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CF6 JET ENGINE DIAGNOSTICS PROGRAM

LONG-TERM CF6-6D
LOW-PRESSURE TURBINE DETERIORATION

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GENERAL ELECTRIC COMPANY

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FOREWORD

The work was performed by the CF6-6 and CF6-50 Programs Departments, and the Commercial Engineering Operation of General Electric's Aircraft Engine Group, Commercial Engine Projects and Aircraft Engine Engineering Divisions, respectively. The program was conducted for the National Aeronautics & Space Administration, Lewis Research Center, Cleveland, Ohio under Task II of the CF6 Jet Engine Diagnostics Program, Contract Number NAS3-20631. The NASA Project Engineers for this program were Robert Dengler and Charles M. Mehalic.

The General Electric Company would like to acknowledge the support of United Airlines, National Airlines, American Airlines, and the Douglas Aircraft Company for their support in supplying CF6-6D data, engines and low pressure turbine modules for use in this program.

The requirements of NASA Policy Directive NPD 2220.4 (September 14, 1970) regarding the use of SI Units have been waived in accordance with the provisions of paragraph 5d of that Directive by the Director of Lewis Research Center.

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1.0 SUMMARY

This report presents the test cell performance results of back-to-back testing of seven CF6-6D serviceable low pressure turbine (LPT) modules. These tests were performed as part of the NASA CF6 Jet Engine Diagnostics Program.

The objective of this series of tests was to measure the level of performance deterioration (sfc) of airline serviceable LPT modules relative to new CF6-6D production hardware. In addition, three of the LPT modules were analytically inspected and tested back-to-back following refurbishment (restore clearances) to evaluate current performance restoration practices. The tests were conducted at three different General Electric (GE) test facilities: (1) Evendale Production Test Cell M34, (2) Evendale Development Test Cell 6, and (3) the ASO/Ontario CF6 Test Cell; and in the United Airlines CF6 Test Cell 5.

Four separate CF6-6D production LPT modules were used as baseline modules for this program. A typical test consisted of a baseline test cell run with a production LPT module followed by a test with one of the seven airline-serviceable LPT modules. The resulting change in sfc between the two tests provided a measure of the performance deterioration of the serviceable LPT module. Note that since the program utilized four production and seven serviceable modules, the production LPT's were used as the performance baseline for more than one airline module.

The UAL workscope typically consisted of an inbound test cell run followed by an analytical teardown and refurbishment of the LPT module. The module was then retested on the same CF6-6D engine resulting in a direct measurement of the sfc performance improvement.

The seven serviceable LPT modules tested had logged from 2,800 to more than 13,000 hours time since new (TSN), and from zero to almost 13,000 hours time since overhaul (TSO). The average TSN of the LPT rotor/stator was 9,138 hours; the average TSO, 5,520 hours. The resulting measured level of sfc deterioration at sea level caused by the lower efficiency levels of the serviceable LPT modules ranged from 0.4 percent to 0.7 percent sfc with an average of 0.6 percent sfc at constant thrust. This corresponds to a 0.8 percent loss in LPT efficiency. The 0.6 percent sfc deterioration at sea level corresponds to a 0.4 percent increase in sfc (or fuel-burn) at altitude cruise conditions. The clearance restoration, evaluated by back-to-back testing, indicated that two-thirds (0.4 percent sfc) of the sea level losses were due to blade tip and interstage seal clearances. The remaining 0.2 percent resulted from airfoil surface finish degradation.

2.0 INTRODUCTION

Recognizing that the cost for aviation fuel was soaring and its availability diminishing, NASA established the Aircraft Energy Efficiency (ACEE) program. This program is multi-faceted with separate programs instituted to reduce fuel consumption by 5 percent for current high bypass ratio engines, by 12 percent for new engines in the '80's, and by an additional 15 percent in the early '90's for an advanced turboprop. As part of the Engine Component Improvement (ECI) program aimed at current high bypass ratio engines, the NASA Lewis Research Center is conducting a Jet Engine Diagnostics Program on the CF6 engine, with the General Electric Company as the prime contractor. The overall objective of this program is to develop technology that will be useful in minimizing performance deterioration, and obtaining improvements in performance restoration for large turbofan engines; in particular, as it applies to the CF6 family of engines.

The specific CF6 Jet Engine Diagnostics Program objectives are:

- Define the extent and magnitude of CF6 engine performance deterioration; establish statistical trends.
- Identify the sources and causes of CF6 short- and long-term engine performance deterioration; quantify both kinds.
- Determine sensitivity of component performance to deterioration of engine parts.
- Develop an analytical model which represents a statistical average or typical sfc loss associated with deterioration for parts of each major component in the engine.
- Recommend areas where performance retention items can be applied to current and future engines.

Prior to the initiation of the CF6 Jet Engine Diagnostics Program, analysis of CF6-6D test cell data for refurbished engines indicated the average deterioration of all engines was approximately 4.5 percent sfc at takeoff condition when compared with the new engine performance levels. Assessment of the airlines tests cell component performance data indicated that two-thirds of the loss (3 percent sfc) was in the LP system. Several previous back-to-back tests had verified the deterioration of the fan section to be approximately 0.5 percent. Therefore, the LPT was considered a major contributor to the residual deterioration or unrestored performance for the CF6-6D model engine. For this reason, a special LPT program was implemented specifically to quantify the contribution of LPT deterioration. This report covers that program in detail.

The data obtained as part of this program have since indicated that the average deterioration of an airline refurbished CF6-6D engine is only 2.2 percent sfc worse than a production engine - not the 4.5 percent originally assumed from the earlier studies based on a small amount of data. These studies have concluded that test cell instrumentation problems, hardware configuration of refurbished engines, and test cell correlations were the major causes for the early erroneous assumption. The program has been redirected based on these findings, but the special tests to quantify LPT deterioration had been completed. Some testing of this type was necessary no matter what the deterioration level of the refurbished engines, since back-to-back testing is the only way to isolate the deterioration of the LPT from the fan section. Currently test cell instrumentation is capable of measuring only total LP system deterioration, and not isolating one from the other.

The program included two separate back-to-back testing sequences. The first sequence consisted simply of back-to-back test cell runs, comparing a new CF6-6D production LPT module with a serviceable airline module. Three separate GE test facilities were used in order to better utilize the available new production LPT modules and new and used engines for the test vehicle. The ASO/Ontario facility utilized a new production engine that was there for other programs; the Evendale Production test facility allowed access to brand new engines and modules; the Evendale Development test facility used an older serviceable engine and featured expanded instrumentation capabilities.

The advantages in back-to-back testing are threefold:

1. It eliminates measurement problems arising from hardware distress. Changes in engine flow areas (HPT and LPT nozzle areas) and in temperature and pressure profiles make component analysis of deteriorated engines very difficult. With back-to-back testing, any change in fuel-burn would be due to the LPT substitution.

2. It eliminates test cell data measurement problems. Comparison testing of engines in different facilities creates problems with test cell correlation and potential instrumentation differences.

3. There is but one component change - the LPT module. This simplicity reduces the number of independent variables that influence overall engine performance. The impact of the remaining variables on engine components is secondary.

The second LPT program testing sequence consisted of back-to-back test cell runs at United Airlines (UAL), comparing the as-received serviceable LPT module to the same LPT module refurbished with new tip shrouds and stationary interstage seals (restored clearances). The modules were analytically inspected prior to the refurbishment to compare the performance assessment based on the used parts condition with the back-to-back test cell deterioration results.

The following sections of this report detail the results of the LPT back-to-back testing program and analytical teardown inspections. In total, seven serviceable LPT modules were compared to four new CF6-6D production modules. In addition, three of the serviceable modules were analytically inspected at

UAL, with two modules being refurbished and tested back-to-back. The results were consistent and repeatable, yielding an accurate assessment of the long-term CF6-6D LPT performance loss and a measurement of current clearance refurbishment techniques.

3.0 LOW PRESSURE TURBINE MODULE

3.1 LOW PRESSURE TURBINE (LPT) MODULE DESCRIPTION

The CF6-6 engine is a dual-rotor, variable-stator high-bypass-ratio turbofan powerplant designed for subsonic commercial airline service. The design and configuration of the engine have been based on obtaining long life, high reliability, and easy access for line maintenance. The engine is of modular design, which permits the changing of a module without completely disassembling the engine. The LPT module consists of the turbine midframe, low pressure turbine, and turbine rear frame. Figure 1 presents a cross-sectional view of the LPT module.

Turbine Midframe

The turbine midframe is located between the high pressure and the low pressure turbines. It forms the gas flowpath between the two turbines and contains the rear engine mount, the aft bearings of the core engine, and the forward bearing of the low pressure turbine.

Low Pressure Turbine

The low pressure turbine consists of five stages of blades and vanes. The rotor stages are the same outside diameter, making the low pressure turbine cylindrical. The stator casing is made of removable halves in which the stator vane dovetail slots are machined. This construction facilitates inspection and maintenance of the low pressure turbine. The low pressure turbine drives the fan rotor through the inner concentric shaft, and is aerodynamically coupled to the high pressure system.

Turbine Rear Frame

The turbine rear frame is located aft of the low pressure turbine. It contains the aft low pressure turbine bearings, and supports the primary exhaust system.

3.2 LOW PRESSURE TURBINE MODULE SELECTION

The requirements for selecting the seven LPT modules used in this program were subject to various criteria, the most important being that the module had to be available. Also, the number of spares at the participating airline was the critical factor in determining if any modules were available. Next, permission had to be granted for their use in the NASA Jet Engine Diagnostics Program. Once made available, the following criteria were used to determine whether an available LPT model would be acceptable for the NASA program:

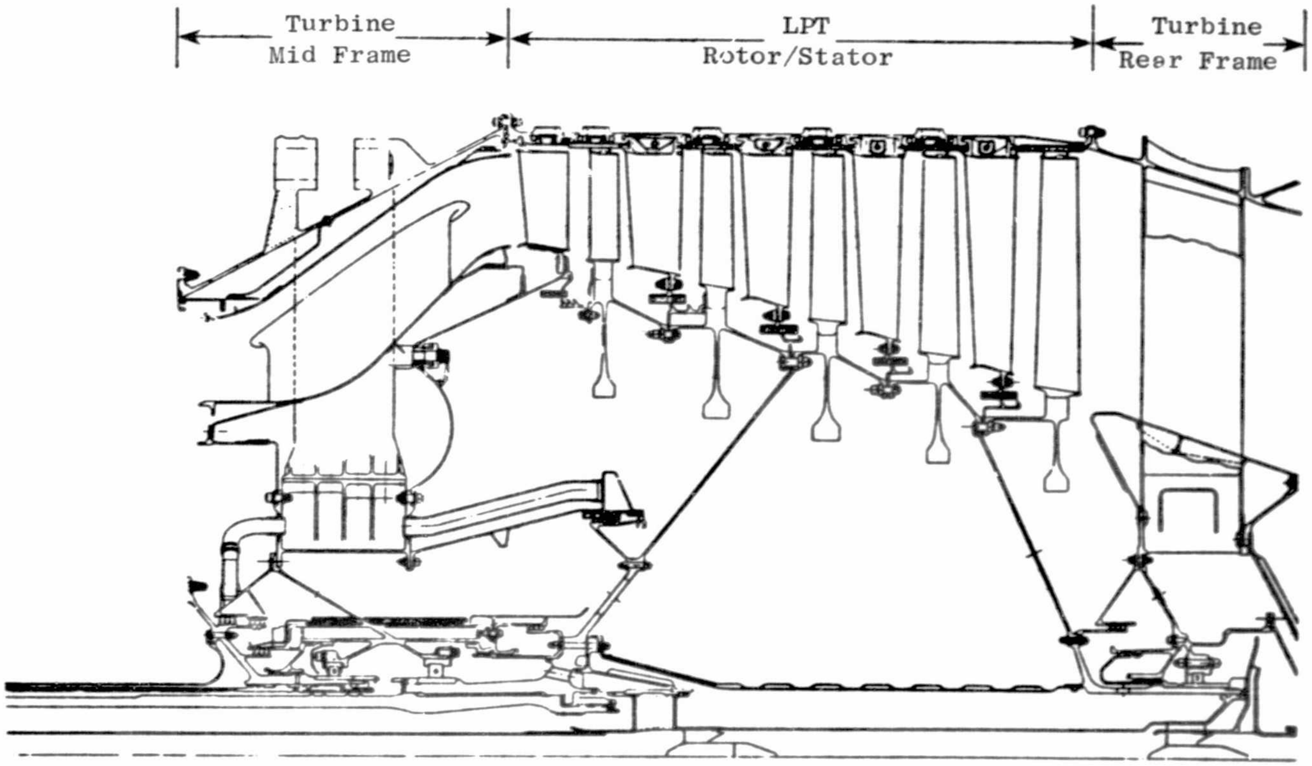


Figure 1. CF6-6 Low Pressure Turbine Module.

