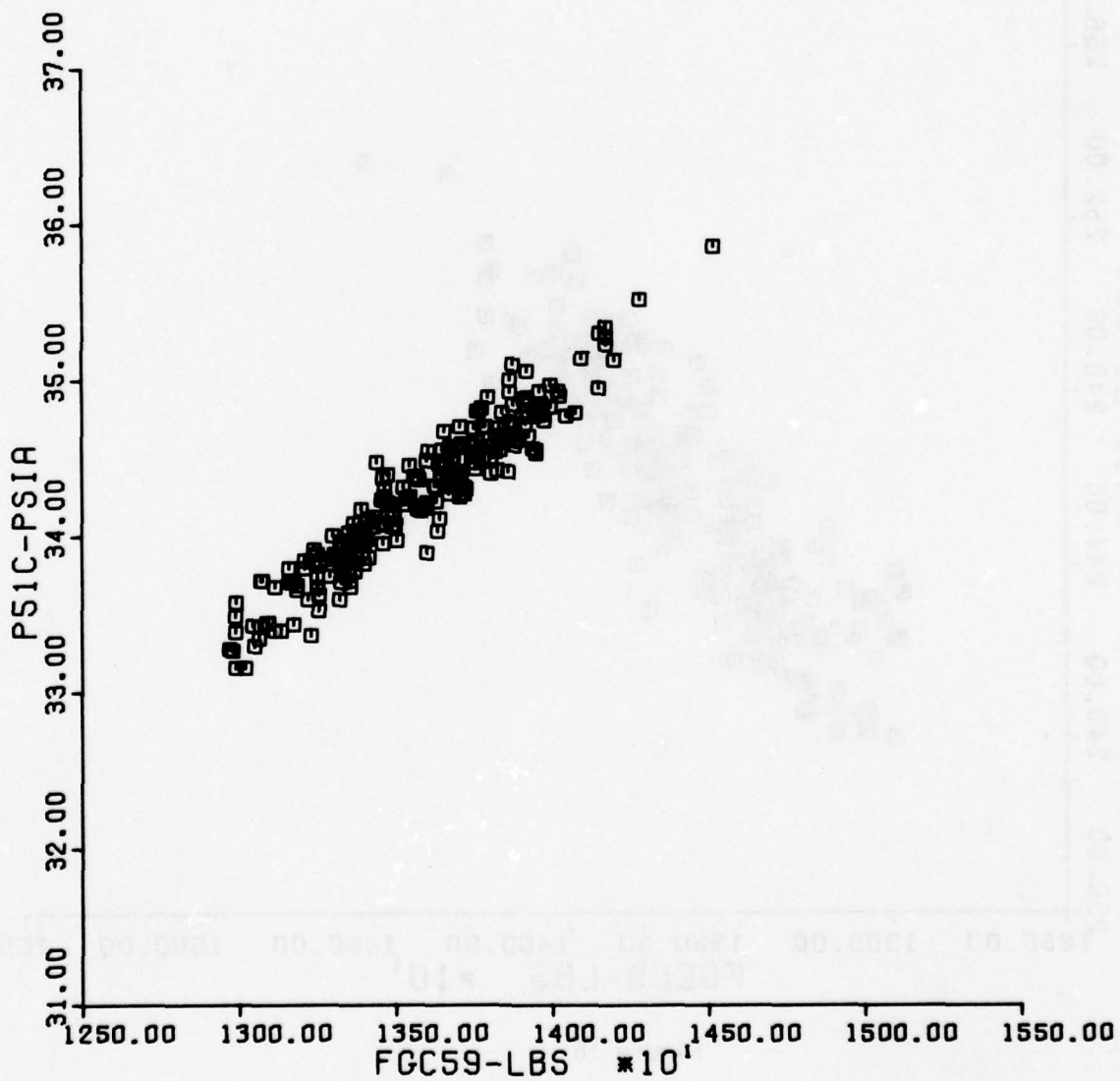


Figure 15 - Corrected Turbine Discharge Pressure versus Corrected Thrust

# CORRECTED INLET AIRFLOW VS CORRECTED THRUST

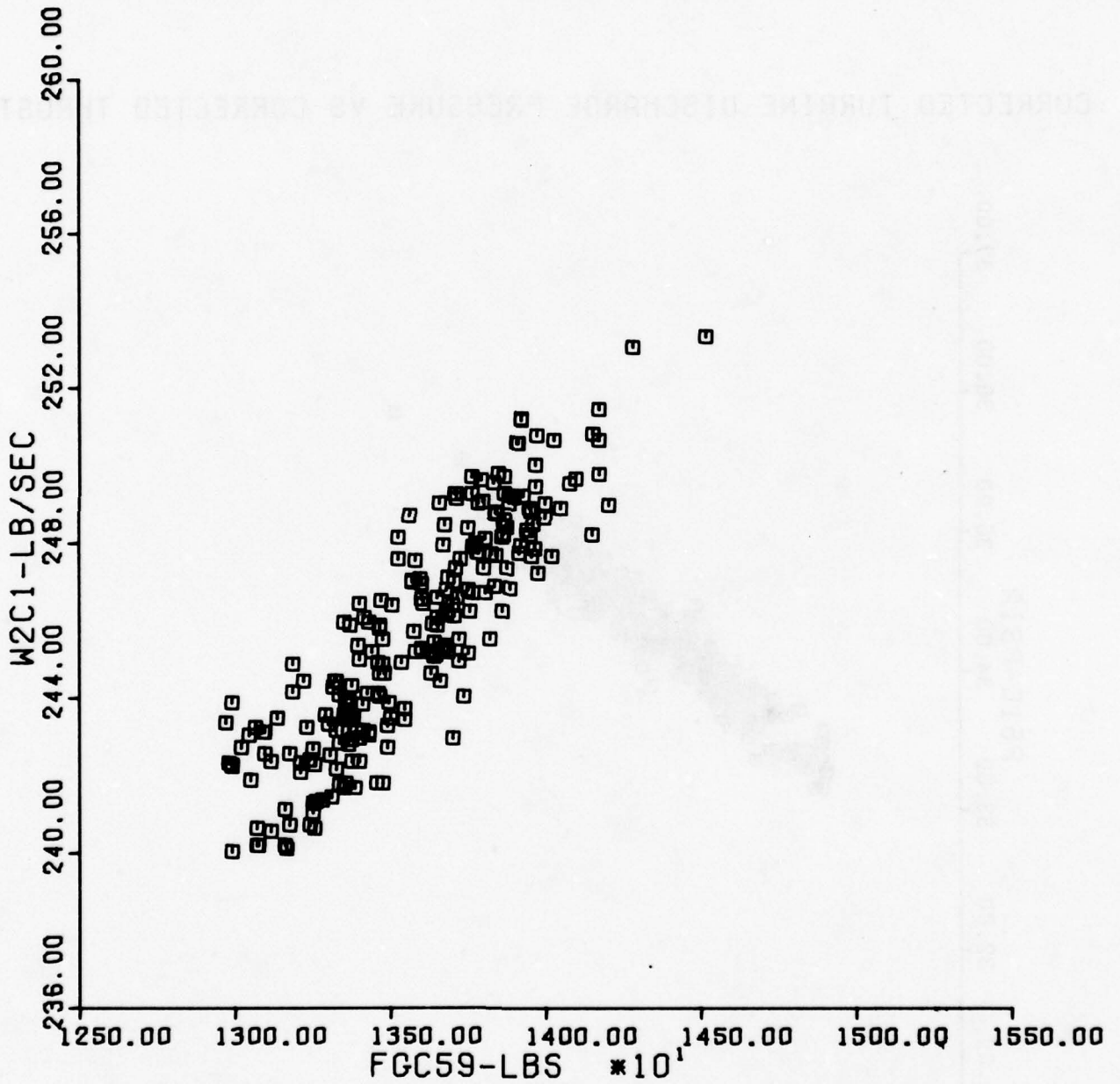


Figure 16

Corrected Inlet Airflow versus Corrected Thrust

CORRECTED TURBINE INLET TEMPERATURE VS CORRECTED THRUST

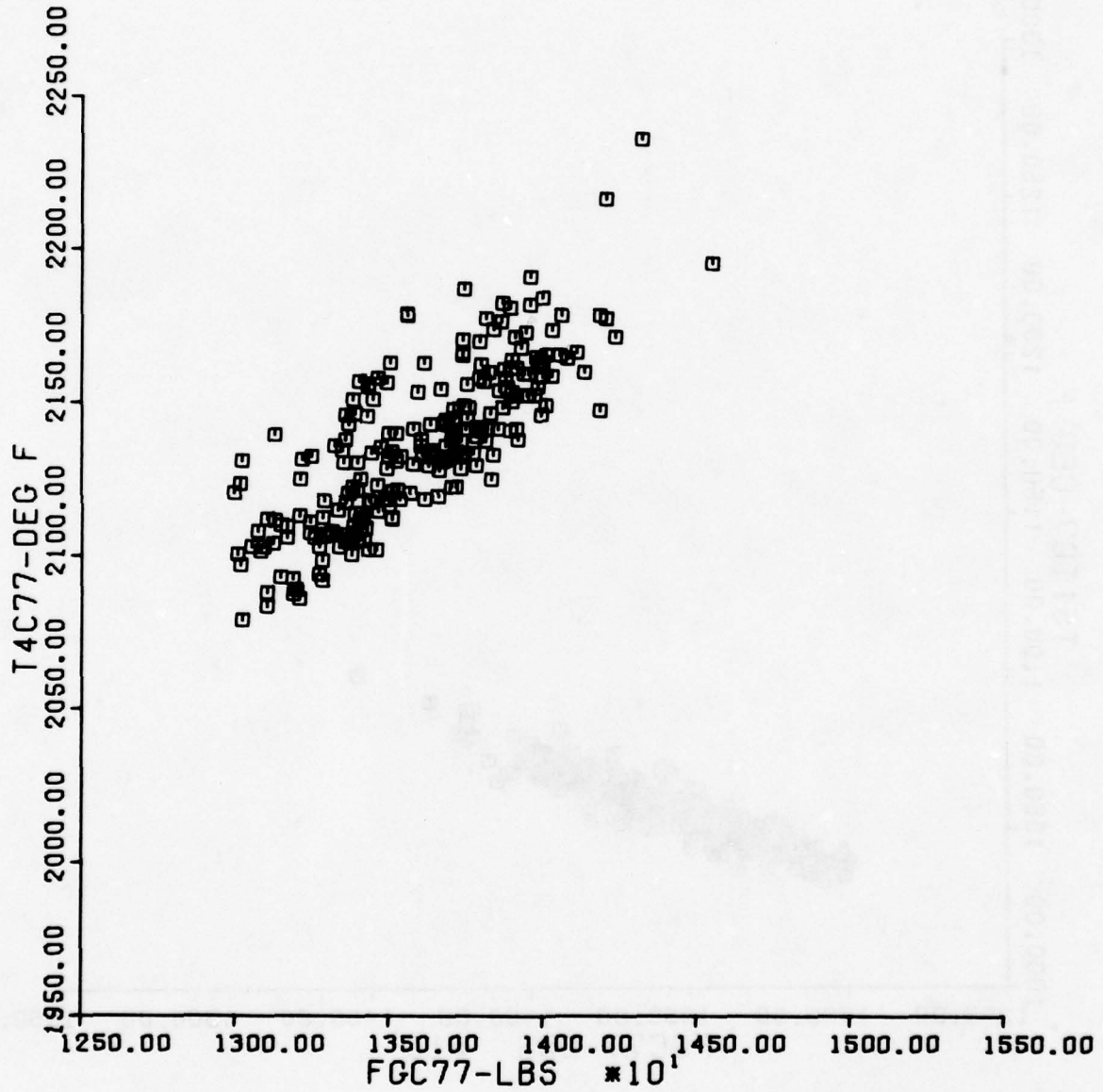


Figure 17

Corrected Turbine Stator Inlet Temperature versus Corrected Thrust

# CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED THRUST

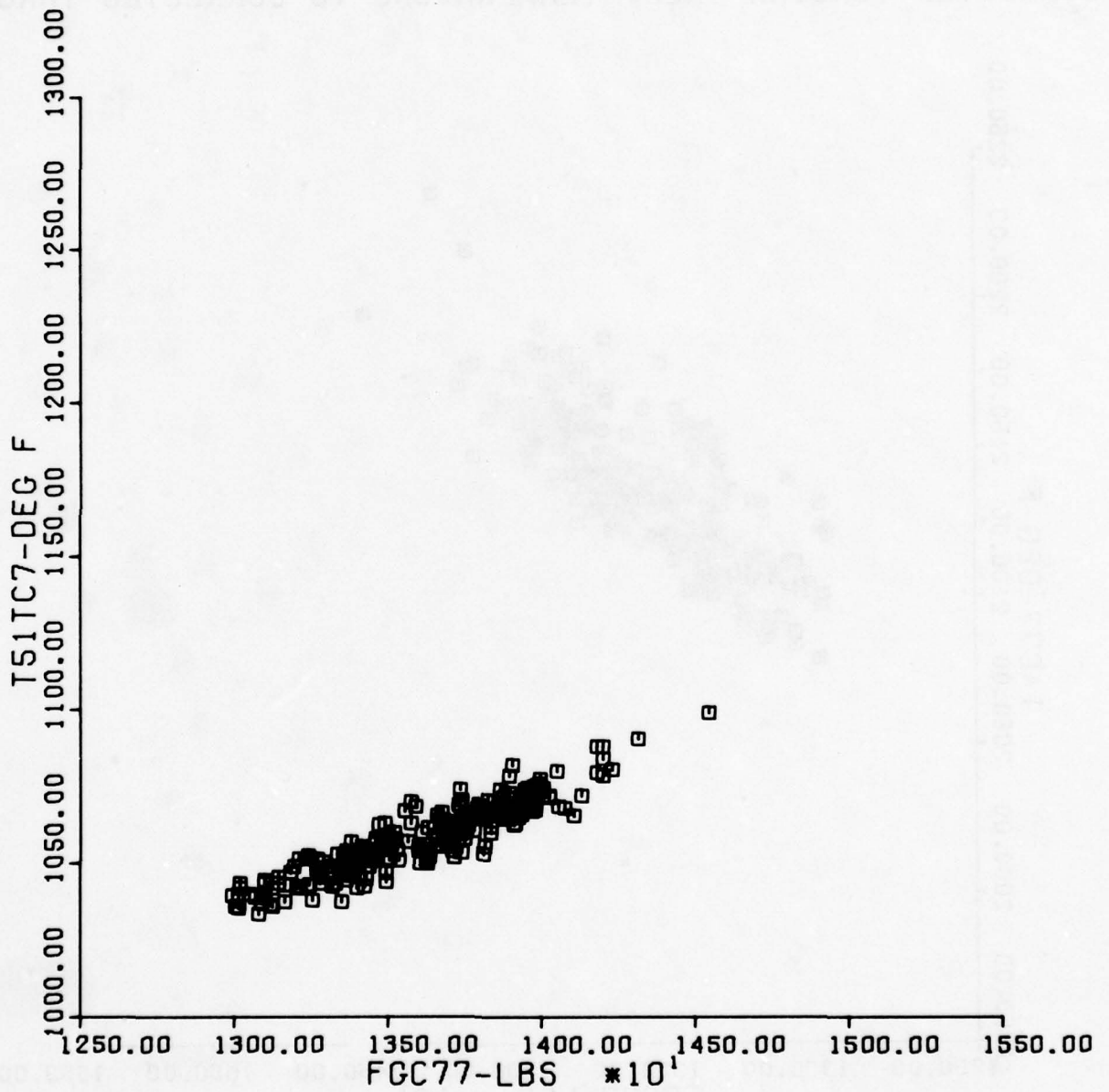


Figure 18

Corrected Exhaust Gas Temperature versus Corrected Thrust

# CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED THRUST

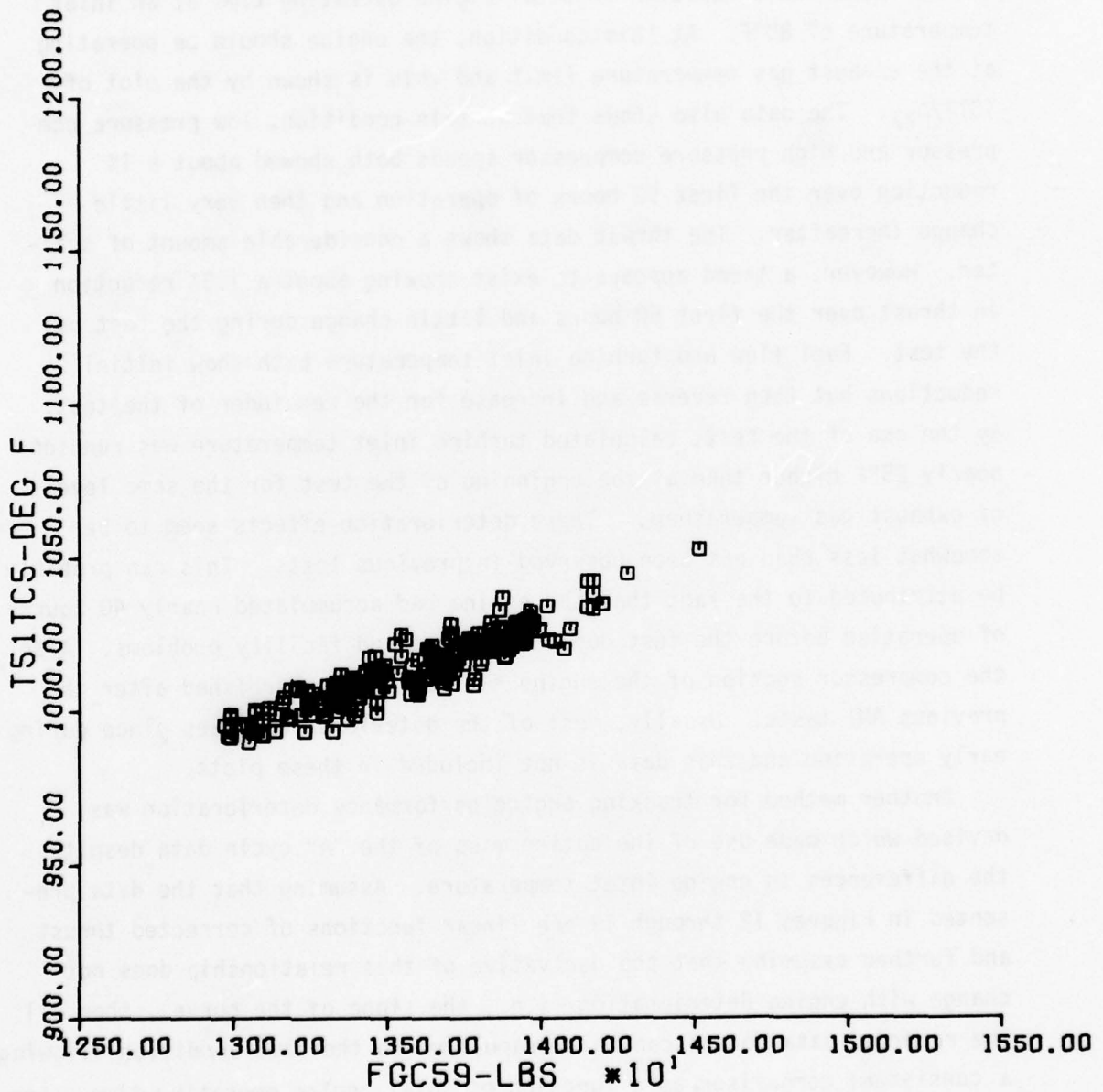


Figure 19

Corrected Exhaust Gas Temperature versus Corrected Thrust

One of the problems with this approach is that thrust is a function of ambient temperature and in Propulsion Laboratory facilities, there is no control over inlet air temperature. Therefore, a search of the data must be made to determine an ambient condition with a reasonable spread in engine hours and enough data points to be able to draw meaningful conclusions.

Figure 20 presents some corrected engine performance parameters at maximum power as a function of total engine operating time at an inlet temperature of 80°F. At this condition, the engine should be operating at the exhaust gas temperature limit and this is shown by the plot of  $T_{51T}/\theta_{77}$ . The data also shows that at this condition, low pressure compressor and high pressure compressor speeds both showed about a 1% reduction over the first 50 hours of operation and then very little change thereafter. The thrust data shows a considerable amount of scatter. However, a trend appears to exist showing about a 1.5% reduction in thrust over the first 50 hours and little change during the rest of the test. Fuel flow and turbine inlet temperature both show initial reductions but then reverse and increase for the remainder of the test. By the end of the test, calculated turbine inlet temperature was running nearly 25°F higher than at the beginning of the test for the same level of exhaust gas temperature. These deterioration effects seem to be somewhat less than has been observed in previous tests. This can probably be attributed to the fact that the engine had accumulated nearly 40 hours of operation before the test due to build-up and facility problems. Also the compressor section of the engine had not been refurbished after the previous AMT tests. Usually, most of the deterioration takes place during early operation and this data is not included in these plots.

Another method for tracking engine performance deterioration was devised which made use of the entire mass of the "A" cycle data despite the differences in engine inlet temperature. Assuming that the data presented in Figures 12 through 19 are linear functions of corrected thrust and further assuming that the derivative of this relationship does not change with engine deterioration (i.e., the slope of the curve), then all the recorded data points can be extrapolated to the same condition allowing a consistent comparison as a function of total engine operating time. Comparisons were made extrapolating the data to a constant corrected trimmed exhaust gas temperature and also for a constant corrected low pressure rotor speed.

TAMB=80°F

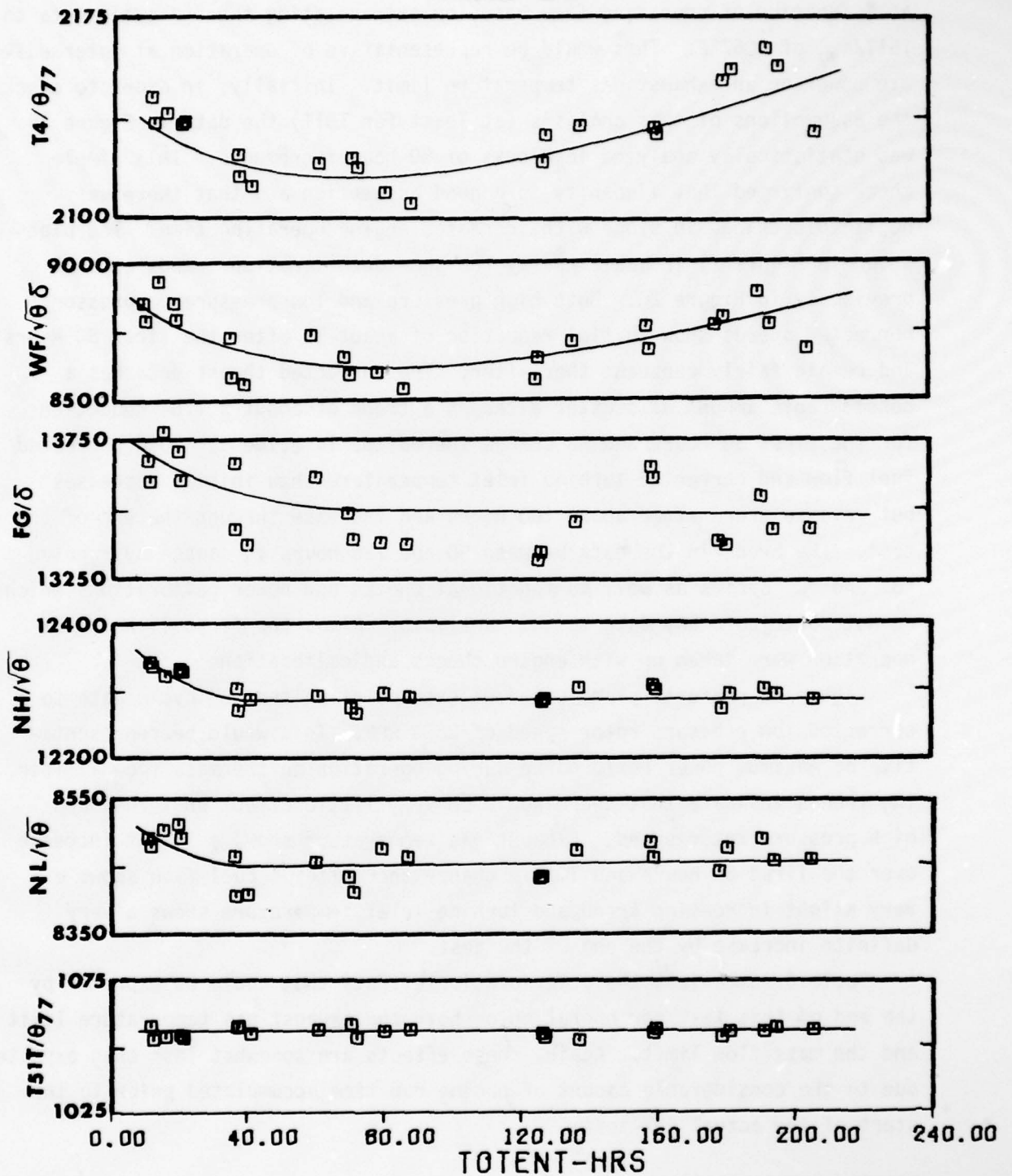


Figure 20

Deterioration Characteristics at Constant Ambient Temperature

Figure 21 presents plots of some important engine performance parameters as a function of operating time based on extrapolating the "A" cycle data to  $T_{51T}/\theta_{77}$  of  $1067^{\circ}\text{F}$ . This would be representative of operation at intermediate power on an exhaust gas temperature limit. Initially, in order to check the assumptions of this analysis (at least for T51T) the data in Figure 18 was statistically analyzed in blocks of 50 hour increments. This simple check confirmed that linearity is a good assumption and that there was negligible change in slope with increased engine operating time. The plots shown in Figure 21 indicate nearly the same deterioration trends as seen previously in Figure 20. Both high pressure and low pressure compressor corrected speeds show initial reduction of about 1% after the first 50 hours and remain fairly constant thereafter. The corrected thrust data has a considerable amount of scatter although a trend of about a 1.5% reduction for the first 50 hours and no change thereafter is evident. Both corrected fuel flow and corrected turbine inlet temperature show initial decreases but reverse trend after about 100 hours and increase through the end of the test. The break in the data between 90 and 125 hours is caused by running "B" and "C" cycles as well as functional checks and power calibrations which do not contribute any data to this analysis. Also, the first 11 hours of operation were taken up with engine checks and calibrations.

Figure 22 presents plots based on extrapolating the "A" cycle data to a corrected low pressure rotor speed of 8600 RPM. This would be representative of maximum power performance during operation on the mass flow limiter. The trends indicate that there would be very little effect on thrust and high pressure rotor speed. Exhaust gas temperature shows a slight increase over the first 50 hours and little change thereafter. Fuel flow shows a very slight increasing trend and turbine inlet temperature shows a very definite increase by the end of the test.

Table 6 summarizes the deterioration effects that could be expected by the end of this test for operation on both the exhaust gas temperature limit and the mass flow limit. Again, these effects are somewhat less than expected due to the considerable amount of engine run time accumulated prior to the start of the actual AMT test.

#### PERFORMANCE CALIBRATIONS

Steady state power calibrations were performed before the AMT test and after 100 AMT hours (121 total test hours). The engine was allowed to

$T_{51T}/\theta_{77} = 1067^{\circ}F$

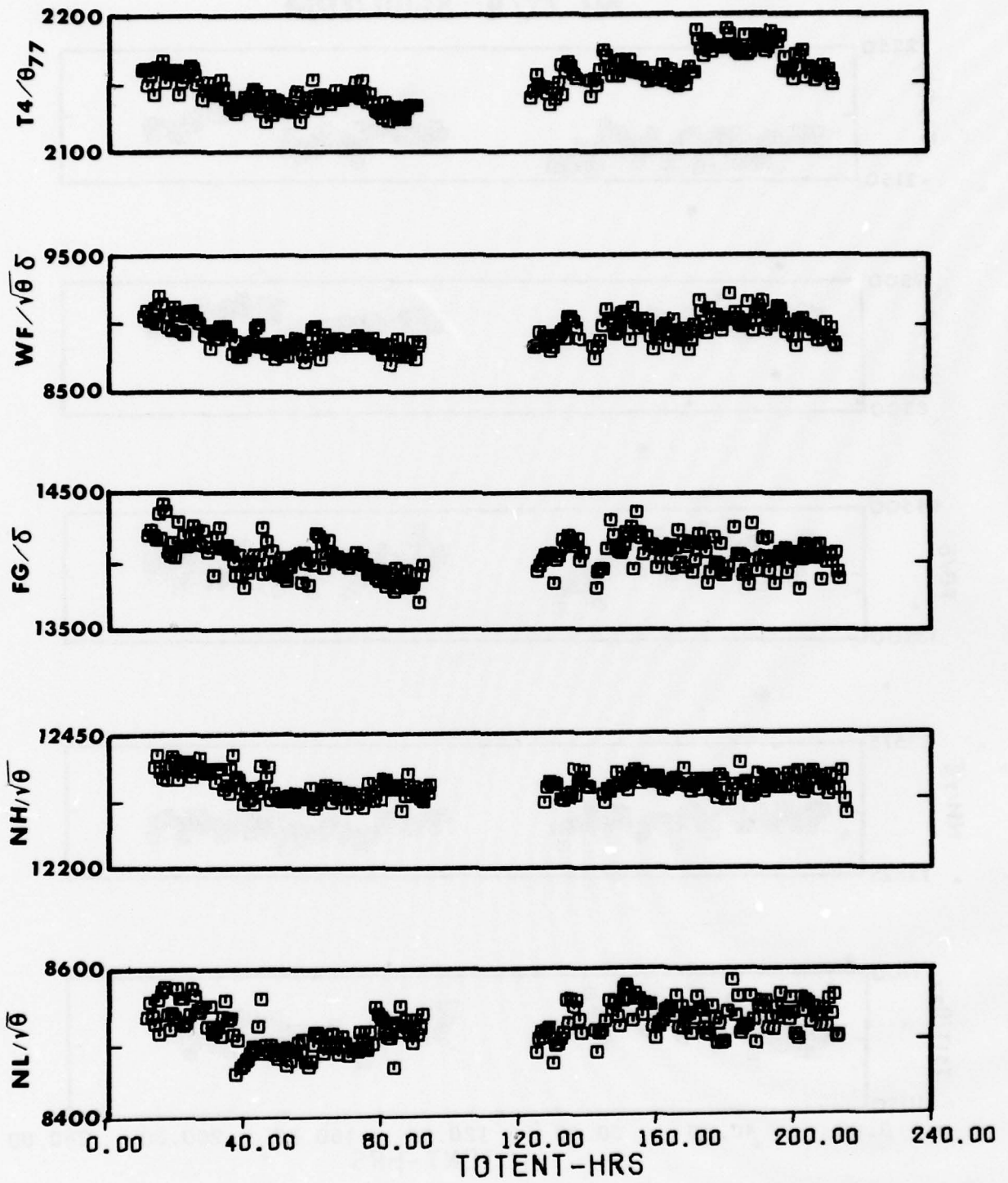


Figure 21

Deterioration Characteristics at Constant Corrected Exhaust Gas Temperature

NL  $\sqrt{\theta} = 8600$  RPM

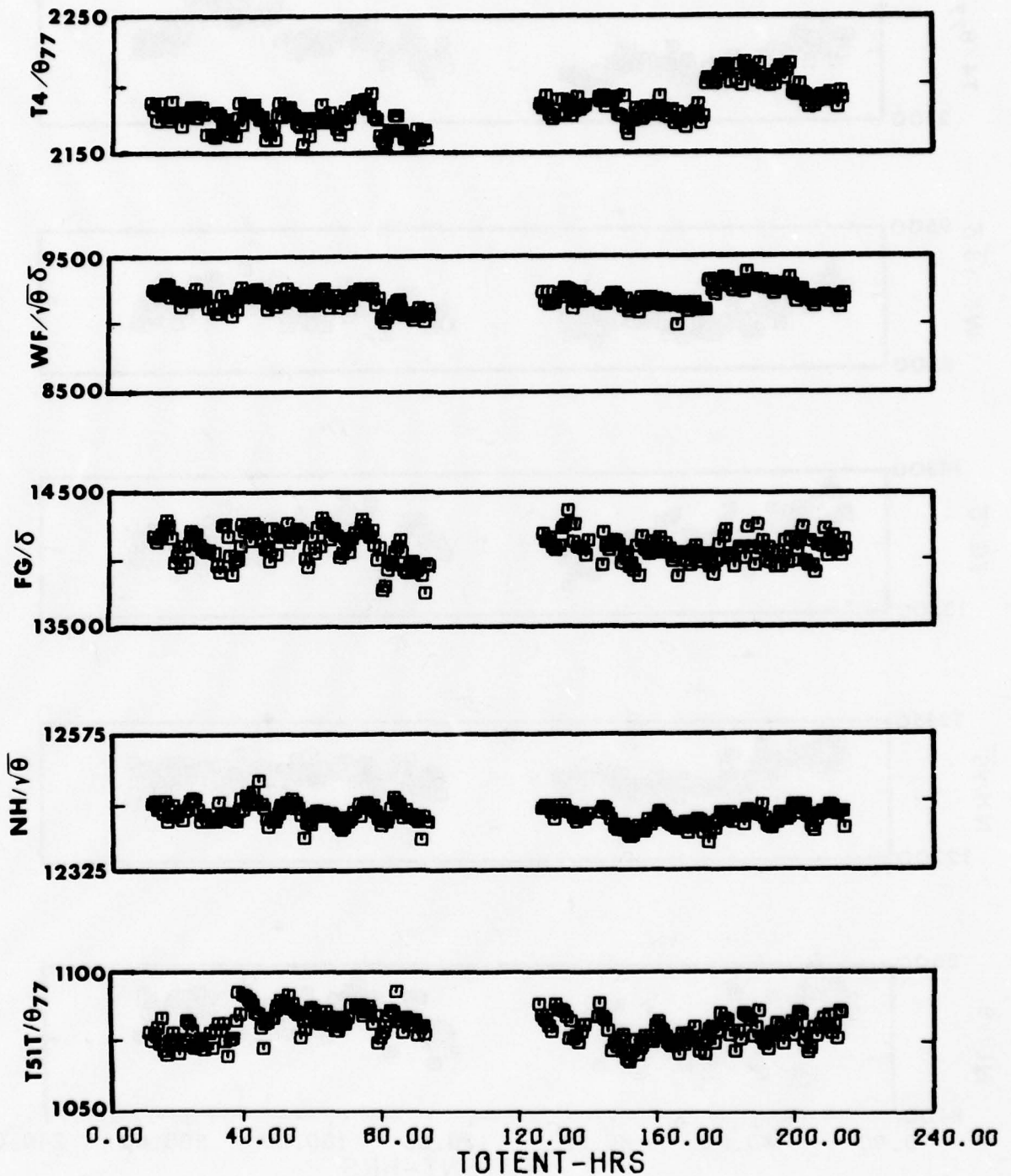


Figure 22

Deterioration Characteristics at Constant Corrected Low Pressure  
Rotor Speed

TABLE 6  
 ESTIMATED DETERIORATION EFFECTS AFTER  
 214 OPERATING HOURS

PARAMETER	$T_{51T}/\theta_{77} = 1067^{\circ}\text{F}$	$NL/\sqrt{\theta} = 8600\text{RPM}$
$FG/\delta$	-1.5%	0
$NL/\sqrt{\theta}$	- .5%	N/A
$NH/\sqrt{\theta}$	- .5%	0
$T_{51T}/\theta_{77}$	N/A	+ .7%
$WF/\sqrt{\theta\delta}$	+ .5%	+ .8%
$T_4/\theta_{77}$	+1.2%	+1.2%