- The degree of repair or refurbishment (the less provided, the better)

- The hours and cycles since new or since overhaul (the more, the better)

- The LPT flow function

An effort was made to obtain modules that had not been refurbished for at least 4,000 hours. For test purposes, plans were made to obtain even longer-time parts. One module was selected, however, that had been completely refurbished: new shrouds; new stationary seals; and cleaned and/or new blades and vanes. This module presented an excellent opportunity to evaluate the effectiveness of LPT refurbishment techniques. The module times ranged from 2,800 to over 13,000 hours since new (TSN) and to almost 13,000 hours since overhaul (TSO). The average TSN was 9,138 hours; the average TSO, 5,520 hours. The hours-to-cycle ratio is essentially equal for all the CF6-6D operators, so no effort was made to obtain LPT modules with different hours-to-cycle ratio.

The CF6-6D engine has had an LPT flow function increase to improve EGT margin at constant fan speed. There is little impact, however, on fuel burn (sfc). This performance improvement was initiated in early 1972; thus, some older in-service engines do not have the increased flow area. Therefore, one of the airline modules was selected with the old, smaller flow function in order to evaluate its long-term performance deterioration.

The four production LPT modules utilized for this program were selected at random from the production line. These four modules were shipped on CF6-6D engine S/N's 451-507, -515, -516, and -524. Figure 2 presents the LP system efficiency level of these four engines. Assuming the fan performance of these four engines is equal, the LP system efficiency level is a good approximation of LP turbine performance. It can be seen that the LP system efficiency level of the four-engine sample closely approximates the average of other new CF6-6D production engines. For this reason, and because various ages of the serviceable airline modules were utilized, the results from this test are considered valid and representative of in-service losses for the CF6-6D LPT module.

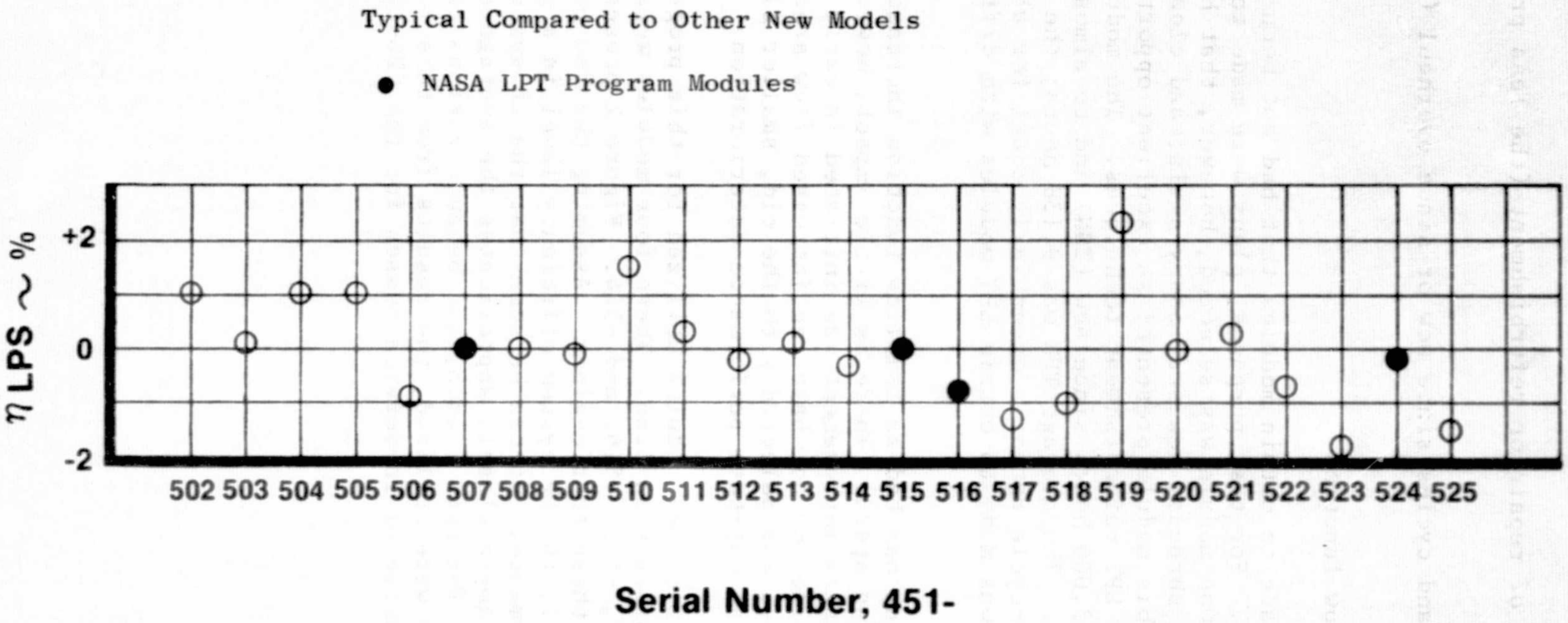


Figure 2. New LPT Modules for NASA Program.

4.0 DATA ACQUISITION SYSTEM AND TEST FACILITY DESCRIPTIONS

4.1 ASO/ONTARIO CF6 TEST CELL

The data recording system used at the ASO/Ontario CF6 test cell is supplied by the manufacturer, VIDAR. The system capability includes 132 pressures, 130 temperatures, and 10 frequencies. The pressure capability consists of 11 transducers for 0-500 psia, 11 for 0-150 psia, 44 for 0-25 psia, and 66 for 0-10 psig. The transducers are 12-port scanner valves, each having one port reserved for a barometric reference. Each of the 10 frequencies can average up to a 10-second time base. The temperature capability includes recording both C-C (copper-constantan) and C-A (chroml-alumel) thermocouples. The thrust load cell is calibrated in excess of 50,000 pounds. The two Cox turbine fuel flowmeters (main and verification fuel flow) are connected in series upstream of the engine fuel inlet.

The VIDAR system stores the test data reading on a punched paper tape. This tape, containing coded raw output in millivolt units, is loaded into the General Electric time-sharing computer system for data reduction and analysis. Figure 3 shows the Ontario CF6 test cell control room.

The ASO/Ontario CF6 test cell is fully enclosed and constructed to the same cross-sectional dimensions (20 x 30 ft) as the Evendale production cells M34 and M35. The cell inlet consists of two rows of acoustic panels and a foreign object damage (FOD) screen. The engine exhaust flows through the augmentor and acoustically treated exhaust stack. Figure 4 shows a CF6 engine installed in the Ontario test cell. Note the inlet acoustic panels and FOD screen. The CF6 lightweight bellmouth is supported by the overhead rail system against the left wall of the test cell.

The test cell, capable of handling engines having up to 100,000 pounds of thrust, presently contains a 50,000-lb load cell. The cell duplicates the Evendale, Ohio, production facilities and permits complete engine performance and functional testing. It has been correlated to the Evendale CF6 production test cells through back-to-back tests, the most recent using CF6-50 engine 517-130. In addition, other engines (both CF6-6 and CF6-50) have been tested back-to-back, with only nonperformance modifications made between tests. A cell correlation test involves testing the engine at both locations with full performance instrumentation (including nozzle discharge rakes). A portable data system is used at both locations to verify the measurement system at the test cell being correlated. Cell correlations include not only verifying instrumentation and establishing a thrust "cell factor," but also setting the correct fan and core nozzle discharge areas.

4.2 EVENDALE PRODUCTION CF6 TEST CELLS

Automatic Data Acquisition System

A digital Automatic Data Acquisition System (ADAS) is available to process performance data in the Production Engine test cell facility. The

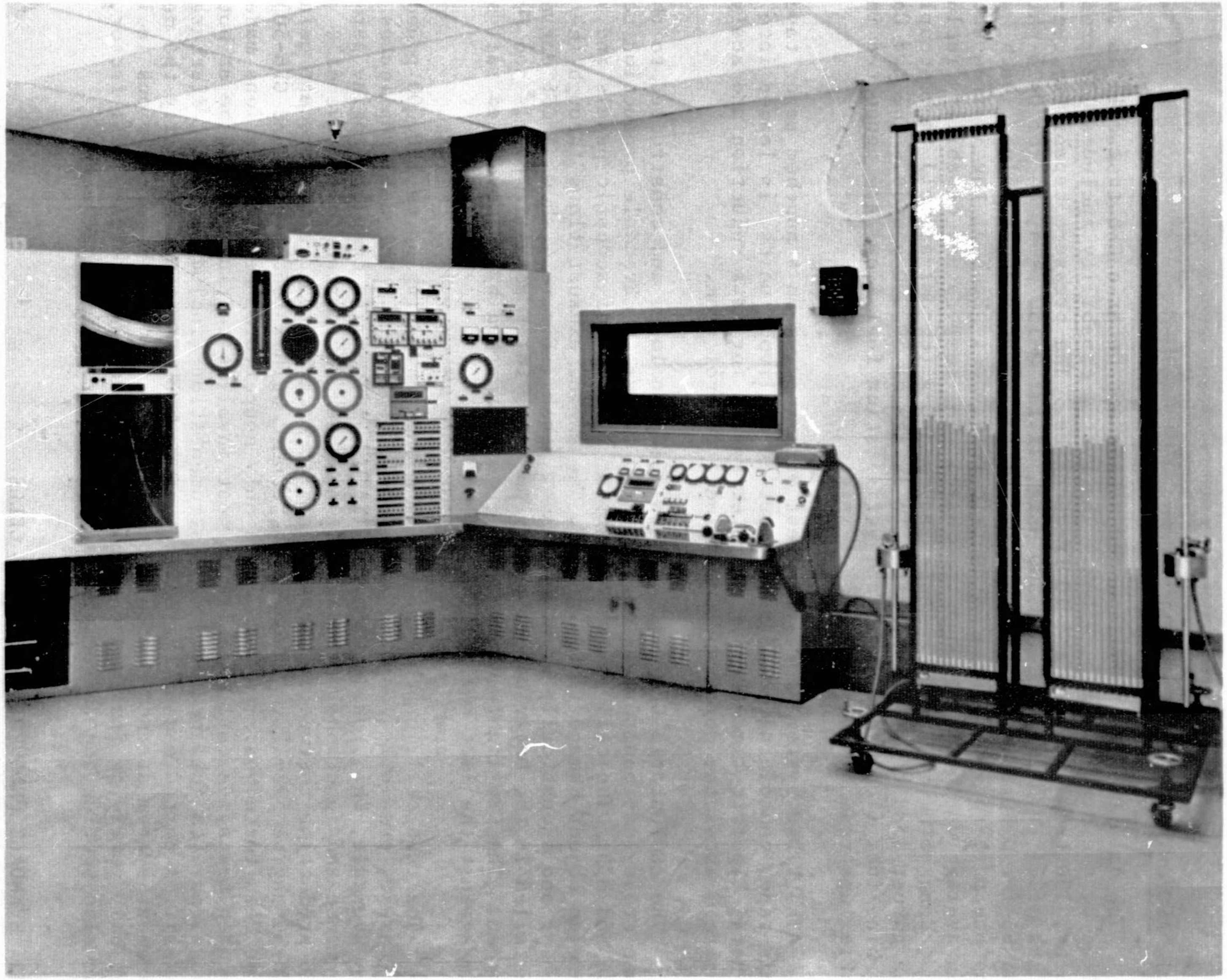


Figure 3. CF6 Test Facility Control Room, Ontario.