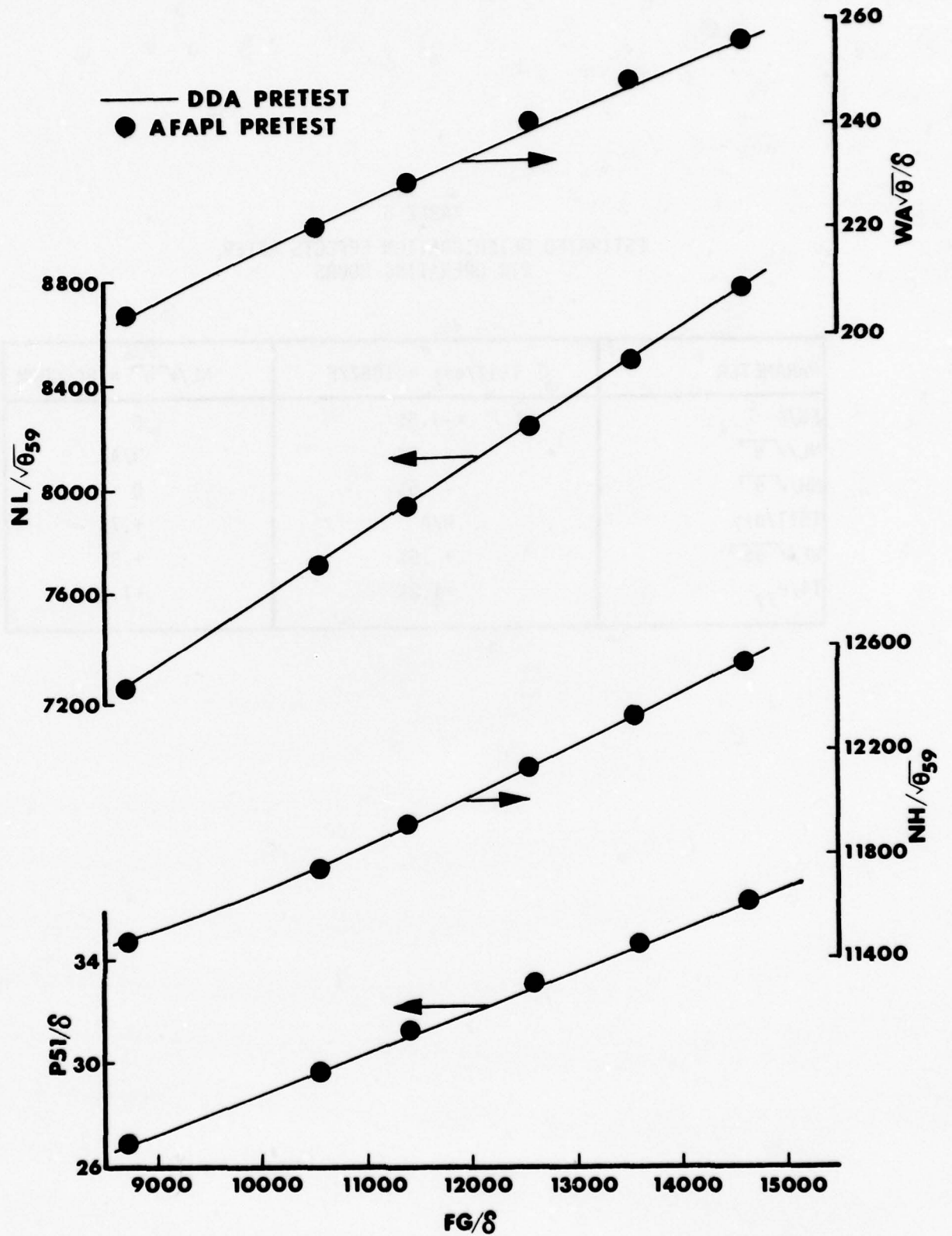


Figure 23 - Comparison of AFAPL and DDA Pre-Test Power Calibration Data

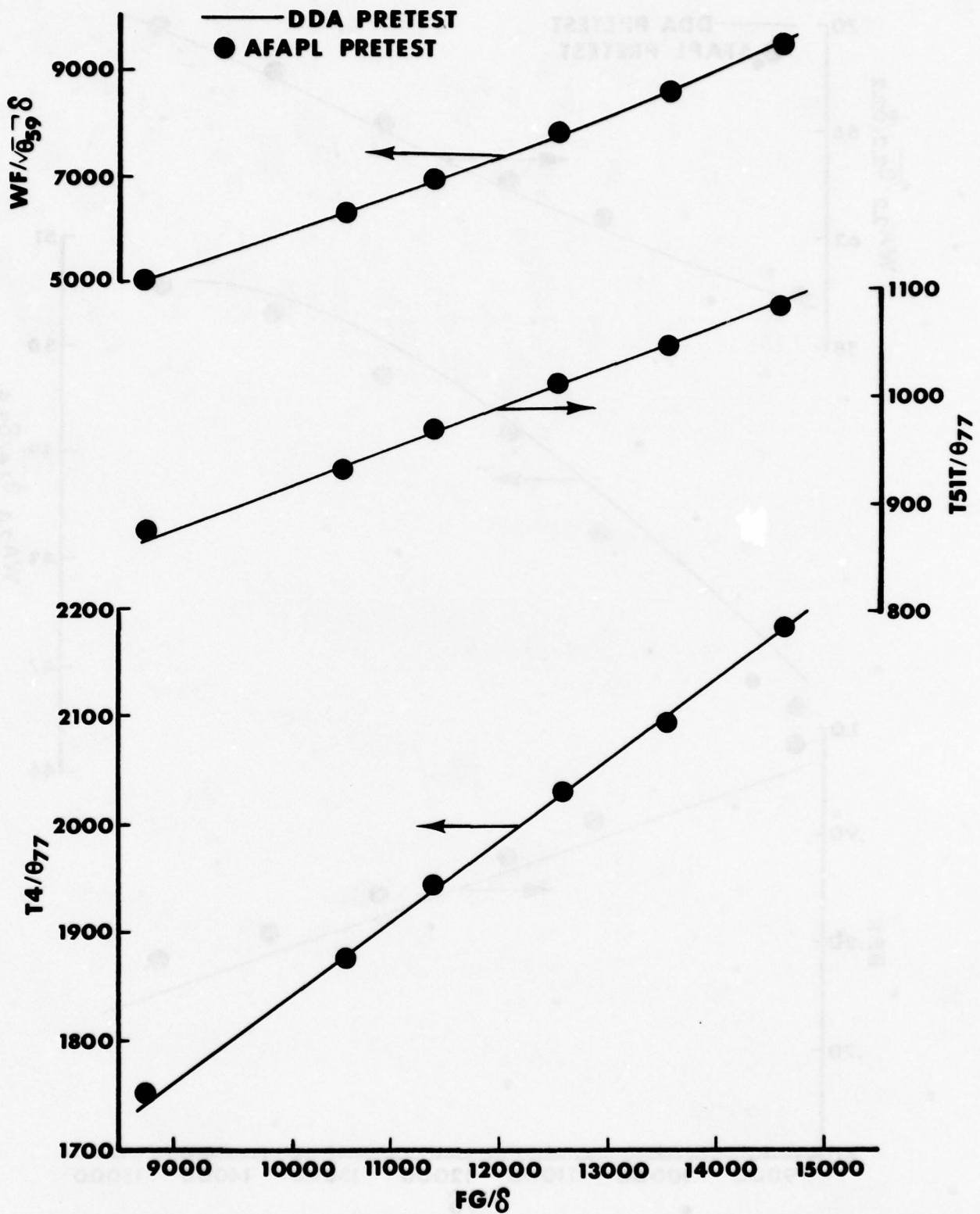


Figure 24 - Comparison of AFAPL and DDA Pre-Test Power Calibration Data

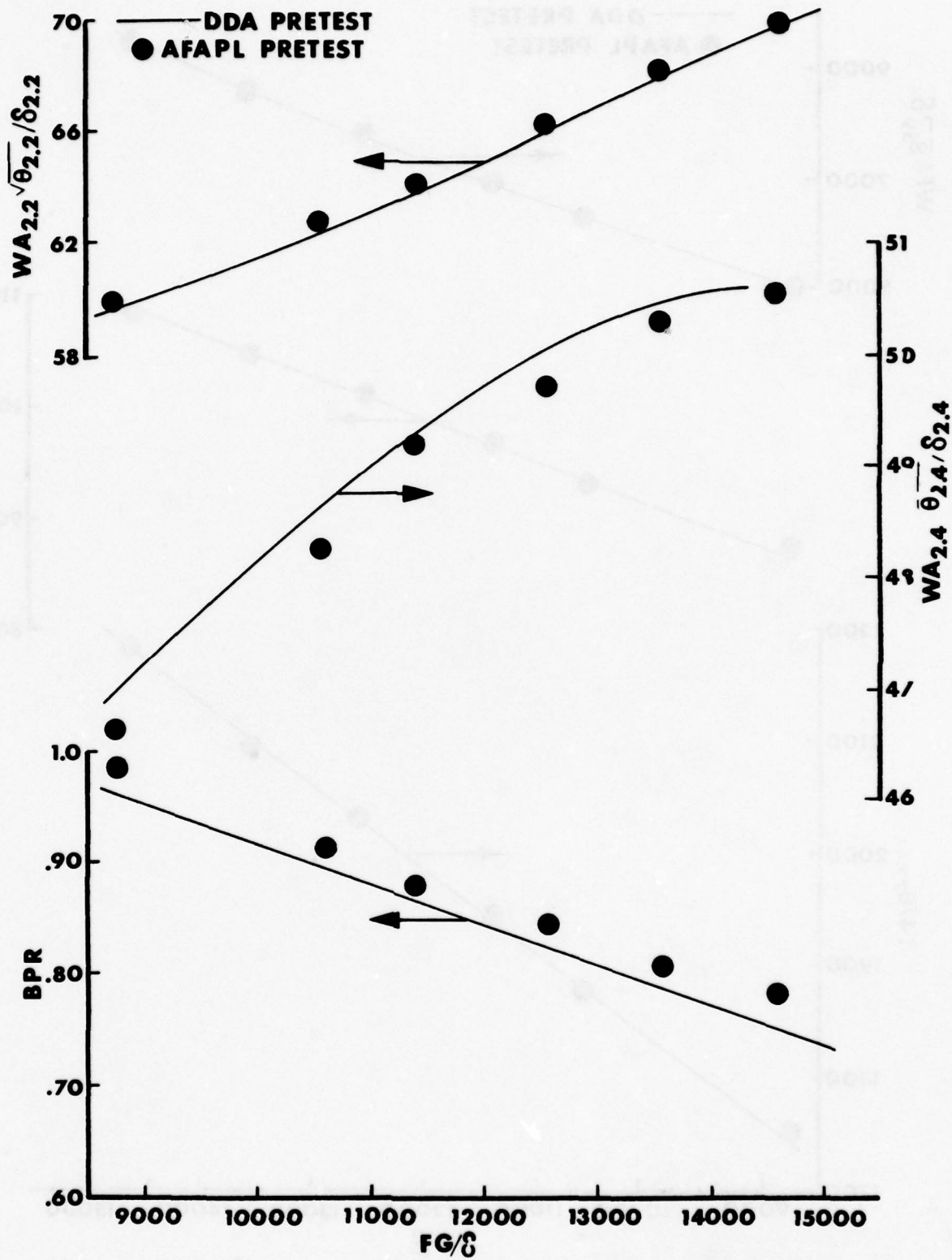


Figure 25 - Comparison of AFAPL and DDA Pre-Test Power Calibration Data

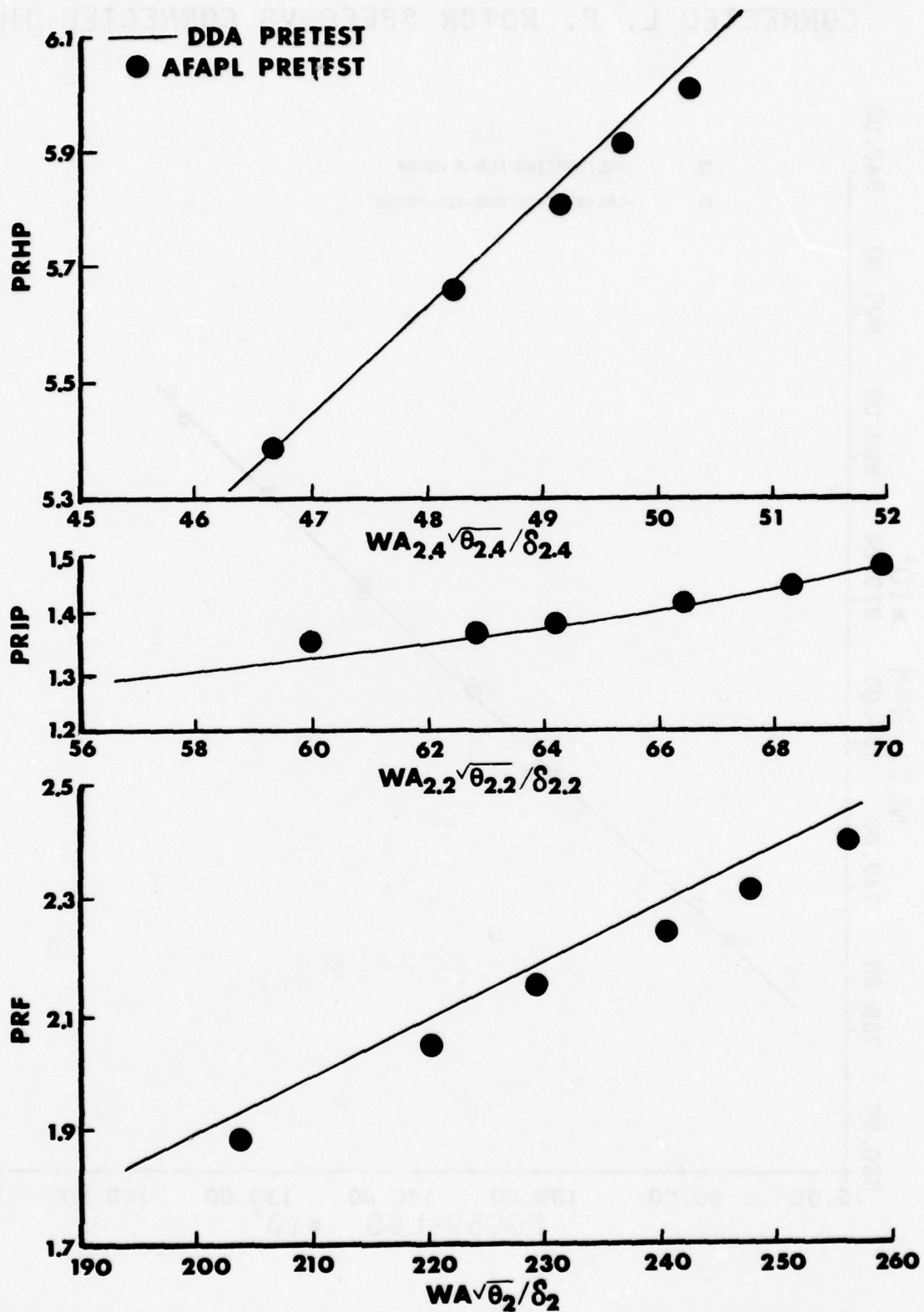


Figure 26 - Comparison of AFAPL and DDA Pre-Test Power Calibration Data

# CORRECTED L. P. ROTOR SPEED VS CORRECTED THRUST

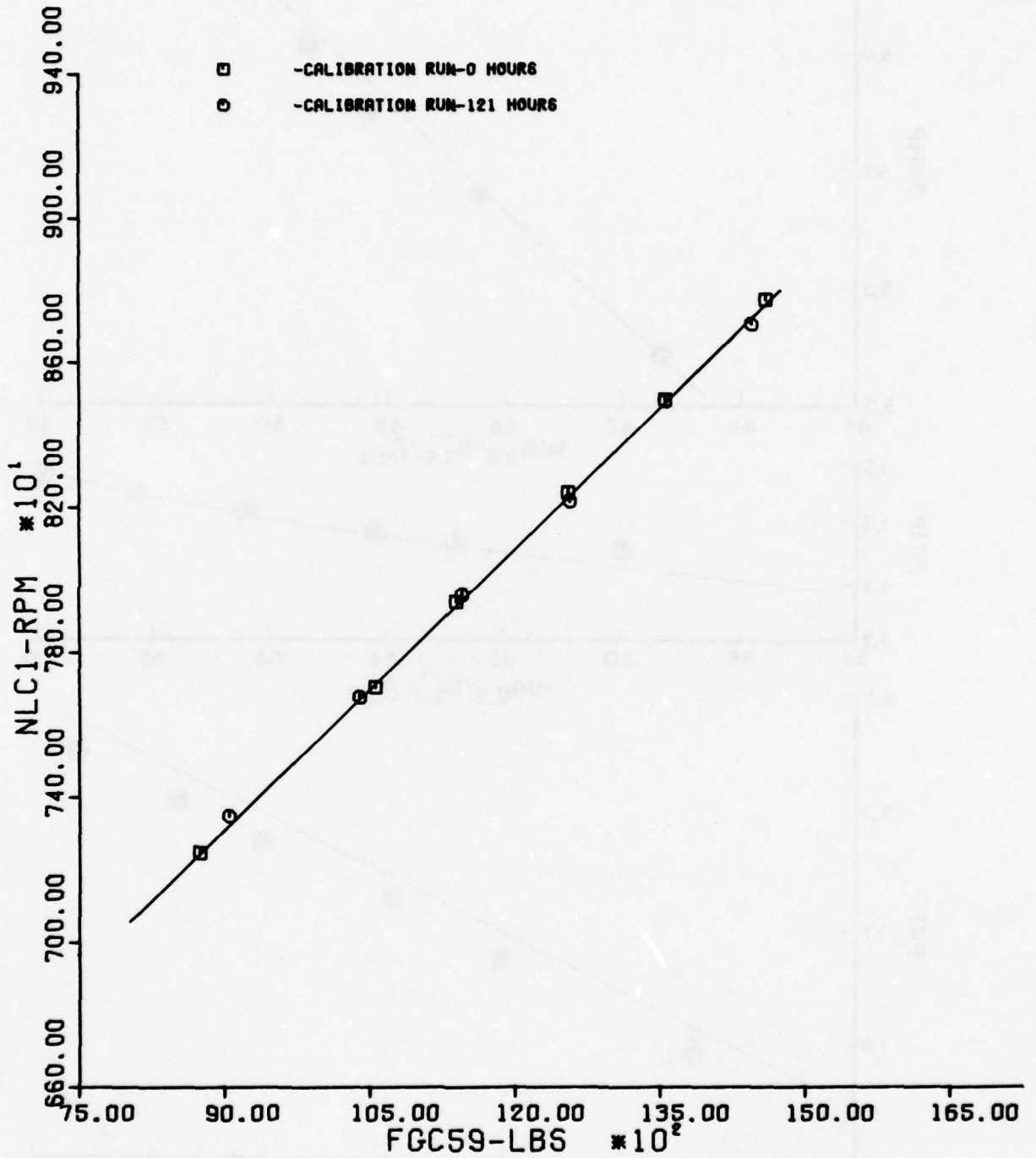


Figure 27 - Corrected L.P. Rotor Speed versus Corrected Thrust

CORRECTED EXHAUST GAS PRESSURE VS CORRECTED THRUST

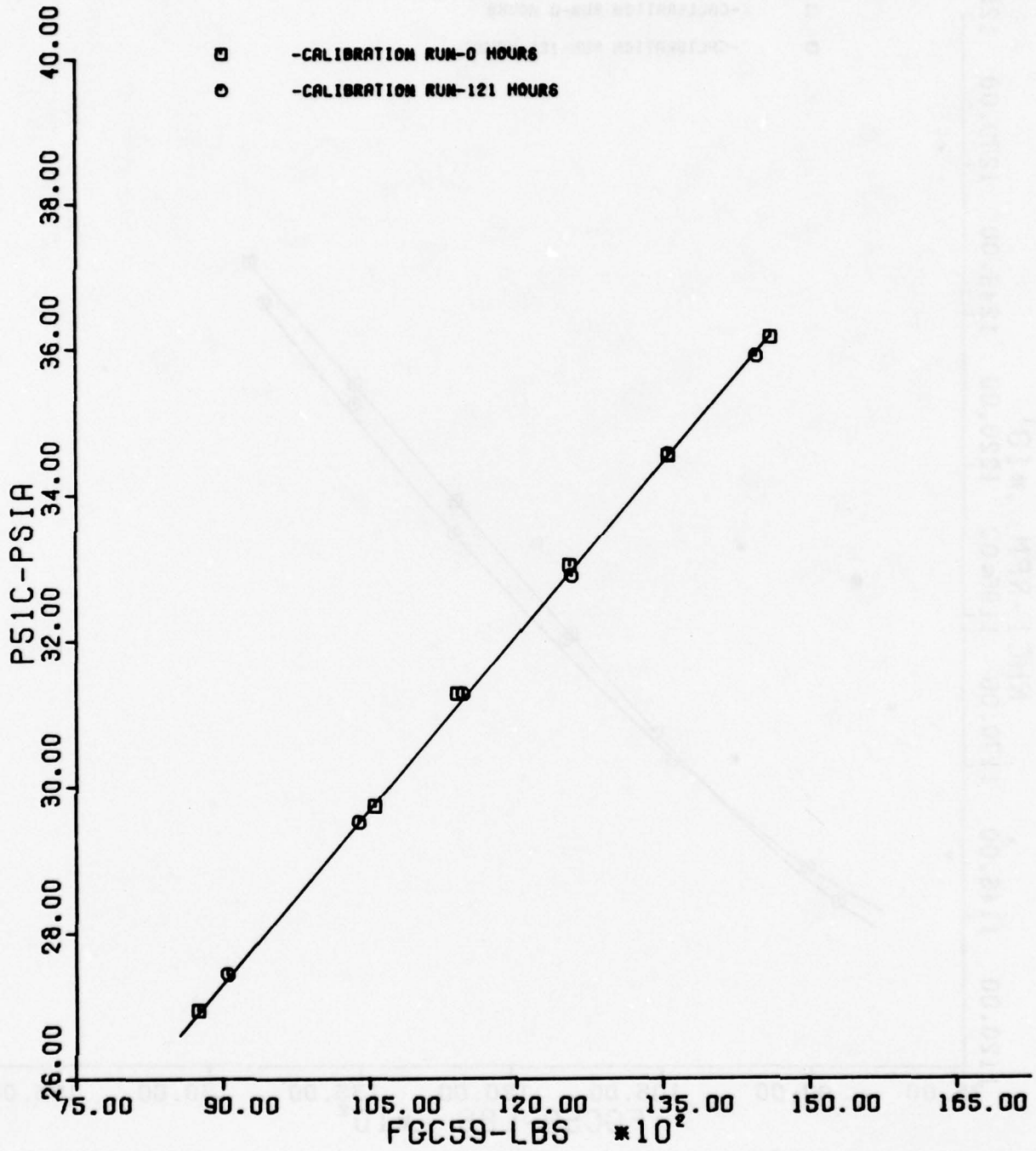


Figure 28 - Corrected Exhaust Gas Pressure versus Corrected Thrust

# CORRECTED H. P. ROTOR SPEED VS CORRECTED THRUST

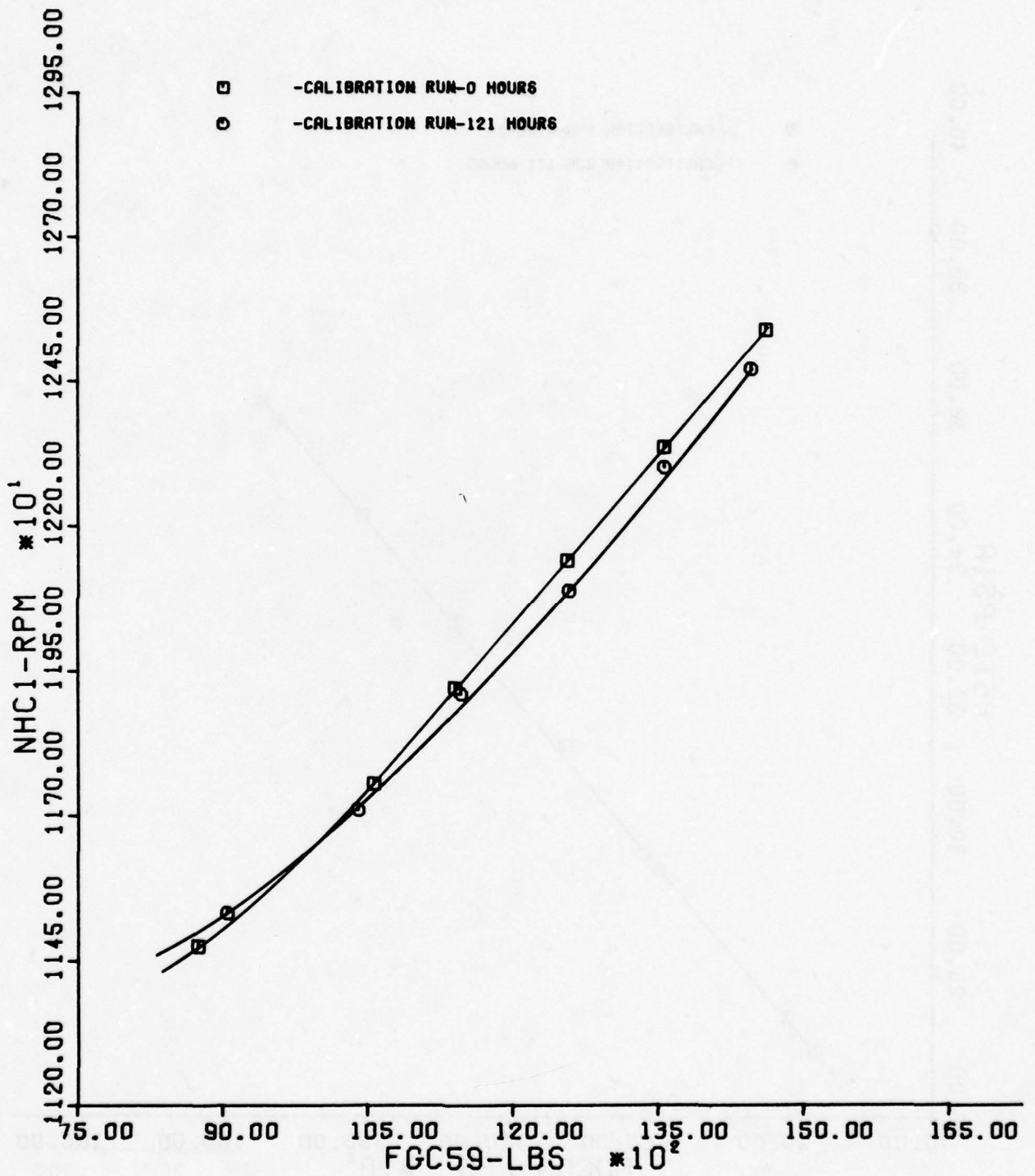


Figure 29 - Corrected H.P. Rotor Speed versus Corrected Thrust

# CORRECTED INLET AIRFLOW VS CORRECTED THRUST

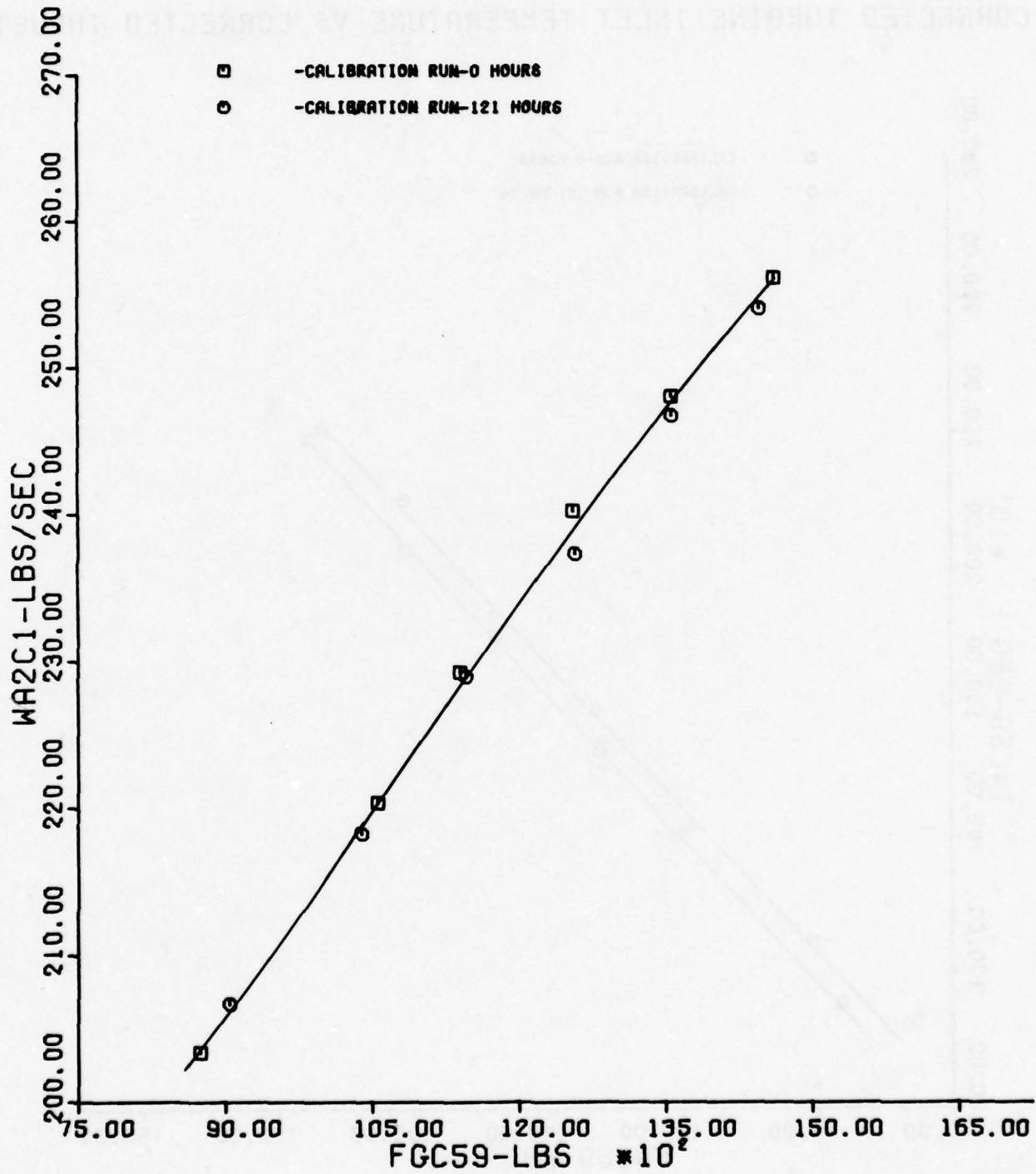


Figure 30 - Corrected Inlet Airflow versus Corrected Thrust

CORRECTED TURBINE INLET TEMPERATURE VS CORRECTED THRUST

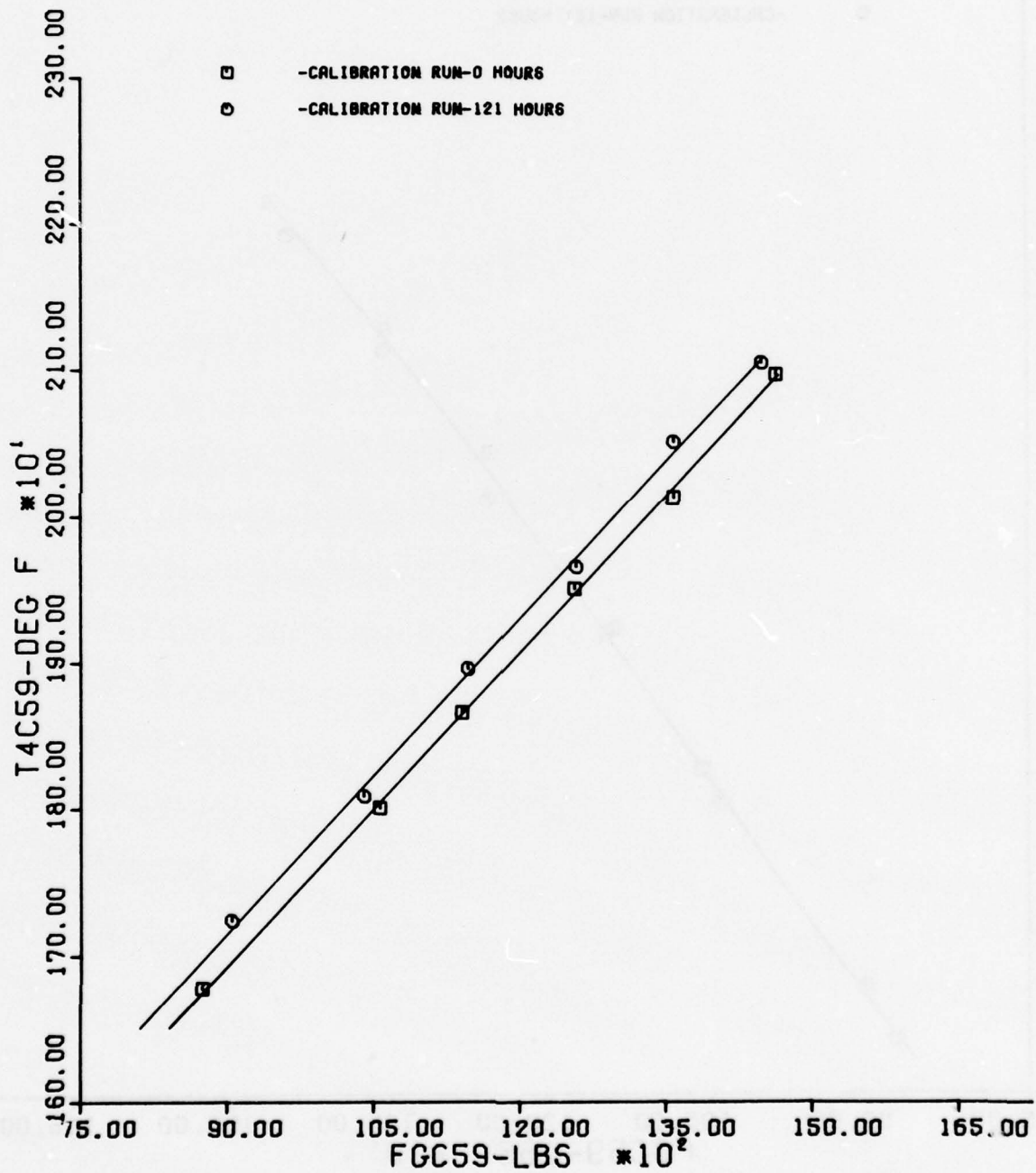


Figure 31 - Corrected Turbine Stator Inlet Temperature versus Corrected Thrust

# CORRECTED TURBINE INLET TEMPERATURE VS CORRECTED THRUST

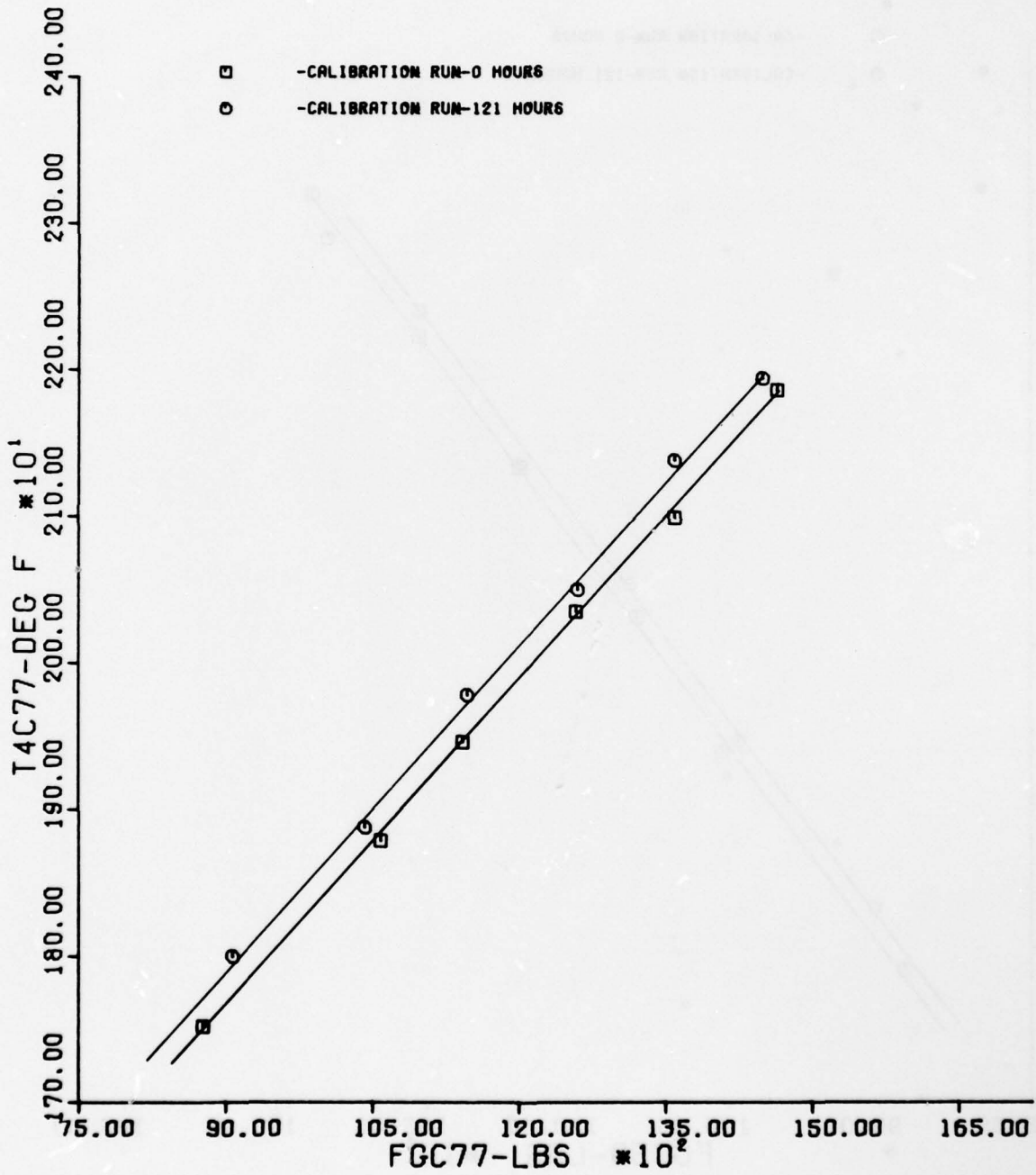


Figure 32 - Corrected Turbine Stator Inlet Temperature versus Corrected Thrust

# CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED THRUST

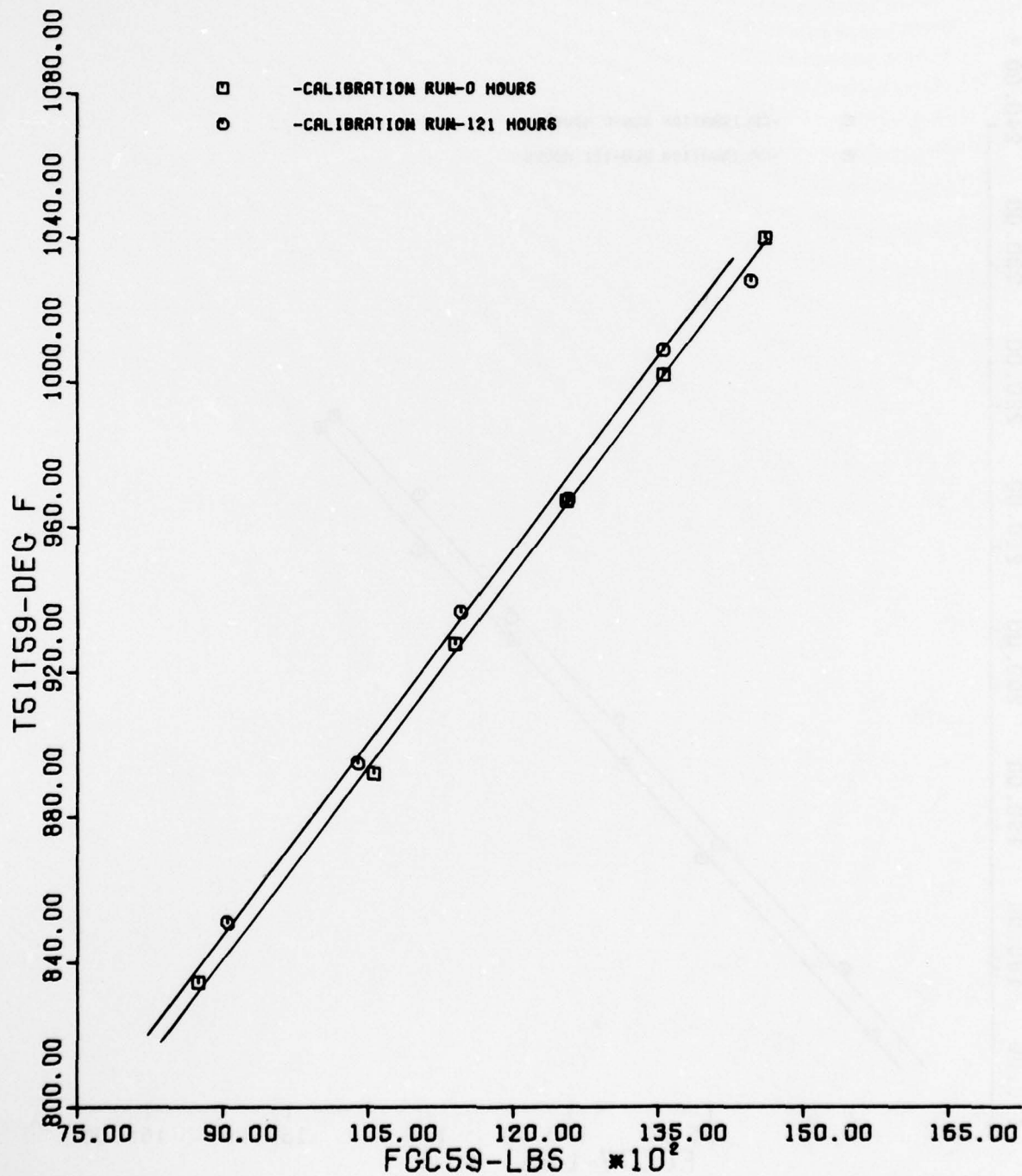


Figure 33 - Corrected Exhaust Gas Temperature versus Corrected Thrust

# CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED THRUST

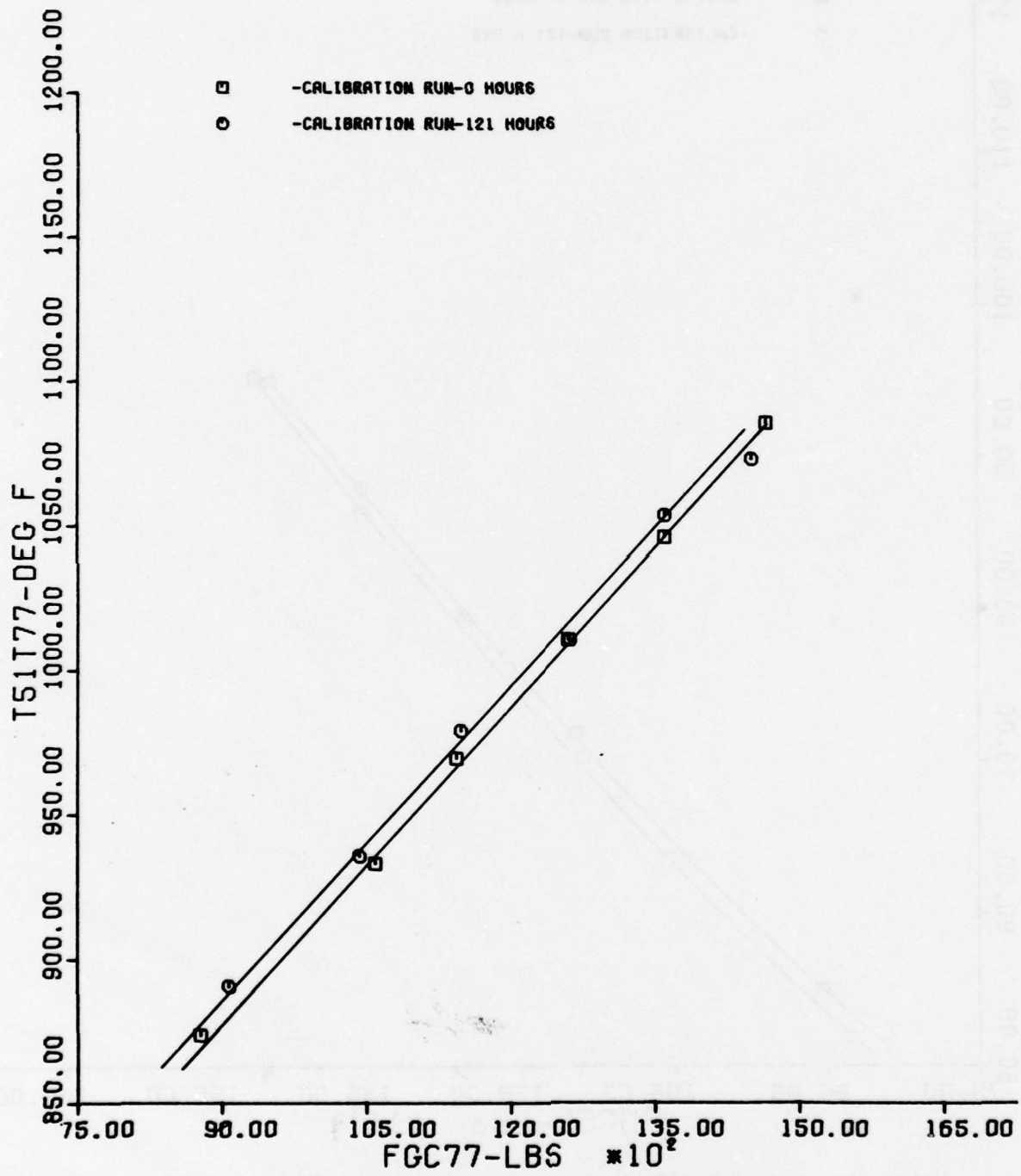


Figure 34 - Corrected Exhaust Gas Temperature versus Corrected Thrust

# CORRECTED FUEL FLOW VS CORRECTED THRUST

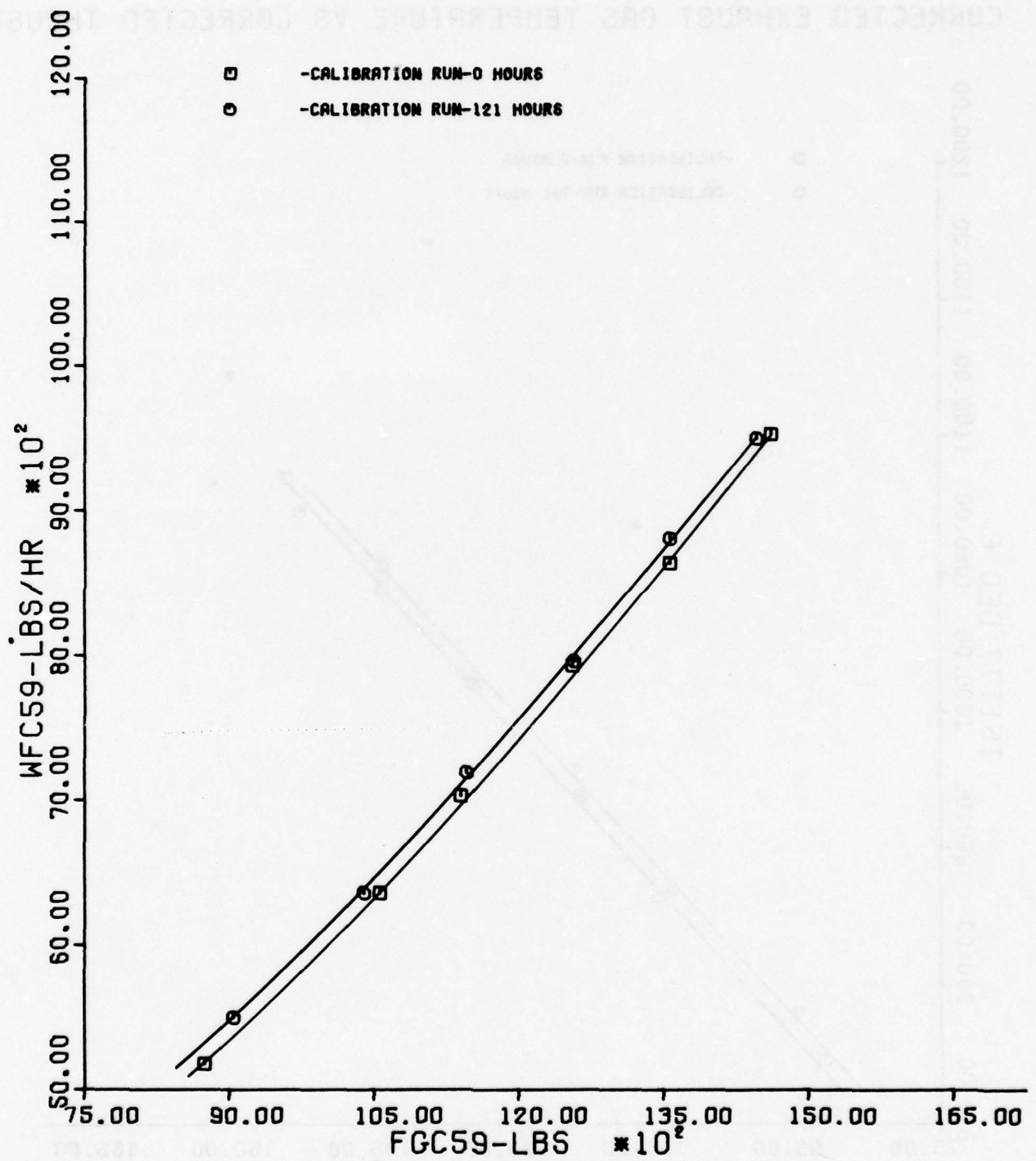


Figure 35 - Corrected Fuel Flow versus Corrected Thrust

# CORRECTED SFC VS CORRECTED THRUST

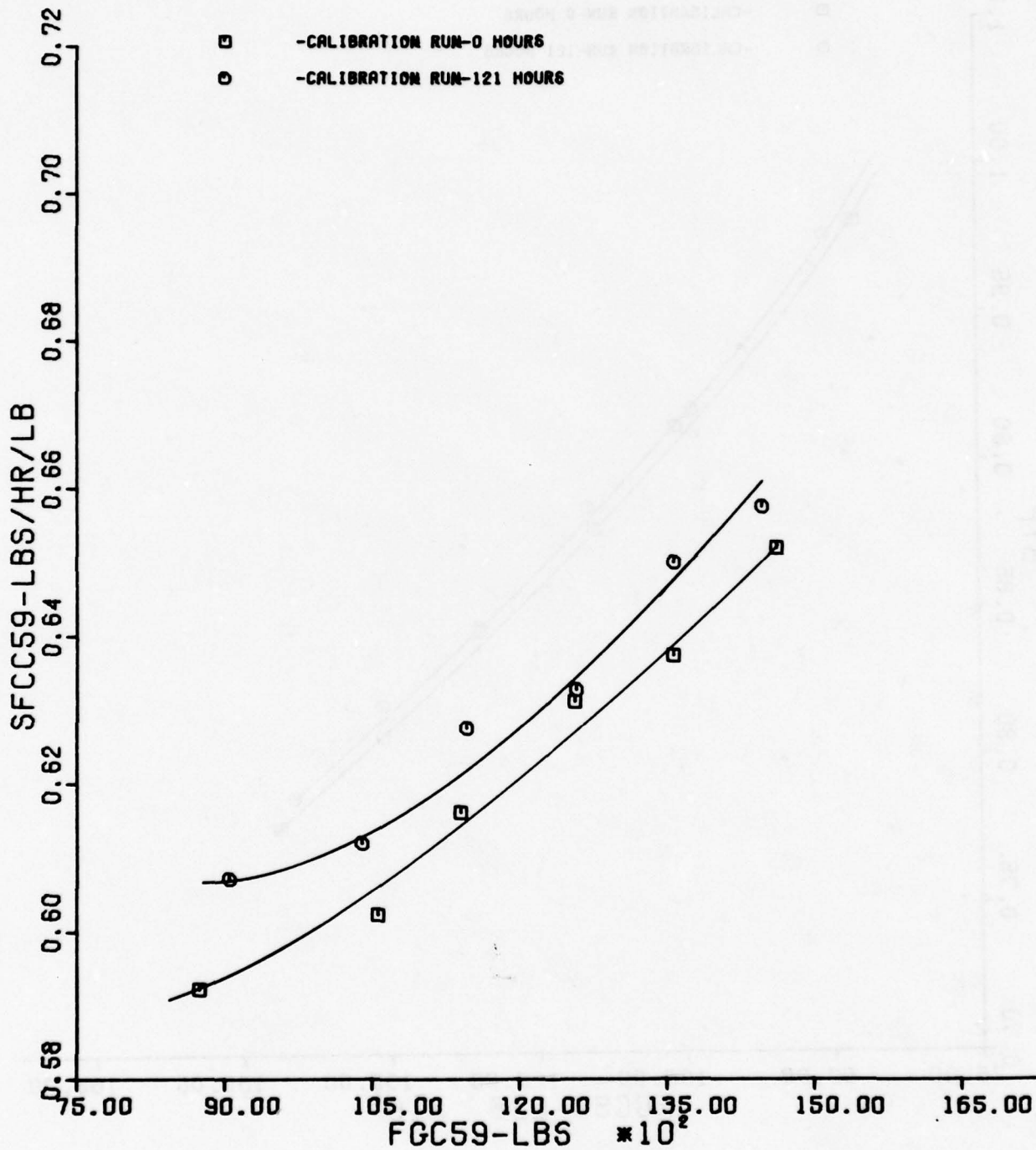


Figure 36 - Corrected SFC versus Corrected Thrust

# BYPASS RATIO VS CORRECTED THRUST

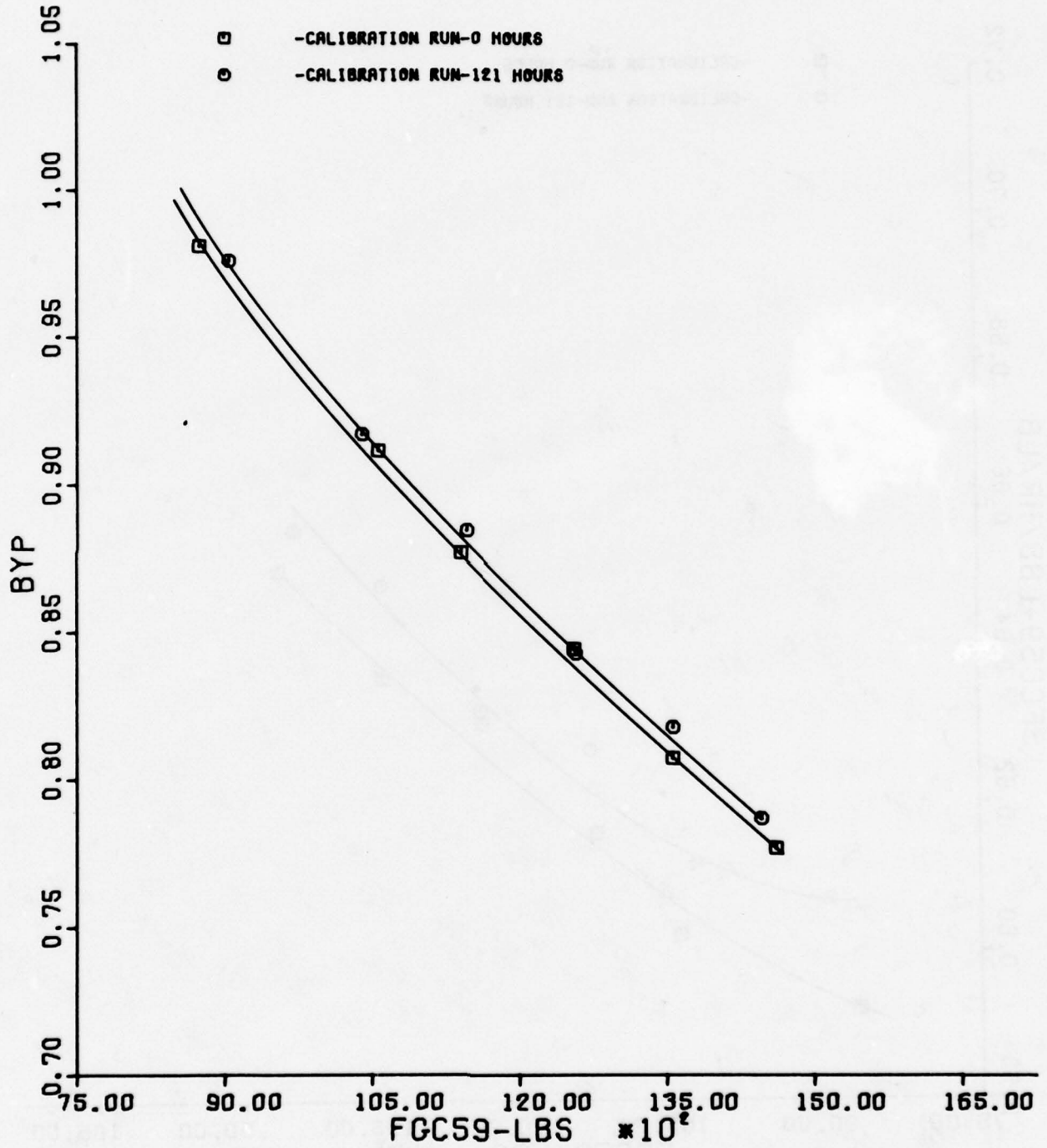


Figure 37

Bypass Ratio versus Corrected Thrust

# I.P. CORRECTED FLOW VS CORRECTED THRUST

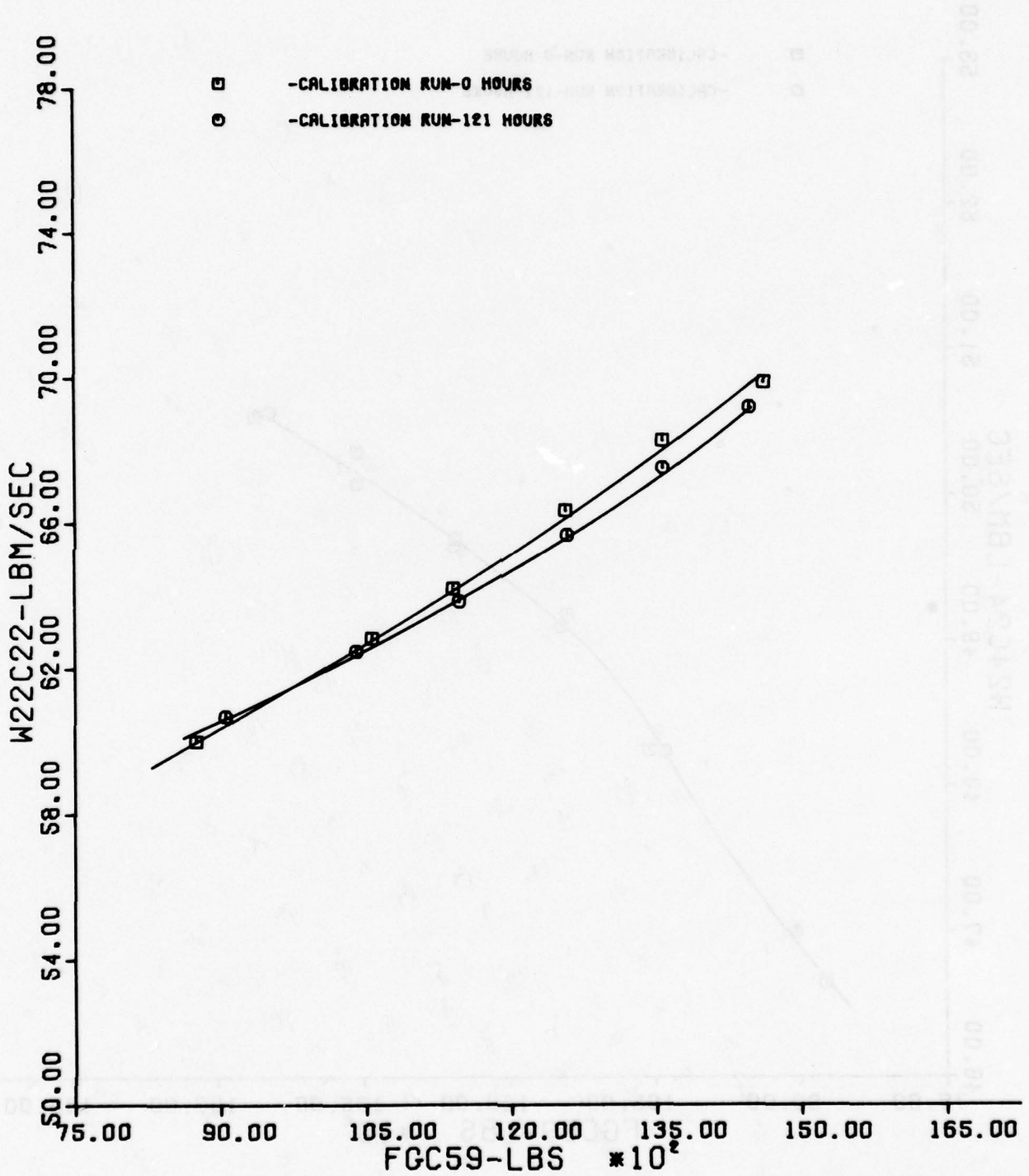


Figure 38 - I.P. Corrected Flow versus Corrected Thrust

# H.P. CORRECTED FLOW VS CORRECTED THRUST

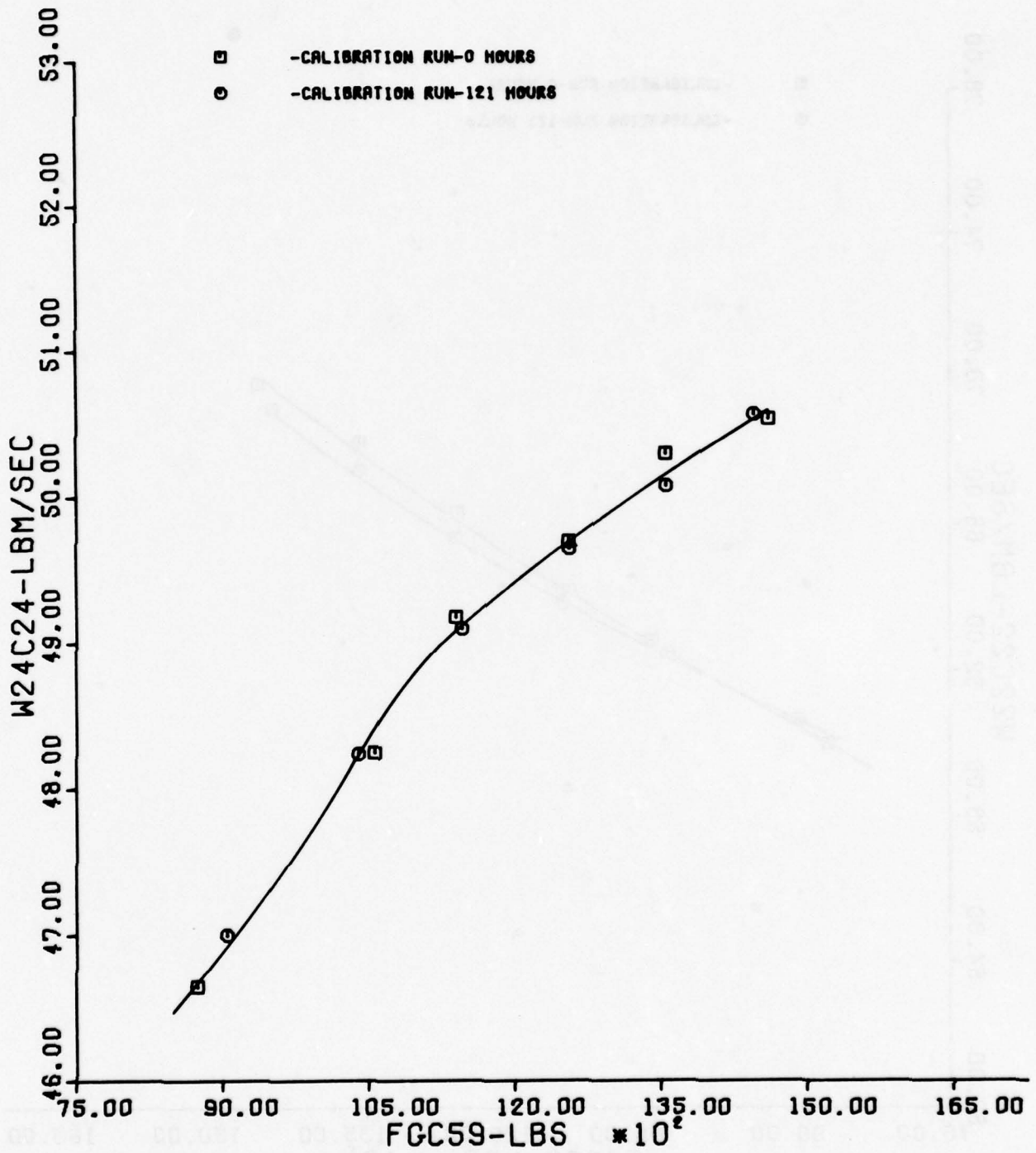


Figure 39 - H.P. Corrected Flow versus Corrected Thrust

# FAN OPERATING LINE

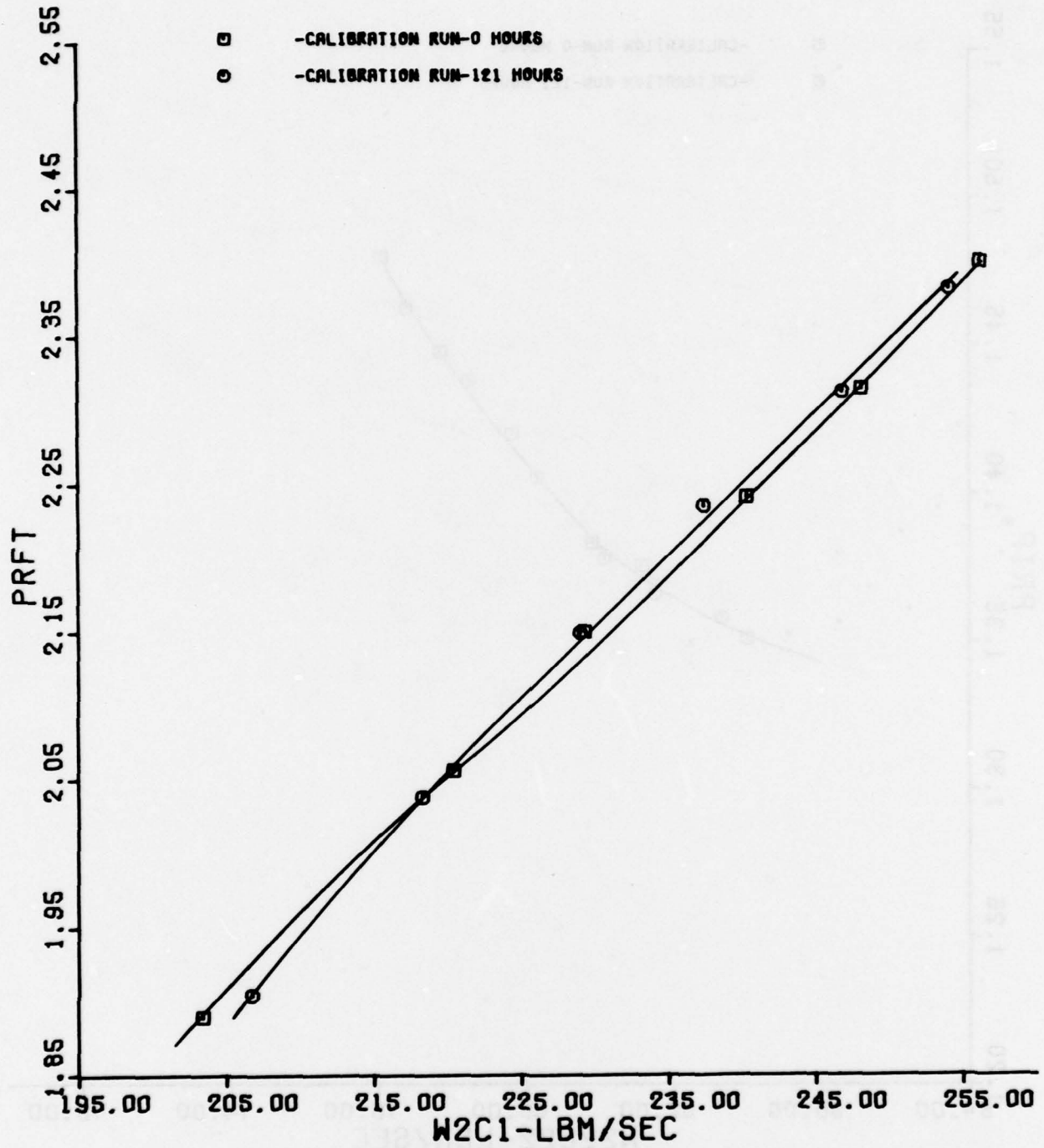


Figure 40 - Fan Operating Line

# I.P. COMPRESSOR OPERATING LINE

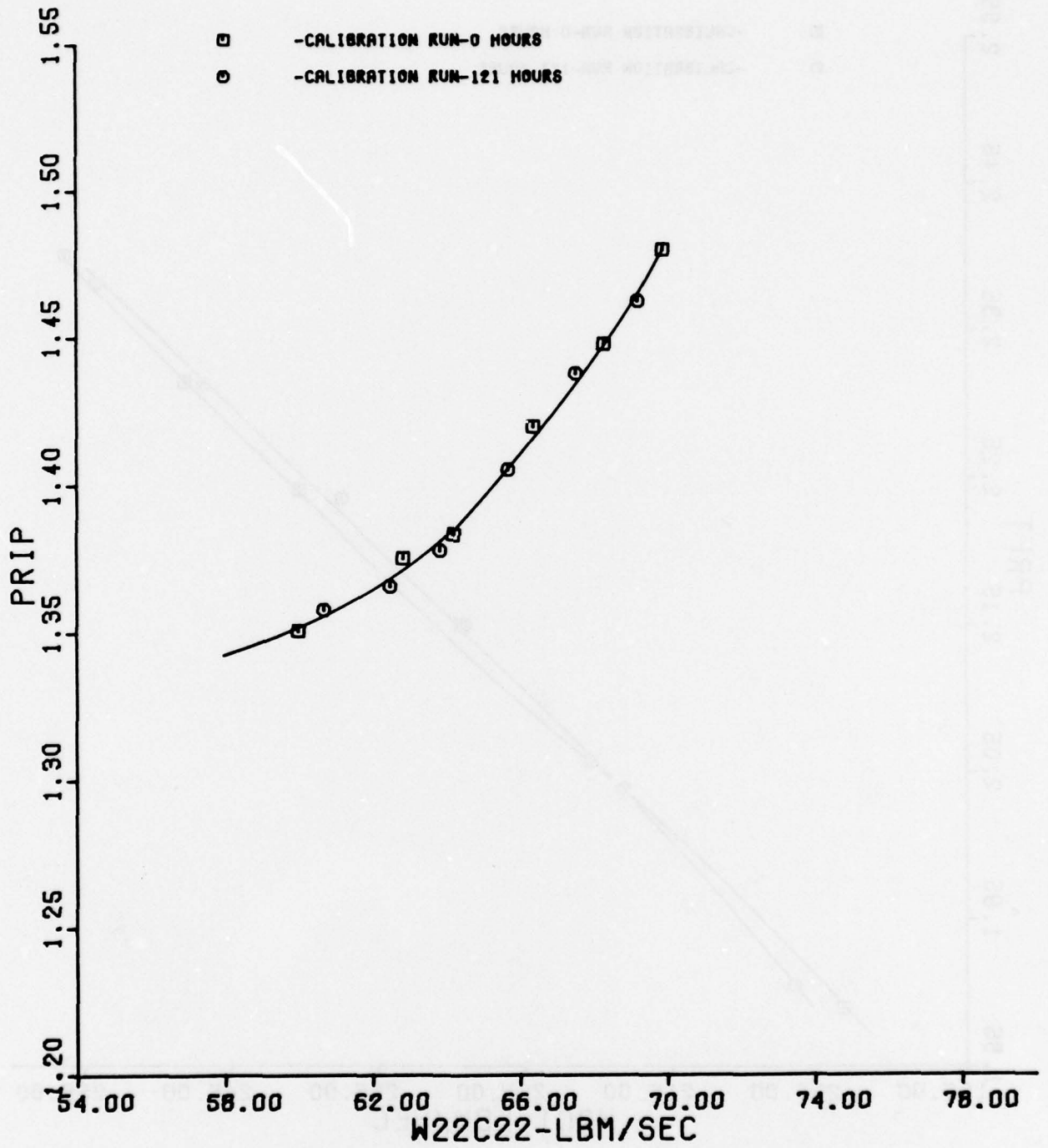


Figure 41 - I.P. Compressor Operating Line

# H.P. COMPRESSOR OPERATING LINE

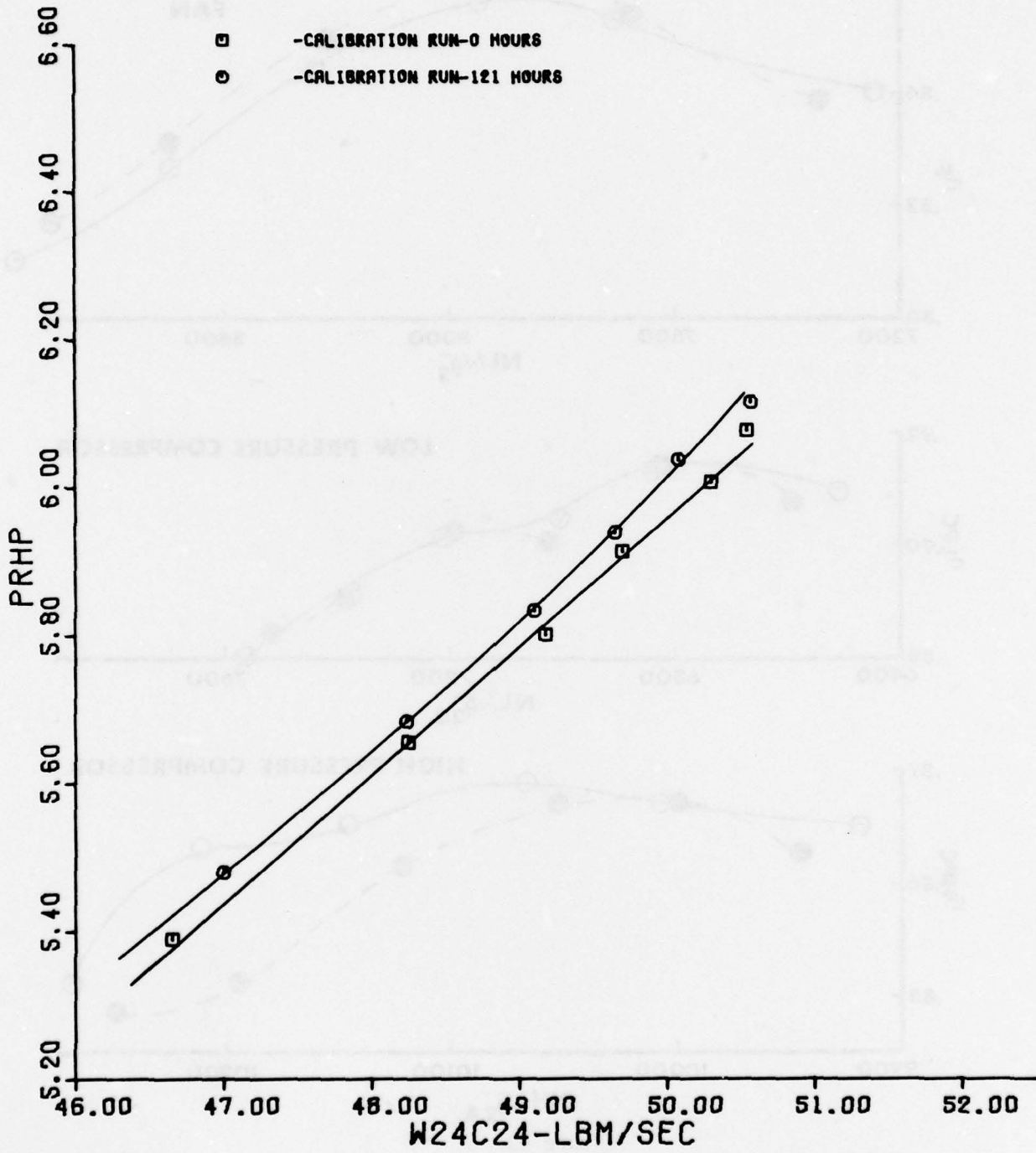


Figure 42 - H.P. Compressor Operating Line

TF41 S/N142163 BU2 COMPRESSION SYSTEM PERFORMANCE

○ — 0 HOURS  
 ● — 121 HOURS

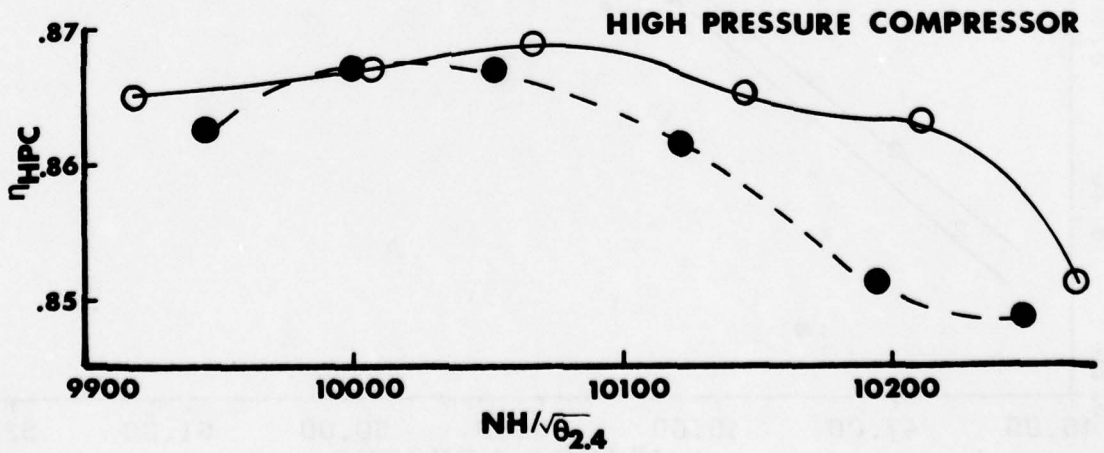
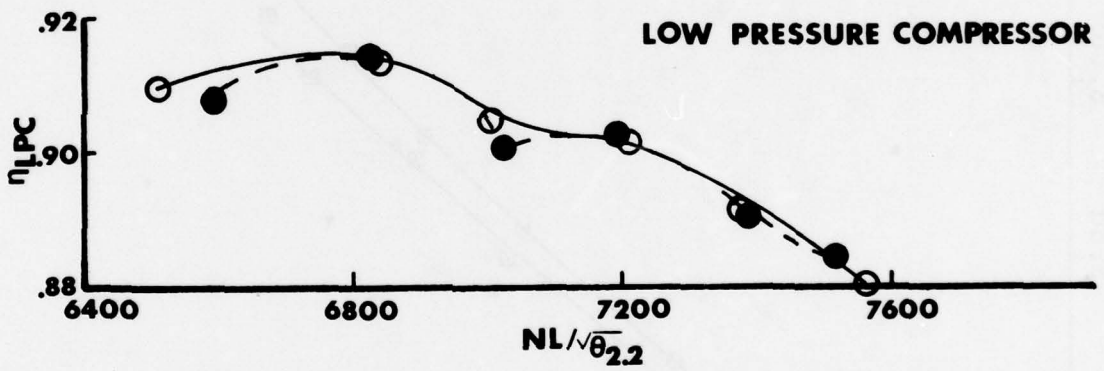
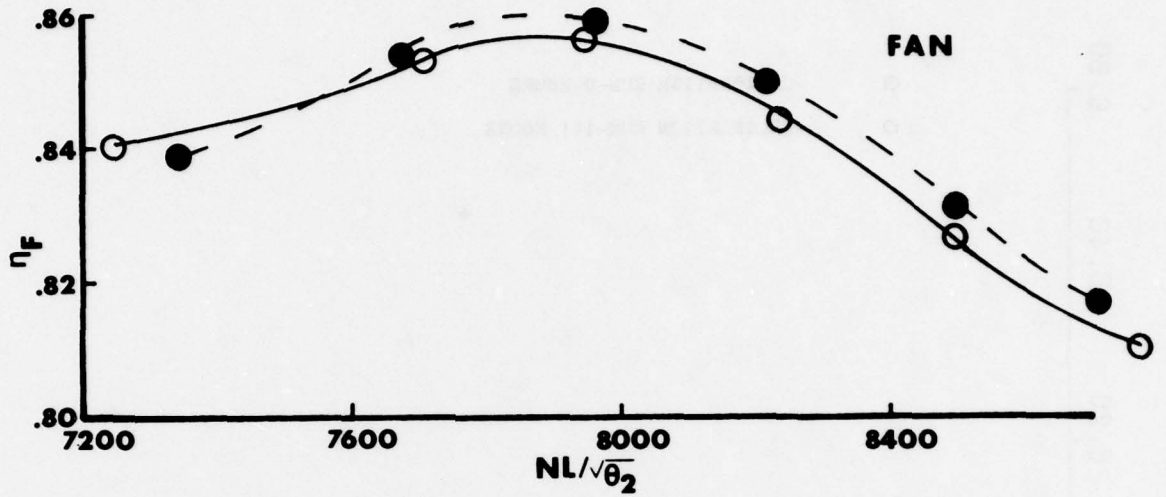


Figure 43

Changes in Compression System Performance

stabilize for at least five minutes before data was recorded at four or five power settings between 8500 pounds thrust and intermediate power. Two complete data points were recorded after the engine had stabilized and were averaged. The data was then corrected according to the procedures outlined in Appendix A.

Fan and intermediate pressure compressor discharge temperature and pressure probes were used during the steady-state power calibration portion of the test. Normal test procedures call for this instrumentation to be inserted in the forward borescope ports on either side of the engine. However, the design of the thrust frame adapter did not allow access to this left hand port. Thus, two separate calibrations had to be run, one with pressure and one with temperature instrumentation. The data was then plotted as a function of corrected low pressure compressor rotor speed in order to establish a consistent set of pressures and temperatures.

Figures 23 through 26 compare the AFAPL pre-test performance calibrations with Allison's "as shipped" performance data. The overall engine performance data (Figures 23 and 24) show excellent agreement with the Allison data. However, the AFAPL compression system component data (Figures 25 and 26) shows a consistent 1% difference with the "as shipped" data. This is probably due to the inability to run both compressor pressure and temperature instrumentation simultaneously. This does not present a major problem though, since the changes in these parameters are more important than their absolute values.

Figure 27 through 42 present plots of the corrected performance data for the two steady-state power calibrations. The most significant changes appear to be a 1.5% increase in specific fuel consumption, a 20°F increase in turbine inlet temperature at constant thrust, and a 1% upward shift in high pressure compressor operating line.

The addition of the inter-compressor instrumentation allows calculation of the individual compressor component efficiencies. This data is presented in Figure 43. The fan efficiency shows a slight increase after 121 operating hours, probably due to the small change in operating line shown in Figure 40. The overall low pressure compressor efficiency shows a negligible change. The high pressure compressor efficiency did show some loss, approximately 1% at high corrected speeds. This shift is most likely due to the change in high compressor operating line, shown in Figure 42. These relatively small changes in compression system performance could probably be

expected since most deterioration effects take place early when clearances, etc, are tight and the compressors were not refurbished after the initial AMT (144 operating hours).

Historically, most engine performance deterioration is caused by turbine efficiency losses, especially in the high pressure turbine. Inter-turbine instrumentation is not available to allow definition of turbine efficiencies. However, based on the assumptions and calculations detailed in Appendix A, estimates of high pressure and low pressure turbine efficiency can be made and are shown as a function of turbine pressure ratio in Figure 44. First of all, these calculated efficiencies show very good agreement with the turbine efficiencies predicted by the steady-state average production TF41 performance simulation (ref 7) with the exception of the lower values of low pressure turbine pressure ratio. Comparing the data between the 0 and 121 hour power calibration shows that there was less than 1/2% loss in low pressure turbine efficiency but nearly a 1-1/2% - 2% loss in high pressure turbine efficiency.

This steady-state performance data provides the necessary information to understand what is happening to the engine as it deteriorates. The effects of deterioration on the cycle match can best be understood by initially comparing the operating characteristics of a deteriorated and undeteriorated engine at a constant turbine inlet temperature and assuming operating with a choked nozzle and no control system constraints. The degradation in turbine performance causes a reduction in available work at a constant turbine pressure ratio. The deteriorated turbine can no longer extract the necessary energy to drive the compressors to the same speeds as an undeteriorated engine. Consequently, both the low pressure and high pressure rotors must unwind to lower speeds. There will be a greater impact on the high pressure rotor due to the larger reduction in high pressure turbine performance.