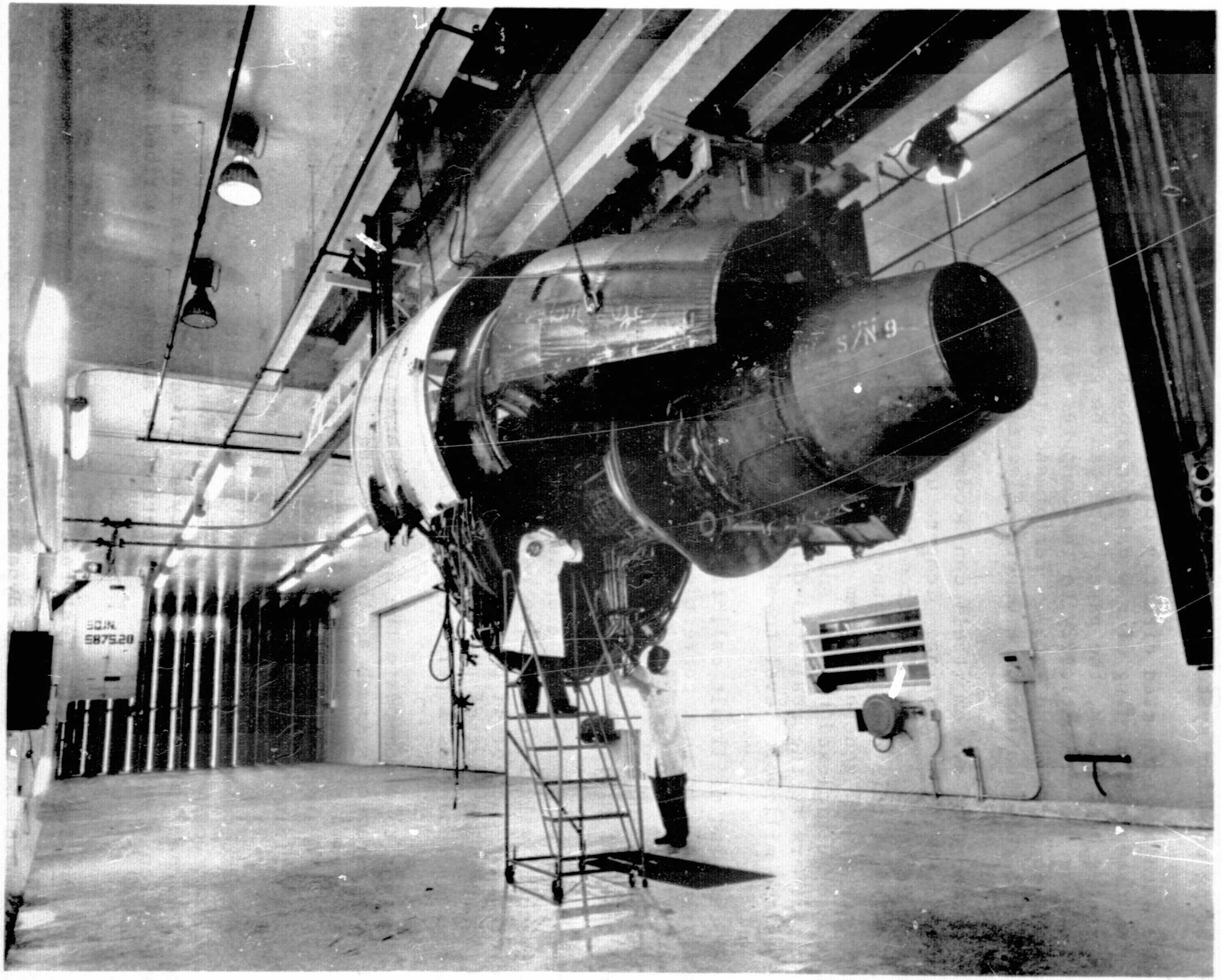


Figure 4. CF6 Engine Installed in Ontario Test Cell.

actual calculations on the data, with the associated conversion to engineering units and calculations for performance characteristics, are accomplished by a time-sharing computer system.

The data are connected directly to the computer system via a data phone with simultaneous recording of raw data on a backup paper tape. In the event of a computer bottleneck, the paper tape can be generated and off-line information can be fed automatically to the computer via the same phone system (operating at a 1200-baud rate). Performance results are printed out at the test control room station on a General Electric Terminet 1200.

The recording system itself can accommodate all of the normal sensors encountered in engine testing. Temperature signals are processed through a reference maintained at 150° F from the alloy wire to the copper wire; the actual value of this reference junction is checked by the insertion of a 32° F reference signal generated from a Joseph Kaye ice point reference. The signals are multiplexed through solid-state switches to fixed-gain differential amplifiers to the analog-to-digital converter. The computer program converts the millivolt level to a temperature value through a table lookup.

Voltage and millivolt calibration standard signals also are simultaneously recorded so that corrections can be made for overall system drift in the amplifier/A-D converter components. The system has a resolution of one part in 10,000 and, in general, precision can be expected to three parts in 10,000 or eight microvolts, whichever is larger.

Pressure parameters are processed through a sequencing of pneumatic 12-port scanning valves, each valve having an individual transducer. A system of referencing each of 11 parameters on a valve, to a pneumatic transducer short of the 12th port of the scanning valve, makes any errors in the pressure signals appear as a percentage of the reading in accuracy.

In order to accommodate the dynamic characteristics exhibited by a vehicle, key parameters (such as thrust, speed, and fuel flow) are programmed and interspersed at described intervals throughout the data scan. The value for these parameters, utilized in performance calculations, is the average of these multiple readings.

The basic data scan rate is approximately eight channels per second with voltage indirectly connected to the signals, and two channels per second with pressure signals that are pneumatically switched. This scan rate allows a stabilization that is sufficient to obtain the accuracies described above.

Production Engine Test Facility

The General Electric High-Bypass Fan Production Engine Test Facility, shown in Figure 5, is located in Evendale, Ohio. It consists of two cells, M34 and M35, separated by a common access aisle on the lower level and by a control room (Figure 6) on the second level. Figure 7 shows the engine "prep" area located between the two cells. Auxiliary equipment rooms are

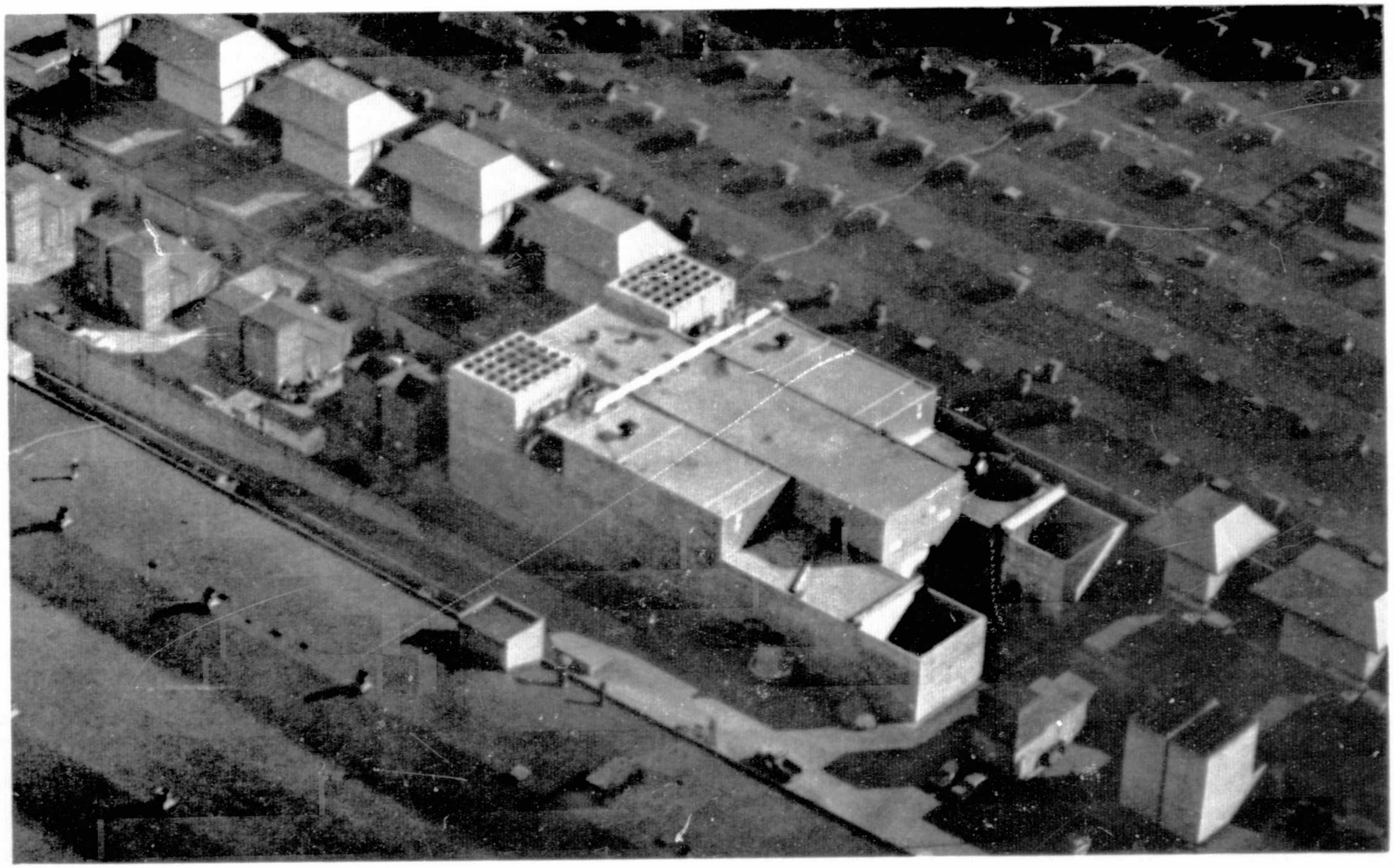


Figure 5. Aerial View of Production Engine Test Facility.

Figure 6. Production Engine Test Facility Control Room.

Figure 7. Engine "Prep" Area, Production Engine Test Facility.

located fore and aft of the control room and above the cells. A radio-frequency-shielded room is located at the rear of the access aisle. The cells, each 30 feet wide by 20 feet high by 188 feet in overall length, have horizontal air inlets and vertical exhaust systems. Engine access is through a large, vacuum-sealed door in the side wall of the cell. Figure 8 shows a typical test engine installation in one of the cells.

Each cell is equipped with: an air intake system, exhaust gas system, fuel system, lube oil and hydraulic oil fill systems, air system for engine starting, CO_2 fire extinguishing system, 24-volt DC and 400-cycle electrical power packages, and automatic data handling equipment; display instrumentation for airflow, fuel flow, thrust, oil consumption, vibrations, pressures, and temperatures; special instrumentation wiring for high-speed recorders; and other high-accuracy equipment used for transient and dynamic measurements. The data handling equipment shown in Figure 9 is wired directly to the General Electric Computer Facilities for rapid computation of engine performance.