In addition to the speed reduction, a different operating line is followed by the high pressure compressor as speed is reduced. Assume that both the deteriorated and the undeteriorated engines could be run at power settings that would result in equal high pressure compressor corrected inlet airflow. At this condition, the deteriorated engine would be running at a higher turbine inlet temperature due to the reduced turbine performance

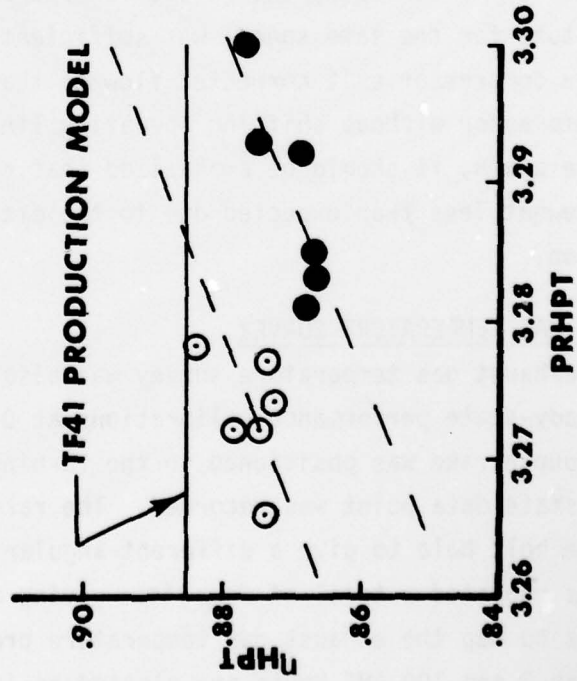
TF41 S/N 142163 BU 2

TURBINE PERFORMANCE

○ - 0 HOURS

● - 121 HOURS

HIGH PRESSURE TURBINE



LOW PRESSURE TURBINE

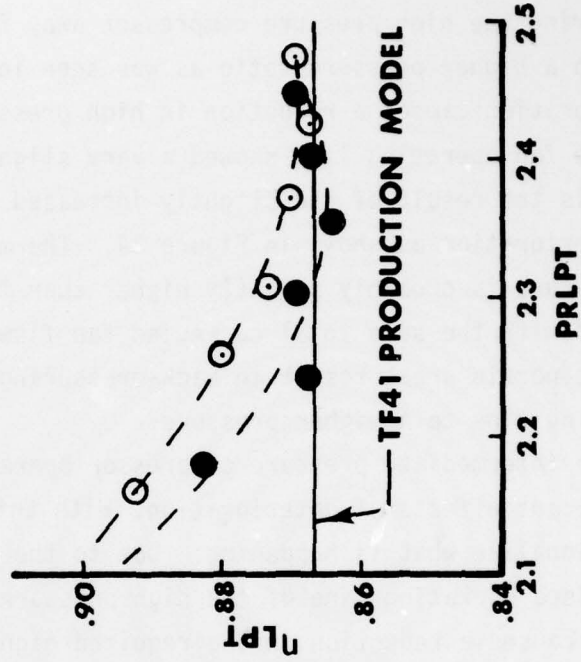


Figure 44 - Changes in Turbine Performance

capability. In order to choke the high pressure turbine nozzle with the higher turbine inlet temperature but the same flow, requires the deteriorated engine to have a higher pressure. This is the same as backpressuring the high pressure compressor away from its normal operating line to a higher pressure ratio as was seen in Figure 42. Thus, deterioration causes a reduction in high pressure compressor surge margin.

The fan operating line showed a very slight shift upward (Figure 40) which is the result of the slightly increased exhaust gas temperature due to deterioration as shown in Figure 34. The mixed exhaust nozzle total temperature is probably slightly higher than the undeteriorated case. Coupled with the same total corrected fan flow (Figure 30) and the fixed exhaust nozzle area, result in back-pressuring the fan away from its normal operating line to a higher pressure.

The intermediate pressure compressor operating line did not show any significant effects of deterioration. With this component it is more difficult to rationalize what is happening. Due to the shape of the speed lines, the raised operating line of the high pressure compressor in the deteriorated engine causes a reduction in the required high compressor inlet corrected flow. Apparently, the reduction in intermediate pressure compressor corrected speed caused by the raised fan operating line (higher discharge temperature for the same speed) was sufficient to reduce the intermediate pressure compressor exit corrected flow to that required by the high pressure compressor without shifting operating line.

Once again, it should be emphasized that these deterioration effects are somewhat less than expected due to the extensive pre-test engine operation.

#### EXHAUST GAS TEMPERATURE SURVEY

An exhaust gas temperature survey was also run in conjunction with the steady-state performance calibrations at 0 and 100 AMT hours. A 45 thermocouple rake was positioned in the turbine exhaust (Figure 45). A steady-state data point was recorded. The rake was then rotated one tailpipe bolt hole to give a different angular positioning of the probes. This was repeated a total of four times giving a total of 180 temperature readings to map the exhaust gas temperature profile. The results of this survey at 0 and 100 AMT hours are plotted as isotherms in Figures 46 and 47.

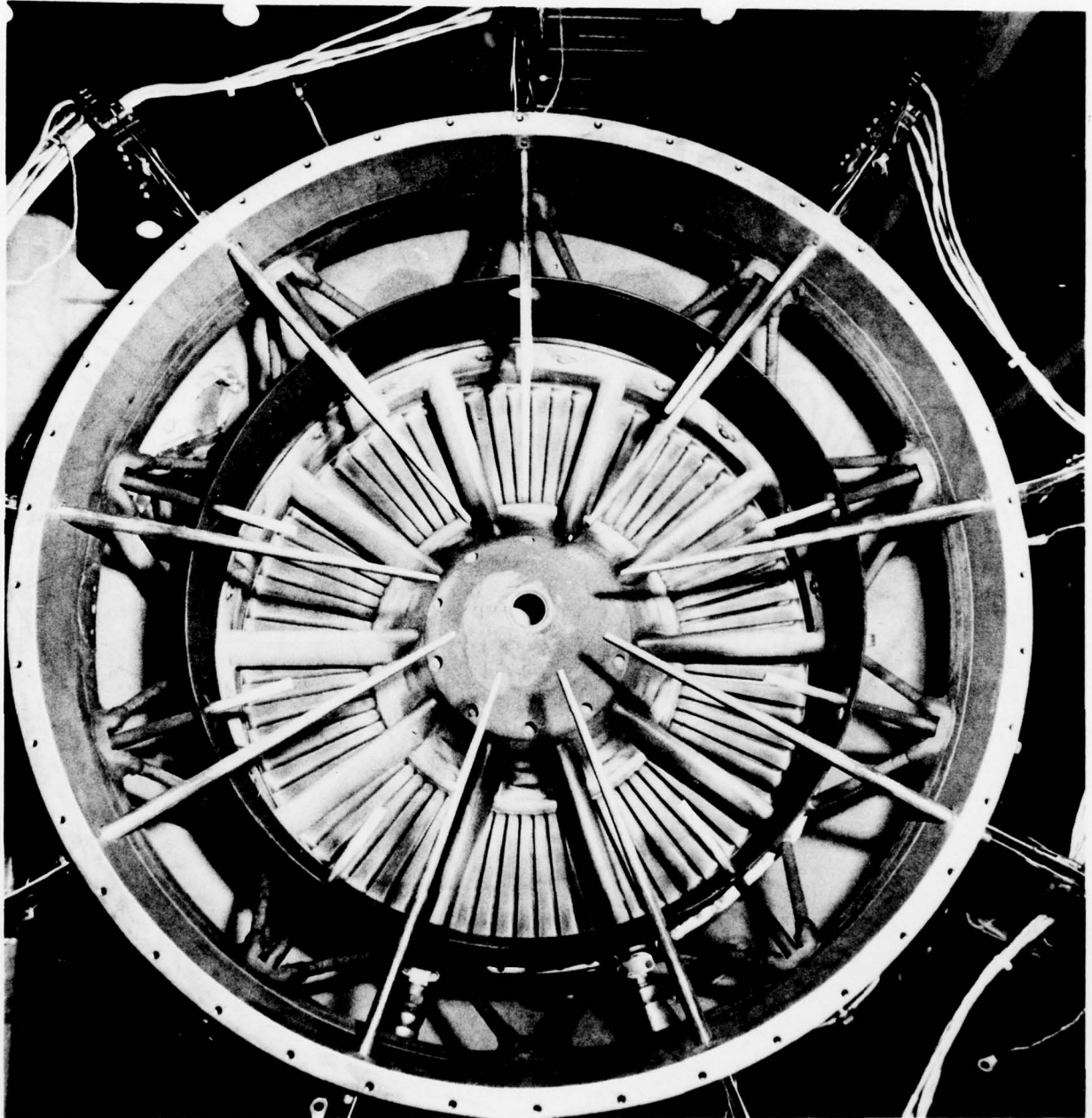
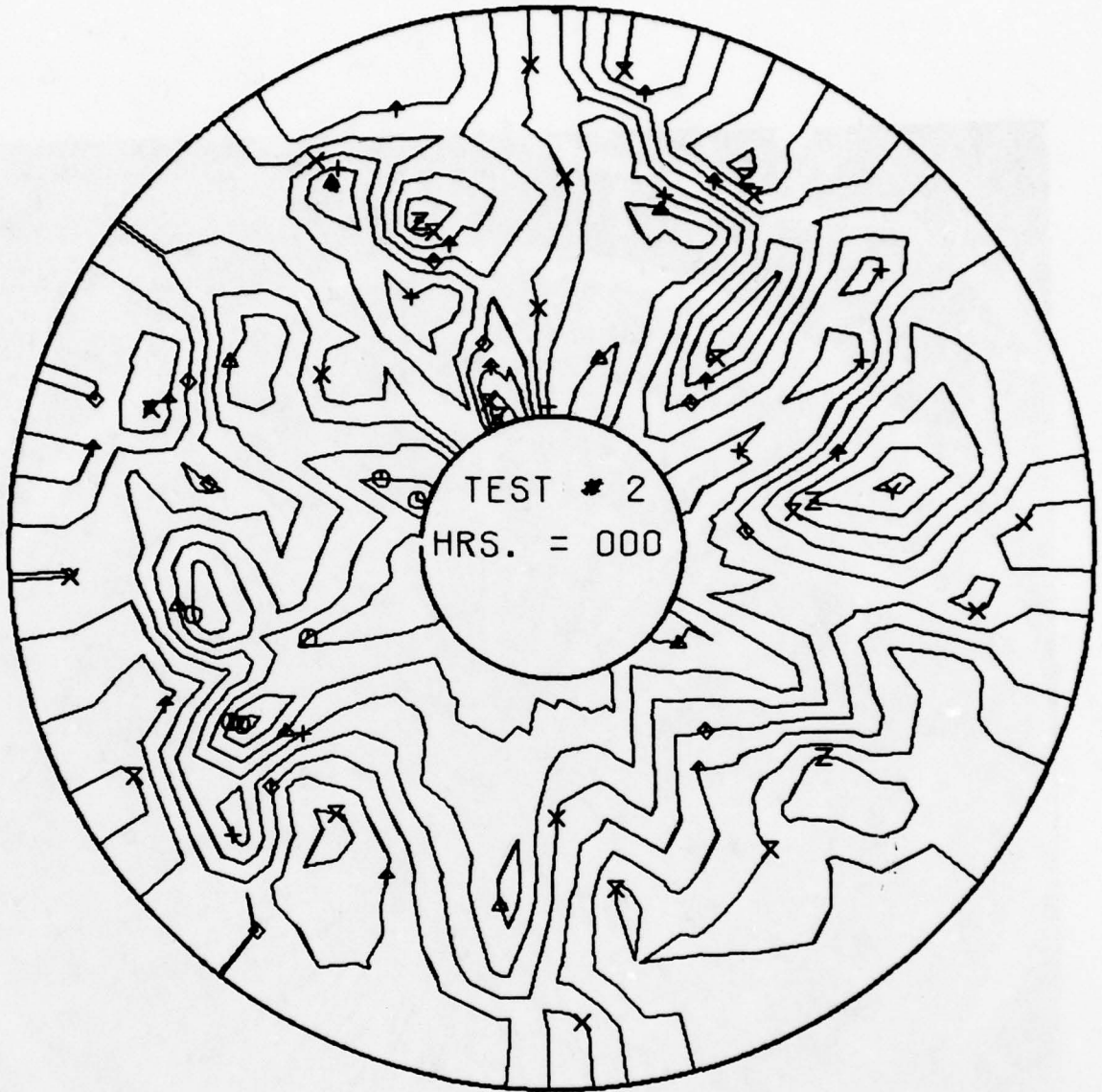


Figure 45  
Temperature Probes Installed in Tailpipe

TURBINE EXIT ISOTHERMS FOR TF41  
S/N 142163

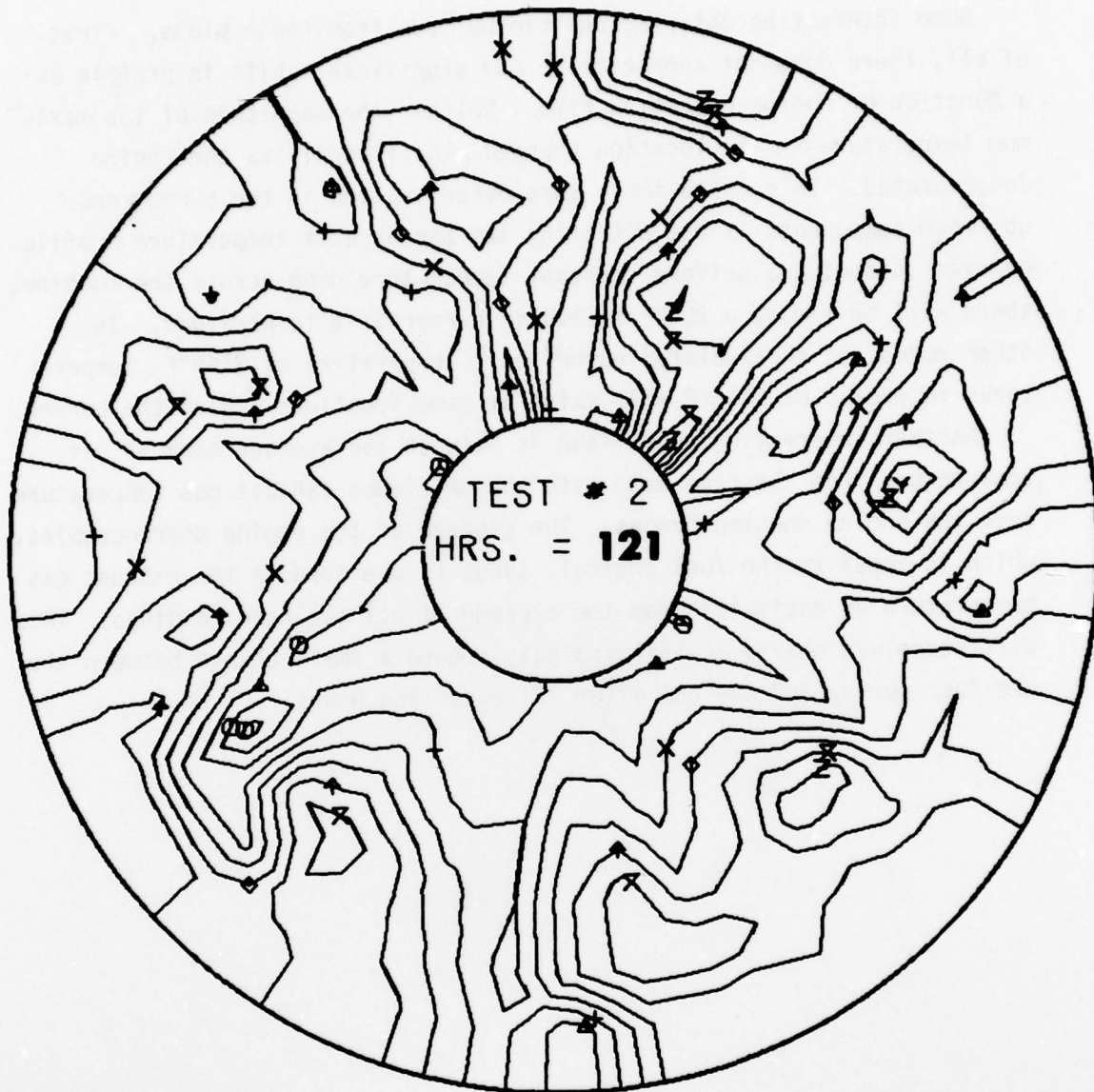


□	=	1080	◇	=	1180
○	=	1100	↑	=	1200
△	=	1120	X	=	1220
+	=	1140	Z	=	1240
X	=	1160	Y	=	1260

(TEMPERATURES IN DEG. F)

Figure 46 - Turbine Isotherms, 0 Hours

TURBINE EXIT ISOTHERMS FOR TF41  
S/N 142163



□ = 1080	◇ = 1180
○ = 1100	↑ = 1200
△ = 1120	× = 1220
+ = 1140	Z = 1240
X = 1160	Y = 1260

(TEMPERATURES IN DEG. F)

Figure 47 - Turbine Exit Isotherms, 121 Hours

(See reference 8 for details). Table 7 also presents some pertinent data from this analysis.

Some interesting observations can be made from these plots. First of all, there does not appear to be any significant shift in profile as a function of engine operating time. Neither the magnitude of the maximum temperature nor its location changed significantly as the engine deteriorated. This would imply that deterioration in the burner and upstream components is not affecting the burner exit temperature profile. However, assuming a uniform constant temperature drop across the turbine, there will be almost a 200°F spread in burner exit temperature. In other words, for a calculated burner exit temperature of 2165°F, temperatures in excess of 2265°F will exist at some locations behind the burner.

Another interesting comparison is between the average exhaust gas temperature from the rake data with the untrimmed exhaust gas temperature from the engine mounted probes. The average of the engine thermocouples, which is input to the fuel control, tends to overpredict the exhaust gas temperature as estimated from the average of all the rake readings. This difference was nearly 10-15°F and only showed a small change between the pre-test survey and the one after 121 operating hours.

TABLE 7  
EXHAUST GAS TEMPERATURE SURVEY RESULTS

PARAMETER	0 HOURS	121 HOURS
T5.1 Max	1267.3°F	1261.9°F
T5.1 Min	1079.8°F	1071.7°F
T5.1 Avg Rake	1168.3°F	1166.6°F
T5.1 Eng Harness	1174.2°F	1182.7°F

SECTION IX  
RESULTS OF TEARDOWN INSPECTION AND FAILURE ANALYSIS

After approximately 189 AMT hours, during a snap accel from idle to intermediate, turbine vibrations displayed a marked increase in level and erratic behavior. This "A" cycle was completed without further incident. However, on the initial accel of the following "A" cycle, turbine vibrations peaked at well over 5.0 mils. The engine was immediately returned to idle power and then shutdown. The engine was prepared for borescoping which revealed a broken first stage high pressure turbine blade. The engine was removed from the cell and returned to Allison for a failure investigation.

At Allison, the engine was torn down to its major modules. The details of the teardown inspection are contained in Appendix C. A brief summary of the major findings follows:

- L.P. Turbine (Figure 48)
  - Some blades and vanes have light FOD damage.
- H.P. Turbine
  - First stage vanes showed some cracks and distress (Figures 49 and 50).
    - First stage blades - one broken and five with leading edge cracks (Figures 51 thru 53).
      - Second stage vanes showed light to heavy FOD and some vanes have large pieces missing from the trailing edge (Figure 54).
      - Second stage blades showed light to heavy FOD (Figure 55).
- Burner
  - Eight primary air scoops showed crack indications.
  - All liners and nozzle assemblies showed cracks and fretting.

FAILURE ANALYSIS

The primary cause of engine failure was the broken forged first stage high pressure turbine blade. The blade failure occurred in fatigue which initiated at the leading edge .95 inches from the platform. The origin of failure was in an area of deterioration which extended .65 inches from the fracture along the leading edge toward the platform.

Fluorescent penetrant inspection of the failed blade showed no additional indication of cracks or surface irregularities.