4.3 EVENDALE DEVELOPMENT CF6 TEST CELLS

Figure 10 is a typical schematic of engine test Cells 5, 6, and 7 in Building 500 of General Electric's Evendale Plant. These are large turbofan or turbojet test facilities with inlet air heaters capable of up to 150° F at 2000-lb/sec airflow. The cell exhausts are water-cooled with sound-controlled vertical intakes and discharges. Overhead thrust frames will handle thrust loads of up to 100,000 pounds. All cells are equipped for automatic data handling, including transient recording of up to 400 analog channels at speeds ranging from 200 to 10,000 channels per second. Printed data are available within two minutes after initiation of a reading. These cells have undergone extensive modernization since their original construction in the 1953-1955 time period. Attached to each cell is a control room, with visual data displays for operator control of the engines.

Evendale Performance and Steady-State Data Acquisition

Performance and steady-state engine data are recorded and computed on a very fast and accurate digital recording system. This Astrodata System has three major functions:

- Measurement of analog signals (temperatures, flows, position, speed, etc.)
- Measurement of pneumatic pressures
- Recording and computing of data

The analog inputs from the engine are obtained by connecting the engine instrumentation leads to permanent connectors overhead of the engine. These leads, in turn, are routed to the control room and connected to a PDS (Portable Digital Subsystem). The PDS accommodates five major functional components:

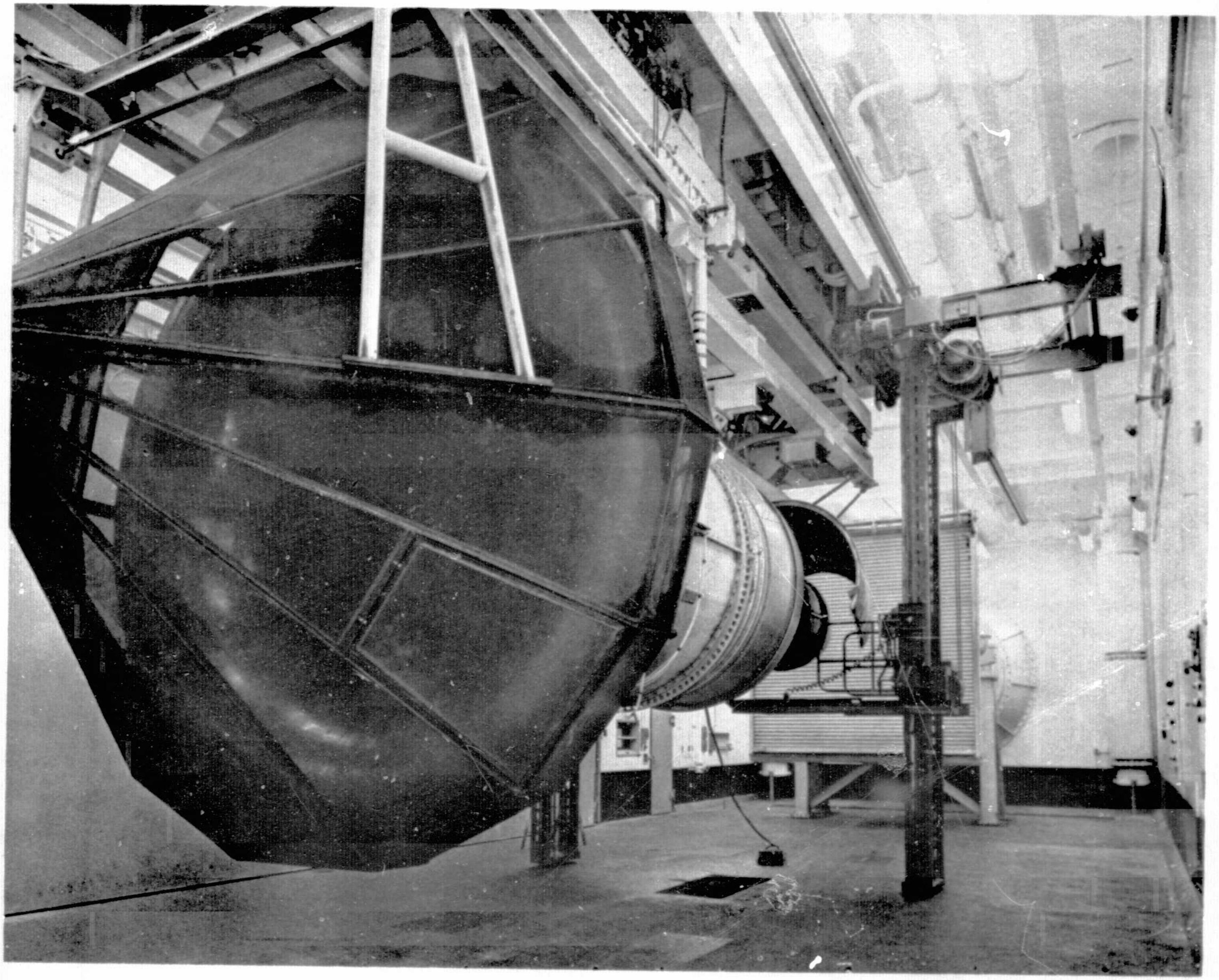


Figure 8. Test Engine Installed in Cell M34, Production Engine Test Facility.

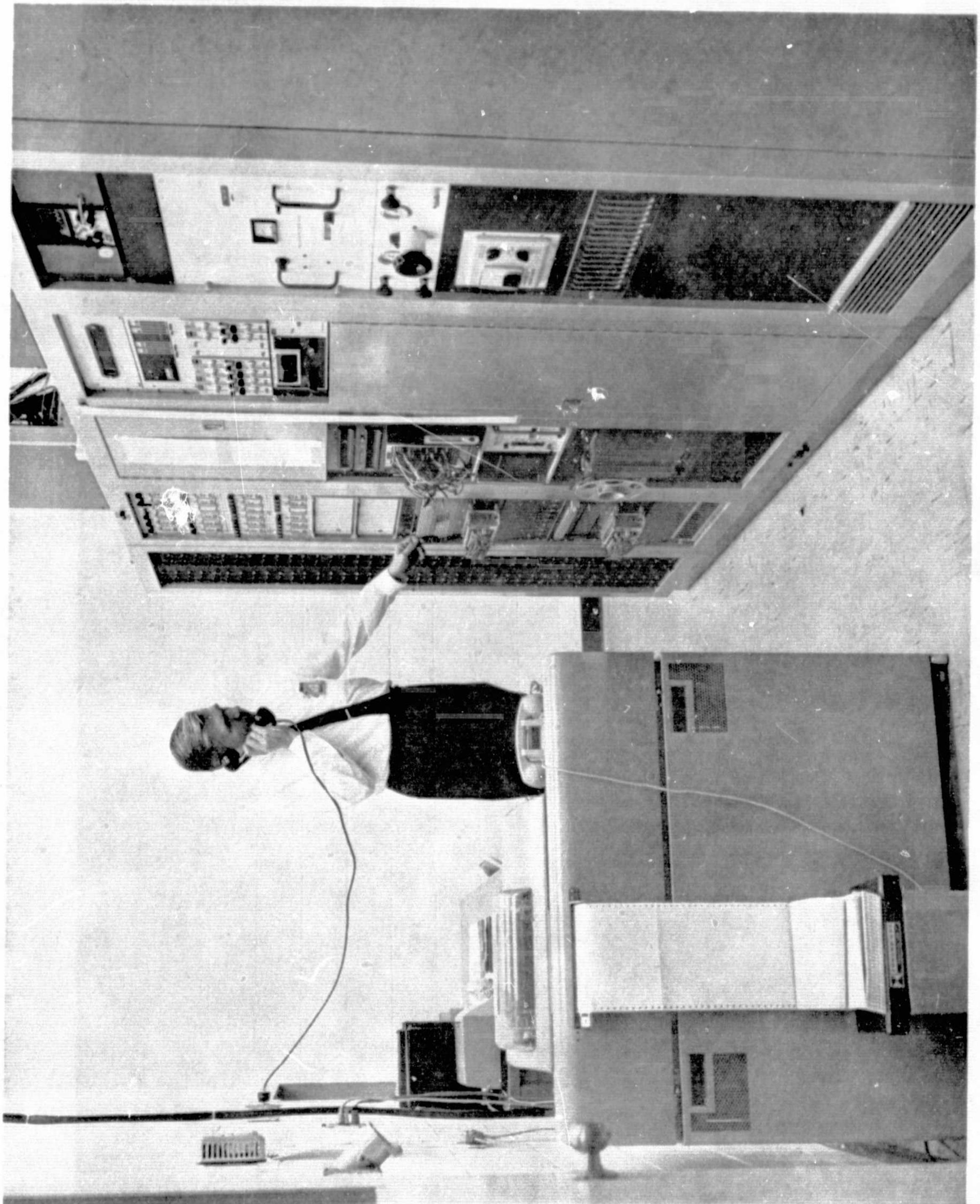


Figure 9. Production Engine Test Facility Data Center.

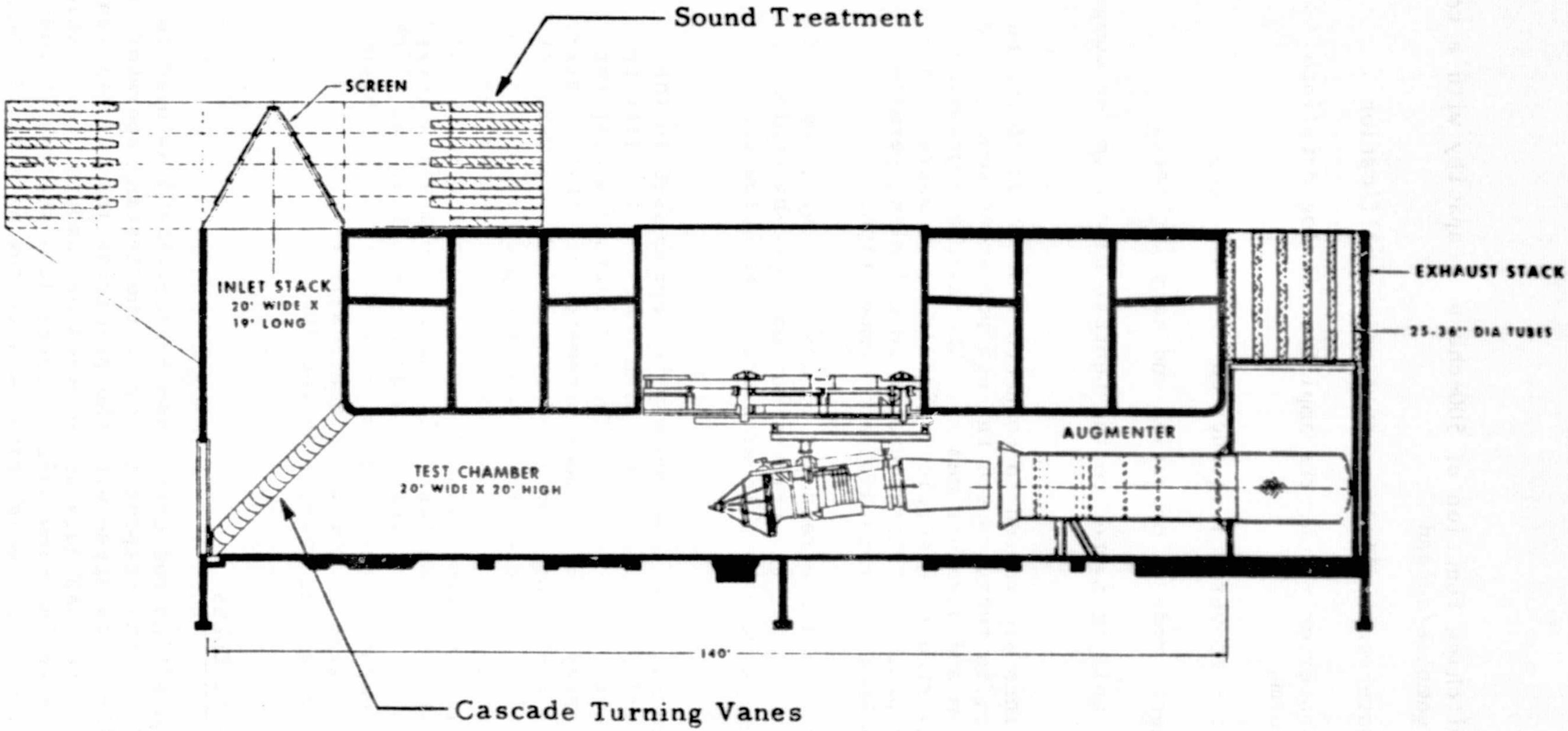


Figure 10. Evendale Test Cells 5, 6, and 7, Building 500.

- Multiplexer - switching function of 500-channel capacity with a top limit of 10,000 samples/second
- Amplifier - computer-controlled variable-gain amplification
- Analog/Digital Converter - converts amplified analog data into digital binary form
- Frequency Counter - converts frequency to digital output
- Controller - selects mode of operation and sampling rate.

The output of the PDS unit is routed to the Central Data Room for computations and recording.

The engine pressure lines are routed to connectors overhead of the engine. These connectors are, in turn, routed through permanent tubing to a central scanner valve system and pressure memory. The multiple pressure inputs are scanned and converted to electrical signals by pressure transducers. The output of the pressure transducers is routed along permanent wiring to the Central Data Room for recording and computation.

The pressure and analog data are recorded on magnetic tape, computed and converted to engineering units, and printed out on paper by equipment located in the Instrumentation Data Room located one floor below the test cell complex in Building 500.

All data are stored on magnetic tape and may be reprocessed in the Instrumentation Data Room and in the more extensive computer facility in Building 800 on the Honeywell-6000 computer. The IDR Astrodata computer has a configuration input array which includes parameter selection, calibration, curve inputs, data averaging, engine constants, and error-reject tolerances. The configuration is stored in the on-line processing system and can be changed on demand prior to or during testing. The Astrodata system is shown schematically in Figure 11. A limited number of computer parameters can be retransmitted to the test cell control room via teletype prints. Converted data may be transmitted via a data communications link to the H6000 time-sharing computer center in Building 800 for more extensive on-line processing. On-line output is automatically retransmitted from the H6000 and printed on a line printer in the IDR.

4.4 UNITED AIRLINES CF6 TEST CELLS

An automatic data acquisition and correction system (ADAS) is used in the UAL CF6 test cells. It is the responsibility of the testing operator to verify that the observed ADAS data agree with the precision instrumentation on the test console panel. The ADAS data are punched on computer cards which contain averaged raw data in engineering units. These data are then loaded into the General Electric computer time-sharing network for data reduction and analysis.

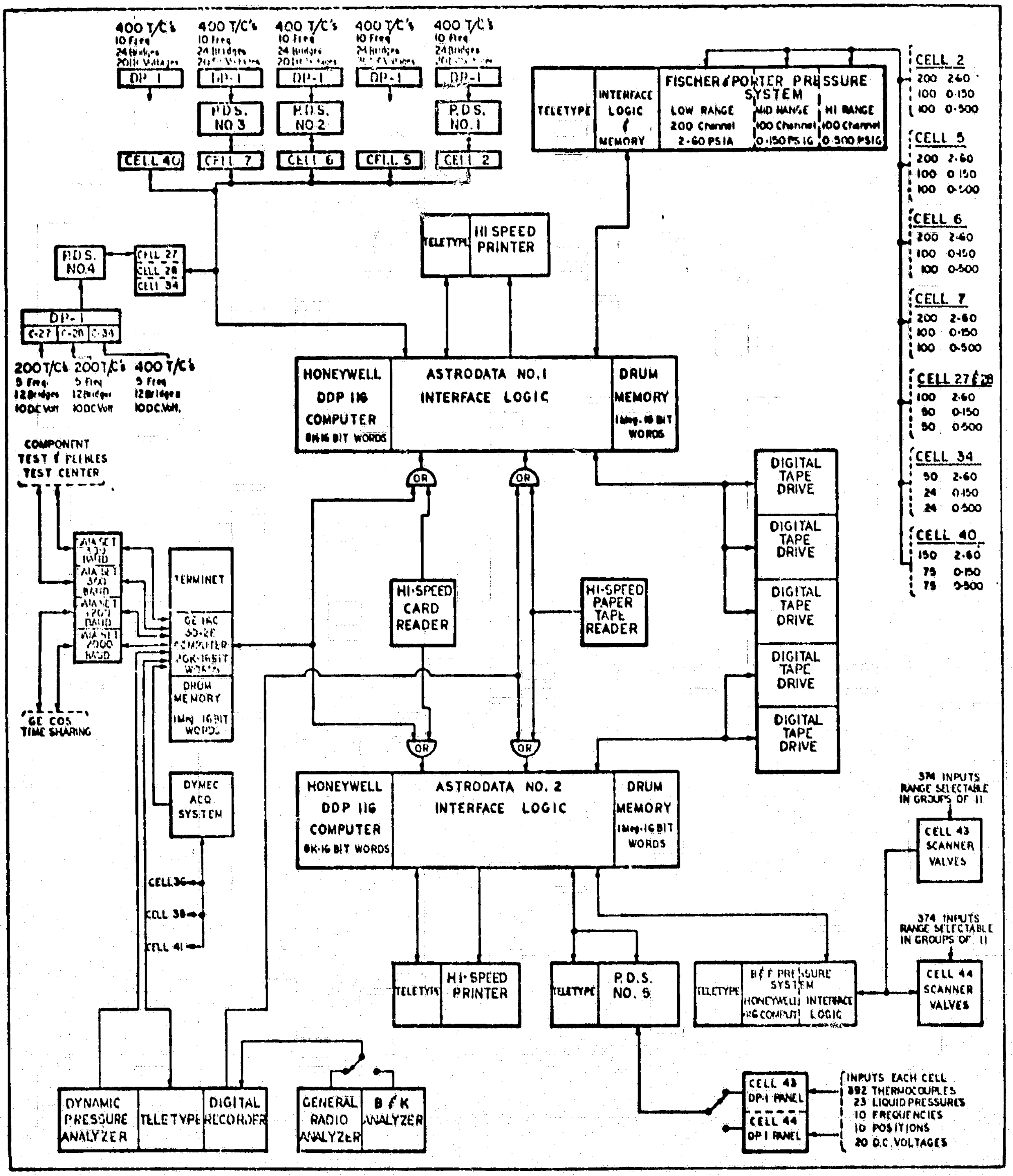


Figure 11. Automatic Data Acquisition and Processing Systems, Building 500.

UAL test cells 4 and 5 are fully enclosed with cross-sectional dimensions of 28 feet wide by 29 feet high. The cell inlet consists of vertical splitters and a FOD (foreign object damage) screen. The engine exhaust flows through the augmentor and acoustically treated exhaust stack with horizontal splitters. The test cells contain 50,000 pound load cells which permit duplication of the General Electric Evendale production facilities (Section 4.2). The test cells have been correlated numerous times, most recently using CF6-6D engine S/N 451-153.

5.0 INSTRUMENTATION

5.1 INSTRUMENTATION DESCRIPTION

The following test cell instrumentation was used to measure engine performance. All parameters were measured and recorded in the Evendale, Ontario, and UAL CF6 test cell control rooms. Figure 12 depicts the performance instrumentation locations.

- Barometric Pressure (PBAR) - The local (control room) barometric pressure
- Humidity (HUM) - The absolute humidity in grains of moisture per pound of dry air
- Ambient Temperature (T2) - C-C thermocouples mounted on the test cell screen
- Cell Static Pressure (PO) - Test cell wall static pressure
- Fan Speed (N1) - Low pressure rotor speed
- Core Speed (N2) - High pressure rotor speed
- Bellmouth Total Pressure (PT2) - Four six-element Pitot-static rakes (manifolded by rake) located in the engine bellmouth forward of the fan face. Rake P/N 4013034-682G01 and -682G02 (2 each)
- T49 Exhaust Gas Temperature (EGT) - LPT inlet temperature indicating system consisting of 11 dual-immersion C-A thermocouple probes electrically averaged. The system is composed of four harnesses which are joined together by means of an aft lead which, in turn, connects to a forward lead. The forward lead has another electrical connector for transmission of the signal to the EGT indicator (Figures 13 and 14).
- Main Fuel Flow (WFM) - Facility engine fuel flow measured on a volumetric turbine flowmeter
- Verification Fuel Flow (WFV) - Facility engine fuel flow measured on a volumetric turbine flowmeter
- Fuel Temperature (TF) - Facility engine fuel temperature measured at the flowmeters using a C-C thermocouple