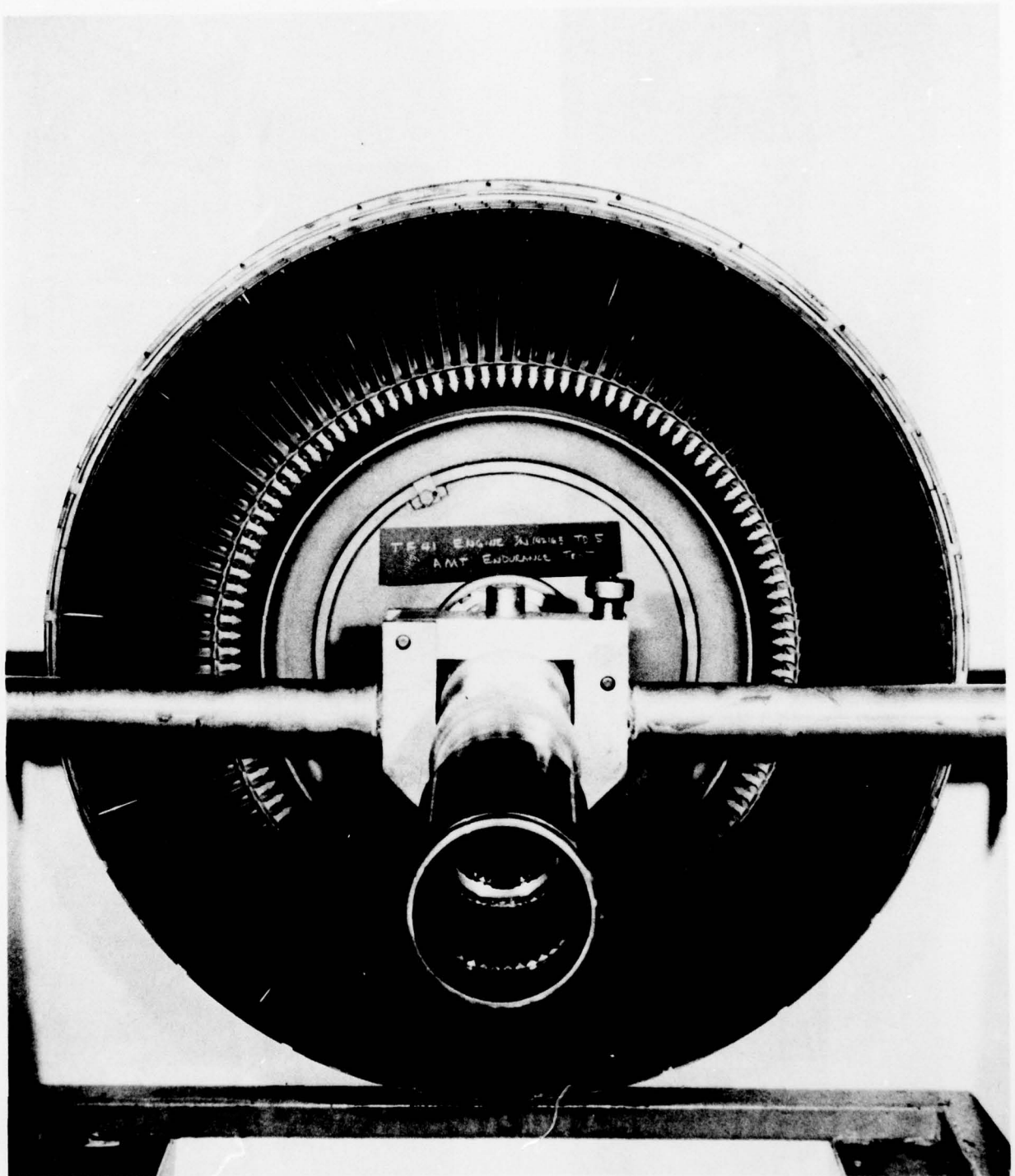


Figure 48  
Low-Pressure Turbine Rotor Assembly

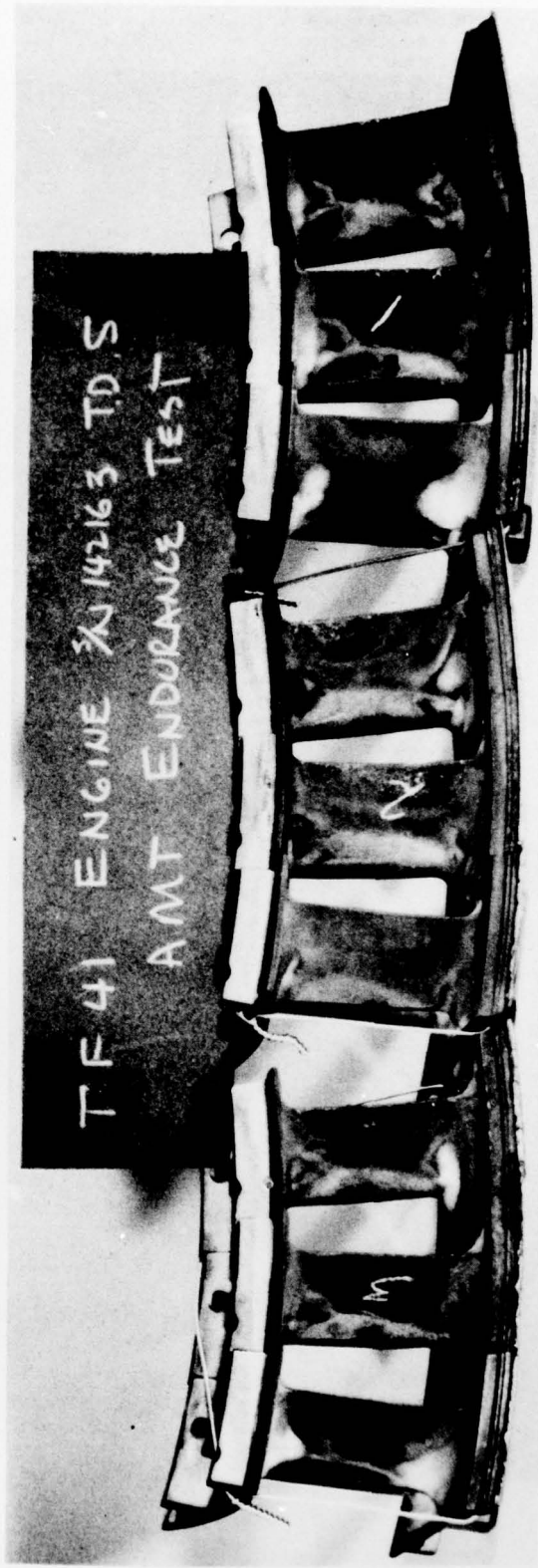
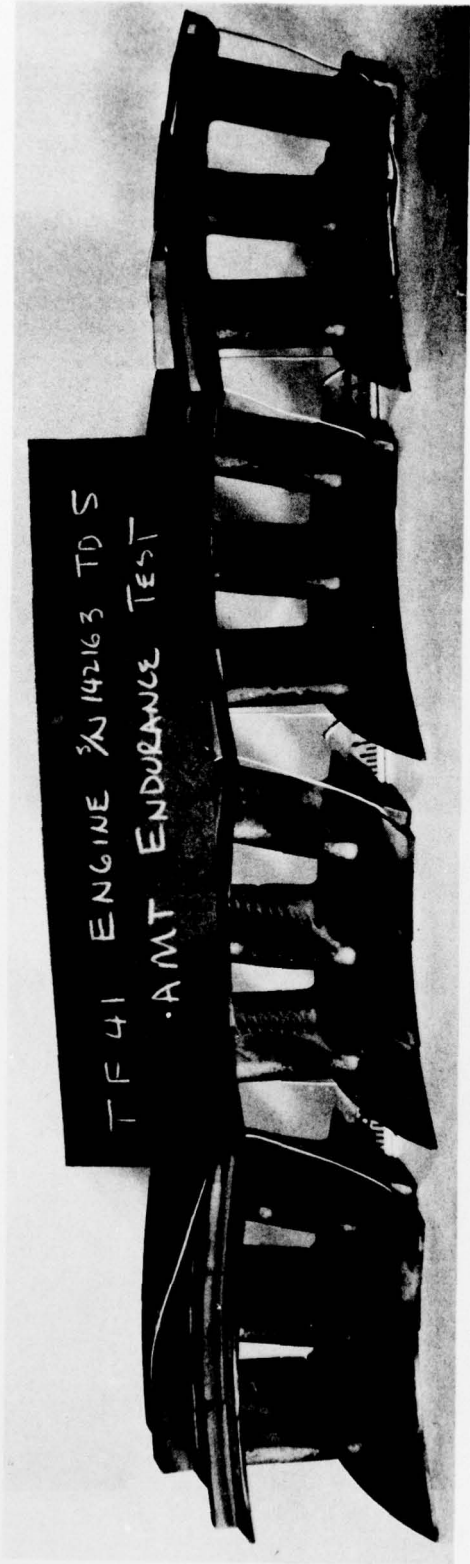


Figure 49 - First-Stage High-Pressure Turbine Vanes

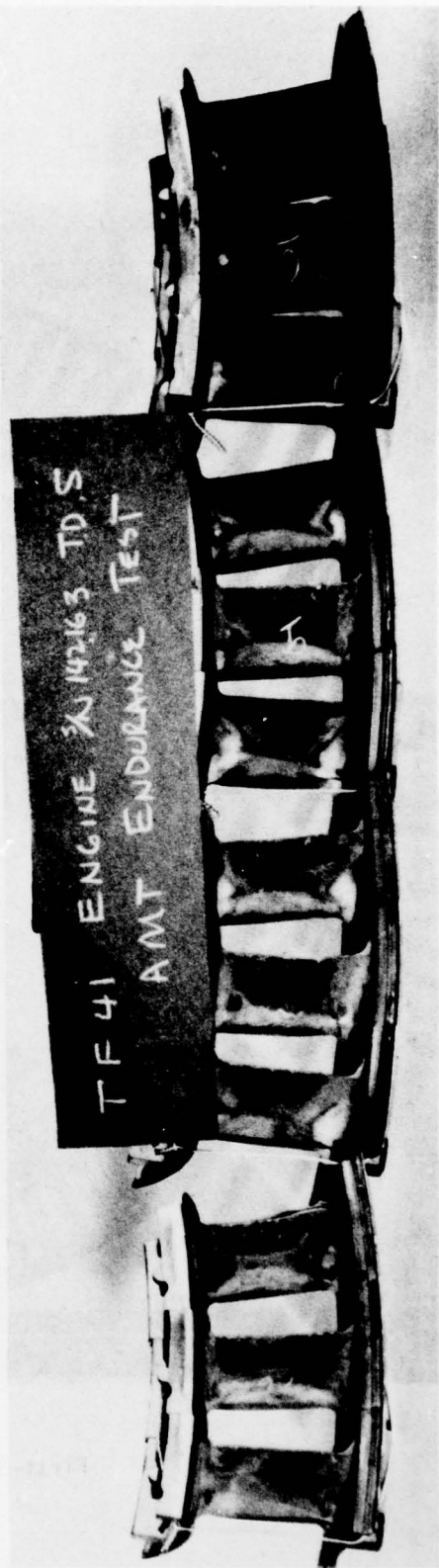
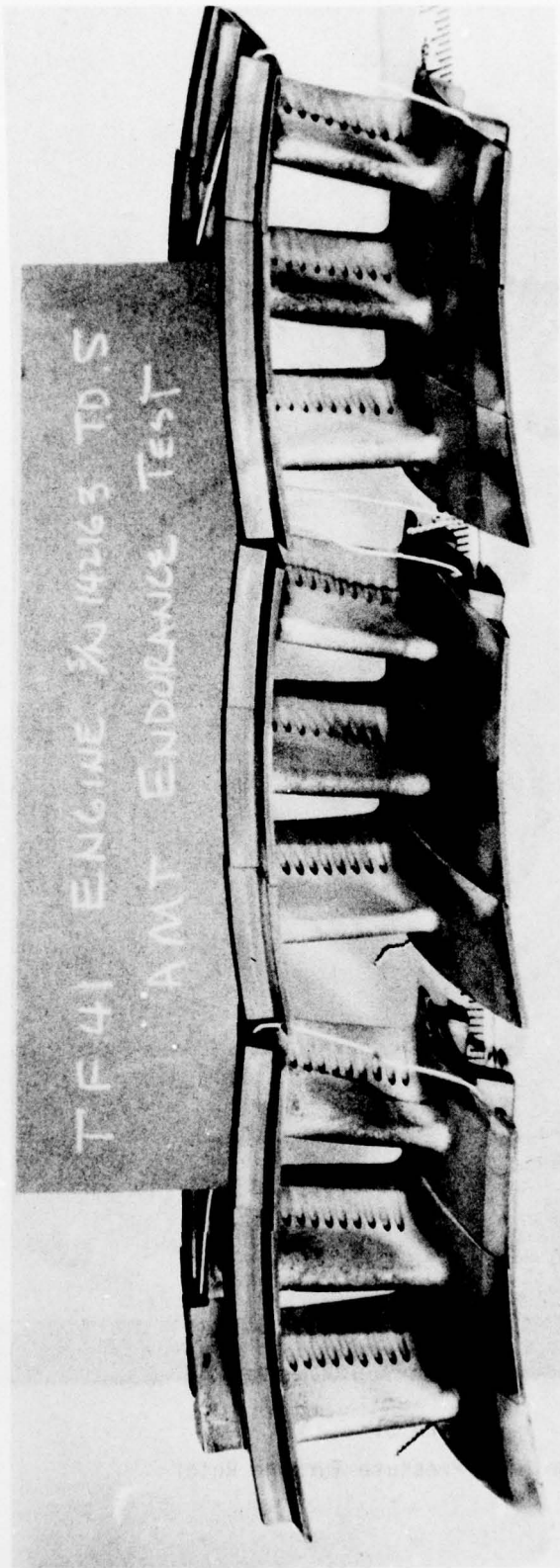


Figure 50 - First-Stage High-Pressure Turbine Vanes

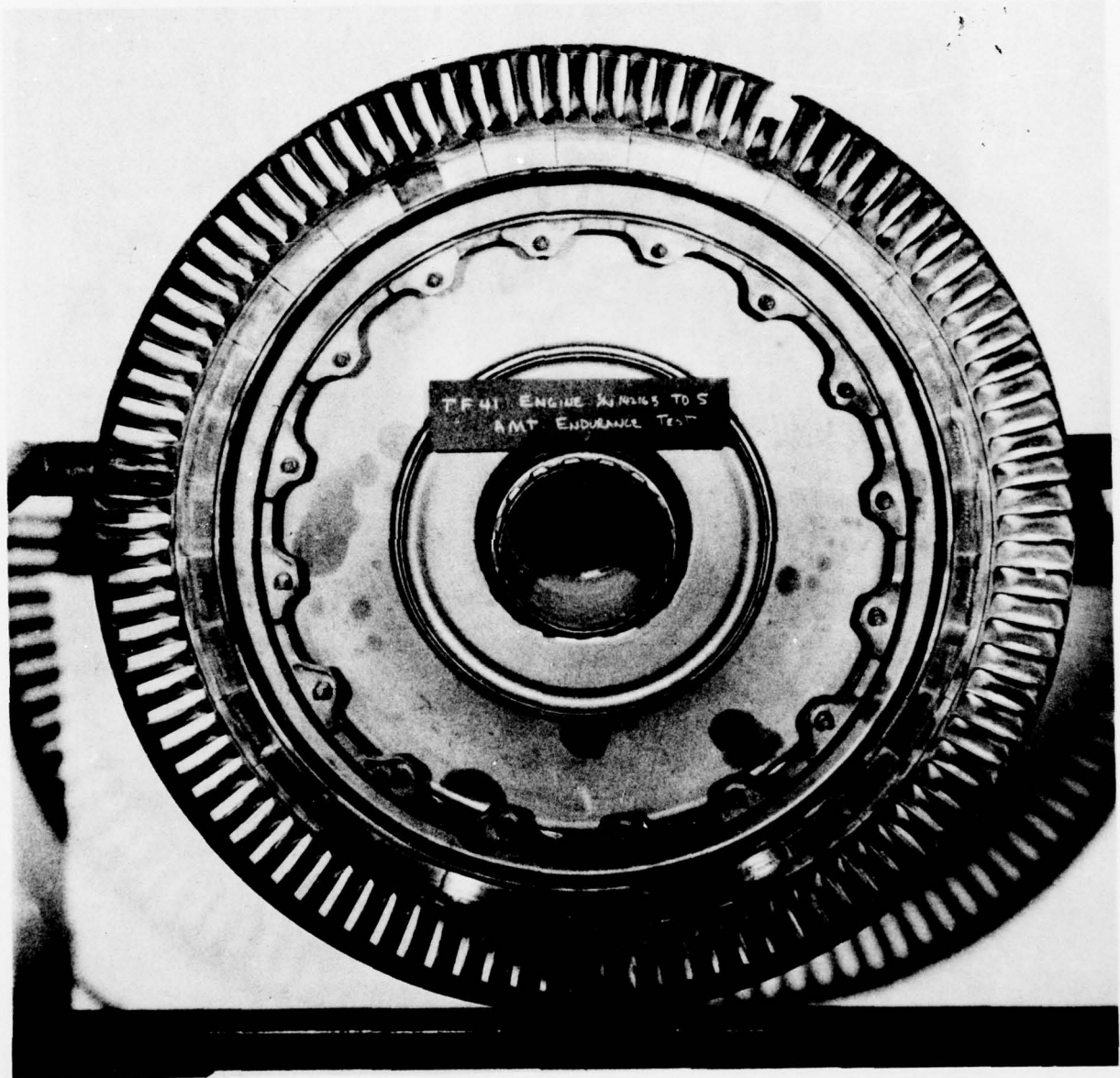


Figure 51  
First-Stage High-Pressure Turbine Rotor



Figure 52  
Failed First-Stage High Pressure Turbine Blade  
85

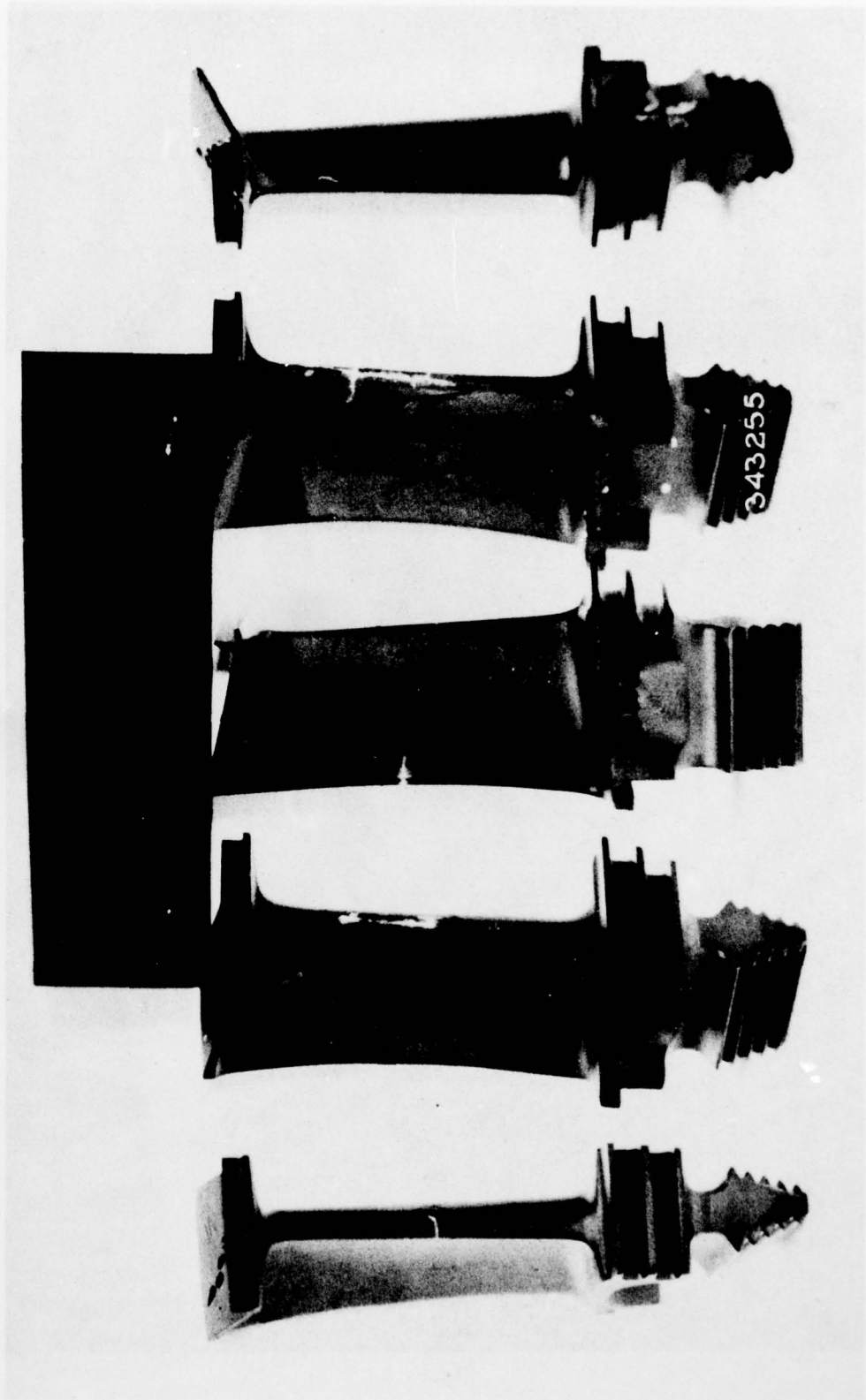


Figure 53 - Blacklite Photo of Cracked First-Stage High-Pressure Turbine Blades

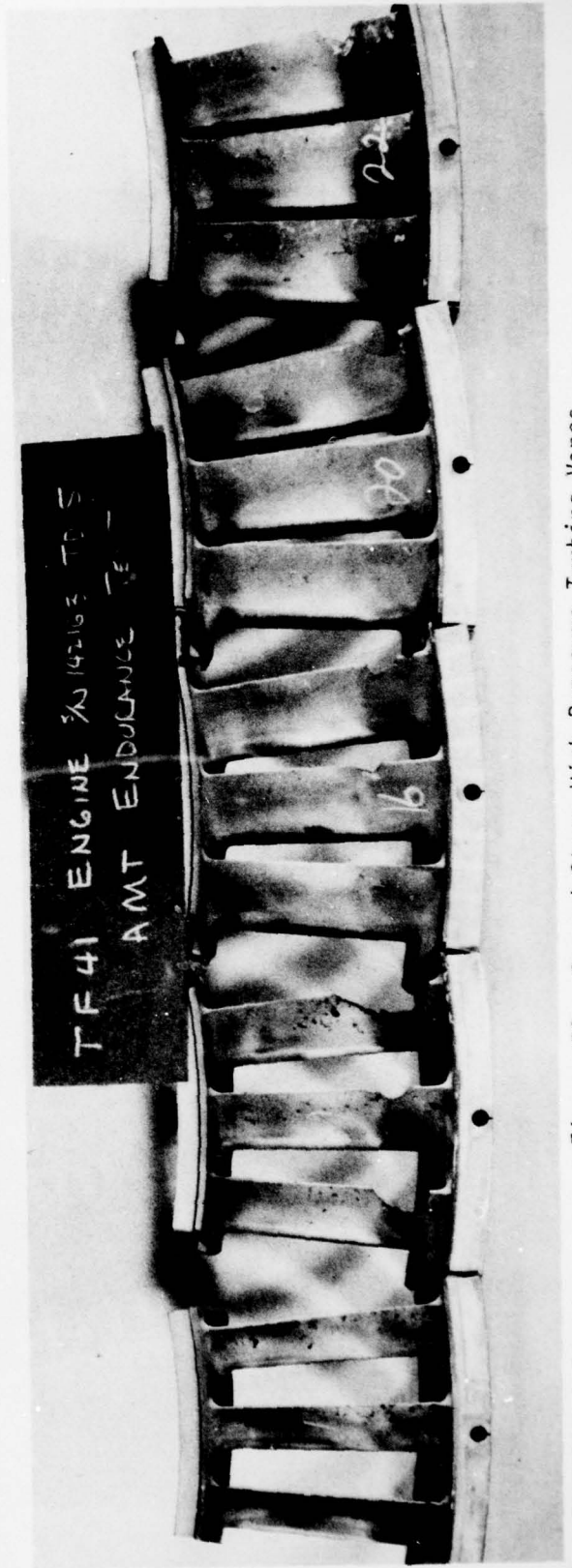
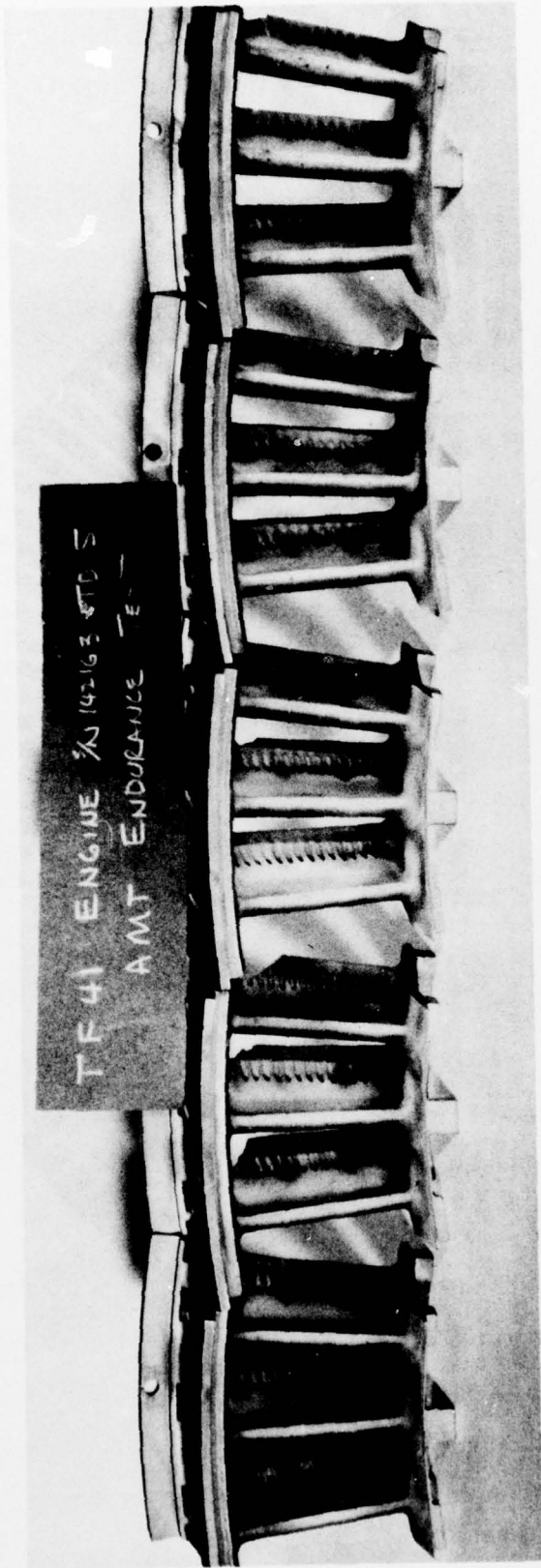


Figure 14 Second-Stage High-Pressure Turbine Vanes

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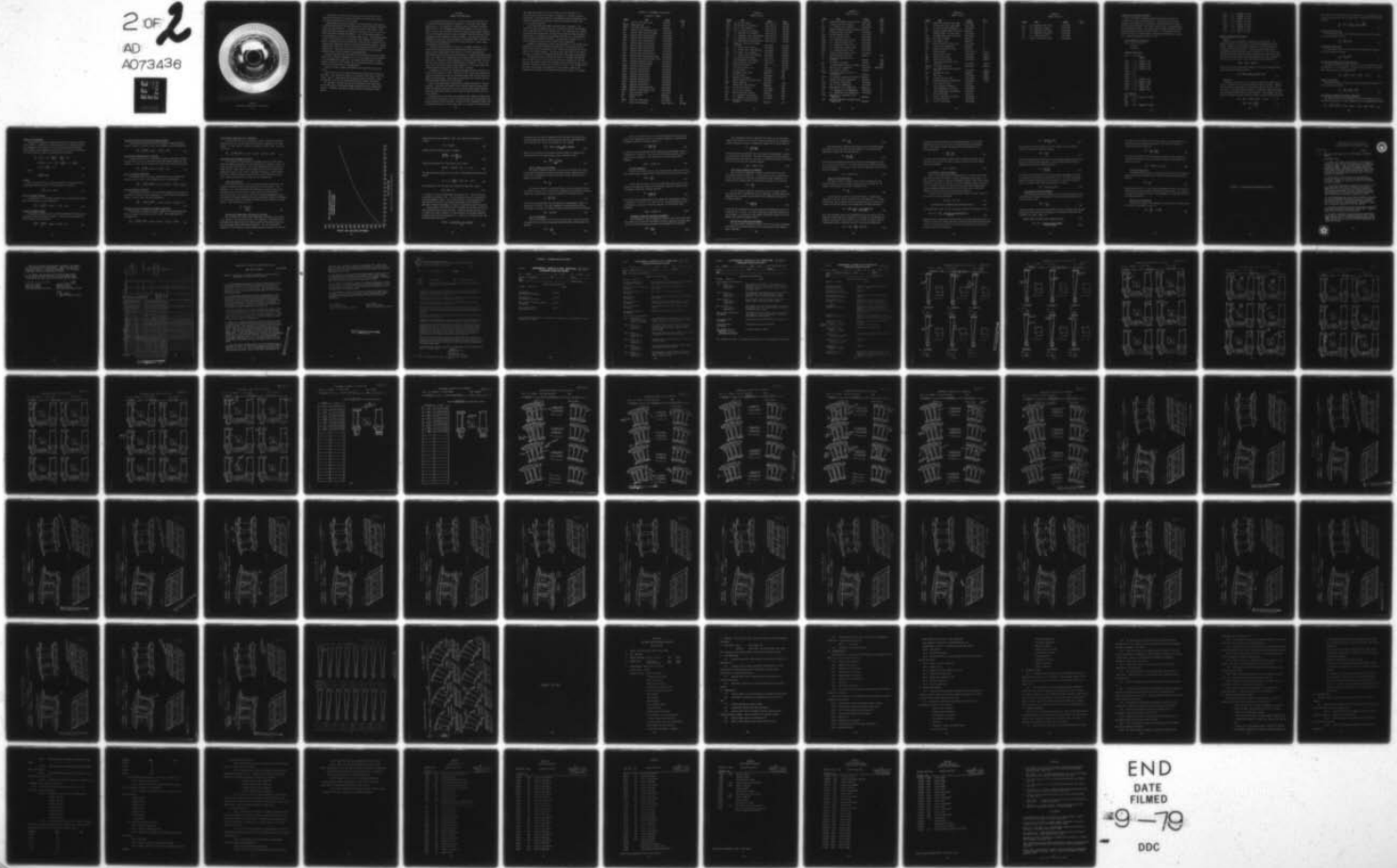
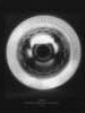
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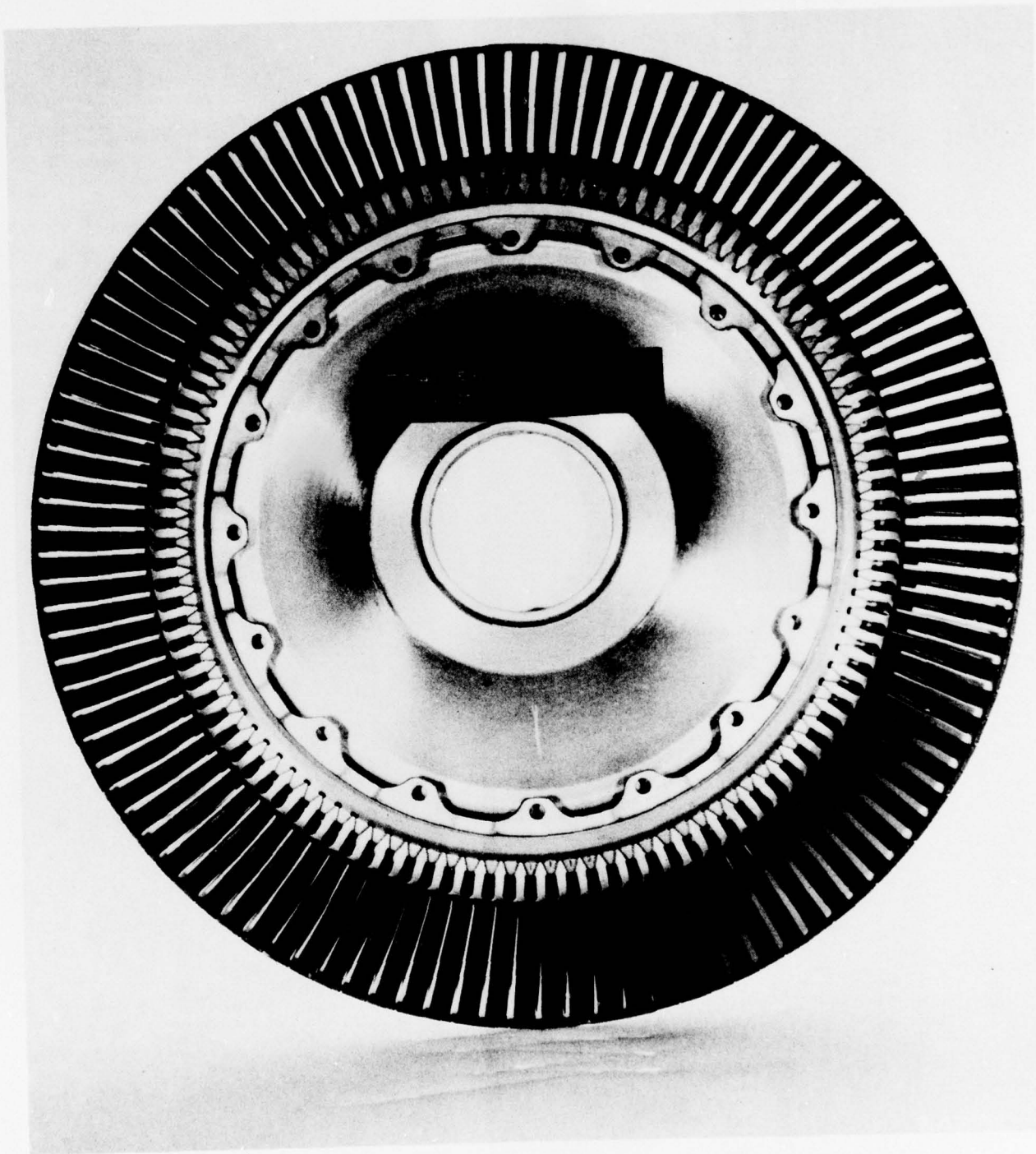


Figure 55  
Second-Stage High-Pressure Turbine Rotor

Examination of the fracture surface using the Scanning Electron Microscope showed that striations indicative of fatigue were present and progressed toward the trailing edge.

Metallographic examination showed a line type fracture path typical of fatigue progressing from the deteriorated leading edge which contained oxide and alloy depletion. A transverse section of the blade .1 inch below the fracture showed the maximum wall thickness to be .05 inch which meets engineering drawing requirements. Part of the leading edge was missing adjacent to an area of oxidation type attack. Coating was present at the trailing edge with a structureless zone adjacent to the coating which is presumed to be alloy depletion. Areas of heavy oxidation at the leading edge surface and internal cooling passages were observed. Coating thickness was .0005 and .001 inch along the pressure and suction surfaces respectively. Base metal structure at the leading and trailing edges appeared normal with no evidence of overtemperature.

Hardness determinations were made for the leading and trailing edges, mid-airfoil, and base to determine if a lack of internal cooling resulted in an overtemperature condition. The values obtained showed a slight hardness reduction at the leading and trailing edge which is considered normal and not indicative of overtemperature.

Chemical analysis showed conformance to the appropriate specified limits.

The blades in the first stage high pressure turbine were not new for this test. They had been originally run through an AMT test on TF41 S/N 141677 (ref 2). These blades had accumulated nearly 350 hours of AMT testing and a total of 429 total operating hours before the failure.

All the other teardown findings were considered to be normal wear for 189 AMT hours, or secondary damage caused by the first stage blade failure. Therefore, they were not metallurgically analyzed in great detail.

SECTION X  
SUMMARY AND CONCLUSIONS

An accelerated mission test of a TF41-A-1 engine S/N 142163 was run at the Air Force Aero Propulsion Laboratory's "D"-Bay sea level engine test facility. The objectives of the test were to continue to test the durability of a set of hardware modifications known as "Block 76" hardware, to verify the reliability of several rework and part repair schemes, to track and document overall engine performance deterioration and investigate burner outlet temperature profile changes. The test was initially scheduled for 263 hours but was prematurely terminated after 189 AMT hours (214 total engine operating hours) due to the failure of a first stage high pressure turbine blade.

The engine was returned to Allison for a teardown inspection. The forged first stage high pressure turbine blade failed in fatigue originating at the leading edge of the blade in an area of deterioration. Alloy depletion and oxidation was pronounced in a leading edge deteriorated zone. Five other first stage blades also showed leading edge deterioration and cracks. These were not new blades but had been run through a previous AMT test and failed with nearly 350 AMT hours of operation. This is the first time this failure mode has been observed in a TF41 first stage high pressure turbine blade and the actual cause is unknown.

In general, the "Block 76" hardware performed very well and was not a factor in the engine's failure. Many of the first stage vanes showed some cracks and distress but this was considered normal wear for the equivalent amount of running time. These vanes also had been run on 141677 and thus had accumulated 350 AMT hours of operation.

None of the reworked and repaired parts showed indications of unusual distress. The other items noted in the teardown inspection report were either considered normal wear and tear or are secondary damage caused by the first stage high pressure turbine blade failure and are not areas of major concern.

Deterioration effects were less pronounced than expected, probably due to the significant amount of run time accumulated on this engine before the actual AMT test (nearly 40 hours). Analysis of the intermediate power data recorded during each "A" cycle shows that, at a constant corrected exhaust

gas temperature, about 1.5% in net thrust was lost with most of it occurring during the first 50 hours of operation. The data also predicted that little deterioration in performance could be expected if this engine was operated at a constant corrected low pressure rotor speed (i.e., cold day operation).

The steady-state part power calibration data indicated a 1.5% increase in fuel consumption and a 20° increase in turbine inlet temperature at constant thrust after 100 AMT hours. Fan operating line shifted up slightly and high pressure compressor operating line moved up about 1%. These shifts in performance were probably the result of a deterioration in high pressure turbine performance. Calculations indicate a 1.5% - 2% loss in turbine efficiency after 100 AMT hours of operation.

Exhaust gas temperature surveys were performed at 0 and 100 AMT hours. Analysis of this data indicates that there was no significant shift in profile with increasing operating time. Neither the magnitude of the hot spot nor its location changed. This would imply that there is no significant shift in burner exit temperature profile as the engine deteriorated.

The original plan for testing the "Block 76" hardware included 526 hours of AMT testing in two builds, separated by a teardown and overhaul. This was the second failure that occurred on this engine during AMT testing, neither of which was related to the "Block 76" parts. Only 295 AMT hours have been accumulated, so the engine will once again be rebuilt and returned to "D"-Bay for continued AMT testing of the "Block 76" hardware.

APPENDIX A: PERFORMANCE CALCULATIONS

APPENDIX A SYMBOLS

<u>SYMBOL</u>	<u>NAME</u>	<u>SOURCE</u>	<u>UNITS</u>
A4	Turbine inlet nozzle area	Constant	IN <sup>2</sup>
ABLEED	Bleed port area	Constant	IN <sup>2</sup>
ASCRN	Inlet FOD screen area	Constant	-
CPFG	Specific heat correction/thrust	Calculated	-
CPN	Specific heat correction/speed	Calculated	-
CPP21	Specific heat correction/P21	Calculated	-
CPP23	Specific heat correction/P23	Calculated	-
CPP3	Specific heat correction/P3	Calculated	-
CPP5	Specific heat correction/P5	Calculated	-
CPT21	Specific heat correction/T21	Calculated	-
CPT23	Specific heat correction/T23	Calculated	-
CPT3	Specific heat correction/T3	Calculated	-
CPT5	Specific heat correction/T5	Calculated	-
CPWA	Specific heat correction/airflow	Calculated	-
CPWF	Specific heat correction/fuel flow	Calculation	-
CVPFG	Humidity correction/thrust	Calculated	-
CVPN	Humidity correction/speed	Calculated	-
CVPP21	Humidity correction/P21	Calculated	-
CVPP23	Humidity correction/P23	Calculated	-
CVPP3	Humidity correction/P3	Calculated	-
CVPP5	Humidity correction/P5	Calculated	-
CVPT21	Humidity correction/T21	Calculated	-
CVPT23	Humidity correction/T23	Calculated	-
CVPT3	Humidity correction/T3	Calculated	-
CVPT5	Humidity correction/T5	Calculated	-
CVPWA	Humidity correction/airflow	Calculated	-
CVPWF	Humidity correction/fuel flow	Calculated	-
EPR	Engine pressure ratio	Calculated	-
FGM	Measured thrust	Measured	LB <sub>F</sub>
FG	Thrust	Calculated	LB <sub>F</sub>
FSCRN	Inlet FOD screen force	Calculated	LB <sub>F</sub>
H1	Engine inlet enthalpy	Table Look Up	BTU/LBM

APPENDIX A  
SYMBOLS (Cont'd)

<u>SYMBOL</u>	<u>NAME</u>	<u>SOURCE</u>	<u>UNITS</u>
H21H	Fan hub exit enthalpy	Table Look Up	BTU/LBM
H21HI	Fan hub ideal exit enthalpy	Table Look Up	BTU/LBM
H21T	Fan tip exit enthalpy	Table Look Up	BTU/LBM
H21TI	Fan tip ideal exit enthalpy	Table Look Up	BTU/LBM
H22	I.P. compressor exit enthalpy	Table Look Up	BTU/LBM
H22I	I.P. compressor ideal exit enthalpy	Table Look Up	BTU/LBM
H23	H.P. compressor inlet enthalpy	Table Look Up	BTU/LBM
H3	H.P. compressor discharge enthalpy	Table Look Up	BTU/LBM
H3I	Ideal H.P. compressor discharge enthalpy	Calculated	BTU/LBM
H4	H.P. turbine inlet enthalpy	Calculated	BTU/LBM
H41	H.P. turbine rotor inlet enthalpy	Calculated	BTU/LBM
H42	H.P. turbine exit enthalpy	Calculated	BTU/LBM
H42I	L.P. turbine ideal inlet enthalpy	Calculated	BTU/LBM
H43	L.P. turbine inlet enthalpy	Calculated	BTU/LBM
H5	Untrimmed exhaust gas enthalpy	Table Look Up	BTU/LBM
H5I	Ideal turbine exit enthalpy	Calculated	BTU/LBM
HF4	Enthalpy of the fuel	Table Look Up	BTU/LBM
LHV	Fuel lower heating value	Constant	BTU/LBM
NH	HP rotor speed	Calculated	RPM
NHM	Measured HP rotor speed	Measured	RPM
NL	LP rotor speed	Calculated	RPM
NLM	Measured rotor speed	Measured	RPM
OPR	Overall compressor pressure ratio	Calculated	-
PAMB	Ambient pressure	Measured	IN HG
P1	Engine inlet total pressure	Measured	PSIA
P21H	Fan hub exit pressure	Calculated	PSIA
P21T	Fan tip exit pressure	Calculated	PSIA
P21M	Measured fan exit pressure	Measured	PSIG
P22	I.P. compressor exit pressure	Calculated	PSIA
P23	H.P. compressor inlet pressure	Calculated	PSIA
P23M	Measured H.P. compressor inlet pressure	Measured	PSIG

APPENDIX A  
SYMBOLS (Cont'd)

<u>SYMBOL</u>	<u>NAME</u>	<u>SOURCE</u>	<u>UNITS</u>
P3	Compressor discharge total pressure	Calculated	PSIA
P4	Turbine inlet total pressure	Calculated	PSIA
P43	L.P. turbine inlet pressure	Calculated	PSIA
P5M	Measured exhaust gas total pressure	Measured	PSIG
P5	Exhaust gas total pressure	Calculated	PSIA
PRFH	Fan hub pressure ratio	Calculated	-
PRFT	Fan tip pressure ratio	Calculated	-
PRHP	H.P. compressor pressure ratio	Calculated	-
PRHPT	H.P. turbine pressure ratio	Calculated	-
PRIP	I.P. compressor pressure ratio	Calculated	-
PRLP	L.P. compressor pressure ratio	Calculated	-
PRLPT	L.P. turbine pressure ratio	Calculated	-
PRT	Overall turbine pressure ratio	Calculated	-
PS1	Bellmouth static pressure	Measured	PSIA
PS3	Compressor discharge static pressure	Measured	PSIG
RES	T5 Ballast resistance	Constant	OHMS
RH	T5 thermocouple harness resistance	Constant	OHMS
SFC	Specific fuel consumption	Calculated	LBM/HR/LBF
SGF	Fuel specific gravity	Constant	-
SGFM	Calibrated specific gravity of flow meter	Constant	-
SGFT	Fuel specific gravity at fuel tank	Measured	-
T1	Engine inlet total temperature	Measured	°F
T21H	Fan hub exit temperature	Calculated	°F
T21T	Fan tip exit temperature	Calculated	°F
T21M	Measured fan exit temperature	Measured	°F
T22	I.P. compressor exit temperature	Calculated	°F
T23	H.P. compressor inlet temperature	Calculated	°F
T23M	Measured H.P. compressor inlet temperature	Measured	°F
T3M	Measured compressor discharge total temperature	Measured	°F

APPENDIX A  
SYMBOLS (Cont'd)

<u>SYMBOL</u>	<u>NAME</u>	<u>SOURCE</u>	<u>UNITS</u>
T3	Compressor discharge total temp	Calculated	°F
T4	Turbine inlet total temperature	Calculated	°F
T43	L.P turbine inlet temperature	Calculated	°F
T5M	Measured trimmed exhaust gas temp	Measured	°F
T5	Trimmed exhaust gas total temp	Calculated	°F
T5UT	Untrimmed exhaust gas total temp	Calculated	°F
TFUEL	Fuel temp at engine	Measured	°F
TFUEL T	Fuel temp at tank	Measured	°F
TPR	Overall turbine pressure ratio	Calculated	-
TJB	Junction box temperature	Measured	°F
TJBS	Standard junction box temp	Constant	°F
Vp	Vapor pressure	Table Look Up	IN HG
WA	Engine inlet airflow	Calculated	LBM/SEC
WA22	Engine core airflow	Calculated	LBM/SEC
WA4	Turbine inlet airflow	Calculated	LBM/SEC
WAI	Total corrected engine inlet airflow	Calculated	LBM/SEC
WBLEED	11th stage bleed flow	Calculated	LBM/SEC
WFCS	Fuel flow corrected for specific gravity	Calculated	LBM/SEC
WFM	Measured fuel flow	Measured	LBM/HR
WF	Fuel flow	Calculated	LBM/HR
WG4	Turbine inlet gas flow	Calculated	LBM/SEC
$\Delta P$	Bellmouth pressure differential	Calculated	IN H <sub>2</sub> O
$\Delta P_B$	Burner pressure drop	Constant	-
$\delta$	Inlet pressure correction	Calculated	-
$\theta$	Inlet temperature correction	Calculated	-
$\theta^*$	Inlet temperature correction/T5	Calculated	-
$\eta_B$	Burner efficiency	Constant	-
$\eta_C$	Overall compressor efficiency	Calculated	-
$\eta_{FH}$	Fan hub efficiency	Calculated	-
$\eta_{FT}$	Fan tip efficiency	Calculated	-

APPENDIX A  
SYMBOLS (Cont'd)

<u>SYMBOL</u>	<u>NAME</u>	<u>SOURCE</u>	<u>UNITS</u>
$\eta_{HP}$	H.P. compressor efficiency	Calculated	-
$\eta_{HPT}$	H.P. turbine efficiency	Calculated	-
$\eta_{IP}$	I.P. compressor efficiency	Calculated	-
$\eta_{LP}$	L.P. compressor efficiency	Calculated	-
$\eta_{LPT}$	L.P. turbine efficiency	Calculated	-
$\eta_T$	Overall turbine efficiency	Calculated	-

## CORRECTION OF MEASURED PARAMETERS

Most of the engine parameters measured during the test must be corrected for several different effects. These effects include the standard inlet temperature and pressure corrections as well as empirically derived corrections for humidity, specific heat, instrumentation, and installation effects. The expressions for these correction factors were obtained from Technical Order 2J-TF41-3. The procedure for correcting the data is outlined below. Note that corrections can be made for a standard temperature of 59°F or 77°F.