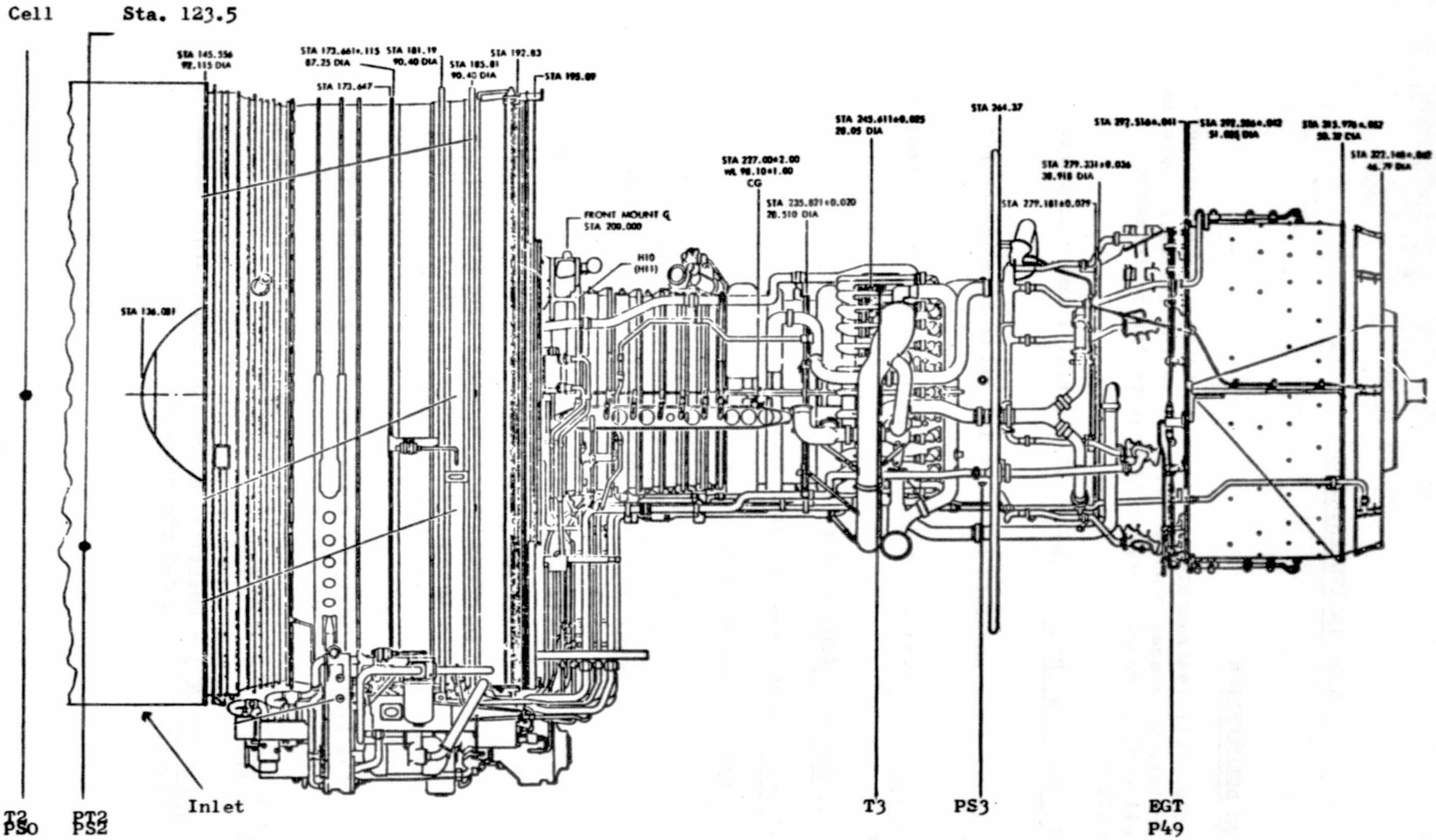
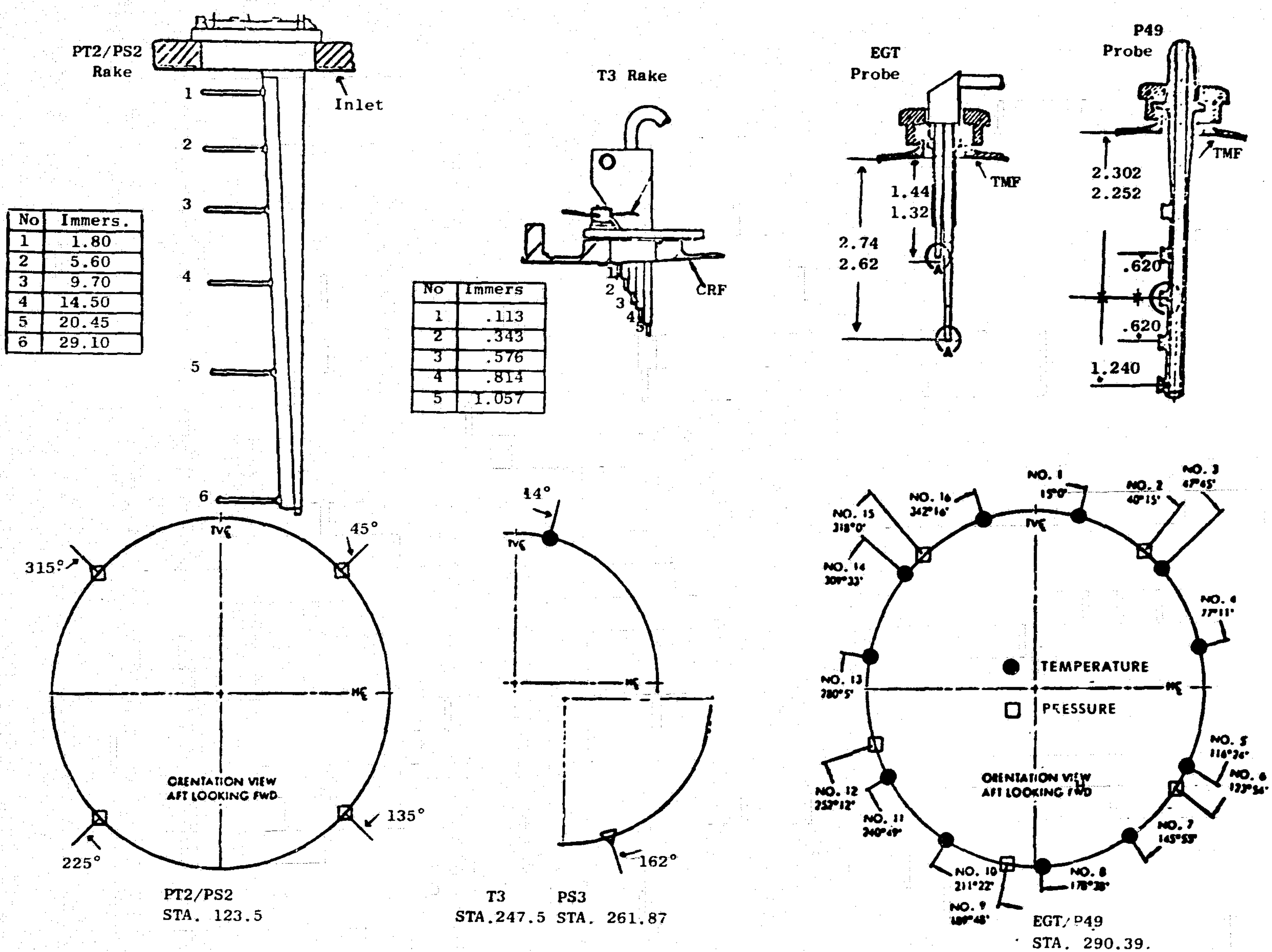


Figure 12. CF6-6D Performance Instrumentation.



No	Immers.
1	1.80
2	5.60
3	9.70
4	14.50
5	20.45
6	29.10

No	Immers
1	.113
2	.343
3	.576
4	.814
5	1.057

Figure 12. CF6-6D Performance Instrumentation (Concluded).

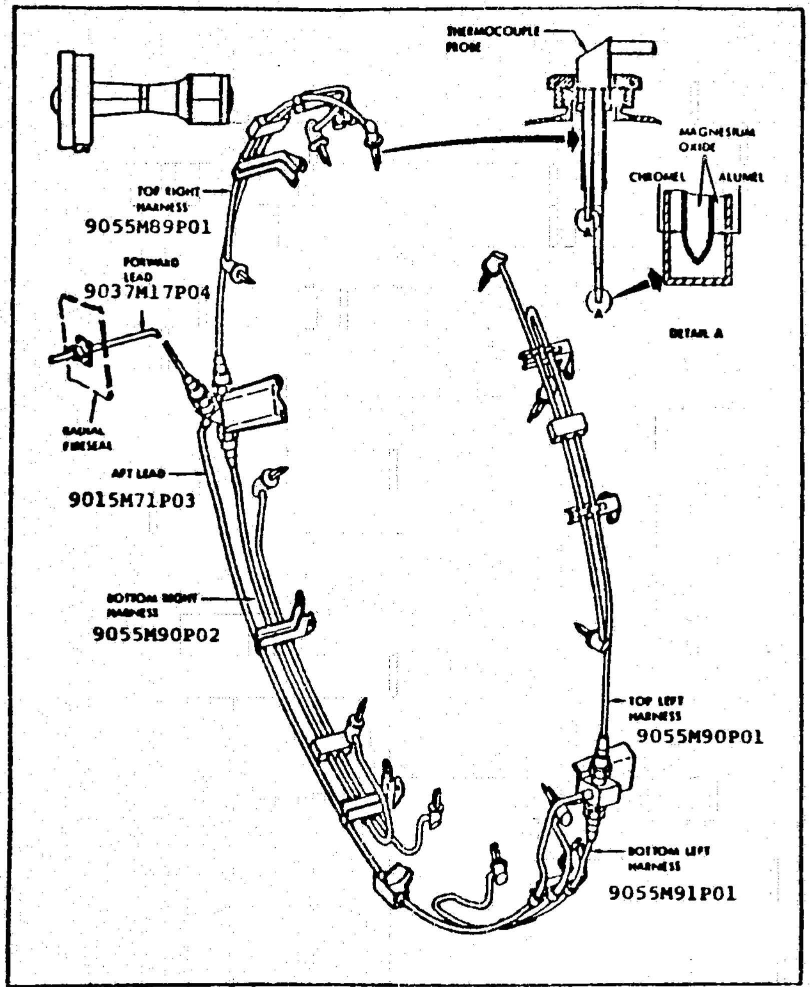


Figure 13. EGT Thermocouple Harness.

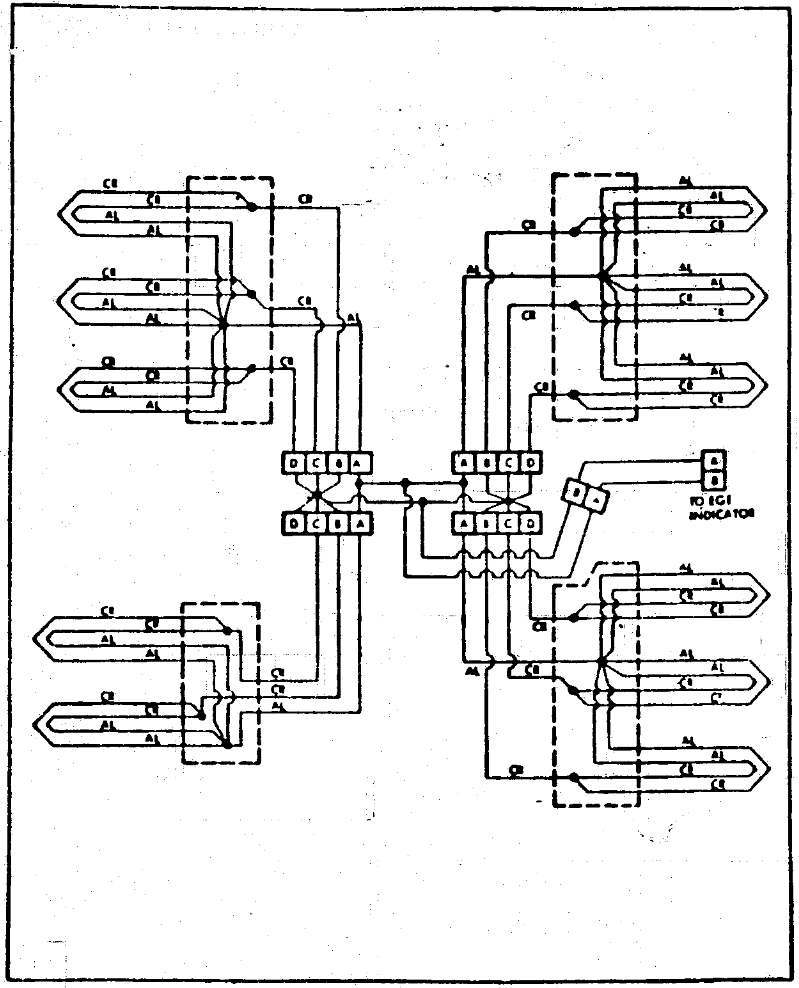


Figure 14. EGT Indicating System Circuit.

- <u>Fuel Sample Specific Gravity (SGSAMP)</u> - Specific gravity of the fuel sample

- <u>Fuel Sample Temperature (TSAMP)</u> - Fuel sample temperature read during the specific gravity measurement

- <u>Fuel Lower Heating Value (LHV)</u> - Lower heating value of the fuel sample as determined by a bomb calorimeter

- <u>Load Cell Thrust (FG)</u> - Thrust frame axial force measured using a 50,000-lb load cell

- <u>Compressor Discharge Temperature (T3)</u> - Five-element C-A thermocouple rake measured individually. Rake P/N 4012403-847G01

- <u>Compressor Discharge Static Pressure (PS3)</u> - Wall static located in a combustor borescope port

- <u>LP Turbine Inlet Total Pressure (P49)</u> - Five four-element probes manifolded by probe. Probe P/N 9664M54G06

- <u>Variable Stator Position (VSV)</u> - LVDT readout measured on a 0-to-5-volt scale

5.2 ADDITIONAL INSTRUMENTATION DESCRIPTION (EVENDALE DEVELOPMENT)

Additional instrumentation was recorded at the Evendale Development test facility to more fully understand any engine component changes that were due to changing the LPT modules. This instrumentation consisted of a segmented EGT harness. The segmented EGT harness measured the 22 EGT harness thermcouples individually (rather than being electrically manifolded), indicating any shift in temperature profile.