### Inlet Condition Corrections

$$TSTD = 518.7 \text{ or } 536.7^\circ R$$

$$= T1/TSTD$$

$$= P1/14.696$$

### Humidity Corrections

$$HUM = 4353.2 \left( \frac{V_P}{PAMB - V_P} \right)$$

$$CVPFG = 1.0 + .0000143 \times HUM$$

$$CVPN = 1.0 - .0000343 \times HUM$$

$$CVPWA = 1.0 + .0000457 \times HUM$$

$$CVPWF = 1.0 - .0000814 \times HUM$$

$$CVPP21 = 1.0$$

$$CVPP23 = 1.0$$

$$CVPP3 = 1.0$$

$$CVPP5 = 1.0 + .0000079 \times HUM$$

$$CVPT21 = 1.0 + .0000107 \times HUM$$

$$CVPT23 = 1.0 + .0000143 \times HUM$$

$$CVPT3 = 1.0 + .00003 \times HUM$$

$$CVPT5 = 1.0 - .0000264 \times HUM$$

### C<sub>p</sub> Corrections

$$CPFG = 1.0 - .0001214 (T1 - TSTD)$$

$$CPN = 1.0$$

$$CPWA = 1.0$$

$$CPWF = 1.0 - .0003846 (T1 - TSTD)$$

CPP21 = 1.0 - .0000806 (T1-TSTD)  
 CPP23 = 1.0 - .0000806 (T1-TSTD)  
 CPP3 = 1.0 - .0000645 (T1-TSTD)  
 CPP5 = 1.0 - .000071 (T1-TSTD)  
 CPT21 = 1.0 - .0000065 (T1-TSTD)  
 CPT23 = 1.0 - .0000097 (T1-TSTD)  
 CPT3 = 1.0 + .0001355 (T1-TSTD)  
 CPT5 = 1.0 - .000071 (T1-TSTD)

#### CORRECTED PARAMETER CALCULATIONS

##### Thrust

During the test, the engine is mounted on a thrust stand. The measured scale force is displayed on the CRT and recorded on the line printer. However, in the "D"-Bay installation, the inlet FOD screen is mounted on the thrust balance. Therefore, the displayed thrust includes the screen drag which must be accounted for. This loss can be estimated by assuming ambient pressure on the upstream side of the screen and engine inlet total pressure on the downstream side with no change in velocity across the screen. The screen force can be calculated as:

$$F_{SCRN} = A_{SCRN} \times (P_{AMB} - P_1) \quad (1)$$

Thrust must also be corrected for humidity, CP, and inlet pressure effects according to the following equation:

$$\frac{FG}{\delta} = \frac{(FGM + F_{SCRN}) \times C_{VPFG} \times C_{PFG}}{\delta} \quad (2)$$

##### Fuel Flow

A flow meter is installed in the fuel line ahead of the engine and its output is displayed on the CRT and recorded on the line printer. However, the flow meter is calibrated for only one fuel specific gravity (.762 in this case). The actual specific gravity is a function of both fuel temperature and the particular batch of fuel being used. The displayed fuel flow must be corrected for specific gravity effects using the following equations:

$$SGF = SGFT - .0004 \times (TFUEL - TFUELT) \quad (3)$$

$$WFCS = WFM \times \left( \frac{SGF}{SGFM} \right) \quad (4)$$

This fuel flow is then corrected for humidity, CP, inlet temperature and pressure, and lower heating value effects according to the following equation:

$$\frac{WF}{\sqrt{\theta}\delta} = \frac{WFCS \times CVPWF \times CPWF \times \frac{LHV}{18400}}{\delta\sqrt{\theta}} \quad (5)$$

#### HIGH PRESSURE ROTOR SPEED

The high pressure rotor tach reading must be corrected for humidity and inlet temperature effects.

$$\frac{NH}{\sqrt{\theta}} = \frac{NHM \times CVPN}{\sqrt{\theta}} \quad (6)$$

#### LOW PRESSURE ROTOR SPEED

The low pressure rotor tach reading must be corrected for humidity and inlet temperature effects.

$$\frac{NL}{\sqrt{\theta}} = \frac{NLM \times CVPN}{\sqrt{\theta}} \quad (7)$$

#### HIGH PRESSURE COMPRESSOR DISCHARGE PRESSURE

The measured variable at this station is a static pressure which must be converted to a total pressure. It must also be corrected for specific heat, inlet pressure, and instrumentation.

$$\frac{P3}{\delta} = \left[ \left( \frac{PS3}{\delta} \times CPP3 \right) + 4.56 \right] \times 1.0512 \quad (8)$$

#### EXHAUST GAS PRESSURE

The measured exhaust gas pressure must be corrected for humidity, CP, and inlet pressure effects.

$$\frac{P5}{\delta} = \frac{P5M \times CVPP5 \times CPP5}{\delta} \quad (9)$$

#### HIGH PRESSURE COMPRESSOR DISCHARGE TEMPERATURE

The measured high pressure compressor discharge temperature must be corrected for humidity, CP, inlet temperature, and instrumentation effects.

$$\frac{T3}{\theta} = \left[ \left( \frac{T3M + 459.7}{\theta} \times CVPT3 \times CPT3 \right) + 1.2 \right] \times 1.003 - 459.7 \quad (10)$$

### EXHAUST GAS TEMPERATURE

The measured exhaust gas temperature must be corrected for humidity and CP effects. In addition, it must be adjusted to a standard junction box temperature and corrected for the ballast and harness resistance. A non-standard inlet temperature correction ( $\theta^{.8788}$ ) is also used because TF41 past history has shown it correlates the data better.

$$\begin{aligned} \frac{T5}{\theta^*} = & \left( \left[ T5m \times \left( 1.0 + \frac{RH}{RES} \right) \right] - \left( \frac{RH}{RES} \times TJB \right) \right. \\ & \left. + \left( \left[ 459.7 \times (1.0 - \theta^*) \right] + \left[ \frac{RH}{RES} \times \theta^* \times TJBS \right] \right) \right) \\ & \div \left( \left[ 1.0 + \frac{RH}{RES} \right] \times \theta^* \right) \end{aligned} \quad (11)$$

where:

$$\theta^* = \frac{\theta^{.8788}}{CVPT5 \times CPT5} \quad (12)$$

### AIRFLOW

The calculated airflow is already corrected for inlet pressure and temperature effects but must still be corrected for humidity.

$$\frac{WA\sqrt{\theta}}{\delta} = WAI \times CVPWA \quad (13)$$

### FAN TIP DISCHARGE PRESSURE

The measured fan tip discharge pressure must be corrected for specific heat, inlet pressure, and instrumentation.

$$\frac{P21T}{\delta} = \left[ \left( \frac{P21M}{\delta} \times CPP21 \right) + 1.19 \right] \times .9911 \quad (14)$$

### FAN HUB DISCHARGE PRESSURE

This measured variable is fan tip discharge pressure and this must be converted to the hub discharge pressure. It must also be corrected for specific heat and inlet pressure.

$$\frac{P21H}{\delta} = \left[ \left( \frac{P21M}{\delta} \times Cpp21 \right) + 4.14 \right] \times .95 \quad (15)$$

#### INTERMEDIATE PRESSURE COMPRESSOR DISCHARGE PRESSURE

The measured intermediate pressure compressor discharge pressure must be corrected for specific heat, inlet pressure, and instrumentation.

$$\frac{P22}{\delta} = \left[ \left( \frac{P23M}{\delta} \times CPP23 \right) + 1.41 \right] \times .9776 \quad (16)$$

#### HIGH PRESSURE COMPRESSOR INLET PRESSURE

The measured variable is intermediate pressure compressor discharge pressure and this must be converted to the high pressure compressor inlet pressure. It must also be corrected for specific heat and inlet pressure.

$$\frac{P23}{\delta} = \left[ \left( \frac{P23M}{\delta} \times CPP23 \right) + 3.38 \right] \times .9413 \quad (17)$$

#### FAN TIP DISCHARGE TEMPERATURE

The measured fan tip discharge temperature must be corrected for humidity, specific heat, inlet temperature, and instrumentation.

$$\frac{T21T}{\theta} = \left[ \left( \frac{T21M + 459.7}{\theta} \times CPT21 \times CVPT21 \right) + 68.1 \right] \times .9028 \quad (18)$$

#### FAN HUB DISCHARGE TEMPERATURE

The measured variable is fan tip discharge temperature which must be converted to fan hub discharge temperature. It must also be corrected for humidity, specific heat, and inlet temperature.

$$\frac{T21H}{\theta} = \left[ \left( \frac{T21M + 459.7}{\theta} \times CPT21 \times CVPT21 \right) + 200.8 \right] \times .76 \quad (19)$$

#### INTERMEDIATE PRESSURE COMPRESSOR DISCHARGE TEMPERATURE

The measured intermediate pressure compressor discharge temperature must be corrected for humidity, specific heat, inlet temperature and instrumentation.

$$\frac{T22}{\theta} = \left[ \left( \frac{T23M + 459.7}{\theta} \times CPT23 \times CVPT23 \right) - 58.7 \right] \times 1.0895 \quad (20)$$

### HIGH PRESSURE COMPRESSOR INLET TEMPERATURE

The measured variable is intermediate pressure compressor discharge temperature and must be converted to high pressure compressor inlet temperature. It must also be corrected for humidity, specific heat, and inlet temperature.

$$\frac{T_{23}}{\theta} = \left[ \left( \frac{T_{23M} + 459.7}{\theta} \times CPT_{23} \times CVPT_{23} \right) - 60.9 \right] \times 1.0926 \quad (21)$$

### CALCULATIONS OF PERFORMANCE VARIABLES

The following section presents the methods used to calculate some engine performance parameters from the temperatures, pressures, forces, and flows measured during the test. The engine parameters that can be calculated include: total engine airflow, engine core airflow, turbine inlet temperature, bypass ratio, overall compressor efficiency, overall turbine efficiency, overall compressor pressure ratio, overall turbine pressure ratio, engine pressure ratio, and specific fuel consumption.

#### Total Engine Airflow

The inlet bellmouth has static and total pressure probes which have readings displayed on the CRT and recorded on the line printer. The parameter,  $\Delta P/\delta$  is calculated from the difference in these pressure readings and used to enter the curve in Figure 58 to yield engine total corrected airflow. (This curve is from the bellmouth manufacturer and is only good for bellmouth number 6872762 and screen number 7872166 or 67983644). This airflow must then be corrected for humidity and Cp effects as outlined earlier. The calculation of  $\Delta P/\delta$  is:

$$\frac{\Delta P}{\delta} = \frac{P_1 - P_{S1}}{P_1} \times 14.696 \quad (22)$$

#### Turbine Inlet Temperature and Engine Core Airflow

The calculation of turbine inlet temperature and engine core airflow is an iterative calculation using fuel flow, compressor discharge pressure and temperature (appropriately corrected), turbine inlet nozzle flow area, and some assumed burner performance parameters. For the calculations summarized in this appendix, burner pressure drop was assumed to be .055 and

**Note: Use Only With Air Inlet Bell  
No. 6872762 and Screen  
No. 6872168 or 6798364**

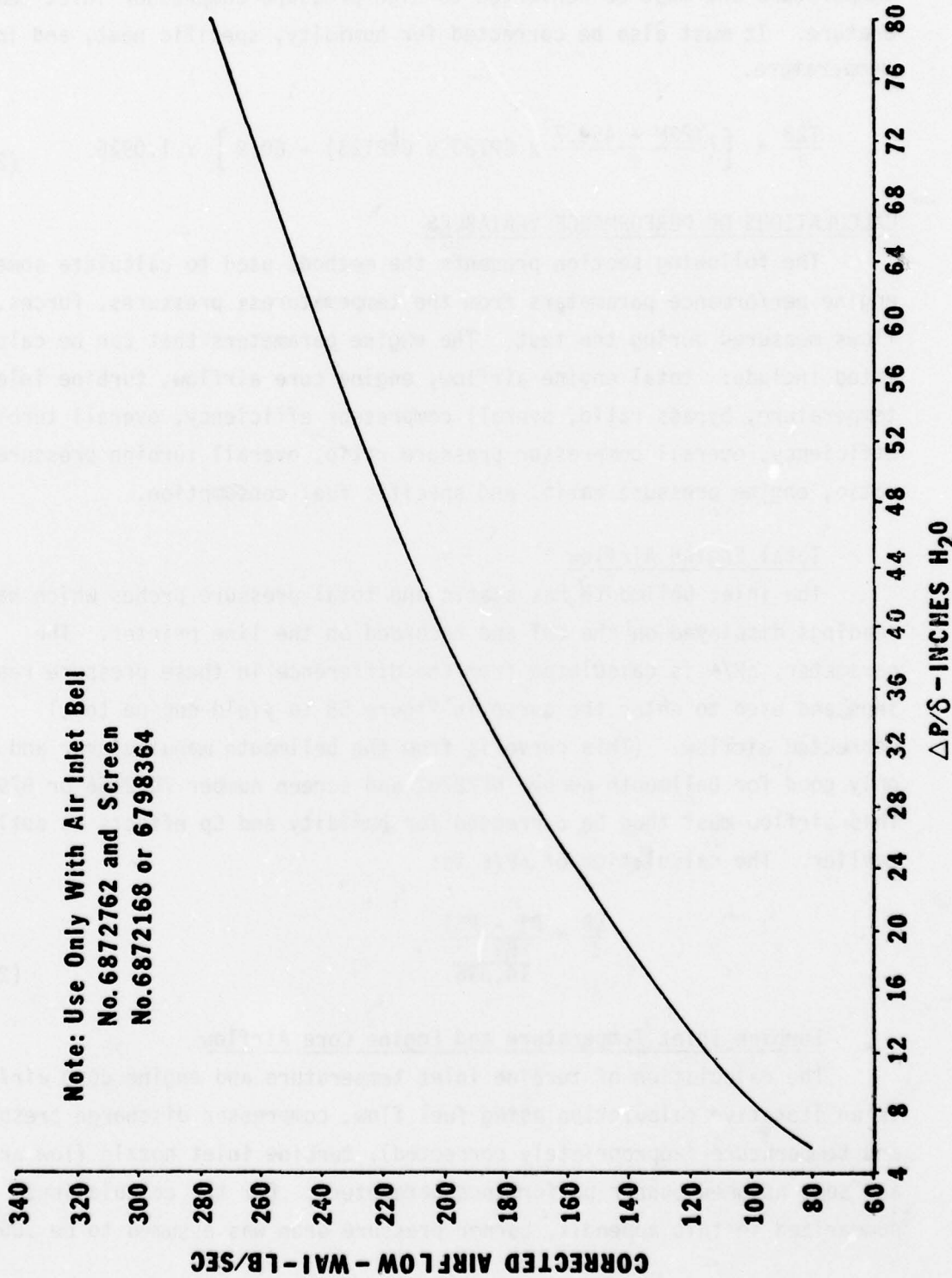


FIGURE 56 - INLET BELLMOUTH CHARACTERISTICS

burner efficiency was assumed at .999. The calculation procedure is as follows:

$$P_4 = (1 - \Delta P_B) P_3 \quad (23)$$

Assuming that the turbine nozzle is choked:

$$\frac{WG_4 \sqrt{T_4}}{P_4 A_4} = .5312 \frac{\text{LBM}}{\text{SEC}} \frac{\sqrt{^\circ R}}{\text{LB}_F} \quad (24)$$

Substituting equation (23) into equation (24) yields:

$$WG_4 \sqrt{T_4} = .5312 (A_4) (P_3) (1 - \Delta P_B) \quad (25)$$

The other governing equation in this case is the energy balance across the burner:

$$H_4 = H_3 + \eta_B \left( \frac{WF}{WA_4} \right) (LHV + 182. - HF_4) \quad (26)$$

The procedure for solving these two simultaneous equations, noting:

$$WA_4 = WG_4 - WF \quad (27)$$

is to guess a  $T_4$  and calculate  $WG_4$  from equation (25). An  $H_4$  can then be calculated from equation (26).  $T_4$  can be obtained from the calculated  $H_4$  using thermodynamic tables. The entire procedure is then repeated until the guessed  $T_4$  and the  $T_4$  calculated from equation (26) are within  $1^\circ$ . When this iteration converges, a solution is obtained for both  $T_4$  and  $WA_4$ .

Before engine core airflow can be calculated, an estimate of the 11th stage customer bleed flow must be made. Assuming that the discharge port is choked and further assuming a 5% total pressure loss between compressor discharge and the bleed discharge and a 5% reduction in effective area, the estimated bleed flow rate is:

$$WBLEED = \frac{.532 (.95 x P_3) (.95 x ABLEED)}{\sqrt{T_3}} \quad (28)$$

The engine core airflow (IP compressor inlet airflow) can then be calculated by adding the turbine cooling flow and the 11th stage bleed flow to the turbine inlet airflow and allowing .2% for leakage.

$$WA_{22} = \frac{WA_4 + (.0604 \times WA_4) + W_{BLEED}}{.998} \quad (29)$$

Bypass ratio can then be calculated using the results of equation (29) and the previously calculated engine total corrected airflow.

$$BPR = \frac{\frac{WA\sqrt{\theta}}{\delta} \left( \frac{\delta}{\sqrt{\theta}} \right) - WA_{22}}{WA_{22}} \quad (30)$$

#### Overall Compressor Performance

The overall compressor pressure ratio can be calculated very simply by dividing the measured compressor discharge pressure (appropriately corrected for instrumentation, humidity and specific heat effects) by the engine inlet pressure.

$$OPR = \frac{P_3}{P_1} \quad (31)$$

The overall compression system efficiency can be calculated, knowing the overall pressure ratio, engine inlet temperature and compressor discharge temperature (appropriately corrected) through the following equation:

$$\eta_c = \frac{H_{3I} - H_1}{H_3 - H_1} \quad (32)$$

H<sub>1</sub> and H<sub>3</sub> can be determined from the appropriate thermodynamic tables as a function of T<sub>1</sub> and T<sub>3</sub>. The ideal compressor discharge enthalpy can be calculated as a function of overall pressure ratio and engine inlet enthalpy.

$$H_{3I} = f(OPR, H_1) \quad (33)$$

#### FAN TIP PERFORMANCE

The fan tip pressure ratio can be calculated very simply by dividing the measured fan tip pressure (appropriately corrected) by the engine inlet pressure.

$$PRFT = \frac{P_{21T}}{P_1} \quad (34)$$

The fan tip efficiency can be calculated knowing the pressure ratio, engine inlet temperature and fan tip discharge temperature (appropriately corrected) through the following equation:

$$\eta_{FT} = \frac{H_{21TI} - H_1}{H_{21T} - H_1} \quad (35)$$

$H_1$  and  $H_{21T}$  can be determined from the appropriate thermodynamic tables as a function of  $T_1$  and  $T_{21T}$ . The ideal fan tip discharge enthalpy can be calculated as a function of fan tip pressure ratio and engine inlet enthalpy.

$$H_{21TI} = f(\text{PRFT}, H_1) \quad (36)$$

#### FAN HUB PERFORMANCE

The fan hub pressure ratio can be calculated very simply by dividing the fan hub pressure (appropriately corrected) by the engine inlet pressure.

$$\text{PRFH} = \frac{P_{21T}}{P_1} \quad (37)$$

The fan hub efficiency can be calculated knowing the pressure ratio, engine inlet temperature and fan hub discharge temperature (appropriately corrected) through the following equation:

$$\eta_{FH} = \frac{H_{21HI} - H_1}{H_{21H} - H_1} \quad (38)$$

$H_1$  and  $H_{21H}$  can be determined from the appropriate thermodynamic tables as a function of  $T_1$  and  $T_{21H}$ . The ideal fan hub discharge enthalpy can be calculated as a function of fan hub pressure ratio and engine inlet enthalpy.

$$H_{21HI} = f(\text{PRFH}, H_1) \quad (39)$$

#### INTERMEDIATE PRESSURE COMPRESSOR PERFORMANCE

The intermediate pressure compressor pressure ratio can be calculated very simply by dividing the intermediate pressure compressor discharge pressure by the fan hub discharge pressure (both appropriately corrected).

$$\text{PRIP} = \frac{P_{22}}{P_{21H}} \quad (40)$$

The intermediate pressure compressor efficiency can be calculated knowing the pressure ratio, fan hub discharge temperature and intermediate pressure compressor discharge temperature through the following equation:

$$\eta_{IP} = \frac{H_{22I} - H_{21H}}{H_{22} - H_{21H}} \quad (41)$$

H<sub>21H</sub> and H<sub>22</sub> can be determined from the appropriate thermodynamic tables as a function of T<sub>21H</sub> and T<sub>22</sub>. The ideal intermediate pressure compressor enthalpy can be calculated as a function of intermediate pressure compressor pressure ratio and fan hub discharge enthalpy.

$$H_{22I} = f(\text{PRIP}, H_{21H}) \quad (42)$$

#### LOW PRESSURE COMPRESSOR PERFORMANCE

The low pressure compressor is made up of both the fan and the intermediate pressure compressor. The low pressure spool pressure ratio can be calculated by dividing the intermediate pressure compressor discharge pressure (appropriately corrected) by the engine inlet pressure.

$$\text{PRLP} = \frac{P_{22}}{P_1} \quad (43)$$

The low pressure compressor efficiency can be calculated knowing the pressure ratio, intermediate pressure compressor discharge temperature (appropriately corrected) and the engine inlet temperature through the following equation:

$$\eta_{LP} = \frac{H_{22I} - H_1}{H_{22} - H_1} \quad (44)$$

H<sub>1</sub> and H<sub>22</sub> can be determined from the appropriate thermodynamic tables as a function of T<sub>1</sub> and T<sub>22</sub>. The ideal low pressure compressor enthalpy can be calculated as a function of low pressure compressor pressure ratio and engine inlet enthalpy (equation (42)).

#### HIGH PRESSURE COMPRESSOR PERFORMANCE

The high pressure compressor pressure ratio can be simply calculated by dividing its discharge pressure by its inlet pressure (both appropriately corrected).

$$PRHP = \frac{P3}{P23} \quad (45)$$

The high pressure compressor efficiency can be calculated knowing the pressure ratio, and high pressure compressor inlet and discharge temperature through the following equation:

$$\eta_{HP} = \frac{H3I - H23}{H3 - H23} \quad (46)$$

H23 and H3 can be determined from the appropriate thermodynamics tables as a function of T23 and T3. The ideal high pressure compressor enthalpy can be calculated as a function of high pressure compressor pressure ratio and inlet enthalpy.

$$H3I = f(PRHP, H23) \quad (47)$$

#### Overall Turbine Performance

The overall turbine pressure ratio can be calculated from the measured exhaust gas total pressure (appropriately corrected) and the turbine inlet pressure calculated in equation (23) ).

$$TPR = \frac{P4}{P5} \quad (48)$$

The calculation of overall turbine efficiency is somewhat more complicated than the similar calculation for the compressor. First the turbine rotor inlet enthalpy must be calculated from the turbine nozzle cooling flow and the turbine inlet temperature calculated previously.

$$H4I = \frac{(WG4) (H4) + .0318 (WA4) (H3)}{WG4 + .0318 (WA4)} \quad (49)$$

Next, the untrimmed exhaust gas temperature must be calculated from the measured trimmed exhaust gas temperature (corrected for instrumentation, humidity, and specific heat effects) the T5 ballast resistance, the T5 thermocouple harness resistance and the T5 junction box temperature.

$$T5UT = T5M + \left(\frac{RH}{RES}\right) (T5M - TJB) \quad (50)$$

The turbine discharge enthalpy can be determined from the calculated temperature and fuel-to-air ratio using the appropriate thermodynamic table. The overall turbine efficiency can be calculated using the following equation.

$$\eta_T = \frac{H_{41} - H_5}{H_{41} - H_{5I}} \quad (51)$$

The ideal turbine discharge enthalpy used in the above equation can be calculated as a function of overall turbine pressure ratio and turbine rotor inlet enthalpy.

$$H_{5I} = f(\text{TPR}, H_{41}) \quad (52)$$

#### LOW PRESSURE TURBINE PERFORMANCE

There is no inter-turbine instrumentation so, in order to calculate low pressure turbine performance, several assumptions must be made. The most critical of these is that the low pressure turbine inlet nozzle remains choked over the region of interest. The TF41 production engine simulation (ref 7) predicts that the low turbine inlet nozzle flow function remains constant between intermediate and idle at sea level static conditions, lending some credibility to the choked flow assumption.

The work of the low pressure turbine must equal the work required to drive the low pressure compressor.

$$W_{LC} \Delta H_{LC} = W_{LT} \Delta H_{LT} \quad (53)$$

$$(W_A - W_{A22})(H_{21T} - H_1) + W_{A22}(H_{22} - H_1) = (W_{A22} + W_F)(H_{43} - H_5) \quad (54)$$

Rearranging and solving for the low pressure turbine inlet enthalpy yields

$$H_{43} = H_5 + \frac{(W_A - W_{A22})(H_{21T} - H_1) + W_{A22}(H_{22} - H_1)}{W_{A22} + W_F} \quad (55)$$

Making use of the appropriate thermodynamic table allows determination of low pressure turbine inlet temperature and, along with the choked flow assumption and the low turbine flow function from the TF41 simulation, yields the low pressure turbine inlet pressure.

$$P43 = \frac{(WA22+WF) \sqrt{T43}}{72.7} \quad (56)$$

The low pressure turbine pressure ratio is simply the inlet pressure divided by the turbine discharge pressure.

$$PRLPT = \frac{P43}{P5} \quad (57)$$

The low pressure turbine efficiency can be calculated knowing the pressure ratio, low turbine inlet temperature, and untrimmed turbine discharge temperature through the following equation:

$$\eta_{LPT} = \frac{H43-H5}{H43-H5I} \quad (58)$$

H43 and H5 can be determined from the appropriate thermodynamics tables as a function of T43, T5UT and fuel-to-air ratio. The ideal low pressure turbine discharge enthalpy can be calculated as a function of pressure ratio, low turbine inlet enthalpy, and fuel-to-air ratio.

$$H5I = f(PRLPT, H43, FAR) \quad (59)$$

#### HIGH PRESSURE TURBINE PERFORMANCE

The high pressure turbine pressure ratio can be calculated using the inlet pressure calculated in equation(31)and the discharge pressure calculated by equation (56)

$$PRHPT = \frac{P4}{P43} \quad (60)$$

The high pressure turbine discharge enthalpy can be calculated from the work balance with the high pressure compressor and allowing an additional 500 horsepower for gears, pumps, etc.

$$WA22(H3-H23)+(353/WA22)=(WG4+.0318WA4)(H41-H42) \quad (61)$$

$$H42 = H41 - \frac{WA22(H3-H23)+(353/WA22)}{(WG4+.0318WA4)} \quad (62)$$

The high pressure turbine efficiency can then be calculated knowing the pressure ratio and high pressure turbine inlet and exit enthalpies through the following equation:

$$\eta_{\text{HPT}} = \frac{H_{41} - H_{42}}{H_{41} - H_{42I}} \quad (63)$$

The ideal high pressure turbine discharge enthalpy can be calculated as a function of pressure ratio, high pressure turbine inlet enthalpy and fuel-to-air ratio.

$$H_{42I} = f(\text{PRHPT}, H_{41}, \text{FAR}) \quad (64)$$

#### Engine Pressure Ratio

The engine pressure ratio can easily be calculated from the measured exhaust gas pressure (appropriately corrected) and measured engine inlet pressure.

$$\text{EPR} = \frac{P_5}{P_1} \quad (65)$$

Engine pressure ratio is a very important parameter because it is directly related to both nozzle pressure ratio and thus thrust and is also generally very close to fan pressure ratio. This parameter is an excellent indicator of engine performance.

#### Specific Fuel Consumption

The engine's specific fuel consumption can easily be calculated using the results of equations (2) and (5).

$$\text{SFC} = \left( \frac{WF}{\sqrt{\theta\delta}} \right) \sqrt{\theta} / \left( \frac{FG}{\delta} \right) \quad (66)$$



DEPARTMENT OF THE AIR FORCE  
HEADQUARTERS, AIR FORCE MATERIEL COMMAND  
WASHINGTON, D. C. 20330

REPORT OF INVESTIGATION

1. The purpose of this investigation was to determine the cause of the failure of the engine of the aircraft described in the report of the pilot. The engine was a Pratt & Whitney JT8D-15 turbofan engine, model number 37-117-10, and was installed on a Boeing 737-400 aircraft, registration number N12345. The engine failed during a flight on 10/10/99, at an altitude of 35,000 feet, approximately 10 minutes before the aircraft landed. The engine failed to develop sufficient thrust to maintain altitude, and the aircraft was forced to land at an alternate airport. The engine was removed from the aircraft and transported to the Air Force Materiel Command for investigation.

**APPENDIX B LUBRICANT MONITORING/BORESCOPE REPORTS**

2. The engine was inspected and found to be in good condition. The oil system was checked and found to be operating normally. The oil pressure was within the normal range, and the oil level was adequate. The oil was analyzed and found to be clean and free of contaminants. The engine was inspected with a borescope and found to be in good condition. The pistons, rings, and valves were all in good condition and showed no signs of wear or damage. The combustion chamber was clean and free of deposits. The engine was found to be in good condition and the failure was determined to be the result of a failure of the engine control system. The engine control system was inspected and found to be in good condition. The engine control system was found to be operating normally and the failure was determined to be the result of a failure of the engine control system. The engine control system was inspected and found to be in good condition. The engine control system was found to be operating normally and the failure was determined to be the result of a failure of the engine control system.



DEPARTMENT OF THE AIR FORCE  
AIR FORCE AERO PROPULSION LABORATORY (AFSC)  
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433



REPLY TO  
ATTN OF: SFL

7 Nov 78

SUBJECT: Analysis of Lubricants from TF-41 AMT Engine, S/N AE142163  
(OP-133)

TO: AFAPL/TBA (R. May)

1. Periodic lube samples were removed from S/N AE142163 for analyses to assess the lubricant condition and to determine wear metals present. Tests included foaming, spectrometric oil analysis (SOAP), complete oil breakdown rate analyzer (COBRA) measurements, ferrography, gas chromatography, viscosity and total acid number (TAN) determinations. Results of the tests are described individually below and all data are summarized in Attachment 1.
2. The engine oil tank site glass was also removed for television viewing of the lubricant to evaluate the extent of foaming. Comments on that test are given in the attached memo for the record.
3. It should be noted that the engine was initially serviced with 0-69-2 (MIL-L-7808 15D-1) followed by 0-78-6 (MIL-L-23699 0-6A-4, Lot 12), and then 0-71-10 (MIL-L-7808 5K-1). The changes were performed to provide information on engine foaming characteristics of two relatively high foaming lubricant formulations as determined by laboratory testing.
4. Gas chromatography was used to monitor changes of lubricant. During the significant test cycles for 0-78-6, it contained less than 2% of 0-69-2. During the equivalent cycles for 0-71-10, less than 1-2% 0-78-6 remained. No abnormal changes due to usage were detected on any of the samples.
5. Foam tests indicated that 0-69-2 did not foam significantly, while both 0-78-6 and 0-71-10 failed the foam test. Samples taken from the engine confirmed those data.
6. Viscosities and TANs of several samples were obtained to ensure that no significant degradation had occurred. Values found indicated that no significant degradation had occurred. COBRA, which is used as a guide to lubricant degradation, confirmed the TAN data.



7. SOAP and ferrography were employed to determine the presence of and characteristics of wear metals. SOAP did not indicate appreciable amounts or significant wear metals. All ferrograms suggested a very low or normal wear situation.

8. In summary, the lubricants did not degrade appreciably during use and the wear situation in the oil-wetted sections of the engine was normal up to and including the last sample.

*Phillip W. Centers*

PHILLIP W. CENTERS  
Lubrication Branch  
Fuels and Lubrication Division

*H. A. Smith*

HOOVER A. SMITH  
Lubrication Branch  
Fuels and Lubrication Division

2 Atch

1. Data Summary
2. Memo for Record 27 Sep 78

SFL LAB #	Sample DATE	ENG NRS	TOT OIL ADD.	SOAP ANALYSIS (PPM)					FOAM TEST 100cc/400cc	FOAM TEST 100cc/400cc	100% VISCOSITY	TAN	COMMENTS
				PC	MA	AL	Ca	Mg					
Standard 1				0						0.100			
" 2				1						100%			
" 3										97%			
" 4										94%			
" 5										87%			
" 6										57%			
CP-133-1	28 Aug 57	0.5	16.2	1						0.12			0-78-6 / 0-69-2 LAB MIXTURES
CP-133-2	29 Aug 57	0.5		2									
CP-133-3	30 Aug 57	19.5		3									
CP-133-4	31 Aug 57			4									
CP-133-5	1 Sept 57			5									
CP-133-6	2 Sept 57												
CP-133-7	3 Sept 57	18.4											
CP-133-8	4 Sept 57	31.3	14.0										
CP-133-9	5 Sept 57	45.24	20%										
CP-133-10	6 Sept 57	62.48											
CP-133-11	7 Sept 57	78.02	18.6										
CP-133-12	8 Sept 57	92.34											
CP-133-13	9 Sept 57	106.78											
CP-133-14	10 Sept 57	121.22											
CP-133-15	11 Sept 57	141.58											
CP-133-16	12 Sept 57	161.94											
CP-133-17	13 Sept 57	182.30											
CP-133-18	14 Sept 57	202.66											
CP-133-19	15 Sept 57	223.02											
CP-133-20	16 Sept 57	243.38											
CP-133-21	17 Sept 57	263.74											
CP-133-22	18 Sept 57	284.10											
CP-133-23	19 Sept 57	304.46											

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MEMO FOR THE RECORD

27 Sep 78

SUBJECT: Evaluation of Foaming Tendencies of 0-71-10 and 0-78-6  
Lubricants in a Test Cell TF-41 Engine

1. An accelerated mission test (AMT) TF-41 engine ran in "D" bay was used to evaluate the foaming tendencies of two lubricants. The lubricants were 0-71-10 (Royal MIL-L-7308G Qual 5K-3) and 0-78-6 (AOS 0-64-4, Lot 12, MIL-L-23699). Both lubricants had previously failed the Federal Test Method 3213 foam test performed in this Laboratory.
2. The evaluation of the above two oils required that the site glass on the TF-41 oil tank be modified so that foaming in the tank could be viewed using a television camera which provided input to Channel B of the TV monitor in the "D" bay control room. It was also necessary to install an additional oil pressure transducer (0-100 psig) on the output side of the main oil pump to accurately monitor variations in oil pressure.
3. The TF-41 engine (S/N AE 142163) was initially serviced with 0-69-2 (Mobil MM-184A MIL-L-7308G). That oil was replaced with 0-78-6 by draining the oil system and/or tank five times. After each refill with 0-78-6, the engine was run a minimum of one-half hour. Changes were scheduled so that a short engine run period followed in the normal AMT procedures.
4. Based upon gas chromatographic analysis of mixed lubricants, the system lube capacity (as equipped on S/N AE 142163) was 3.9 gallons (14.8 L). After the lube 0-69-2 was drained and replaced for the fifth time, the lubricant was analyzed as 97.5 vol. % 0-78-6. The oil change process started at 10:10 total engine hours. That oil was continued in use until about 148:08 total engine hours. At no time during the test through the various cycles (A, B, C) was any more than 1/8 - 1/4 inch of foam detected on the lube in the oil tank. The main oil pressure remained very steady throughout the test. It was also typical that the engine was run one quart low to aid in viewing foam in the lube tank.
5. The 0-78-6 lube was then changed to 0-71-10 using the same procedure as above. At 205:03 total engine hours, the lubricant was 98.4 vol. % 0-71-1. Again, significant variations in oil pressure were not noted. Up to 213:46 total engine hours, no

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more than 1/4 - 3/8 inch of foam was seen in the tank. Again, the engine was operated at one quart low on lubricant. At 213:46 hours, there was a failure in the turbine section of the engine which required termination of the test.

6. In summary, in a non-standard lubricant capacity TF-41 ran for an approximate total of 200 hours, no evidence of significant foaming was found when using either O-73-6 or O-71-10 or mixtures. The engine test lubes consistently failed the laboratory foam test.

7. The above tests and data, along with previous information, tend to confirm the differences in individual engines regarding foaming. This is especially true in engines which have capacities greater than the standard TF41-A-1 Air Force engine.

8. The technique of using TV to monitor engine oil, if the tank is modified, appears to be satisfactory. Future efforts might include a repeat of the test whenever a standard Air Force TF-41 becomes available.

P. W. CENTERS  
Lubrication Branch  
Fuels and Lubrication Division

H. A. SMITH  
Lubrication Branch  
Fuels and Lubrication Division

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**Detroit Diesel Allison** Division of General Motors Corporation  
P. O. Box 894 ■ Indianapolis, Indiana 46206

M-690

To G.C. Van Cleve Address

From A.G. Anderson Date September 1, 1978

Subject Trip Report, Borescope Inspection, TF41 Engine 142163 At Wright-Patterson AFB, OH August 30, 1978

The writer traveled to Wright-Patterson Air Force Base on August 30, 1978 to perform a routine borescope inspection on engine 142163 undergoing mission testing at the ASD Propulsion Laboratory.

The engine in question had undergone some 99 plus hours of simulated mission testing which equates to some 200 hours of service use.

Hot section inspection of this engine disclosed no conditions that would prevent continued operation at this time.

Minor discoloration (dark) was evident in varying degree on the No. 2 and/or No. 5 vanes in the No. 3,4,5,7,8, and 9 liner positions. No erosion or damage was evident at these discolored locations. No vane cracking was evident at any position.

HPT1 blades appeared to be in excellent condition as well as all visible downstream areas of the turbine.

Inspection of the HPC inlet, 7-8 stage area and HPC outlet, LPC inlet and LPC-IPC outlet disclosed no evidence of FOD or ingestion of damaging elements.

All fuel nozzles exhibited carbon build-up considered normal for the time and conditions operated. Mr. Bob May requested information on possible cleaning procedures to remove the carbon deposits. At the time of the visit, carbon remover was not available to the test stand personnel. The writer has since copied nozzle cleaning procedures presently published in T.O. 2J-TF41-6 and forwarded this information to ASD via DAZO. Incidentally, the nozzles in question were to be reinstalled without cleaning at this time.

OJT on the use of the Olympus fiberscope was provided to three ASD maintenance personnel to enable an in-house inspection capability for future inspections. Copies of published limits, procedures and techniques were furnished, discussed and demonstrated. Evaluation of conditions noted were discussed with emphasis on hazardous conditions.

The ASD personnel were most cooperative and appreciative of this assistance and appear to be most capable.

A.G. Anderson  
Senior Service Engineer

jw

DA 3-1 (4-76)

cc: G.A. Williams, D.P. Hoose, R.O. Liedtke, File 15, 142163

APPENDIX C TEARDOWN INSPECTION REPORTS

FORM 1030 (REV. 3/71)

**EXPERIMENTAL ASSEMBLY & TEST INSPECTION  
TEARDOWN INSPECTION REPORT**

S/N 142163/5B  
Page 1 of 1

UNIT 142163 T.D. 5 MODEL TF41 T.D. DATE 7 November 1978  
 INSPECTORS Fisher/Nicely TOTAL ENDURANCE  
 d1 TIME REASON FOR T.D. Addendum "B"

PARTS NOT LISTED ARE VISUALLY O.K.

PART NAME (P/N & S/N)	DEFECTS
Wheel-LPC Stg 1 P/N 6866218D, S/N MM10180	Zyglo OK.
Blade-LPC Stg 1 P/N 6892422W - 25 pieces	Zyglo OK.
Seal & Retainer Plate-LPC Wheel #1 P/N 6868141	Zyglo OK.
Stop Plate-LPC1 Wheel P/N 6866219B, S/N 114	Zyglo OK.

This completes Addendum "B". Any additional information will be submitted as another addendum to this report.

**EXPERIMENTAL ASSEMBLY & TEST INSPECTION  
TEARDOWN INSPECTION REPORT**

S/N 142163/5  
Page 1 of 2

UNIT 142163 T.O. 5 MODEL TF41 T.O. DATE 28 September 1978  
 INSPECTORS Duckett/Toms TOTAL TIME \_\_\_\_\_ ENDURANCE TIME \_\_\_\_\_  
 REASON FOR T.O. HPT Stg 1 Blade Failure

PARTS NOT LISTED ARE VISUALLY O.K.

PART NAME (P/N & S/N)	DEFECTS
Fairing Support Assy-LPT P/N 6866791 - 10 pieces	Light foreign object damage in ID...nicks and dents. One fairing is cracked forward of strut.
Support & Fitting Assy-Brg LPT P/N 6866555	Outer heat shroud cracked forward of struts in three places.
Ring Assy-Ret LP2 Nozzle P/N 6861039	One ring rub spot and two 3/4" cracks.
Rotor Assy-LPT P/N 6867969	Some blades and vanes have light to heavy foreign object damage.
Vane Assy-HPT Stg 2 P/N 6866849	Light to heavy foreign object damage. Some vanes have large pieces missing from trailing edges.
Wheel Assy-HPT Stg 2 P/N 6861136	Light to heavy foreign object damage on several blades.
Seal Segments-HPT Stg 2 P/N 6865628	Light splatter of metal in ID of segments.
Liner & Nozzle Assy-Combustion	
Pos. 1, P/N EX126821 Liner S/N SLF2037A Nozzle S/N S02-2265	Two smoke chutes have heavy erosion. Four large cracks on OD of nozzle. One crack in ID of nozzle... marked. Fretting on flanges of nozzle.
Pos. 2, P/N --- Liner S/N --- Nozzle S/N ---	Four smoke chutes have heavy erosion. Four cracks at crossover tube mountings. Heavy fretting on crossover tubes and flange. Heavy fretting on nozzle flanges.
Pos. 3, P/N --- Liner S/N --- Nozzle S/N ---	Three smoke chutes have medium erosion. Small crack in nozzle and fretting on nozzle flanges.
Pos. 4, P/N --- Liner S/N --- Nozzle S/N ---	Two smoke chutes have heavy erosion. Heavy fretting on nozzle flanges.
Pos. 5, P/N --- Liner S/N --- Nozzle S/N ---	Heavy fretting on nozzle flanges. Light fretting on crossover tube and connector.
Pos. 6, P/N --- Liner S/N --- Nozzle S/N ---	Fretting spots on crossover tube and connector. Heavy fretting on nozzle flanges. Two cracks on nozzle...they are marked.

# EXPERIMENTAL ASSEMBLY & TEST INSPECTION TEARDOWN INSPECTION REPORT

S/N 142163/5

Page 2 of 2

UNIT 142163 T.O. 5 MODEL TF41 T.O. DATE 28 September 1978  
 INSPECTORS \_\_\_\_\_ TOTAL TIME \_\_\_\_\_ ENDURANCE TIME \_\_\_\_\_  
 REASON FOR T.O. \_\_\_\_\_

PARTS NOT LISTED ARE VISUALLY O.K.

PART NAME (P/N & S/N)	DEFECTS
<b>Liner &amp; Nozzle Assy-Combustion</b>	
Pos. 7, P/N --- Liner S/N --- Nozzle S/N ---	Heavy fretting on connector. Two smoke chutes have heavy erosion. One crack at crossover tube mounting. Three cracks in nozzle. Heavy fretting on nozzle flanges.
Pos. 8, P/N --- Liner S/N --- Nozzle S/N ---	One smoke chute has heavy erosion. Crack at crossover mounting. Fretting on crossover tube and connector. Heavy fretting on nozzle flanges.
Pos. 9, P/N --- Liner S/N --- Nozzle S/N ---	Two cracks at crossover mounting. Four cracks in nozzle. Heavy fretting on nozzle flanges.
Pos. 10, P/N --- Liner S/N --- Nozzle S/N ---	Three smoke chutes have medium erosion. Two cracks at crossover mountings. Heavy fretting on connector. Fretting on nozzle flange.
Wheel & Shaft Asm-HPT Stg 1 P/N 6887655	3/4" Broken off one HP1 Blade. Heavy scratches and rub places on shrouds of HP1 Blades. Five blades have cracks on leading edges.
Vane Assy-LPT Stg 2 P/N 6860042	Two vanes have small piece broken out of each vane.
Scoop Asm-Primary P/N 6863363	Eight scoops have cracks as marked.
Vane Assy-HPT Stg 1 P/N <del>6862975</del> - 20 pieces <i>6394686 (Bullnose)</i>	All vanes cracked as marked.

This completes the report. Any additional information will be submitted as an addendum.

# EXPERIMENTAL ASSEMBLY & TEST INSPECTION TEARDOWN INSPECTION REPORT

S/N 142163/9A  
Page 1 of 39

UNIT 142163 T.O. 5 MODEL TF41 T.O. DATE 4 October 1978  
 INSPECTORS Fisher/Nicely/Stephens TOTAL TIME \_\_\_\_\_ ENDURANCE TIME \_\_\_\_\_  
 REASON FOR T.O. Addendum "A"

PARTS NOT LISTED ARE VISUALLY OK

PART NAME (P/N & S/N)	DEFECTS
Wheel Assy-LPT Stg 1 P/N 6867616, S/N 52BD	Sleeve & driving dowels installed at time of Zyglo. Zyglo OK.
Wheel-Turbine Stg 2 HP P/L P/N 6861135, S/N WY15166	Zyglo OK.
Wheel-Turbine Stg 1 HP P/L P/N 6877818, S/N 10121	Shaft attached to wheel at time of Zyglo. Zyglo OK.
Blade-HPT Stg 1 (Finger) P/N 6869795 - 100 pieces	Per Zyglo 50 pieces OK; 49 pieces with indications as charted. Several blades have light to heavy erosion on leading edge.
<sup>LPT</sup> Blade-HPT Stg 1 P/N 6865616 - 109 pieces	Per Zyglo 98 pieces OK although some have foreign object damage. See charts for 11 blades with indications. Several blades have foreign object damage and light fretting on blade shrouds.
Blade-LPT Stg 2 P/N 6864002 - 78 pieces	Several blades have foreign object damage... require rework. Rework of 20 pieces accomplished. Per Zyglo 1 piece had indications as charted.
Vane Assy-LPT Stg 1 P/N 6865418 - 13 pieces	Per Zyglo 7 pieces OK; 6 with indications as charted.
<sup>HPT-1</sup> <sup>3ullnose</sup> <sup>vane</sup> (6894686 - 20 pieces)	See charts for Zyglo results.
Vane Assy-HPT Stg 2 P/N 6866849 - 21 pieces 6868836 - 1 piece	See charts for results of Zyglo.
Wheel-LPT Stg 2 P/N 6860030J, S/N 486BD P/L P/N is 6865722.	Wheel Zygloed with Shaft attached...was OK.
Shaft-LPT Rotor P/N 6860031, S/N KK0104 P.L P/N is 6878261.	Magnaglo OK.
Plate-HPT Stg 1 P/N 6894241 - 32 pieces 6894242 - 1 piece	Zyglo OK.
Blade-HPT Stg 2 P/N 6869079 - 55 pairs	All blades have heavy foreign object damage. Blades Zygloed for other type defects... nothing found other than foreign object damage which was not charted.