5.3 RANGES AND ACCURACIES

Table 1 summarizes the range requirements and instrumentation accuracies for the test cell instrumentation described in the previous section. The accuracies quoted are 2σ values (i.e., 95% confidence limits).

Table 1. Instrumentation Ranges and Accuracies.

Parameter	Range	Accuracy
PBAR	28 to 31-in. Hg	0.1% absolute
HUM	0 to 200 grains	5% relative humidity
T2	-10° to 110° F	1° F
PT2	0 to -10 in. H_2O	0.5% gage
PS2	0 to -85 in. H_2O	0.5% gage
N1	0 to 4200 rpm	5 rpm
N2	0 to 11,000 rpm	20 rpm
EGT	0 to 2000° F	10° F
WFM	0 to 70 gpm	0.5% of reading
WFV	0 to 70 gpm	0.5% of reading
TF	-10 to 110° F	2° F
SGSAMP	0.7 to 0.8	0.15% of reading
TSAMP	-10° to 110°	1° F
LHV	18,000 to 19,000 Btu/lb	0.3% of reading
FG	0 to 50,000 lb	0.5% of reading
T3	0 to 1200° F	10° F
PS3	0 to 500 psig	0.5% of reading
P49	0 to 100 psig	0.5% of reading
VSV	0 to 5 volts	---

6.0 LPT PROGRAM PROCEDURE

Except where noted, the following procedure was followed at all four test locations.

The test engines were removed from the test cell for the LPT module changes, with the exception of module changes during the Evendale Development program, where the modules can be changed while the engine remains in the cell.

6.1 ASO/ONTARIO WORK SCOPE

1. Install a serviceable airline LPT (low pressure turbine) module on CF6-6D engine S/N 451-507.

2. Conduct a performance test (Section 6.5).

3. Reinstall the original new LPT module on S/N 451-507.

4. Conduct a performance test.

5. Return the serviceable LPT module to the airline.

6.2 EVENDALE PRODUCTION WORK SCOPE

1. Install a serviceable airline LPT module on a CF6-6D production engine.

2. Conduct a performance test (Section 6.5).

3. Install the new LPT module on the production engine.

4. Conduct a performance test.

5. Return the serviceable LPT module to the airline.

6.3 EVENDALE DEVELOPMENT WORK SCOPE

1. Install a new LPT module on CF6-6D engine S/N 451-111.

2. Conduct a performance test (Section 6.5).

3. Install a serviceable airline LPT module while the engine is in the test cell.

4. Conduct a performance test.

5. Install a second serviceable airline LPT module while the engine is in the test cell.

6. Conduct a performance test.

7. Return the serviceable LPT module to the airlines.

8. Install the original 451-111 LPT module on the engine while the engine is in the test cell.

9. Conduct a performance test.

6.4 UNITED AIRLINES WORK SCOPE

1. Install a UAL serviceable LPT module (used in either parts 6.1, 6.2, or 6.3) on a serviceable UAL CF6-6D engine.

2. Conduct a performance test (Section 6.5).

3. Remove the LPT and perform an analytical teardown inspection (Section 8.0).

4. Refurbish the LPT with new honeycomb (tip shrouds and stationary interstage seals).

5. Reinstall the refurbished LPT module on the serviceable engine used in Part 1.

6. Conduct a performance test.

6.5 PERFORMANCE TESTS

The following testing sequence was performed for each test. The testing was conducted with a lightweight bellmouth and the standard CF6-6 Acceptance Test Cowling configuration including conic primary nozzle.

1. Install engine in the CF6 test cell and set up per CF6 Shop Manual, 72-00-00 Testing.

2. Install instrumentation as defined by the Instrumentation Plan for Task II engines.

3. Conduct the following performance test:

   A. Perform normal prefire checks including a leak check.

   B. Perform seal run-in and functional test, if required.

C. Start engine and stabilize for 5 minutes at ground idle. Set the following steady-state data points and take two back-to-back data readings after four minutes' stabilization. The engine should be operated at maximum continuous power for a minimum of 6 minutes prior to setting the following points:

Power Settings	Corrected Fan Speed
Takeoff	100.30% (3443 rpm)
Max. Continuous	98.70% (3388 rpm)
Max. Cruise	95.85% (3290 rpm)
75%	90.11% (3093 rpm)

D. Shut down for a minimum of 30 minutes and then repeat Step 3.

Special Instructions

The following special instructions apply for all engine testing:

A. General Electric Evendale personnel will be on site and will assure data quality before the engine can be released from the test cell.

B. Obtain a fuel LHV sample between the two performance power calibrations. A bomb calorimeter will be used to obtain the LHV.

C. No performance data are to be taken when visible precipitation exists or the relative humidity exceeds 85%.

D. Performance transducers, fuel meters, and the thrust load cell must be within FAA calibration limits and the calibrations traceable to the National Bureau of Standards.

7.0 TEST RESULTS

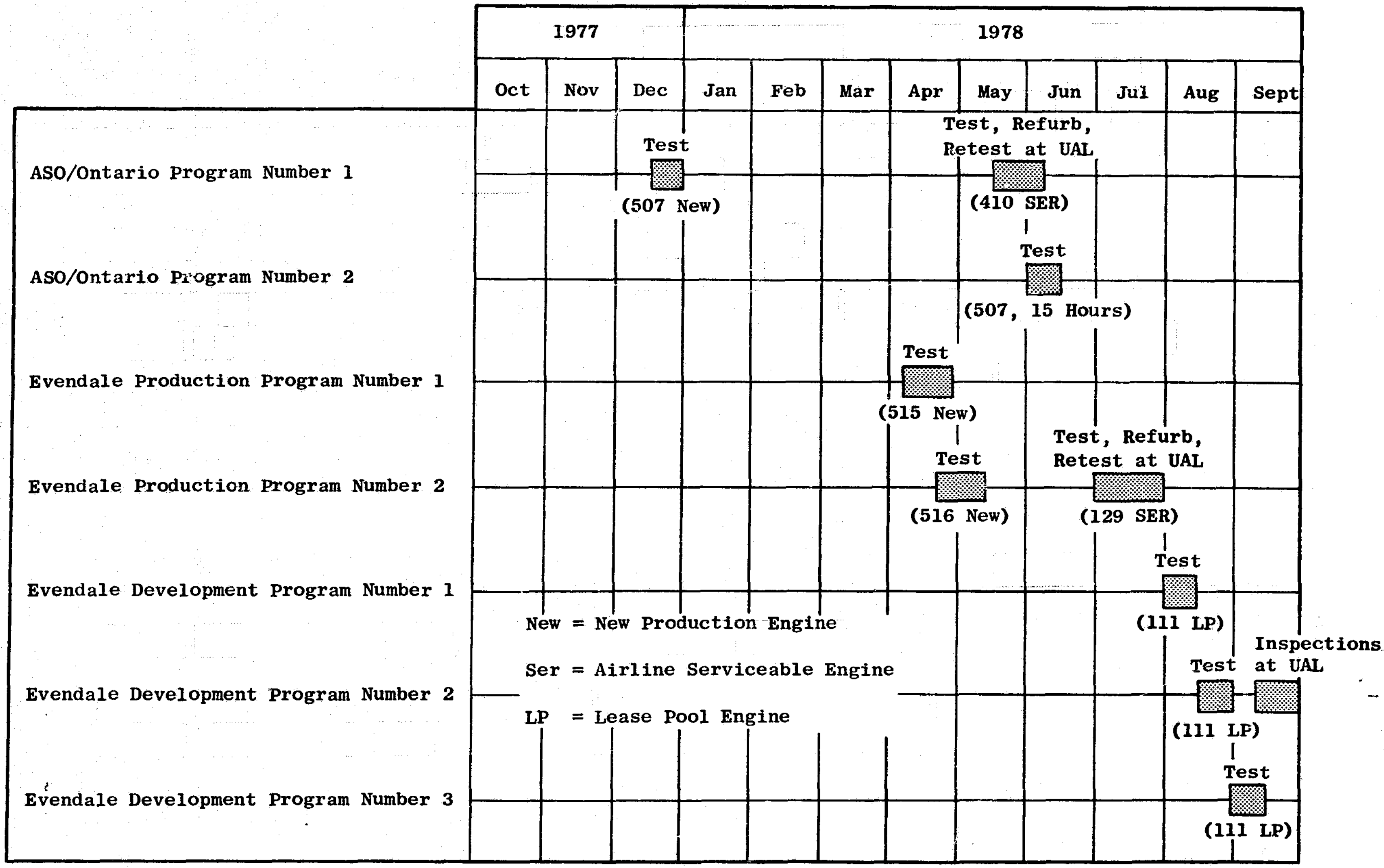
This section presents the results of the LPT back-to-back tests. Seven LPT modules were tested and their performance was compared to new production modules. In addition, two of the modules were tested as received, and then returned to UAL for inspection, refurbishment, and retest. A third LPT module that had been tested back-to-back was inspected at UAL to obtain additional hardware evaluation data. Figure 15 outlines the LPT testing and inpsection/refurbishment activities of the CF6-6D LPT long-term deterioration study.

7.1 ASO/ONTARIO PROGRAM NO. 1

The ASO/Ontario LPT (low pressure turbine) testing program consisted of two separate back-to-back LPT tests on CF6-6D engine S/N 451-507. The first test was run in December 1977 and was used to demonstrate the feasibility of LPT back-to-back testing. Engine 451-507 was already at ASO/Ontario for minor HP compressor airfoil rework. The engine was slated to be installed (when returned) on a DC-10-10 aircraft, but Douglas Aircraft Corporation (DACo) consented to let it first be used for the NASA LPT back-to-back testing program.

The serviceable LPT module selected was a United Airlines (UAL) module with 6150 hours and 2715 cycles on the LPT rotor and stator EMU's (engine maintenance units). As reported in Section 3.2, this module had the older Stage 1 LPT nozzles which have a 2 percent smaller LPT flow area. The Stage 1 nozzle assembly is not considered part of the LPT stator. Table 2 presents the maintenance history (time and cycles since new and time and cycles since overhaul) for this module.

The test cell performance results are summarized in Tables 3 and 4. The data presented are based on both EGT and T5X where T5X is a calculated EGT value using measured fuel flow and internal engine pressures and temperatures. Note that the serviceable module is 0.7 percent poorer in the sfc margin. More significant, however, is that although the summation of the component performance stacks well, the individual component efficiencies give an unrealistic picture of the actual component changes. When installing the new modules, it is impossible to believe that the HP compressor (0.8 percent) and parasitics (0.9 percent) got worse while the HP turbine (0.5 percent) got better with no change to the core engine. Similarly, the calculated 2 percent improvement in LP system efficiency cannot be supported by the 0.7 percent improvement in sfc margin. The 1.3 percent increase in thrust is a result of the larger new module LPT flow area plus a large reduction in humidity at the time of the performance test. This component efficiency problem only emphasizes the advantages in back-to-back testing with direct substitution of LPT engine modules. This test indicated a 0.7 percent sfc improvement due to installing the new LPT module, independent of the measured component performance.



Note: Numbers in parenthesis indicate serial number of engine used for tests.

Figure 15. LPT Testing and Inspection/Refurbishment Sequence.

Table 2. ASO/Ontario No. 1 - Low Pressure Turbine Maintenance Record.