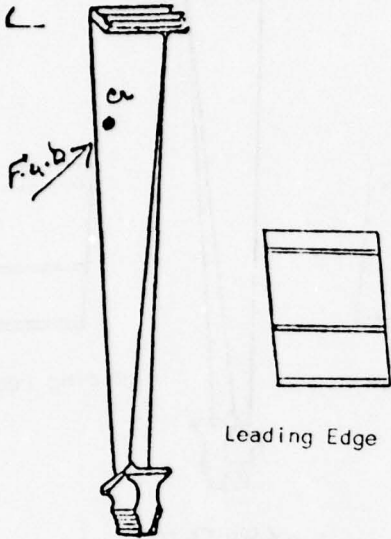
EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

S/N 142163/5A  
Page 2 of 39

TF41 - L.P. TURBINE - 1st STAGE BLADE

Ref: 6860004

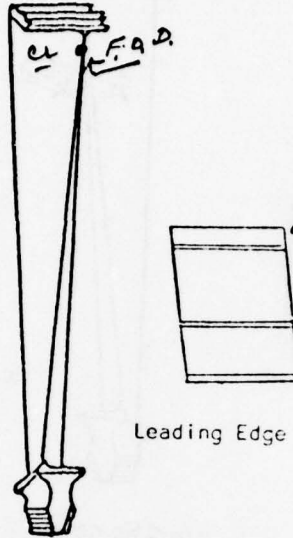
Unit 142163 T.D. 5 Inspector Grady Date 10-12-78



P/N 6865816

S/N \_\_\_\_\_

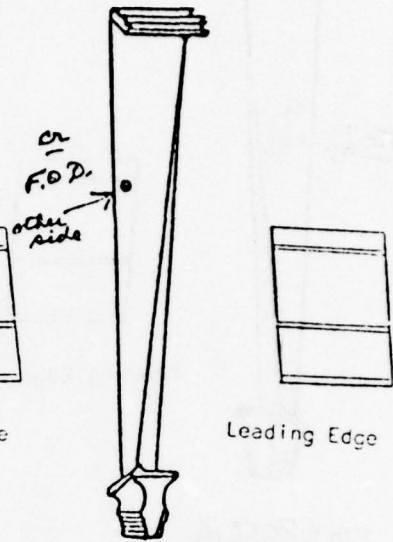
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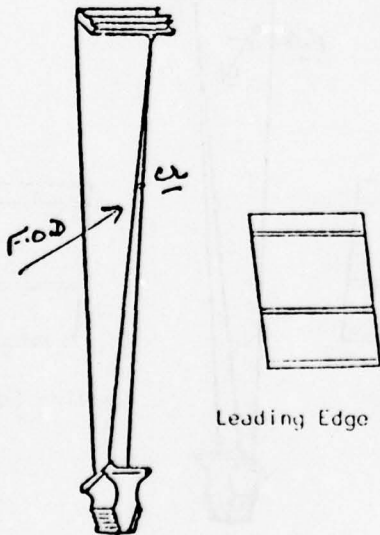
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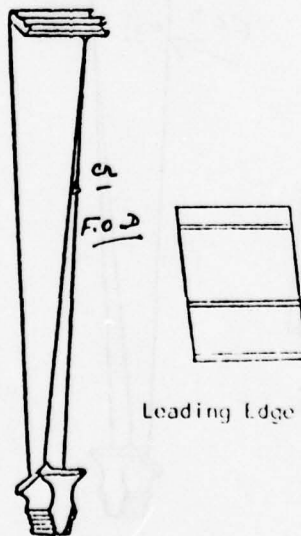
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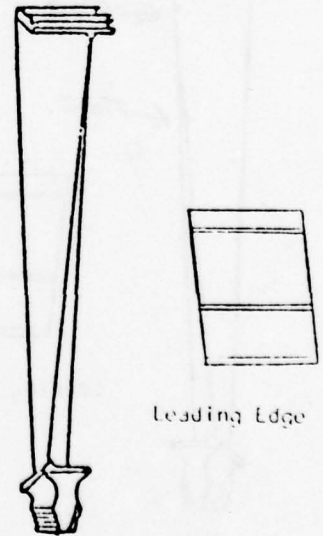
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P/N 6865816

S/N \_\_\_\_\_

Pos. 101



P/N \_\_\_\_\_

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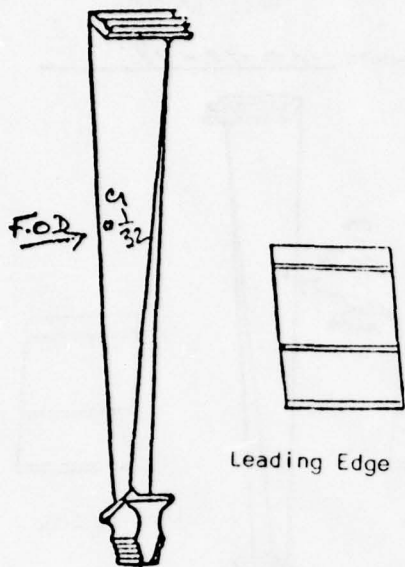
EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

S/N 147163/5A  
Page 5 of 50

TF41 - L.P. TURBINE - 1st STAGE BLADE

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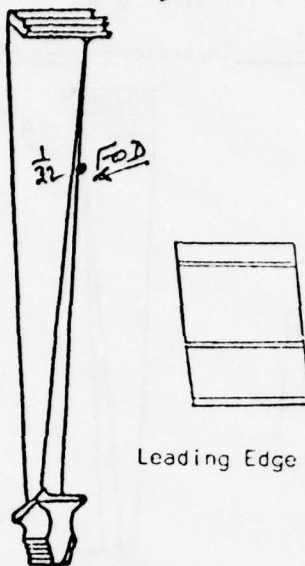
Unit 142163 T.D. 5 Inspector E. Neely - J. Miller Date 10-12-78



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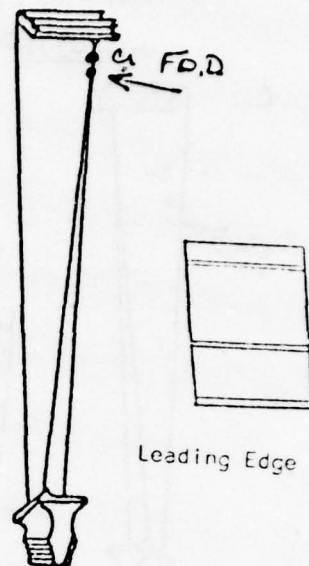
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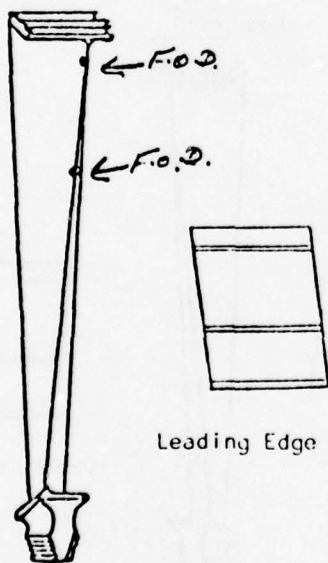
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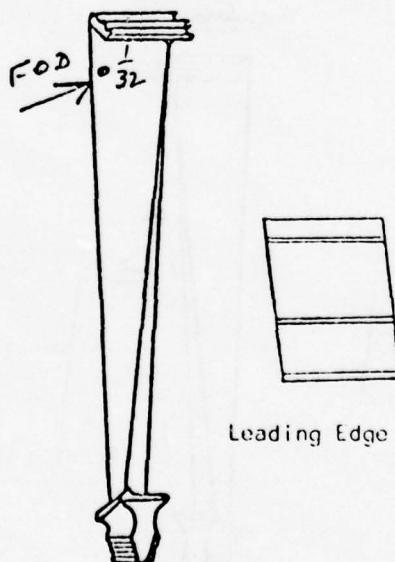
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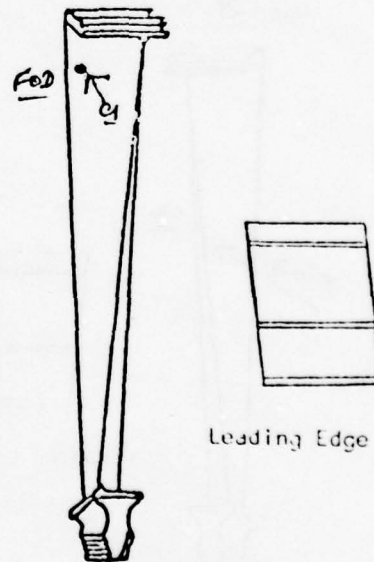
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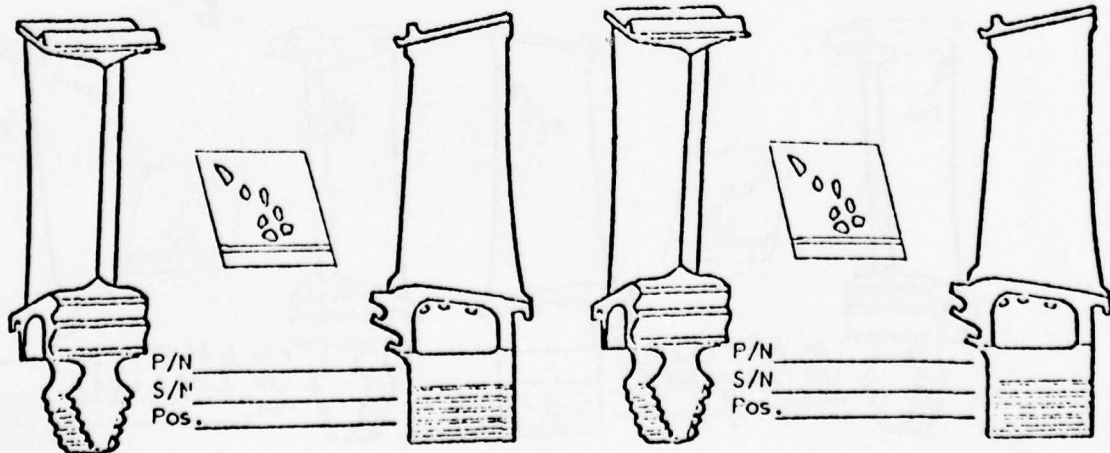
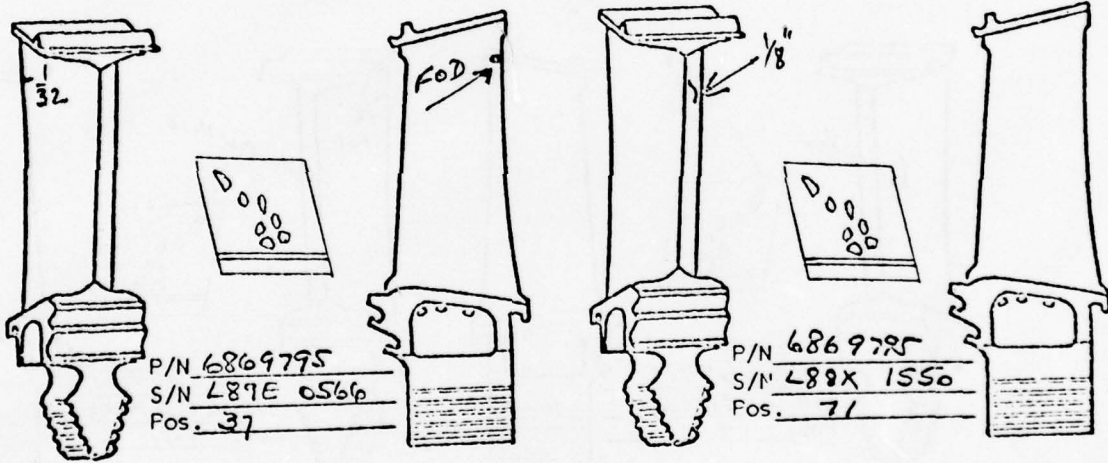
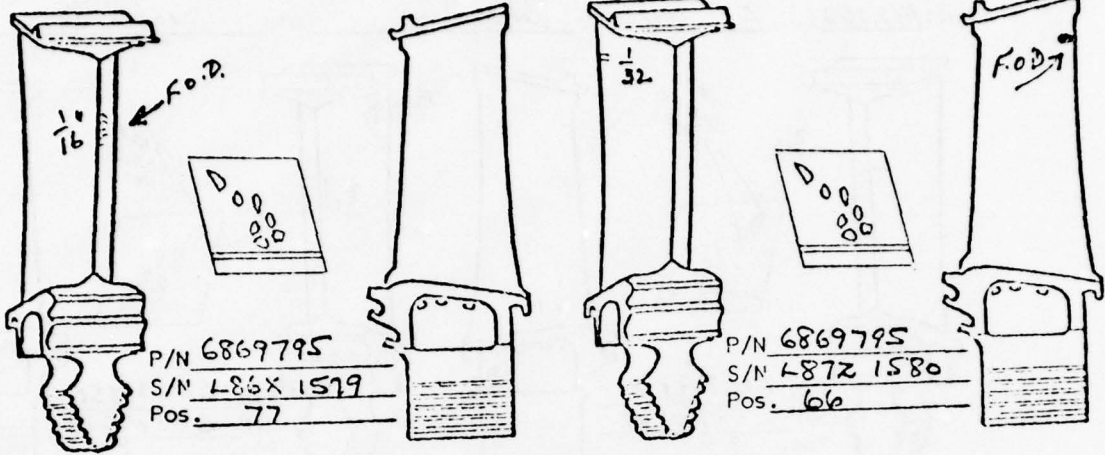
EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

S/N 142163/1A  
Page 4 of 30

TF41 - H.P. TURBINE - 1st STAGE BLADE

Ref: 6866370

Unit 142163 T.D. S Inspector Wally Date 10-11-78

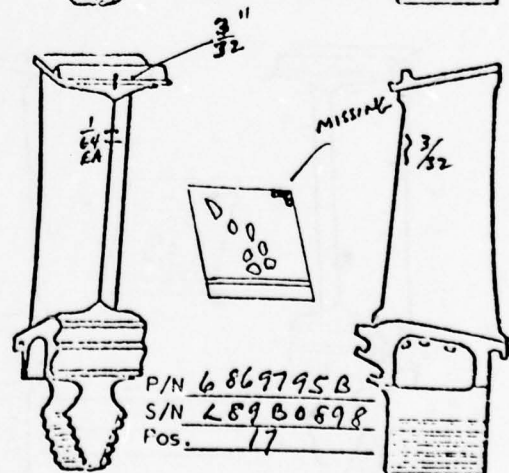
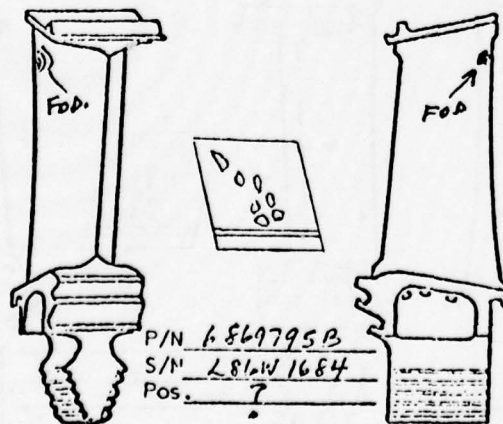
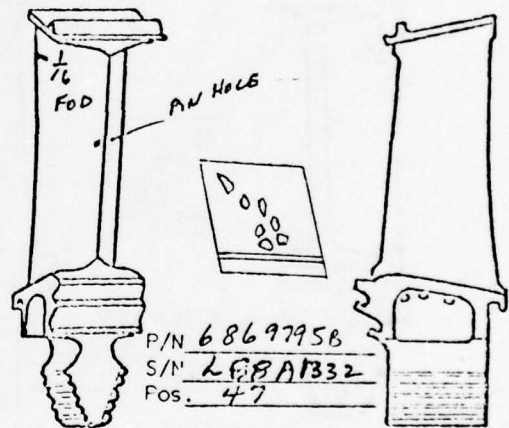
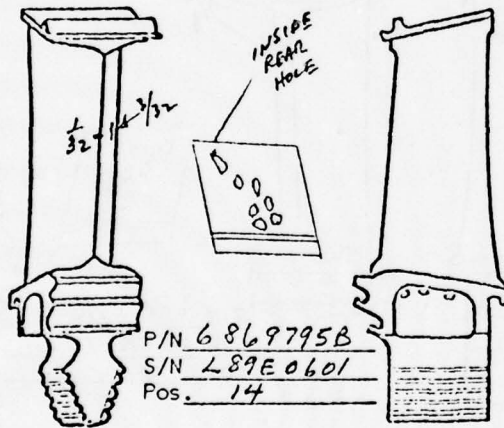
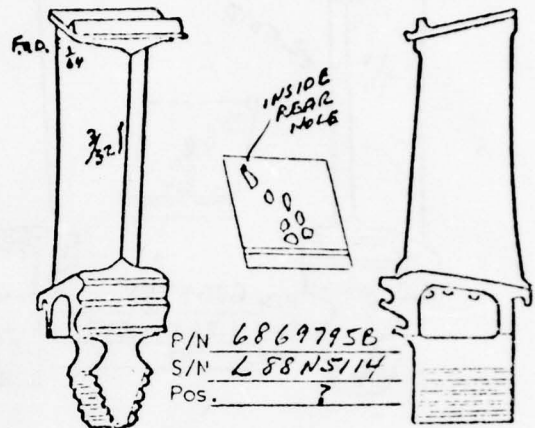
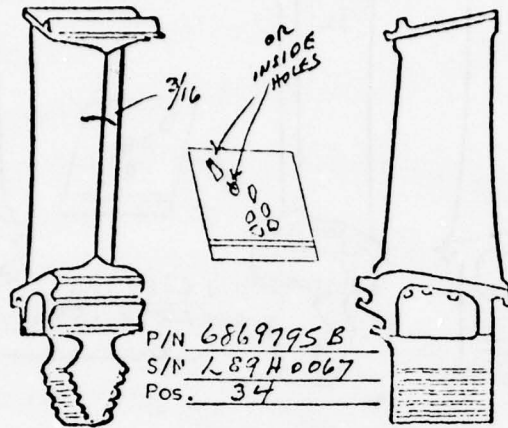


EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

TF41 - H.P. TURBINE - 1st STAGE BLADE

Ref: 6866370

Unit 42.163 T.O. 5 Inspector R. J. Finer Date 10-10-78

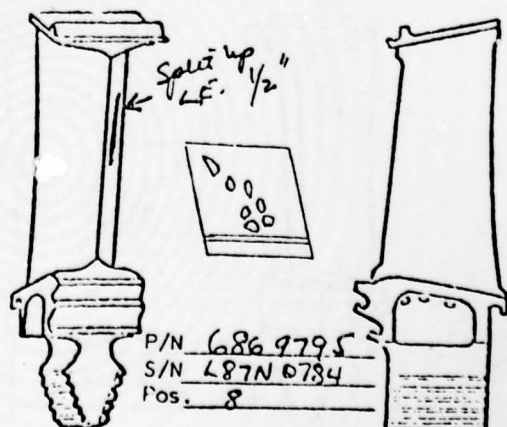
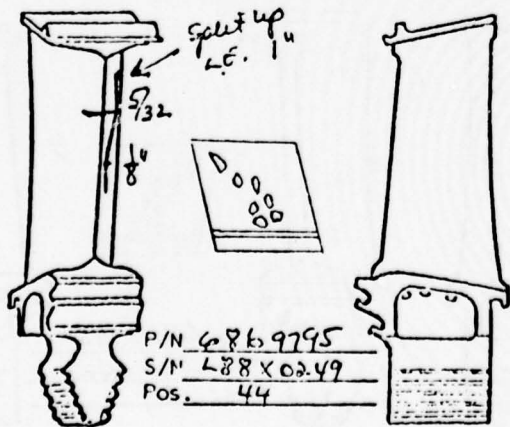
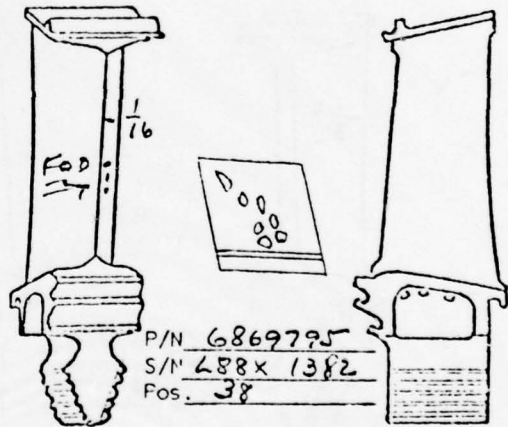
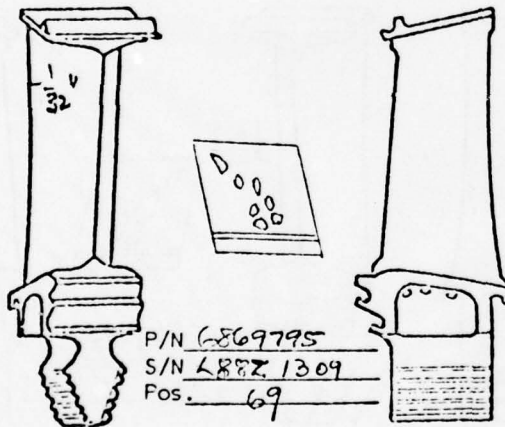
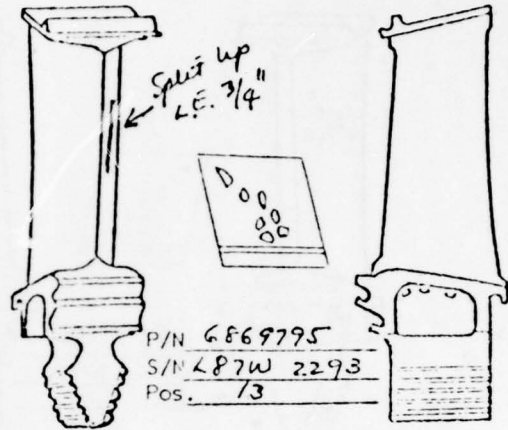
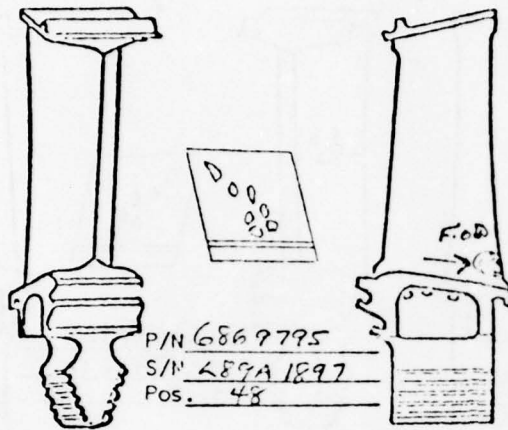


EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

TF41 - H.P. TURBINE - 1st STAGE BLADE

Ref: 6866370

Unit 142163 T.D. 5 Inspector: E. H. King Date 10-10-78

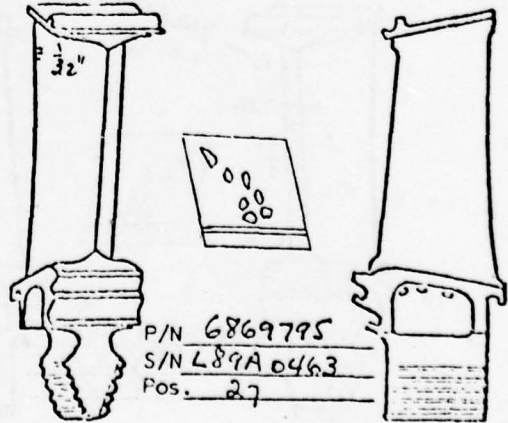
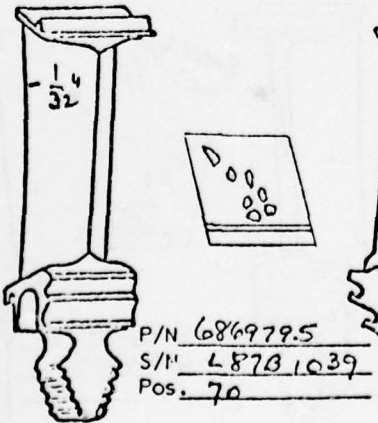
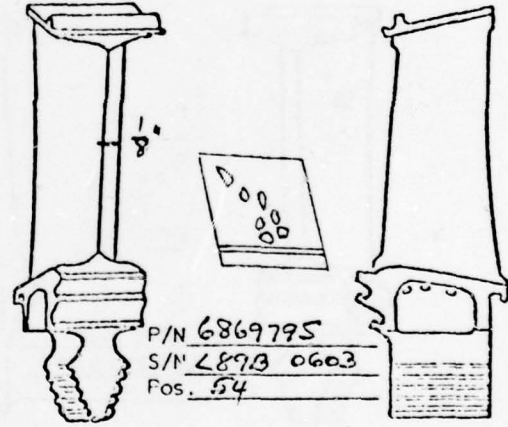
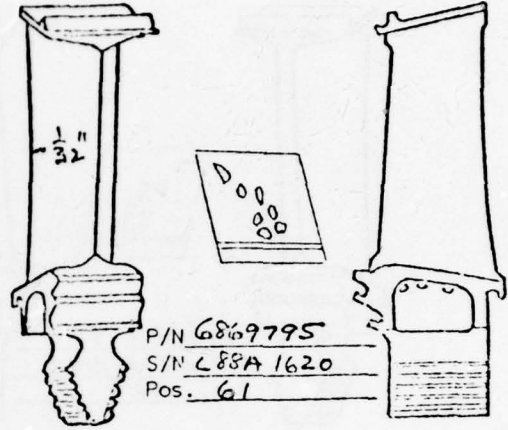
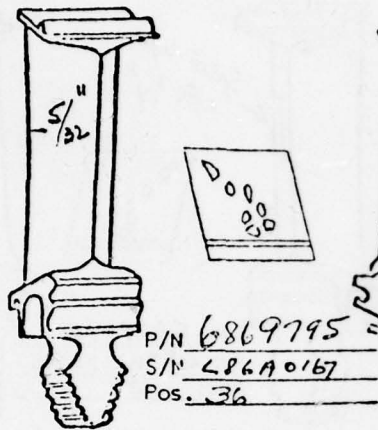


EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

TF41 - H.P. TURBINE - 1st STAGE BLADE

Ref: 6866370

Unit 142163 T.D. 5 Inspector Neely Date 10-10-78



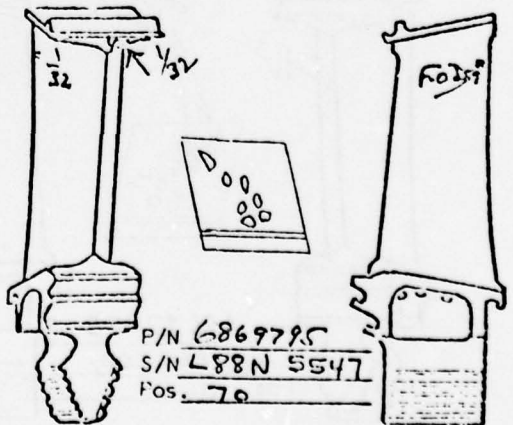
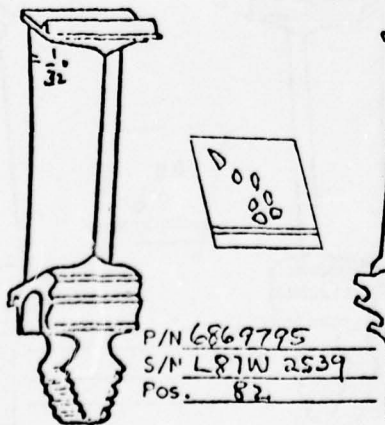
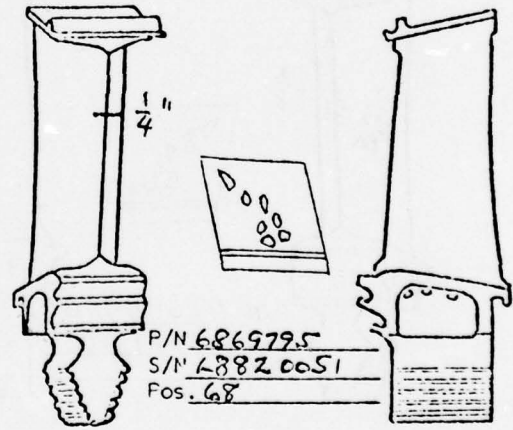
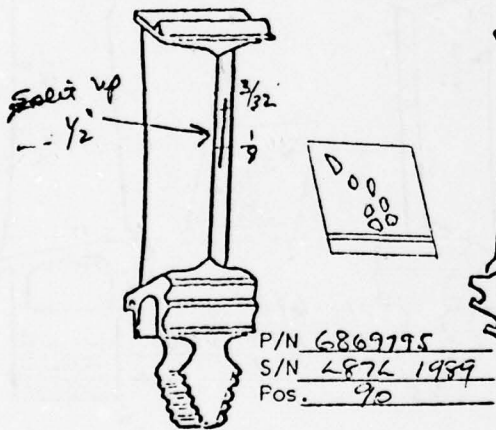
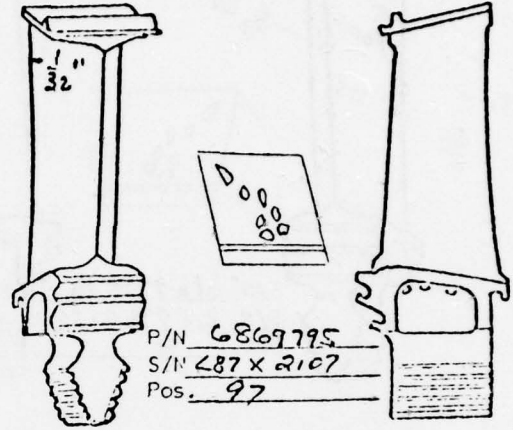
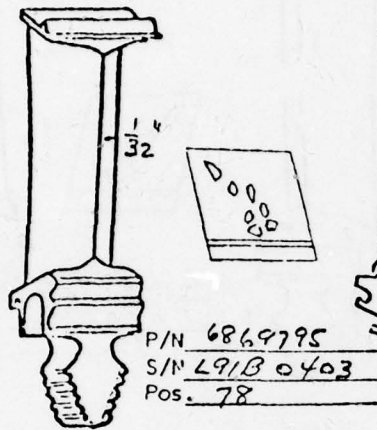
EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

TF41 - H.P. TURBINE - 1st STAGE BLADE

Ref: 6866370

Unit 142163 T.D. 5 Inspector Exiehy

Date 10-11-78

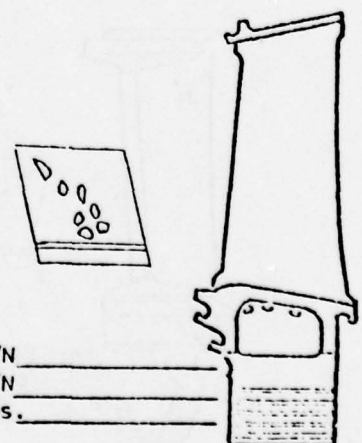
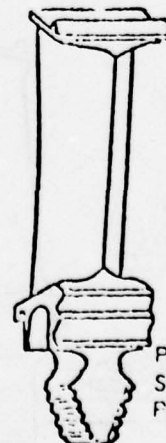
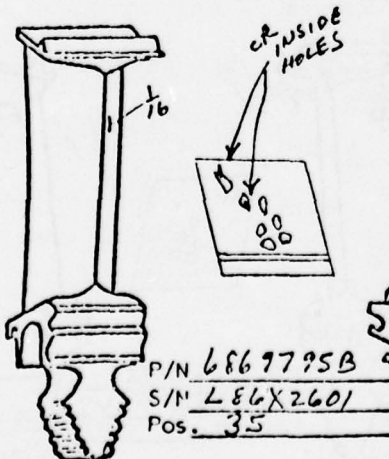
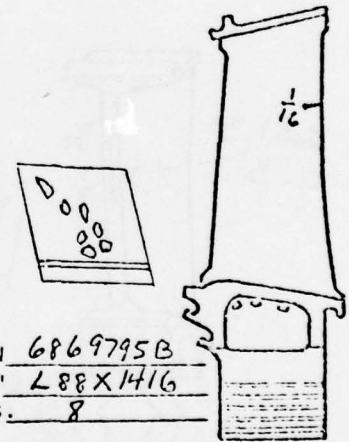
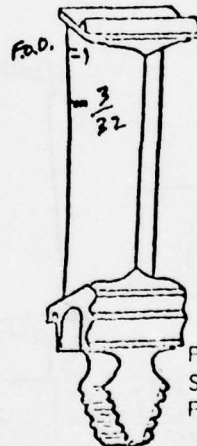
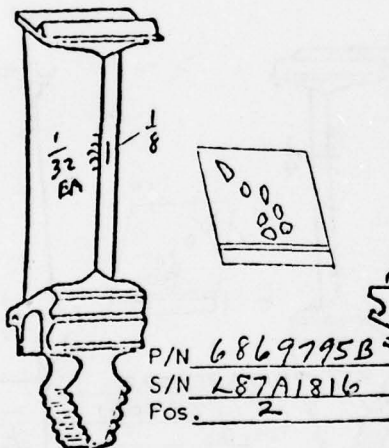
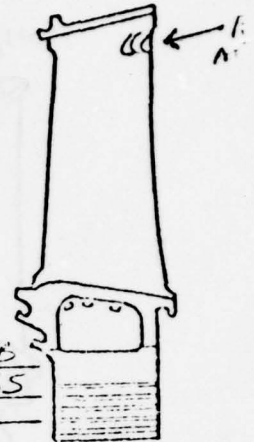
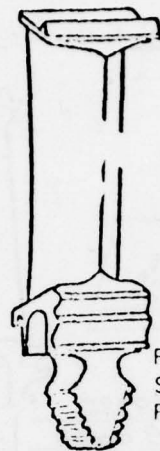
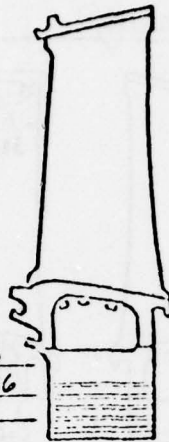
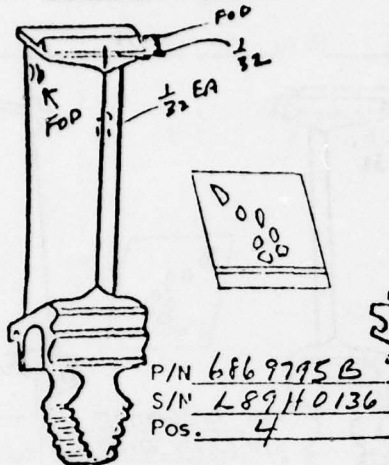


EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

TF41 - H.P. TURBINE - 1st STAGE BLADE

Ref: 6866370

Unit 142163 T.D. 5 Inspector Red Fisher Date 10-10-78







EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

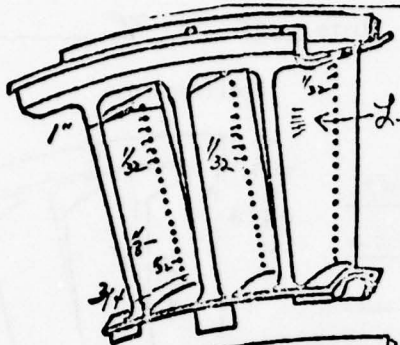
TF41 - H.P. TURBINE - 2nd STAGE VANE ASSY

Ref:

Unit 42163 T.D. 5 Inspector STEPHEN J. S Date 10-17-78

Leading Edge

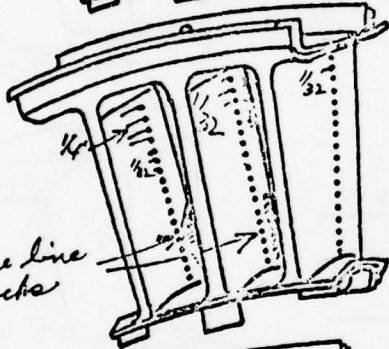
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P/N 6866849

S/N C48055

Pos. \_\_\_\_\_

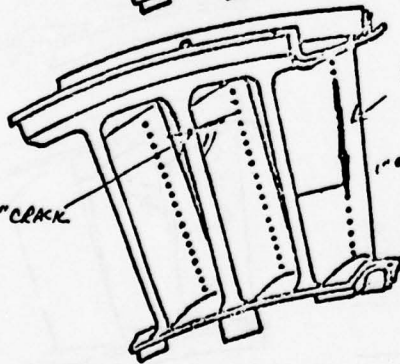


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Pos. \_\_\_\_\_

*Fine line cracks*

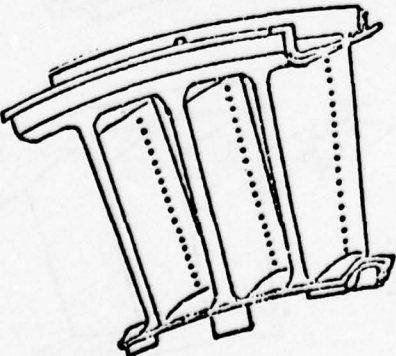


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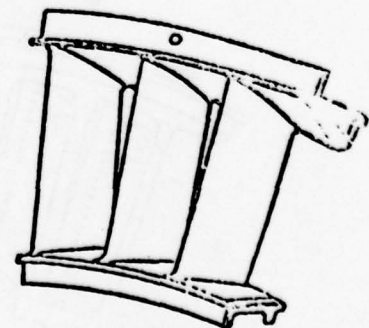
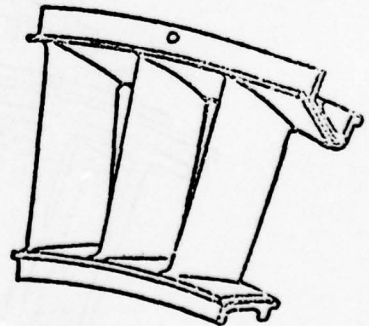
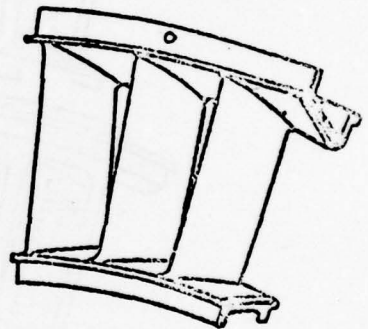
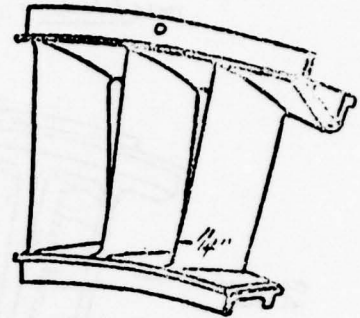
*Cracked holes between*



P/N \_\_\_\_\_

S/N \_\_\_\_\_

Pos. \_\_\_\_\_



EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

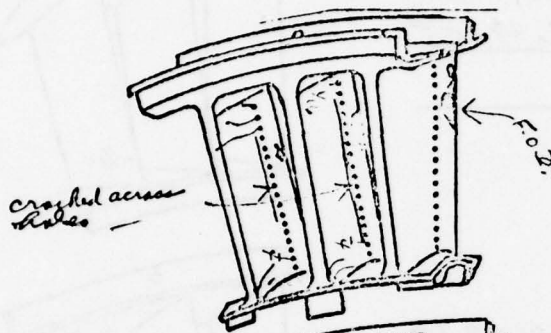
TF41 - H.P. TURBINE - 2nd STAGE VANE ASSY

Ref:

Unit 142163 T.D. 5 Inspector Muelly Date 10-17-78

Leading Edge

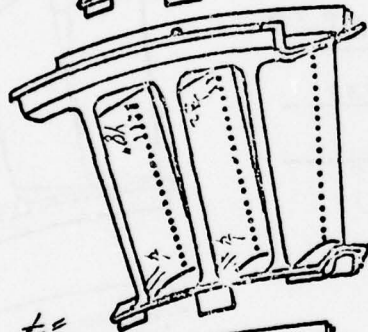
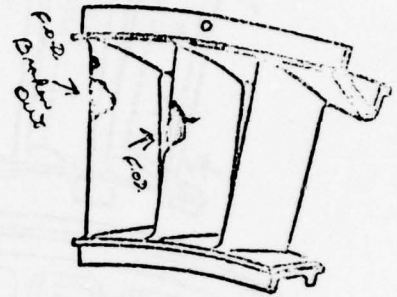
Trailing Edge



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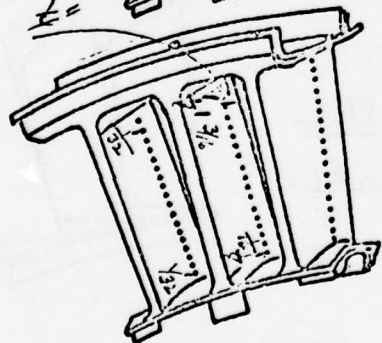
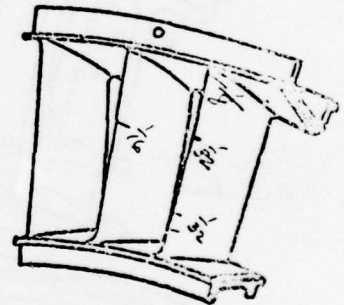
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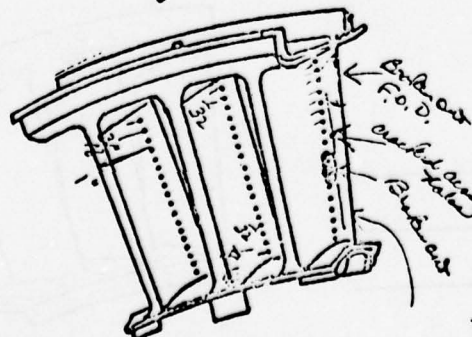
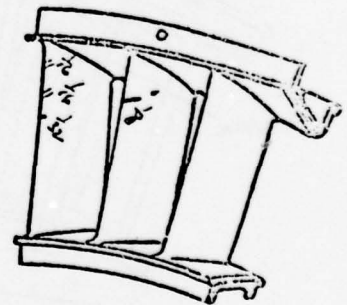
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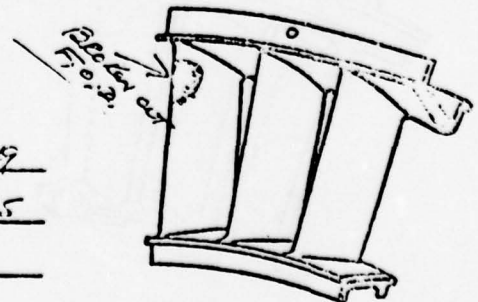
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Pos. ?



EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

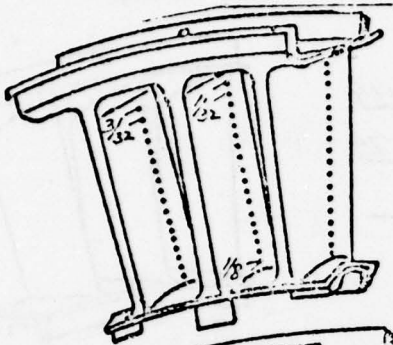
TF41 - H.P. TURBINE - 2nd STAGE VANE ASSY

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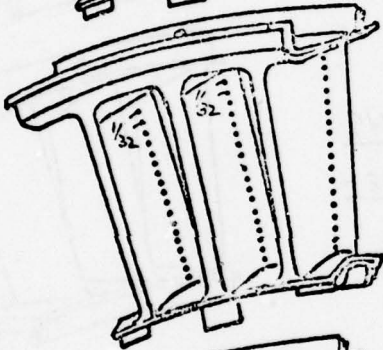
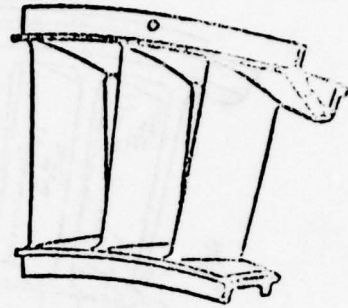
Unit 142163 T.D. 5 Inspector Stephens Date 10-17-78

Leading Edge

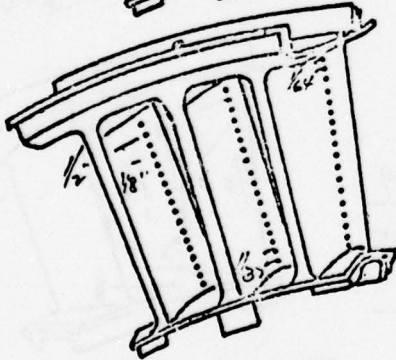
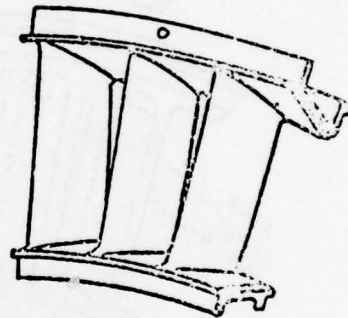
Trailing Edge



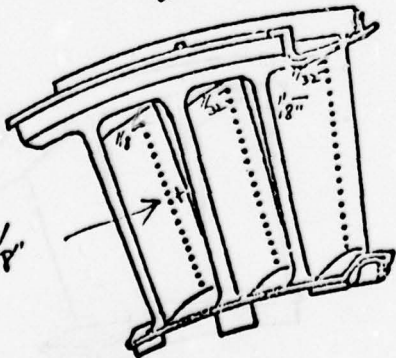
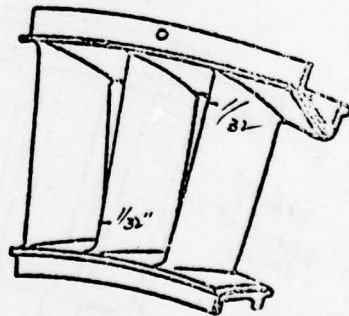
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Pos. \_\_\_\_\_



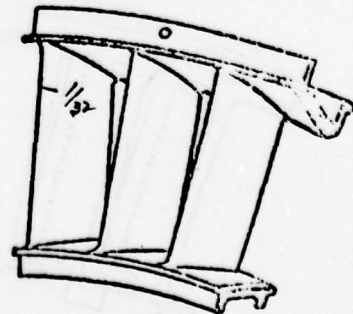
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P/N 6866849  
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Pos. \_\_\_\_\_



P/N 6866849  
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EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

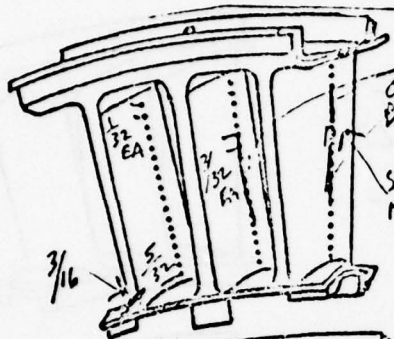
TF41 - H.P. TURBINE - 2nd STAGE VANE ASSY

Ref:

Unit 142163 T.D. 5 Inspector W. J. Shaw Date 10-17-78

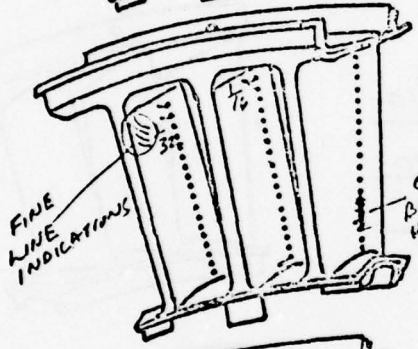
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CRACKS BETWEEN HOLES  
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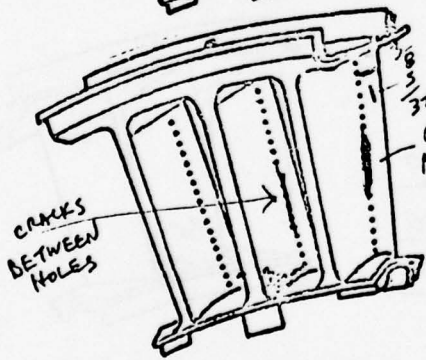
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Pos. \_\_\_\_\_



FINE LINE INDICATIONS

CR BETWEEN HOLES

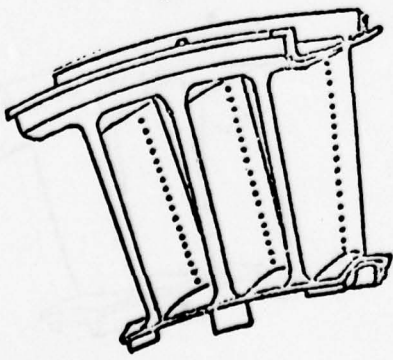
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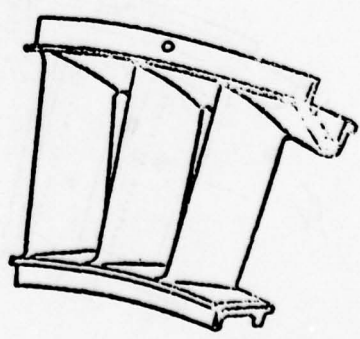
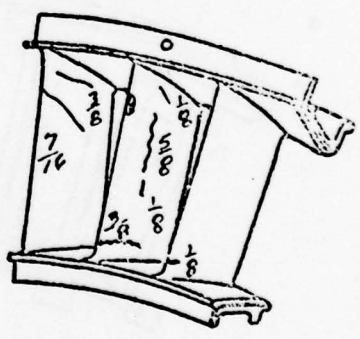
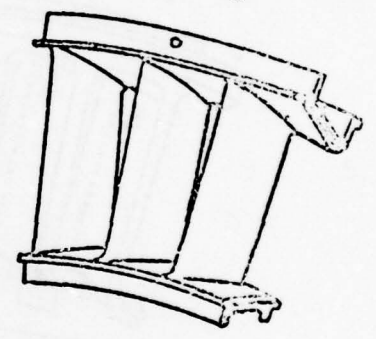
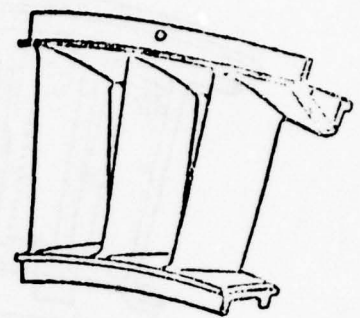
CRACKS BETWEEN HOLES

CRACKS BETWEEN HOLES  
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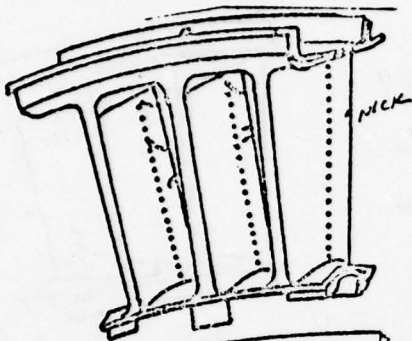
EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

TF41 - H.P. TURBINE - 2nd STAGE VANE ASSY

Ref:

Unit 142163 T.D. 5 Inspector RW Fisher Date 10-17-78

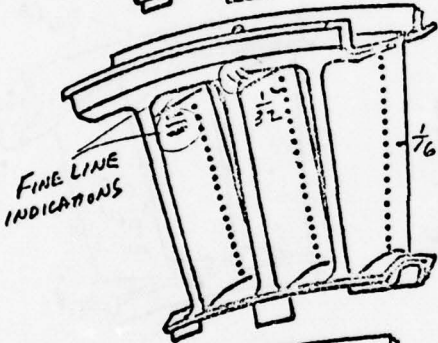
Leading Edge



P/N 6866849

S/N C48168

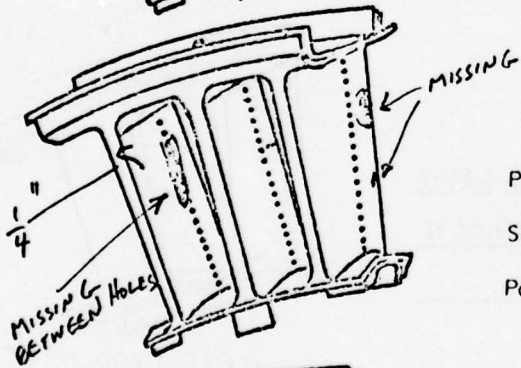
Pos. —



P/N 6866849

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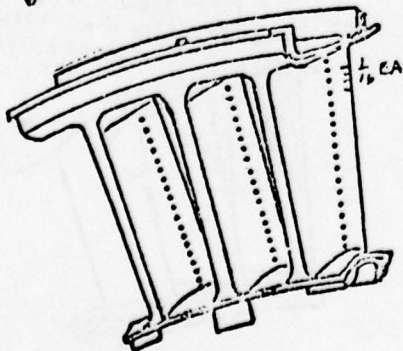
Pos. —



P/N 6866849

S/N C49433

Pos. —

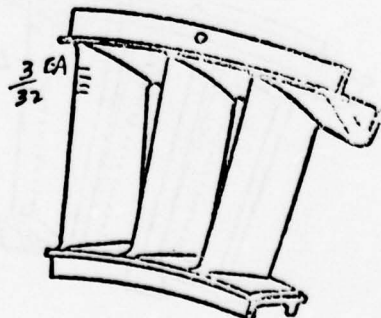
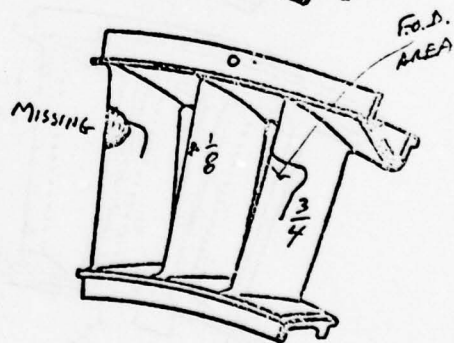
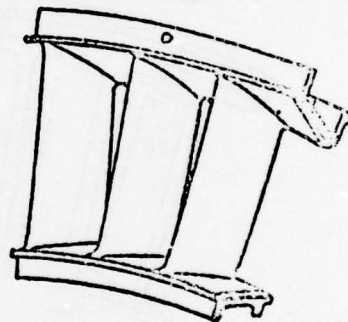
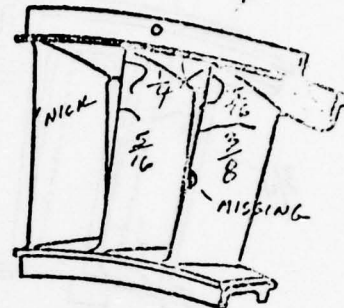


P/N 6866849

S/N C27075

Pos. —

Trailing Edge

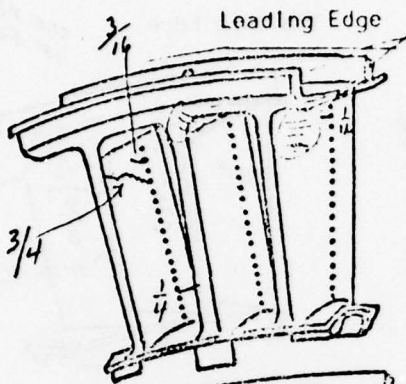


EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

TF41 - H.P. TURBINE - 2nd STAGE VANE ASSY

Ref:

Unit: 142163 T.D. 5 Inspector Pat Fisher Date 10-17-78

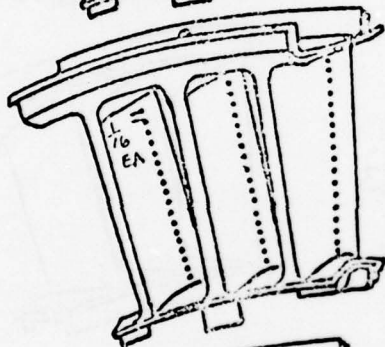


FINE LINE INDICATIONS

P/N 6866849

S/N C48721

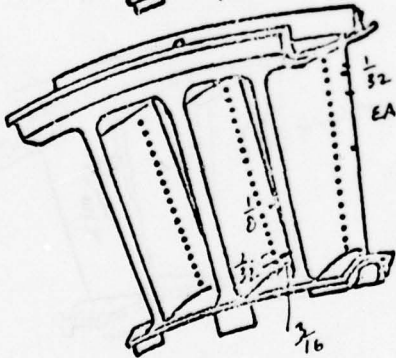
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P/N 6866849

S/N C49088

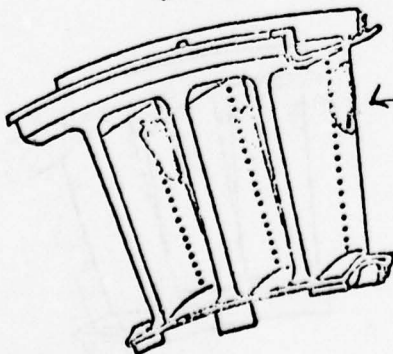
Pos. —



P/N 6866849

S/N C49065

Pos. —

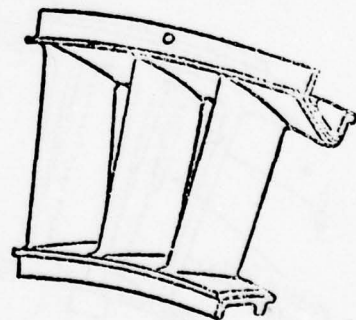
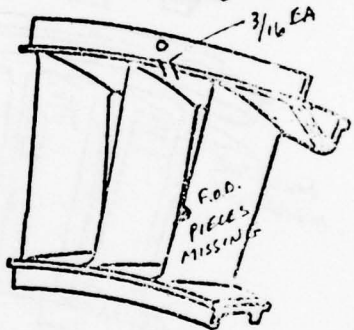
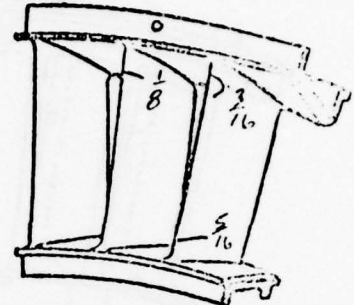


P/N 6866849

S/N C48482

Pos. —

Trailing Edge



EXPERIMENTAL ASSEMBLY & T INSPECTION

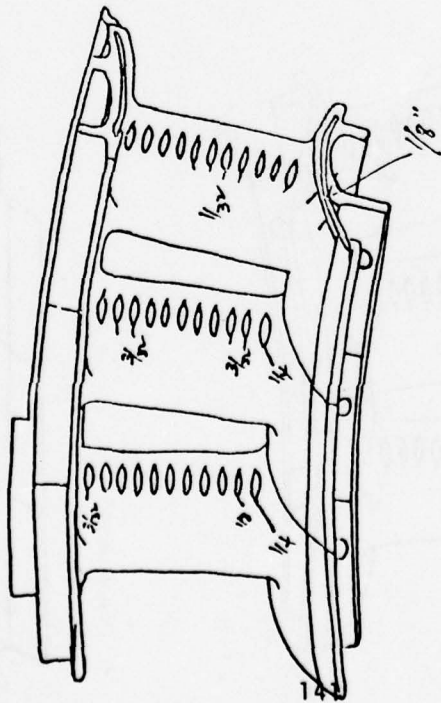
TF41 HP Turbine 1st Stage Vane Asm

Unit 142163 Tu 5 Inspector Stephen

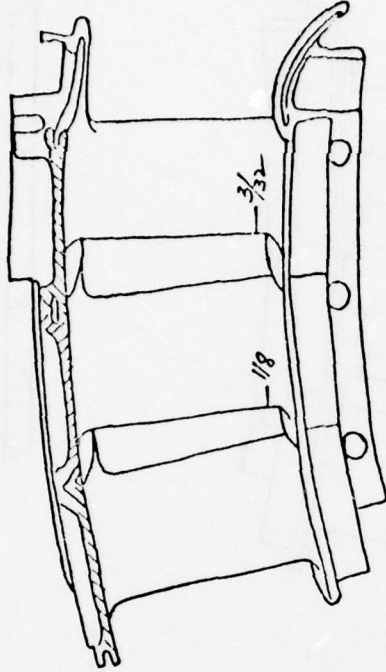
Date 10-17-78

P/N: 6894686 S/N: 001066 Position 40, 41, 42

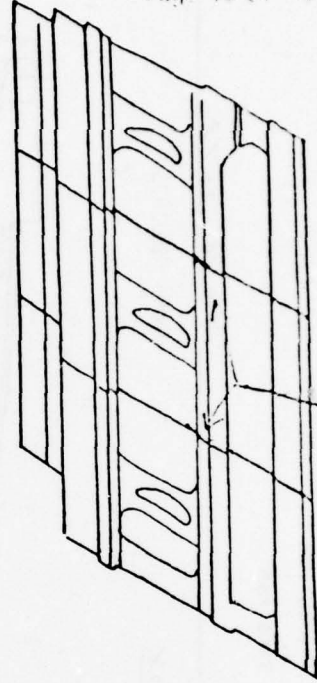
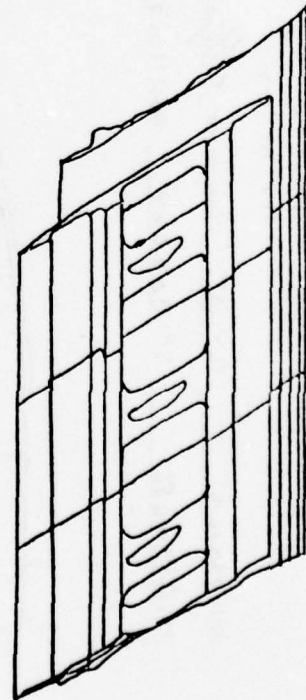
Ref: 6862973



INNER BAND



OUTER BAND



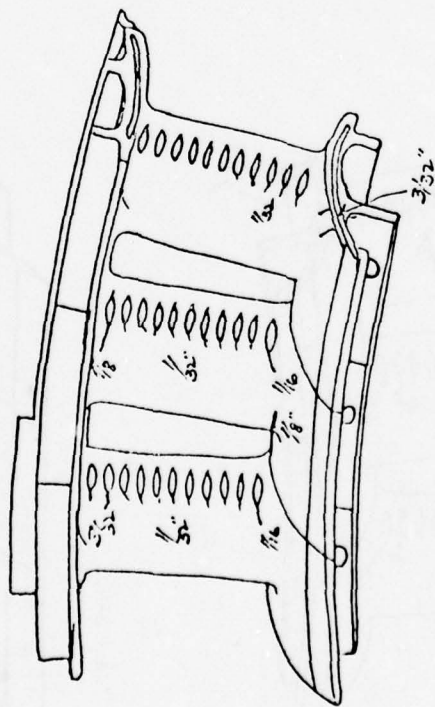
SPOT WELDS CRACKED

S/N 142163/A  
Page 18 of 20

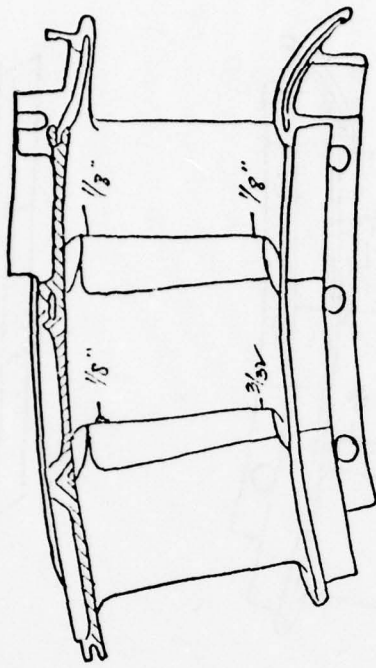
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FOR QUALITY WORKSHOPS TO DO

EXPERIMENTAL ASSEMBLY & BT INSPECTION  
 TF41 HP Turbine 1st Stage Vane Asm

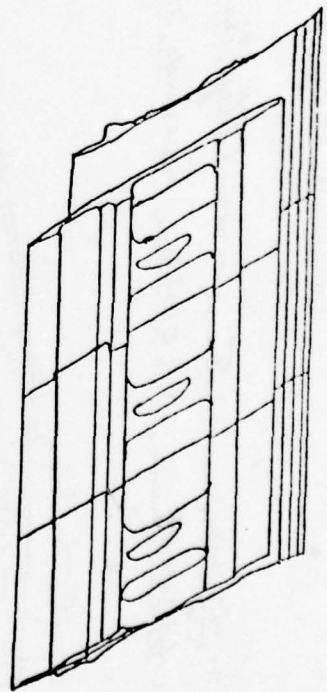
Unit 142163 TU 5 Inspector J. Stephens Date 10-17-78  
 P/N: 6894686 S/N: 002608 Position: 22, 23, 24 Ref: 6862973



INNER BAND



OUTER BAND



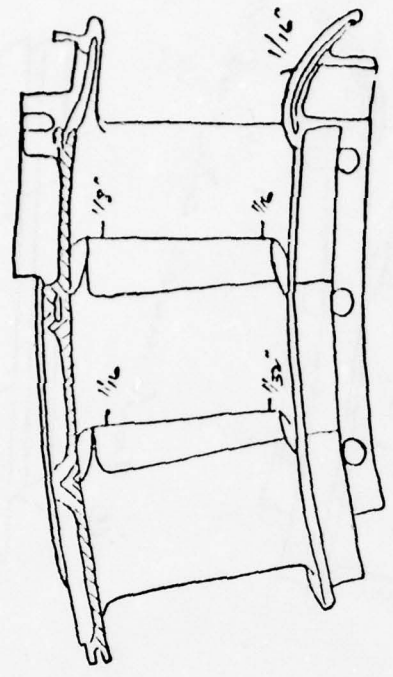
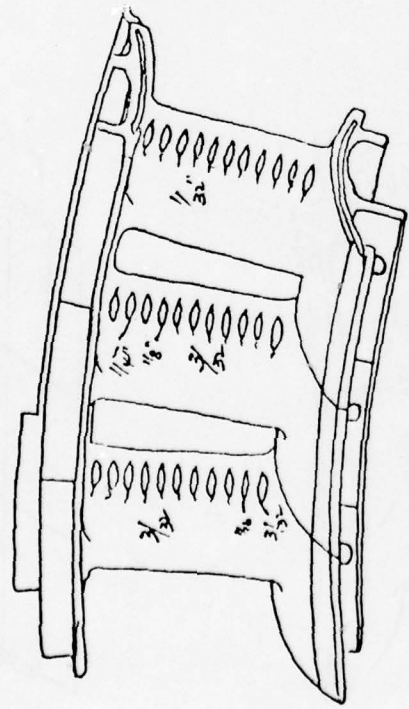
S/N 142163/5A  
 Page 19 of 39

WEIRS GRACED

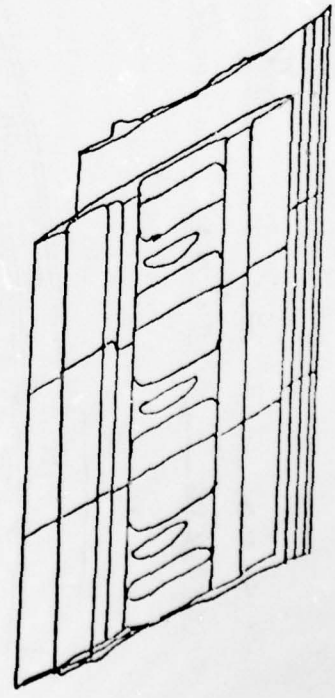
EXPERIMENTAL ASSEMBLY : 1ST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

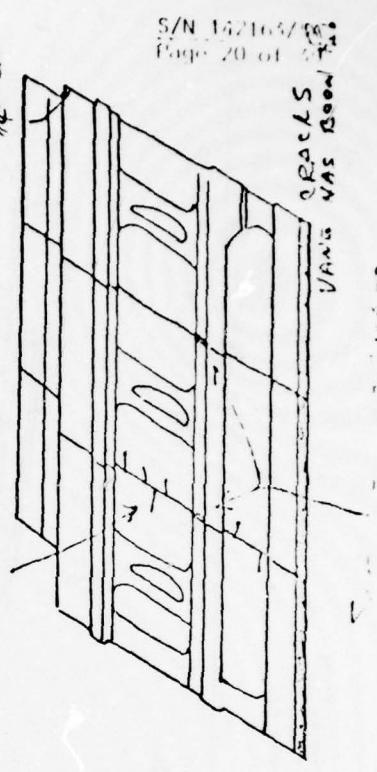
Unit 42163 TU 5 Inspector Stephen Date 10-17-78  
P/N: 6894686 S/N: C 01925 Position 10, 11, 12 Ref: 6962975



OUTER BAND  
all cracks inside band app 1/8" long



INNER BAND



S/N 42163/5  
Page 20 of 25

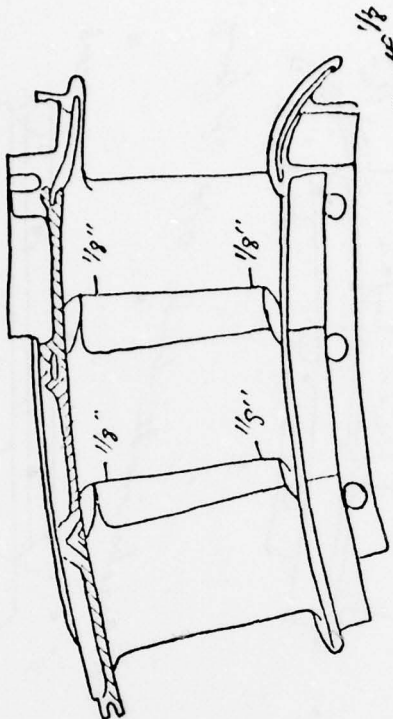
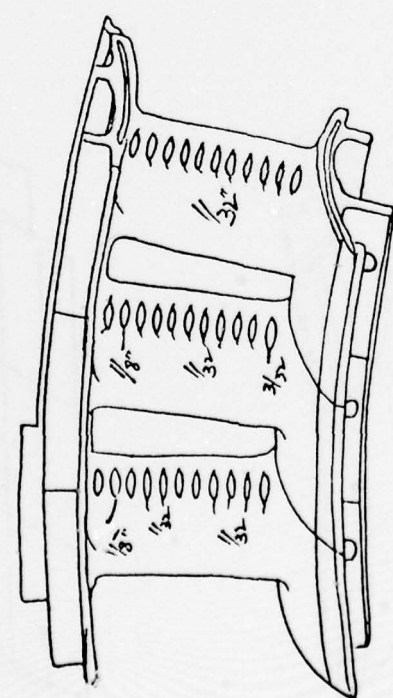
EXPERIMENTAL ASSEMBLY & BT INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

Unit 142163 TU 5 Inspector A. Stephens Date 10-17-78

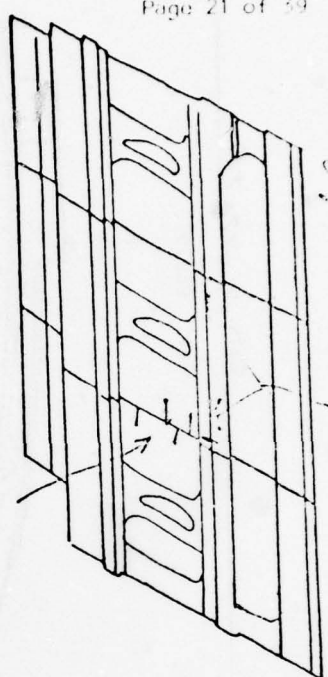
P/N 6874686 S/N C00753 Position 58, 59, 60

Ref: 6962973



OUTER BAND

INNER BAND



Spot weld cracked

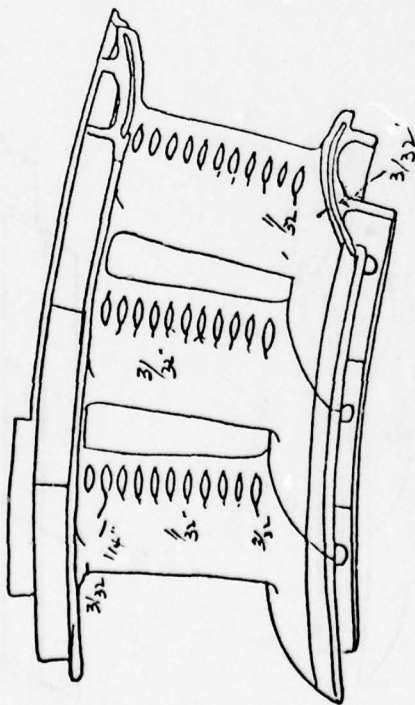
S/N 142163/1A  
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EXPERIMENTAL ASSEMBLY & .ST INSPECTION

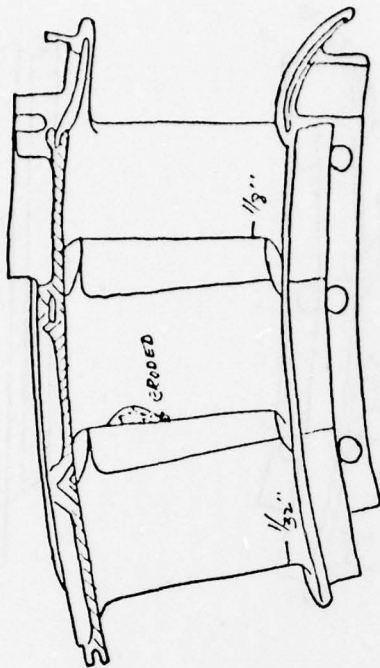
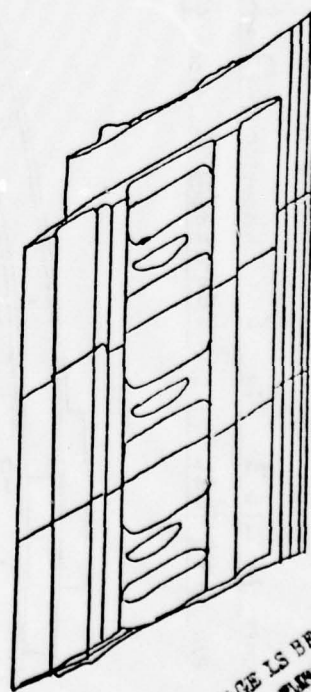
TF41 HP Turbine 1st Stage Vane Asm

Unit 142163 TO 5 Inspector Stephane Date 10-17-78

P/N 6894686 S/N C00782 Position 34, 35, 36 Ref: 6662973

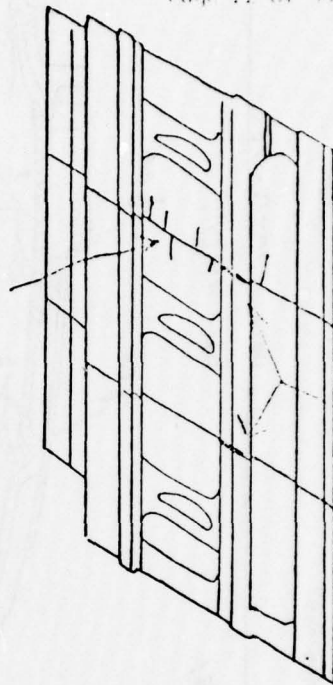


INNER BAND



OUTER BAND

*Tracks on inside of outer band  
Tracks approximately 1/8" long*



*Section 1 of 2*

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EXPERIMENTAL ASSEMBLY & POST INSPECTION

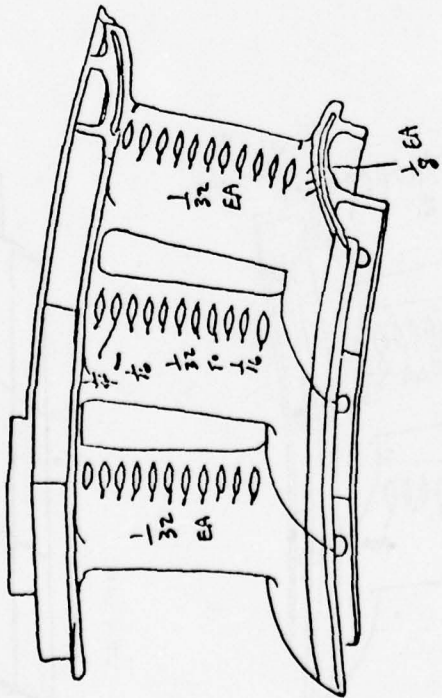
TF41 HP Turbine 1st Stage Vane Asm

Date 10-17-78

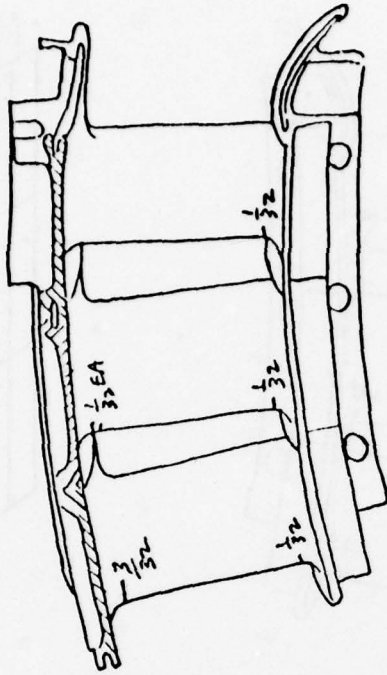
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Unit 142163 Tu 5 Inspector Rob Trachen

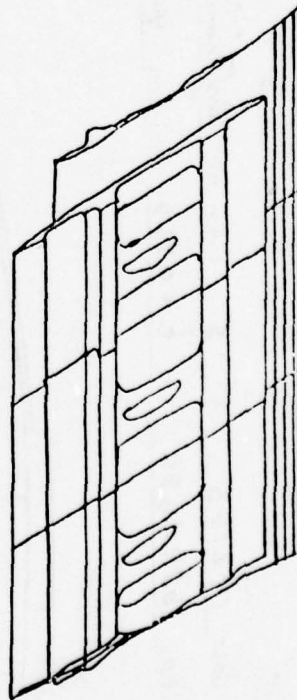
P/N: 6894686 S/N: 001154 Position 19-20-21



INNER BAND



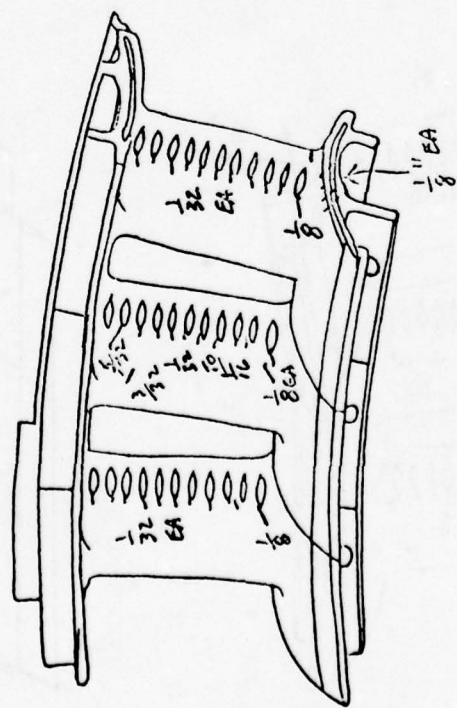
OUTER BAND



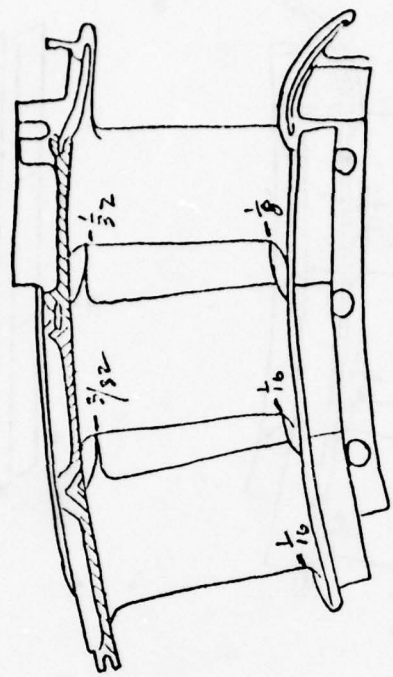
WELDS CRACKED

EXPERIMENTAL ASSEMBLY & BT INSPECTION  
 TF41 HP Turbine 1st Stage Vane Asm

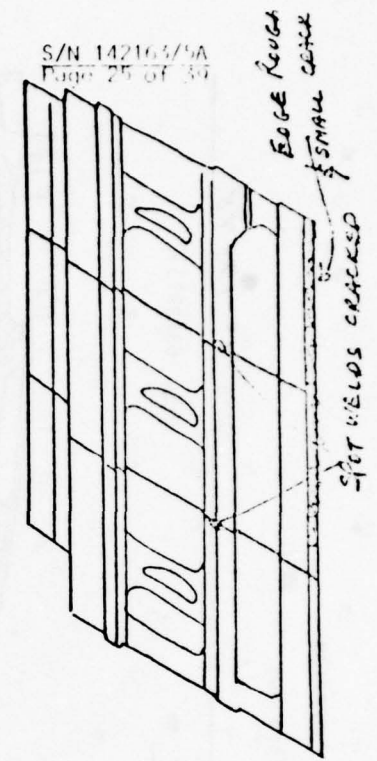
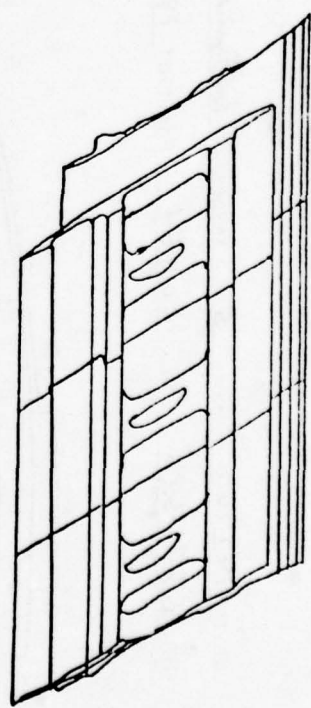
Unit 142163 TU 5 Inspector Bob Fisher Date 10-17-78  
 P/N 6894686 S/N C00766 Position 4-5-6 Ref: 6862973



INNER BAND



OUTER BAND



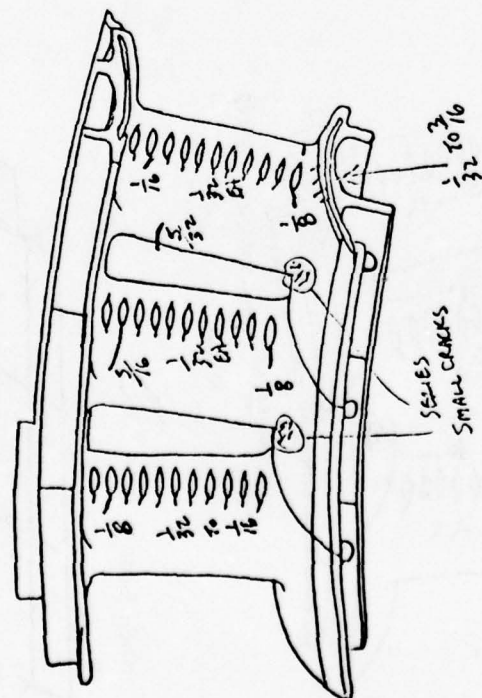
S/N 142163/5A  
 Page 25 of 39

EXPERIMENTAL ASSEMBLY & INSPECTION

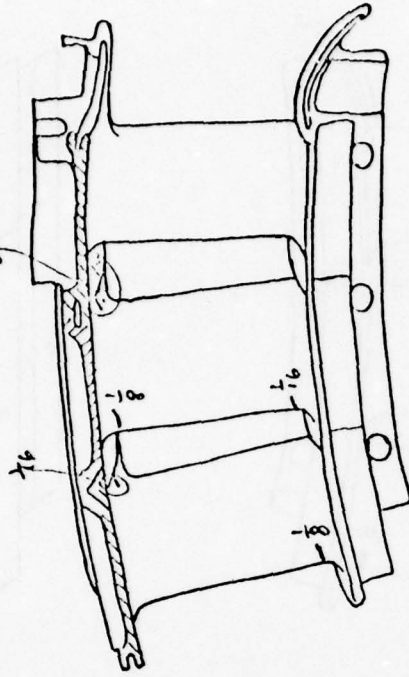
TF41 HP Turbine 1st Stage Vane Asm

Unit 142163 Tu 5 Inspector R. Fisher Date 10-17-78

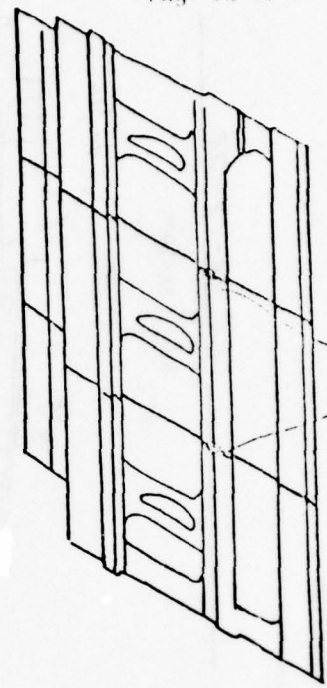
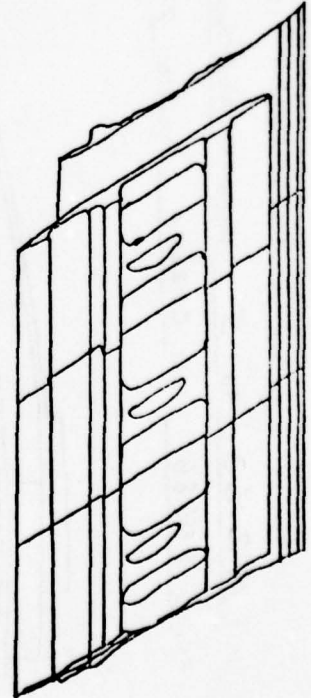
P/N 6894686 S/N CO 8072 Position 55-56-57 Ref: 6862973



INNER BAND



OUTER BAND

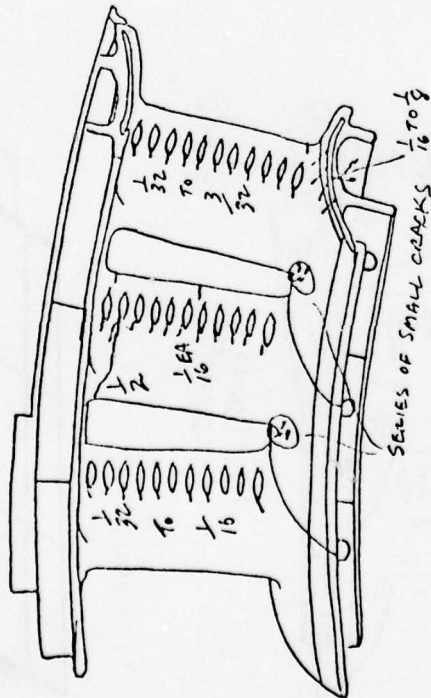
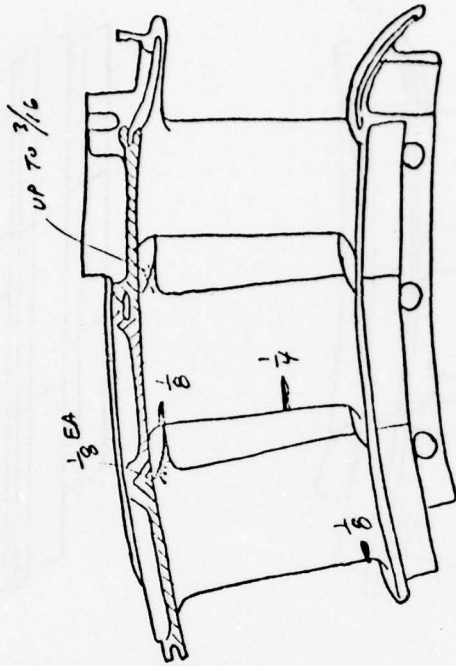


SPOT WELDS CRACKED

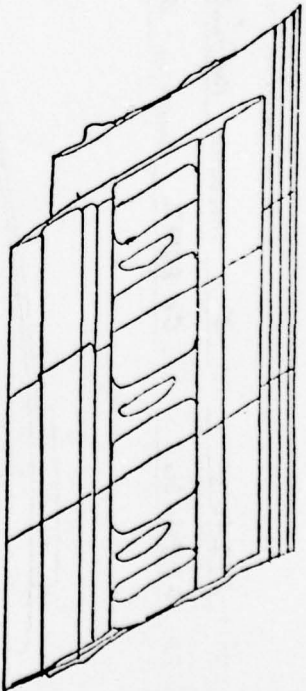
S/N 142163/A  
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EXPERIMENTAL ASSEMBLY & .ST INSPECTION  
 TF41 HP Turbine 1st Stage Vane Asm

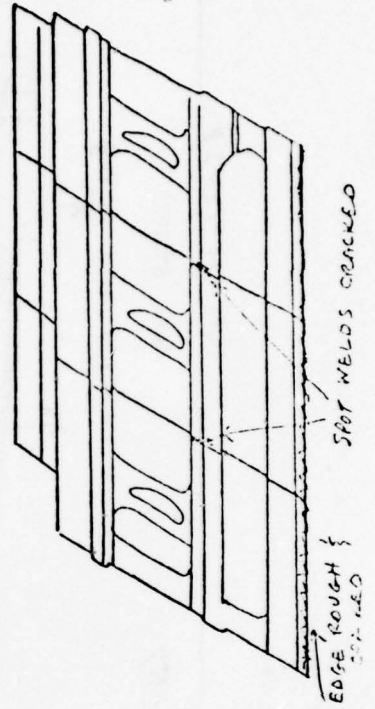
Unit 142163 TD 5 Inspector R. W. Fisher Date 10-17-78  
 P/N: 6894686 S/N: C02091 Position 7-8-9 Ref: 6862973



INNER BAND



OUTER BAND



EXPERIMENTAL ASSEMBLY EST INSPECTION

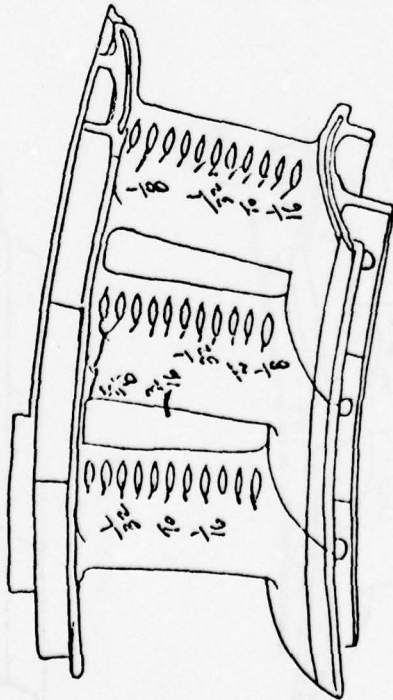
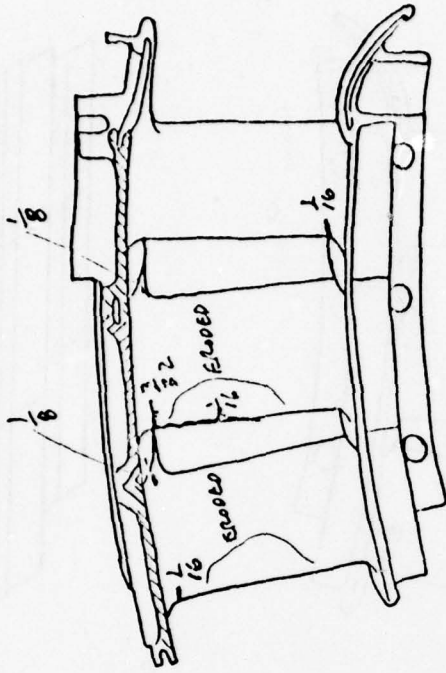
TF41 HP Turbine 1st Stage Vane Asm

Unit 142163 TO 5 Inspector Red Fisher

Date 10-16-78

P/N 6894686A C/I C 00735 Position 25-26-27

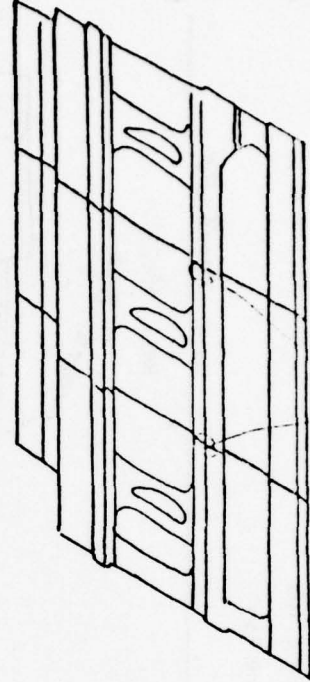
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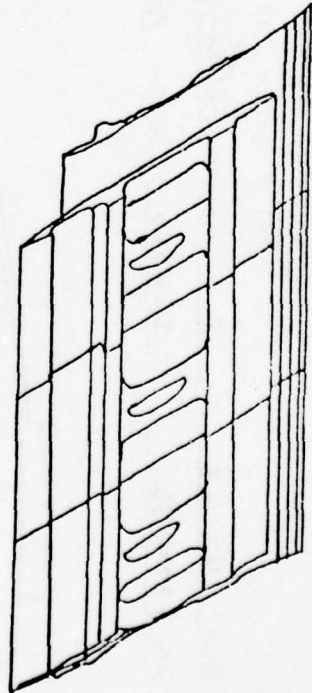
151

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OUTER BAND



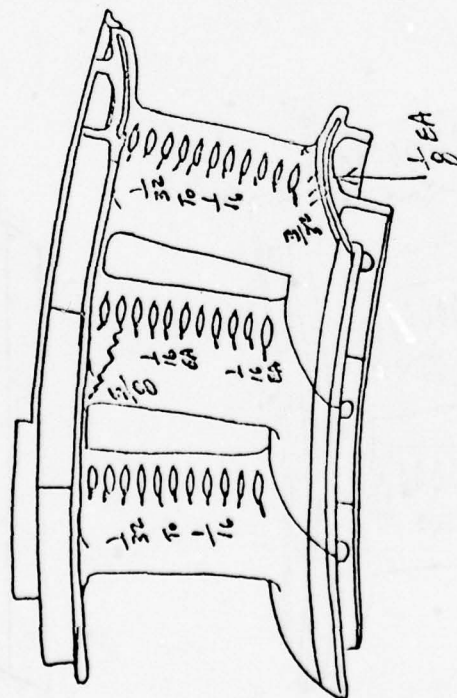
INNER BAND



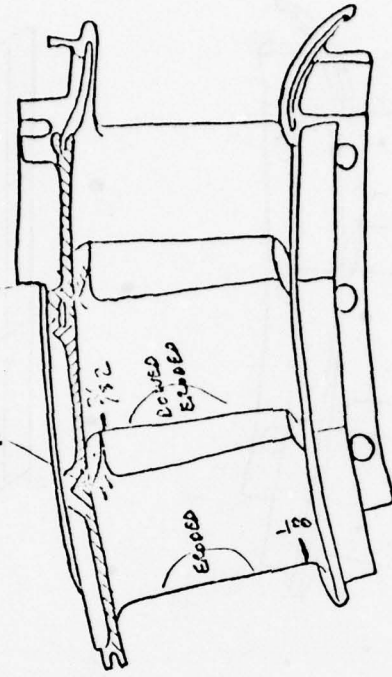
EXPERIMENTAL ASSEMBLY & **IT** INSPECTION  
 TF41 HP Turbine 1st Stage Vane Asm

Unit 142163 To 5 Inspector Ref Fincher Date 10-16-78

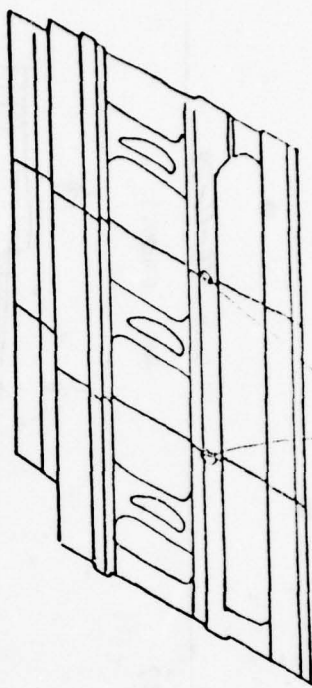
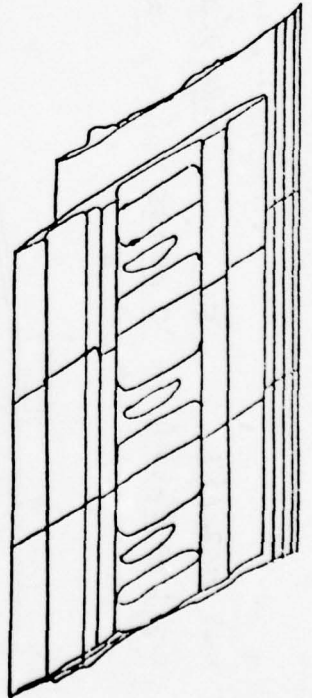
P/N 6894686 S/N C00750 Position 13-14-15 Ref: 6862975



INNER BAND



OUTER BAND







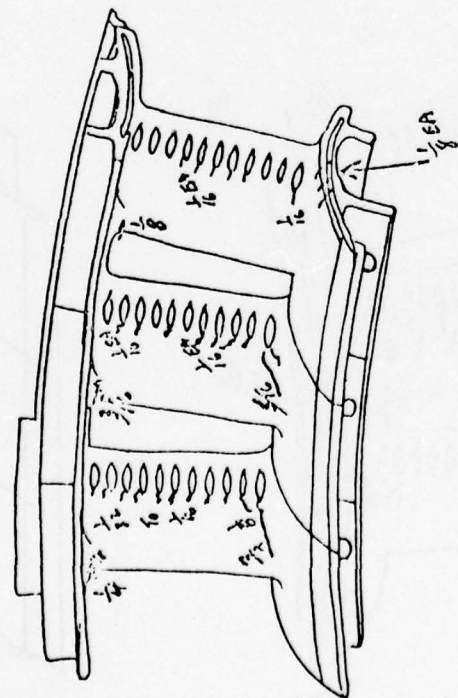
EXPERIMENTAL ASSEMBLY & T INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

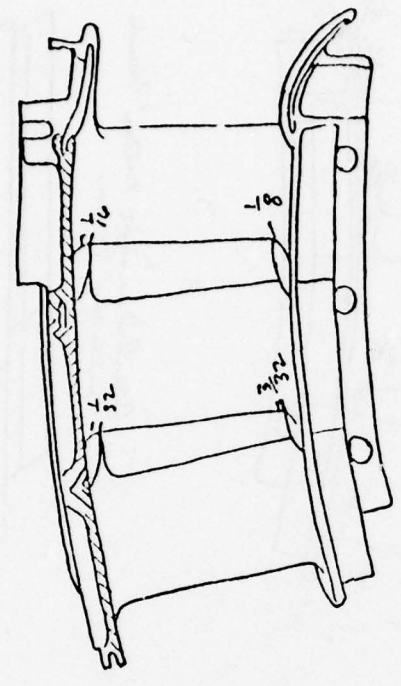
Unit 142163 Tü 5 Inspector R. Fisher Date 10-16-78

P/N: 6894686A S/N: C01423 Position 52-53-54

Ref: 6862973

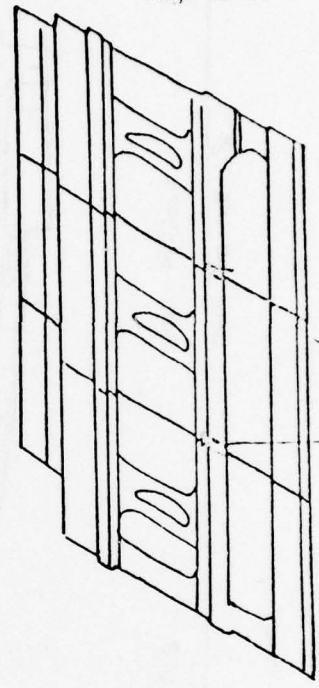
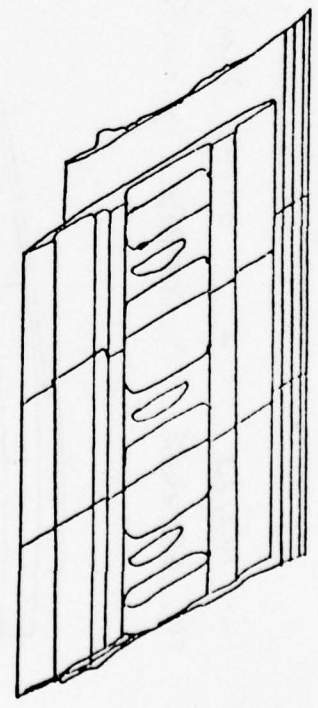


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INNER BAND

OUTER BAND



SPOT WELD CRACKED

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EXPERIMENTAL ASSEMBLY & IT INSPECTION  
 TF41 HP Turbine 1st Stage Vane Asm

Date 10-16-78

Ref: 6862973

Inspector Grady

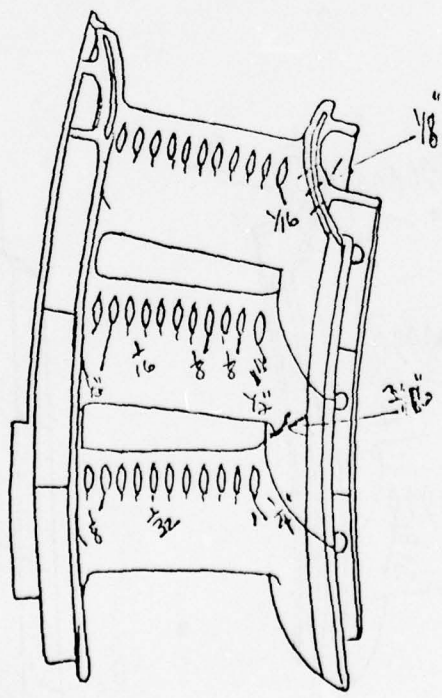
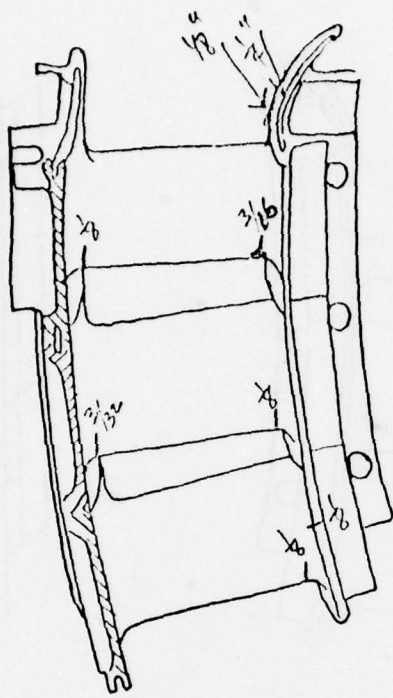
TU 5

Position 46-47-48

Unit 142163

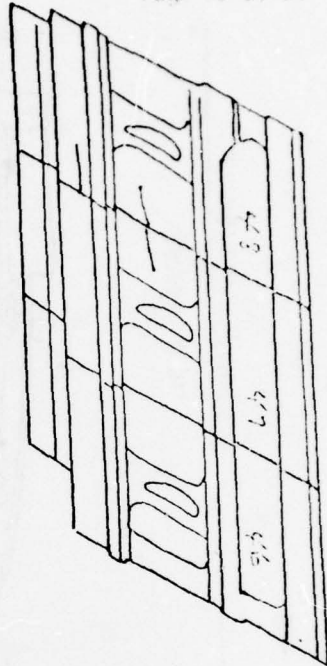
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S/N 00989

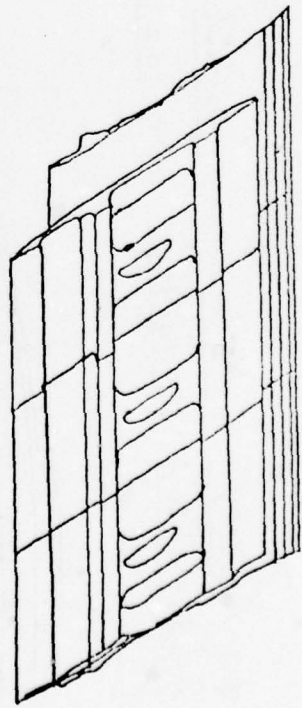


*Check inside outer band  
 between Vanes.*

OUTER BAND



INNER BAND



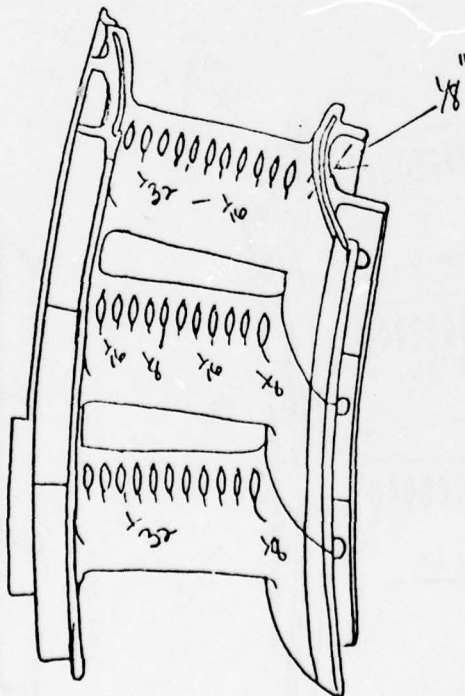
EXPERIMENTAL ASSEMBLY & ST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

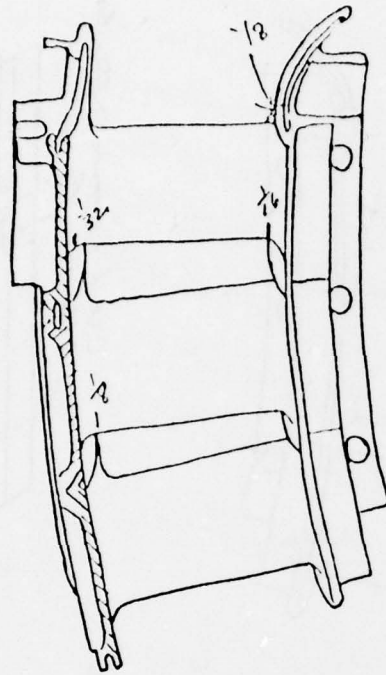
Unit 142163 Tu 5 Inspector Trudy Date 10-16-78

P/N 6894686 S/N 60525 Ref: 6862973

Position 28-29-30

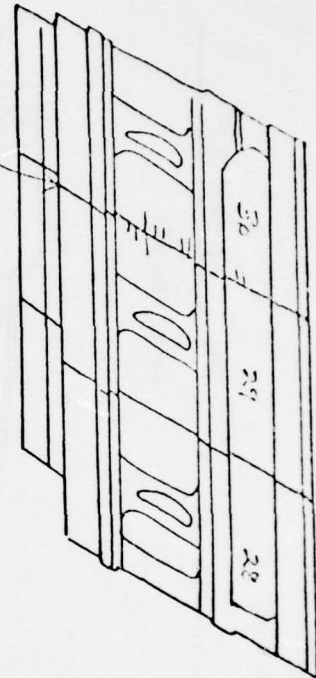


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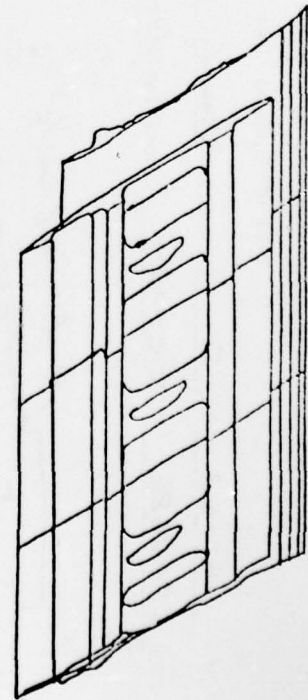


*Cracks Outer Band, inside  
forward Vane*

OUTER BAND



INNER BAND



S/N 142163/A  
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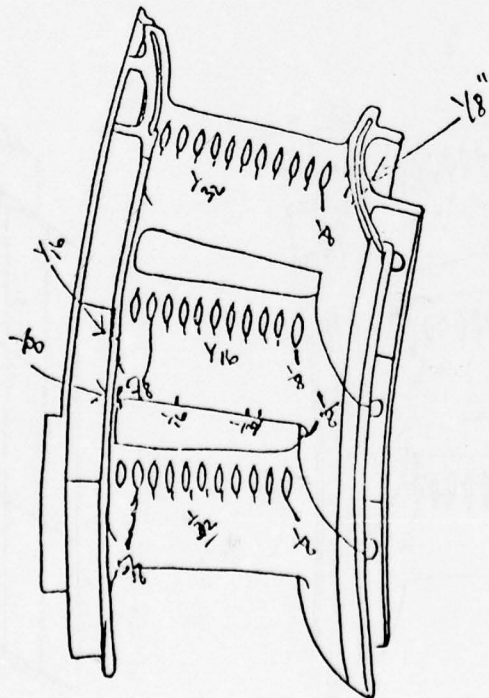
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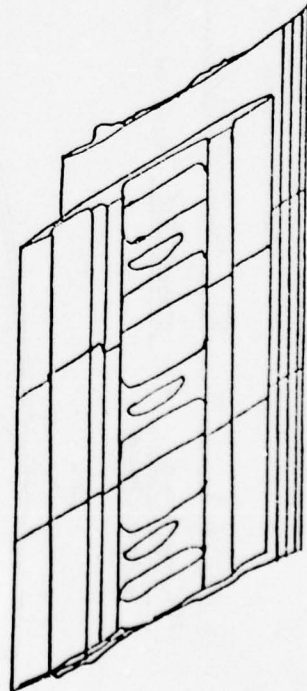
EXPERIMENTAL ASSEMBLY & ST INSPECTION  
 TF41 HP Turbine 1st Stage Vane Asm

Unit 142163 T/L 5 Inspector Preedy Date 10-16-78

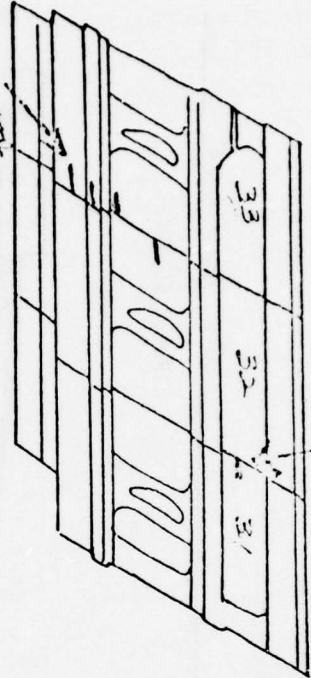
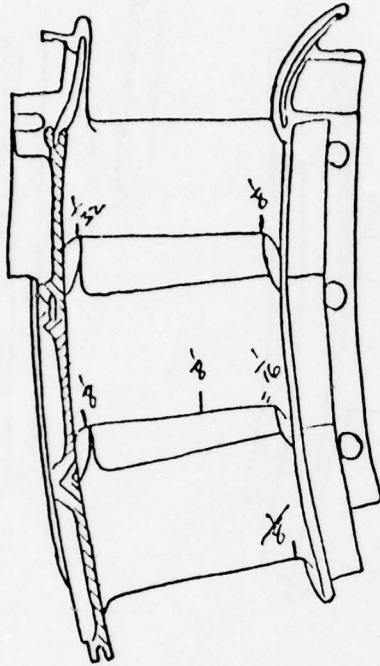
P/N 6894686 S/N C 00424 Position 31, 32, 33 Ref: 6862973



INNER BAND



OUTER BAND



*Check for inside surface  
 damage*

S/N 142163/5A  
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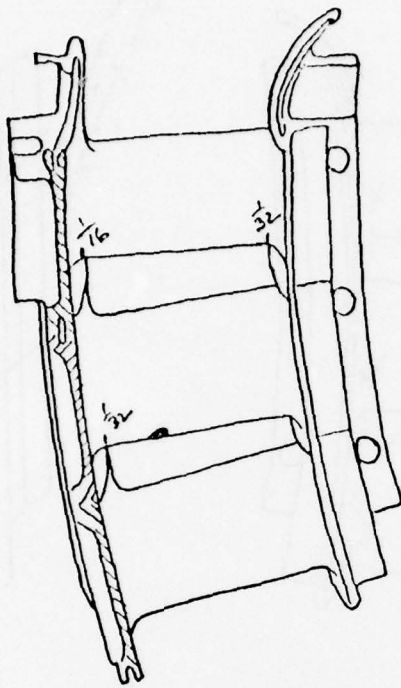
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 AND DEVELOPMENT.

EXPERIMENTAL ASSEMBLY & INSPECTION  
 TF41 HP Turbine 1st Stage Vane ASM

Date 10-16-78

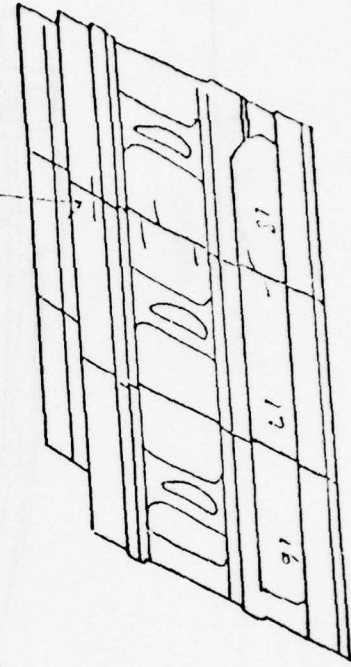
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Unit 142163 TU 5 Inspector Chasey  
 P/N: PL6862973 S/N: 600534 Position 16-17-18  
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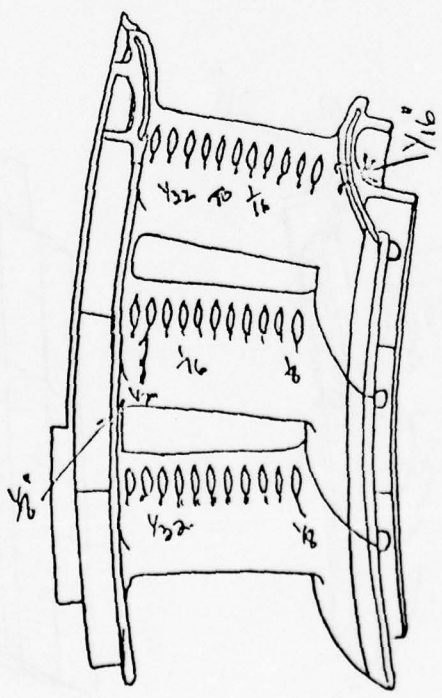


*Cracks inside  
 outer band between  
 vanes.*

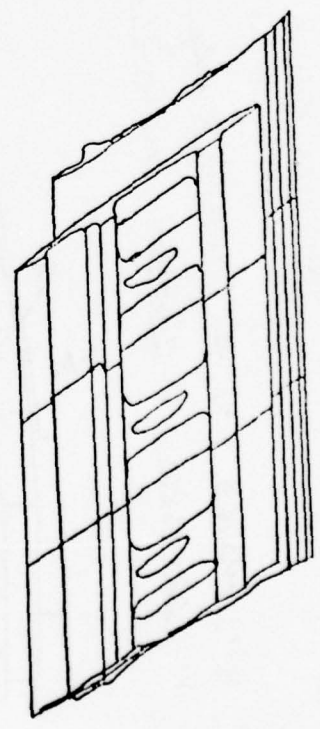
OUTER BAND



S/N 142163/A  
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INNER BAND

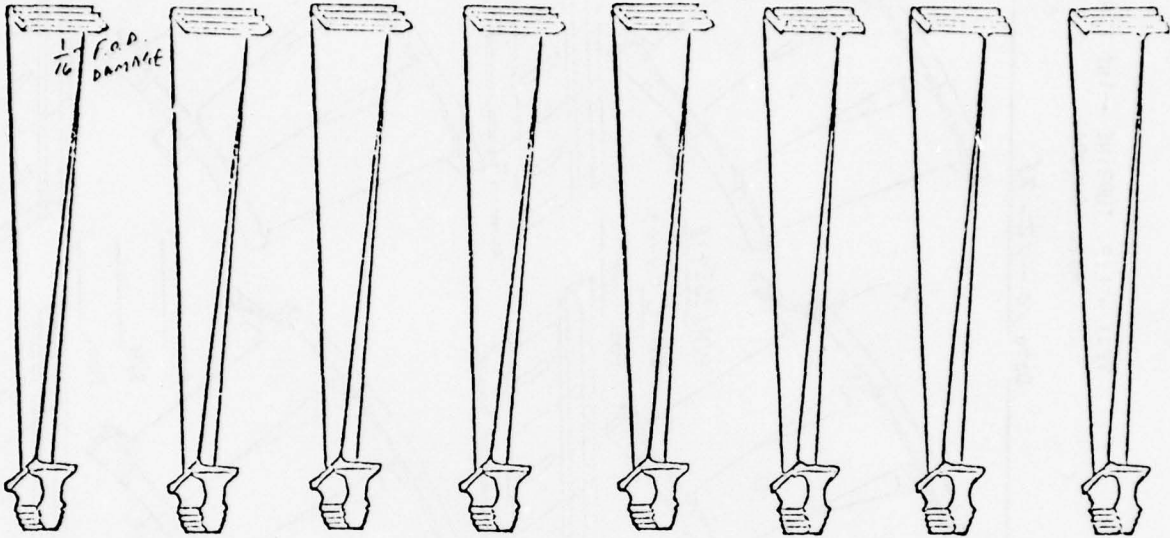


EXHAUSTIVE ASSEMBLY AND TEST INSPECTION

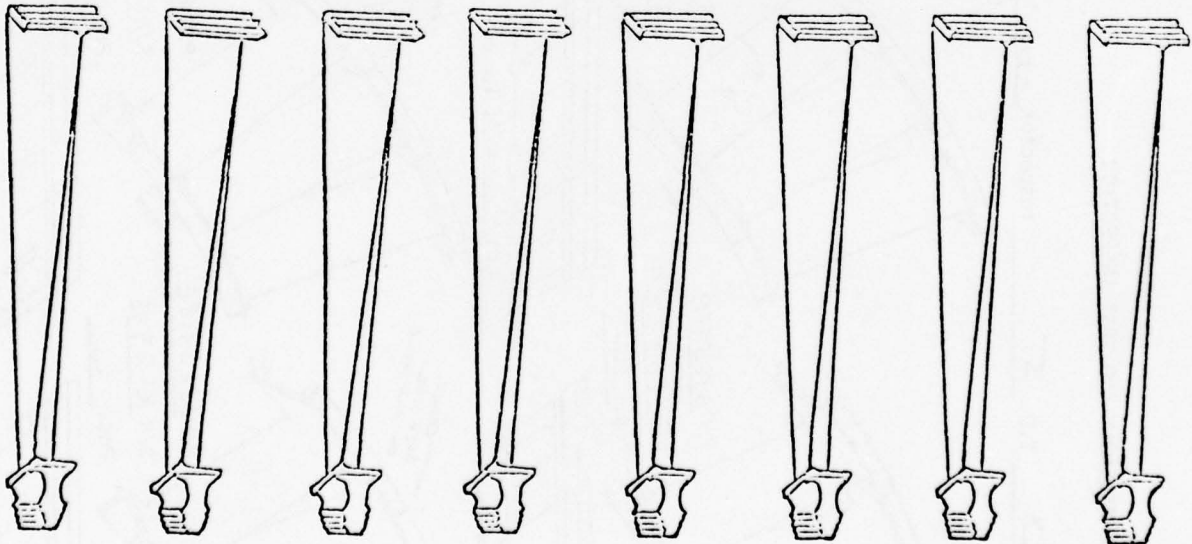
1141 - L.P. TURBINE - 2nd STAGE BEA  
 Ref: 6964002 S/N 13,187/A  
 Page 38 of 39

Unit 147163 T.D. 5 Inspector R. D. Fisher

Date 10-13-78



P/N 6864002 P/N \_\_\_\_\_ P/N \_\_\_\_\_ P/N \_\_\_\_\_ P/N \_\_\_\_\_ P/N \_\_\_\_\_ P/N \_\_\_\_\_ P/N \_\_\_\_\_  
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APPENDIX D TEST PLAN

TEST PLAN

AIR FORCE AERO PROPULSION LABORATORY

10 April 1978

1. TITLE: TF41 Accelerated Mission Test (AMT).
2. JON: 30661602
3. PROJECT ENGINEER: Robert J. May, Jr. TBA 54830
4. PROJECT TEAM: Mark Reitz TBA 54830  
Doretta Holland TFIC 55636
5. CONFIGURATION: Engine Type - TF41-A-1  
Serial Number - 141163  
Special Features - Block 76 Hardware
  - #6 bearing cast support
  - HPT-1 cast blades
  - HPT-1 bull nose vanes
  - #5 bearing rear seal deletion
  - HPC 4-5-6 Eiffel tower vanes
  - HPC-1 blades
  - fuel manifold
  - NL anticipator
  - HPT-1 lockplate damper
  - viton wills ring
  - Reworks and Repair Schemes
    - H.M. Governor - new viton diaphragm
    - 5 liners repaired with L605 ring
    - 10 weld repaired air scoops from Alameda
    - LPC-1 blades (15 weld repaired,  
7 hard coat replacement, 3 standard)

6. FACILITY: "D" stand, sea level engine test facility, AF Aero Propulsion Laboratory.

7. FUEL/LUBES: FUEL: MIL-T-5624, JP4  
LUBE OIL: MIL-L-7808. See Hoover Smith, SFL, 54667  
for a particular drum of MIL-L-7808 to be used for this test in D-bay.

8. TEST OBJECTIVES:

8.1 Establish durability characteristics of a TF41 with "Block 76" modifications.

8.2 Document overall engine performance deterioration of a TF41 with "Block 76" hardware modifications and attempt to isolate major contributions to engine deterioration.

8.3 Document burner outlet temperature profile changes due to engine deterioration.

8.4 Demonstrate durability of several proposed reworks and repair schemes.

9. INSTALLATION:

9.1 Install engine in "D" bay according to standard TF41 procedures.

9.2 Instrument as specified in instrumentation section of this plan.

9.3 Install tailpipe and exhaust nozzle.

9.4 Install TF41 airmeter bellmouth and screen.

9.5 Connect power lever to automatic throttle control and use standard throttle rigging. Refer TO 2J-TF41-3 for specific details.

9.6 Service engine with oil provided by SFL.

9.7 Take a 1 pint sample of oil (from oil drum) to SFL.

9.8 Provide bleed take-off pipe for 11th stage HP compressor bleed ports. The amounts of bleed are:

HPC-11 1.5 lbm/sec

9.9 Recalibrate all instrumentation.

10. INSTRUMENTATION:

The following list describes the instrumentation requirements for the AMT cyclic test on engine S/N 141163.

10.1 Engine inlet temperature

10.2 Engine inlet pressure

10.3 Bellmouth static pressure

10.4 Low pressure rotor speed

10.5 High pressure rotor speed

10.6 Turbine outlet temperature

10.7 Fuel flow

10.8 Fuel inlet temperature

10.9 Low pressure and intermediate pressure compressor discharge pressure (dual probe).

10.10 Low pressure and intermediate pressure compressor discharge temperature (dual probe).

10.11 High pressure compressor discharge static pressure

10.12 High pressure compressor discharge temperature

10.13 Fuel manifold pressures, pilot and main.

10.14 Low pressure turbine outlet pressure.

10.15 Main oil  $\Delta P$

10.16 Engine main oil pressure

10.17 Low pressure cooling air outlet temperature

10.18 Engine vibration

front compressor (vertical) - front flange top

rear compressor (vertical) - fuel manifold boss, top

turbine (near vertical) - LP turbine oil tube boss, bottom

10.19 IGV position

10.20 Power lever position

10.21 Accessory bleed air, total pressures and static pressures for  
the HPC 11th stage.

10.22 Engine oil inlet temperature

10.23 Engine thrust

10.24 Temperature limiter amplifier current

10.25 Junction box temperature

10.26 Exhaust gas temperature rake

10.27 Dry bulb temperature

10.28 Wet bulb temperature

#### 11. SPECIAL REQUIREMENTS:

11.1 A once per second digital recording and storage capability is required for every engine and facility parameter measured and the status of every facility device used during this test.

11.2 Continuous recording of the following parameters on an oscillograph recorder is also required:

- turbine outlet pressure
- turbine outlet temperature
- high pressure rotor speed
- low pressure rotor speed
- fuel flow
- temperature limiter amplifier current
- power lever angle

- oil inlet temperature
- oil outlet temperature
- main oil pressure
- differential oil pressure
- fuel manifold pressure
- fuel temperature
- compressor vibrations
- burner vibrations
- turbine vibrations

## 12. OPERATING LIMITS:

12.1 The engine operating limits are those applicable to any TF41 engine and are spelled out in TO 2J-TF41-6. The operating limits that are entered in the control computer should be coordinated with the TF41 test project team.

12.2 Once the engine and facility limits have been determined and the data base has been prepared and loaded into the control computer, the computer should be set up to simulate the engine running. Each measured parameter should then be arbitrarily set above and below its high and low limit in order to insure that operating limits have been input properly and to document how the computer will react to an out-of-limits situation.

## 13. STANDARD PROCEDURES:

This test will be conducted according to "D" bay standard operating and emergency procedures as outlined in the operator's manual. The TF41 prestart checklist will be complied with before the initial start of the day. In addition, the following procedures will be followed:

- 13.1 Record all start and stop data including reasons for shutdown.

13.2 No control system or operating limit adjustments shall be made during this test without the specific approval of the project engineer or other team member in his absence.

13.3 Take care to note in the engine log all incidents of the run such as overspeeds, overtemperature, leaks, vibrations, irregular functioning of the engine, facility or instrumentation, smoking, or sparking, and describe any corrective action taken.

13.4 Daily record specific gravity of the fuel and reference temperature in the engine log.

13.5 Oil servicing shall be in accordance with current TF41-A-1 instructions. Maintain daily log of oil added and oil consumption during the entire test.

13.6 Log all maintenance, planned inspections, boroscope inspections, etc.

13.7 The low pressure compressor and intermediate pressure compressor pressure and temperature instrumentation should be removed during the cyclic testing portion of this test. This instrumentation should be installed only during power calibrations.

13.8 The exhaust gas temperature rake should be installed in the tailpipe only during power calibrations and not during cyclic testing.

13.9 Turn on data logger just before the 6 minutes flat at intermediate power near the end of each "A" cycle.

13.10 Record T4, T1, and T5.1 at the end of the 6 minutes flat at intermediate power near the end of each "A" cycle.

13.11 Power calibration and exhaust gas surveys should be run with the 11th stage bleeds blocked off.

13.12 The engine should be allowed to stabilize 5 minutes before

recording power calibration data.

13.13 The desired tolerance on speed settings during the "automatic" portion of the test shall be  $\pm 50$  rpm HN ( $\pm 0.4\%$ ),

13.14 Once every four hours measure and record barometric pressure, wet bulb temperature, and look-up vapor pressure from the appropriate curve.

13.15 Check oil level after every four "A" cycles, or more often if oil consumption is running abnormally high.

13.16 Monitor starter oil temperature during all motoring of the engine. The starter oil temperature should not exceed 300°F.

13.17 Thoroughly wash inlet FOD screen when total pressure drop exceeds 8 inches of H<sub>2</sub>O.

13.18 Rotor coast-down speeds need only be recorded when the oil level is to be checked and for the final shutdown each day.

13.19 Maintain a log of total engine time, total AMT time, and the number and types of cycles that have been run.

13.20 Insure that the data acquisition and storage system is operating properly. (Specific instructions to be provided.)

#### 14. INITIAL ENGINE/FACILITY CHECKOUT:

The following procedures should be followed during the initial running of the engine after installation in the test cell:

- motor the engine for at least 30 seconds on the starter,
- start the engine and stabilize at idle for 5 minutes,
- check all instrumentation readings,
- if the facility and engine operation appear normal, perform a walk-around inspection, checking for leaks, loose fittings etc.
- if there are no discrepancies, make a slow "accel" to 85% NH and stabilize, checking all engine and facility parameters,

- if the facility and engine operation appear normal, slowly accel to 90% NH, stabilize, and check all engine and facility parameters.
- if the facility and engine operation appear normal, slowly accel to intermediate power, stabilize, and check all engine and facility parameters.
- perform a slow "decel" to idle and stabilize.
- if the facility and engine operation appear normal, perform a snap accel to intermediate, stabilize, and then a snap decel to idle.
- if no engine or facility discrepancies have been discovered up to this point, continue with the test plan performing the engine functional checks described in the following section. If problems have been identified, shut down, make the necessary repairs, and then complete the remaining steps of this section.

15. ENDURANCE TEST:

The engine will be trimmed and set up before delivery to AFAPL by Allison.

15.1 Engine Functional Check (initially and every 100 hrs thereafter) see TO 2J-TF416, para 10-35 and Table 10-4.

15.1.1 Check IGV ram closing schedule. Determine that the attached schedule is satisfied (IGV = +33° and +7).

15.1.2 Check NL governor with pulldown tool according to TO 2J-TF41-6, para 10-63.

15.1.3 Check T5.1 pulldown according to TO 2J-TF-41-6, para 10-66.

15.1.4 Check P3 limiter according to TO 2J-TF41-6, para 10-64.

15.1.5 Check NH governor according to TO 2J-TF41-6, para 10-59, 10-60, 10-62.

15.1.6 Check ACU and DCU according to TO 2J-TF41-6, para 10-70, 10-71, 10-72, 10-73.

15.1.7 Check mass flow limiter using the T1 simulator and according to TO 2J-TF41-6, para 10-60.

15.2 High pressure rotor speed and power lever calibration (initially and every 100 hours)

15.2.1 Stabilize 5 minutes at each NH speed listed

10,000  $\pm$  100 rpm

10,500  $\pm$  100 rpm

10,900  $\pm$  100 rpm

11,300  $\pm$  100 rpm

11,700  $\pm$  100 rpm

12,100  $\pm$  100 rpm

12,300  $\pm$  100 rpm

15.2.2 Plot NH (rpm) versus power lever angle. Determine power lever angle corresponding to the following speeds and provide this information for input into the automatic throttle control.

<u>NH (rpm)</u>	<u>%rpm</u>	<u>PLA</u>
10,332	80	
10,589	82	
10,977	85	
11,235	87	
11,364	88	

<u>NH (rpm)</u>	<u>%rpm</u>	<u>PLA</u>
11,632	90	
12,010	93	
12,140	94	
12,269	95	

15.3 Performance calibration (initially and every 100 hours)

15.3.1 Blank off bleed ports,

15.3.2 Install low pressure compressor and intermediate pressure compressor discharge instrumentation.

15.3.3 Stabilize for 5 minutes at the following levels of corrected thrust:

9000  $\pm$  200 lb

10,000  $\pm$  200 lb

11,000  $\pm$  200 lb

12,000  $\pm$  200 lb

13,000  $\pm$  200 lb

14,000  $\pm$  200 lb

intermediate

15.4 Exhaust gas temperature survey

15.4.1 Blank off bleed ports

15.4.2 Install thermocouple rake

15.4.3 Stabilize for 5 minutes at intermediate power and record data.

15.4.4 Shut down

15.4.5 Rotate tailpipe one bolt hole and repeat.

15.4.6 Repeat twice until a total of 4 data points have been obtained.

## 15.5 Rescheduled Inspections

15.5.1 Perform engine boroscope inspection of the hot section after each 100 hours of AMT testing.

15.5.2 Standard field service inspections shall be made and documented throughout the test. Reference TF41 Service and Operation Manual, Allison Publication No. 1F2, 1 March 1974, Section 7.

- conduct 50-hour phase inspection
- conduct 100-hour phase inspection
- conduct 150-hour phase inspection
- conduct 200-hour phase inspection

15.5.3 Take two 1 pint oil samples immediately after initial servicing and at approximately 25-test-hour intervals thereafter. The container will be provided by and the samples should be sent to SFL, Hoover Smith, 54667. SOAP and ferrograph analyses should be run.

## 15.6 Cyclic testing

15.6.1 The actual test consists of running the engine through a specified number of test cycles, labeled the "A", "B", and "C" cycles. A detailed description of these cycles is included on the attached pages. The test consists of 15 blocks made up of 20 "A" cycles, 4 "B" cycles, and 1 "C" cycle each.

15.6.2 Set the 11th stage bleed at approximately 1.5 lbs/sec (.62" diameter orifice plate) unless the test engineer specifies a different bleed flow rate.

15.6.3 Remove high pressure compressor and intermediate pressure compressor instrumentation.

15.6.4 Remove exhaust gas survey rake

15.6.5 Enter "A" cycle into autothrottle and run 20 cycles.

15.6.6 Enter "B" cycle into autothrottle and run 4 cycles

15.6.7 Enter "C" cycle into autothrottle and run 1 cycle

NOTE: The sequence of "A", "B", and "C" cycles is relatively insignificant.

The number of each type of cycle run is important. The sequence may be altered to better fit available test time.

15.6.8 Repeat 14.7.5 - 14.7.7, 14 times, performing the required inspections and calibrations etc. Run 5 extra "A" cycles.

(This makes for approximately 263 hours of AMT testing)

15.6.9 Upon completion of 263 hours of cyclic testing, remove the engine and return to Allison for a teardown inspection.

CYCLE A

FLIGHT OPERATION

TIME (Min:Sec)		ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR ALL CIT CONDITIONS
ELAPSED	AT		
0:00	:30	Start Engine and accel to 55% .	
0:30	2:00	Engine at Idle pwr	
2:30	:30	Accel to 90% N <sub>H</sub> Dbl. datum on	
3:00	2:30	Accel to Intermediate Dbl Datum on	
5:30	1:00	Decel to 85% N <sub>H</sub> , Dbl Datum Off	
6:30	2:00	Accel to Intermediate (100% N <sub>H</sub> )	
8:30	:30	Decel to 90% N <sub>H</sub>	
9:00	:15	Decel to 55% N <sub>H</sub>	
9:15	:10	Accel to Intermediate	
9:25	:25	Decel to 93% N <sub>H</sub>	
9:50	3:48	Accel to Intermediate, then Decel to 94% (19 Times). Each transient will take 6 sec.	
13:38	:12	Accel to Intermediate, transient to take 6 sec.	
13:50	:30	Decel to 88% N <sub>H</sub>	
14:20	:08	Accel to Intermediate	
14:28	:15	Decel to 55% N <sub>H</sub>	
14:43	:45	Accel to Intermediate	
15:28	:30	Decel to 88% N <sub>H</sub>	
15:58	:08	Accel to Intermediate	
16:06	:15	Decel to 55% N <sub>H</sub>	
16:21	:45	Accel to Intermediate	
17:06	:30	Decel to 88% N <sub>H</sub>	
17:36	:08	Accel to Intermediate	
17:44	:07	Decel to 85% N <sub>H</sub>	
17:51	:35	Accel to Intermediate	
18:26	:15	Decel to 90% N <sub>H</sub>	
18:41	:08	Accel to Intermediate	
18:49	:07	Decel to 85% N <sub>H</sub>	
18:56	:35	Accel to Intermediate	
19:31	:15	Decel to 90%	

CYCLE A  
FLIGHT OPERATION

TIME (Min : Sec)	ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR ALL CIT CONDITIONS
ELAPSED	AT	
19:46	:08	Accel to Intermediate
19:54	:07	Decel to 85% NH
20:01	:35	Accel to Intermediate
20:36	:15	Decel to 90% NH
20:51	:08	Accel to Intermediate
20:59	:07	Decel to 85% NH
21:06	:35	Accel to Intermediate
21:41	:15	Decel to 90% NH
21:56	:08	Accel to Intermediate
22:04	:15	Decel to 55% NH
22:19	:35	Accel to Intermediate
22:54	:30	Decel to 88% NH
23:24	:03	Accel to Intermediate
23:32	:15	Decel to 55% NH
23:47	:35	Accel to Intermediate
24:22	:30	Decel to 88% NH
24:52	:08	Accel to Intermediate
25:00	:15	Decel to 55% NH
25:15	:35	Accel to Intermediate
25:50	1:00	Decel to 88% NH
26:50	:08	Accel to Intermediate
26:58	:07	Decel to 85% NH
27:05	:35	Accel to Intermediate
27:40	:15	Decel to 90% NH
27:55	:03	Accel to Intermediate
28:03	:07	Decel to 85% NH

CYCLE A

TIME (Min : Sec)		ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR ALL CIT CONDITIONS
28:10	:30	Accel to Intermediate	
28:40	:15	Decel to 90% NH	
28:55	:08	Accel to Intermediate	
29:03	:07	Decel to 85% NH	
29:10	:30	Accel to Intermediate	
29:40	:25	Decel to 90% NH	
30:05	:15	Decel to 55% NH	
30:20	:10	Accel to Intermediate	
30:30	:05	Decel to 88% NH	
30:35	6:00	Accel to Intermediate	
36:35	:15	Decel to 55% NH	
36:50	1:10	Accel to Intermediate	
38:00	:05	Decel to 80% NH	
38:05	:05	Accel to 87% NH	
38:10	:05	Decel to 80% NH	
38:15	:05	Accel to 90% NH	
38:20	:15	Decel to 55% NH	
38:35	:30	Accel to Intermediate	
39:05	:05	Decel to 82% NH	
39:10	:05	Accel to 90% NH	
39:15	:15	Decel to 55% NH	
39:30	:30	Accel to Intermediate	
40:00	:05	Decel to 82% NH	
40:05	:05	Accel to 90% NH	
40:10	3:19	Decel to 55% NH	
43:29		Shutdown engine	
45:29		Motor Engine on Starter	
47:59		Start Engine and Accel to Idle	
48:29		Engine at Idle Pwr Ready for Next Cycle	

TOTAL CYCLE ENDURANCE TIME: 43 Min. 29 Sec.

CYCLE B  
FLIGHT LINE OPERATION

TIME (Min : Sec)		ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR ALL CIT CONDITIONS
ELAPSED	AT		
0:00	3:00	Engine at Idle Pwr	
3:00		Shutdown Engine	
5:00		Motor Engine on Starter	
7:30	:30	Start Engine and Accel to Idle Pwr	
8:00	3:00	Engine at Idle Pwr	
11:00		Shutdown Engine	
13:00		Motor Engine on Starter	
15:30	:30	Start Engine and Accel to Idle Pwr	
16:00	3:00	Engine at Idle Pwr	
19:00		Shutdown Engine	
21:00		Motor Engine on Starter	
23:30	:30	Start Engine and Accel to Idle Pwr	
24:00		Engine at Idle Pwr Ready for Next Cycle (A or C depending on schedule).	

TOTAL CYCLE ENDURANCE TIME 10 Min 30 Sec

CYCLE C  
GROUND OPERATION  
SFE TEST CYCLE SEQUENCE

TIME (Hr : Min : Sec)	ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR ALL CIT CONDITIONS:
ELAPSED	AT	
0:00:00	3:00	Engine at Idle Pwr
0:03:00	3:15	Accel to Intermediate (No DD)
0:06:15	3:00	Decel to Idle Pwr
0:09:15	3:15	Accel to Intermediate
0:12:30	3:00	Decel to Idle Pwr
0:15:30	3:15	Accel fo Intermediate
0:18:45	3:00	Decel to Idle
0:21:45	3:15	Accel to Intermediate
0:25:00	3:00	Decel to Idle
0:28:00	3:15	Accel to Intermediate
0:31:15	3:00	Decel to Idle
0:34:15	3:15	Accel to Intermediate
0:37:30	3:00	Decel to Idle
0:40:30	3:00	Accel to 95%
0:43:30	3:00	Decel to Idle
0:46:30	3:00	Accel to 95%
0:49:30	3:00	Decel to Idle
0:52:30	3:00	Accel to 95%
0:55:30	3:00	Decel to Idle
0:58:30	3:00	Accel to 95%
1:01:30	3:00	Decel to Idle
1:04:30	3:00	Accel to 95%
1:07:30	3:00	Decel to Idle
1:10:30	3:00	Accel to 90%
1:13:30	3:00	Decel to Idle
1:16:30	3:00	Accel to 90%

CYCLE C  
GROUND OPERATION  
SFE TEST CYCLE SEQUENCE

TIME (Hr : Min : Sec)		ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR ALL CIT CONDITIONS
ELAPSED	AT		
1:19:30	3:00	Decel to Idle	
1:22:30	3:00	Accel to 90%	
1:25:30	3:00	Decel to Idle	
1:28:30	3:00	Accel to 90%	
1:31:30	3:00	Decel to Idle	
1:34:30	3:15	Accel to Intermediate	
1:37:45	3:00	Decel to Idle	
1:40:45	3:15	Accel to Intermediate	
1:44:00	3:00	Decel to Idle	
1:47:00	3:15	Accel to Intermediate	
1:50:15	3:00	Decel to Idle	
1:53:15	3:15	Accel to Intermediate	
1:56:30	3:00	Decel to Idle	
1:59:30	3:00	Accel to Intermediate	
2:02:45	3:15	Decel to Idle	
2:05:45		Shutdown Engine	
2:07:45		Motor Engine on Starter	
2:09:45		Start and Accel to Idle Pwr	
2:10:15	:30	Engine at Idle Pwr Ready for Next Cycle	

TOTAL CYCLE ENDURANCE TIME 2 Hrs 6 Min 15 Sec

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6. "TF41-A-1 Engine Operation and Service," Allison Publication Number 1F2, March 1977.
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