	Serial Number	TSN (Hours)	CSN	TSO (Hours)	CSO
TMF	51239	11,402	4,856	3,406	1,483
LPT Stage 1 Nozzle	51239	11,402	4,856	10,947	Unknown
LPT Stator	51468	6,150	2,715	6,150	2,715
- Vanes		6,150	2,715	6,150	2,715
- Tip Shrouds		6,150	2,715	6,150	2,715
- Interstage Seals		6,150	2,715	6,150	2,715
LPT Rotor	51468	6,150	2,715	6,150	2,715
- Blades		6,150	2,715	6,150	2,715
- Interstage Seals		6,150	2,715	6,150	2,715
TRF	51462	4,948	2,180	4,948	2,180

Table 3. ASO/Ontario No. 1 - New Vs. Airline LPT.

	Based on T5X			Based on EGT		
	$\Delta\eta$	ΔEGT	ΔSFC	$\Delta\eta$	ΔEGT	ΔSFC
ΔETAC	-0.8	+15	+0.59	-0.8	+15	+0.59
ΔETAT	+0.5	-11	-0.42	+0.4	- 9	-0.34
ΔPARAS	+0.9	+17	+0.65	+0.8	+15	+0.58
ΔETALPS	+2.1	-13	-1.55	+2.0	-13	-1.49
ΔFN at N1	+1.3	+ 9	0	+1.3	+ 9	0
ΔTFF2	+2.0%	-14	0	+2.0%	-14	0
Stacked		+3° F	-0.7%		+3° F	-0.7%
Measured		+1° F	-0.7%		+3° F	-0.7%

Table 4. ASO/Ontario No. 1 - Test Cell Data.

	SFC Margin	Hot Day EGT	ΔT5X	Based on T5X DETAC	DETAT	DPARAS	DETALPS	DFN1	Based on EGT DETAC	DETAT	DPARAS	DETALPS	DFN1
				Serviceable LPT					**Serviceable LPT**				
	-0.9	1592	0	1.1	0.3	1.0	-2.9	1.2	1.1	0.9	1.1	-2.5	1.2
	-1.4	1591	12	0.9	-0.4	0.8	-2.6	0.9	0.9	0.8	0.9	-1.9	0.9
	-0.8	1524	3	1.2	0.0	0.9	-2.6	0.8	1.2	0.8	1.0	-2.1	0.8
	-0.8	1524	2	1.2	-0.0	0.8	-2.6	0.6	1.2	0.7	0.9	-2.2	0.6
	-1.2	1595	-4	0.9	1.1	1.5	-3.4	1.0	0.9	1.4	1.5	-3.1	1.0
	-1.0	1595	-2	0.7	1.1	1.6	-2.8	1.2	0.7	1.7	1.6	-2.5	1.2
	-0.8	1529	-2	1.0	0.7	1.3	-2.8	0.9	1.0	1.2	1.3	-2.5	0.9
	-1.0	1529	-2	0.7	1.5	1.9	-3.1	0.9	0.7	2.0	1.9	-2.8	0.9
Avg	-1.0	1593/ 1527	1	1.0	0.5	1.2	-2.9	0.9	1.0	1.2	1.3	-2.5	0.9
				New LPT					**New LPT**				
	-0.3	1594	-2	0.1	1.5	2.2	-0.9	2.5	0.1	1.9	2.2	-0.6	2.5
	-0.6	1593	1	-0.0	1.4	2.3	-1.2	2.0	-0.0	2.1	2.3	-0.8	2.0
	-0.6	1530	7	0.2	0.3	1.7	-0.6	2.2	0.2	1.3	1.8	0.0	2.2
	-0.6	1532	0	0.6	0.0	1.4	-1.0	2.1	0.6	0.6	1.4	-0.7	2.1
	-0.5	1596	0	0.2	1.1	2.3	-0.9	2.0	0.2	1.7	2.4	-0.6	2.0
	-0.2	1598	-4	0.1	1.5	2.5	-0.6	2.5	0.1	1.9	2.5	-0.4	2.5
	0.1	1531	-5	0.4	1.0	2.2	-0.5	2.0	0.4	1.4	2.1	-0.3	2.0
	0.0	1530	-3	0.3	1.2	2.3	-0.5	2.0	0.3	1.6	2.3	-0.2	2.0
Avg	-0.3	1595/ 1531	-1	0.2	1.0	2.1	-0.8	2.2	0.2	1.6	2.1	-0.5	2.2

Changes in EPR or EGT profiles due to changing the turbine midframe may affect the component assessment, but they have no influence on the overall fuel-burn (sfc) change.

Following the back-to-back tests at ASO/Ontario, the LPT module (S/N 51468) was returned to United Airlines where it was tested inbound on UAL serviceable engine S/N 451-410. It was then analytically inspected (Section 8.0), refurbished with new honeycomb (tip shrouds and stationary interstage seals), then retested on the same engine (451-410). The test cell results show a 0.3 percent improvement in sfc and are summarized in Tables 5 and 6. The component efficiency data show a larger improvement in LP system efficiency (~1 percent) than can be justified by the 0.3 percent change in sfc. As mentioned above, however, back-to-back testing allows a direct measurement of sfc without the associated problems in calculating component performance.

7.2 ASO/ONTARIO PROGRAM NO. 2

The second ASO/Ontario back-to-back test was run in June 1978. This program was run on CF6-6D engine S/N 451-507 following its use for the Task III Short-Term Deterioration Study. A final Task III report detailing this program will be issued at a later date. American Airlines, the engine owner, consented to the use of 451-507 for the NASA Task II program.

The serviceable LPT module selected was a UAL module with 8658 hours and 3738 cycles on the LPT rotor and stator EMU's. Table 7 presents the maintenance history (time and cycles since new and time and cycles since overhaul) for the module.

The test cell performance results are summarized in Tables 8 and 9. Note that the serviceable LPT module is a 0.5 percent poorer in sfc margin. Unlike the previous ASO/Ontario LPT test (Section 7.1), the component efficiencies measured in this program give a fairly realistic representation of the actual engine performance changes. The changes in core component efficiencies were minor; the 0.5 percent improvement in LP system efficiency agrees reasonably well with the 0.5 percent improvment in sfc margin that was due to installing the original 451-507 LPT module.

A significant result of this test was the 1.7 percent larger LPT flow area observed for the airline module (ΔTFFL Table 8). The calculation of this change was based on a decrease in the measured HP turbine pressure ratio that occurred when the original 451-507 was installed. This LPT flow area change has a significant impact on EGT and thrust at fan speed. Since other LPT modules exhibited similar area increases (0 to 2 percent), a 1 percent increase in LPT flow function is included in the present CF6-6D long-term deterioration model.

Table 5. ASO/Ontario No. 1 - UAL Refurbished Versus Inbound LPT.

	Based on T5X			Based on EGT		
	$\Delta\eta$	ΔEGT	Δ sfc	$\Delta\eta$	ΔEGT	Δ sfc
DETAC	+0.2	- 4	-0.15	+0.2	- 4	-0.15
DETAT	-0.5	+11	+0.42	+0.1	- 2	-0.08
DPARAS	-0.1	+ 2	+0.07	-0.2	+ 4	+0.14
DETALPS	+0.8	- 5	-0.59	+1.2	- 8	-0.89
DFN@N1	-0.3	- 2	0	-0.3	- 2	0
STACKED		+ 2° F	-0.3		-12° F	-1.0
MEASURED		+ 2° F	-0.3 %		-10° F	-0.3 %

Table 6. ASO/Ontario No. 1 - UAL Test Cell Data.

				Based on T5X					Based on EGT				
	SFC MARGIN	HOT DAY EGT	DELT5X	DETAC	DETAT	DPARAS	DETALPS	DFN1	DETAC	DETAT	DPARAS	DETALPS	DFN1
						Inbound LPT							
	-5.3	1655	- 2	-1.1	3.1	4.2	-1.6	-0.0	-1.1	2.8	4.2	-1.6	-0.0
	-5.5	1660	- 2	-0.9	2.5	3.9	-1.6	0.0	-0.9	2.2	3.9	-1.6	0.0
	-5.3	1594	-12	-1.0	3.7	4.5	-1.9	-0.1	-1.0	2.9	4.4	-2.2	-0.1
	-5.2	1589	- 9	-0.9	3.5	4.5	-1.8	-0.3	-0.9	2.8	4.3	-2.0	-0.3
	-5.4	1652	- 4	-1.1	3.9	4.7	-2.2	0.0	-1.1	3.5	4.6	-2.2	0.0
	-5.5	1659	- 2	-0.9	2.9	4.2	-1.9	0.4	-0.9	2.6	4.2	-1.8	0.4
	-5.4	1590	- 2	-0.8	2.7	4.1	-1.6	-0.3	-0.8	2.4	4.0	-1.6	-0.3
	-5.4	1592	- 1	-0.7	2.5	4.0	-1.5	-0.0	-0.7	2.2	4.0	-1.5	-0.0
Avg	-5.4	1657/ 1591	- 4	-0.9	3.1	4.3	-1.8	-0.0	-0.9	2.7	4.2	-1.8	-0.0
						Refurbished LPT							
	-5.1	1648	10	-0.8	2.4	4.1	-0.7	-0.0	-0.8	2.7	4.1	-0.3	-0.0
	-5.2	1646	13	-0.7	2.0	4.0	-0.8	-0.3	-0.7	2.4	4.1	-0.3	-0.3
	-4.9	1589	- 8	-0.5	3.5	4.9	-1.5	-0.2	-0.5	2.9	4.8	-1.6	-0.2
	-4.9	1583	- 6	-0.6	3.9	5.1	-1.6	-0.3	-0.6	3.4	5.0	-1.7	-0.3
	-5.3	1642	22	-0.8	1.8	3.9	-0.7	-0.3	-0.8	2.7	4.1	0.1	-0.3
	-5.1	1649	13	-0.8	2.0	4.0	-0.6	-0.1	-0.8	2.4	4.0	-0.1	-0.1
	-5.2	1575	11	-0.5	2.8	4.5	-1.4	-0.6	-0.5	3.1	4.6	-0.9	-0.6
	-5.1	1581	11	-0.6	2.2	4.2	-0.8	-0.5	-0.6	2.5	4.2	-0.3	-0.5
Avg	-5.1	1646/ 1582	8	-0.7	2.6	4.4	-1.0	-0.3	-0.7	2.8	4.4	-0.6	-0.3

Table 7. ASO/Ontario No. 2 - Low Pressure Turbine Maintenance Record.

	Serial Number	TSN (Hours)	CSN	TSO (Hours)	CSO
TMF	51147	11,416	Unknown	3,506	1,509
LPT Stage 1 Nozzle	51147	11,416	Unknown	3,506	1,509
LPT Stator	51456	8,658	3,738	8,658	3,738
- Vanes		8,658	3,738	8,658	3,738
- Tip Shrouds		8,658	3,738	8,658	3,738
- Interstage Seals		8,658	3,738	8,658	3,738
LPT Rotor	51456	8,658	3,738	8,658	3,738
- Blades		8,658	3,738	8,658	3,738
- Interstage Seals		8,658	3,738	8,658	3,738
TRF	51170	16,041	7,003	16,041	7,003

Table 8. ASO/Ontario No. 2 - New Vs. Airline LPT.

	Based on T5X			Based on EGT		
	$\Delta\eta$	ΔEGT	ΔSFC	$\Delta\eta$	ΔEGT	ΔSFC
ΔETAC	+0.3	- 6	-0.22	+0.3	- 6	-0.22
ΔETAT	-0.2	+ 4	+0.17	-0.4	+ 9	+0.34
ΔPARAS	-0.1	- 2	-0.07	+0.1	- 2	-0.07
ΔETALPS	+0.5	- 3	-0.37	+0.5	- 3	-0.37
ΔFN at N1	-0.7	- 5	0	-0.7	- 5	0
ΔTFF2	-1.7%	+12	0	-1.7%	+12	0
Stacked		0	-0.5%		+ 5° F	-0.3%
Measured		6° F	-0.5%		+ 9° F	-0.5%

Table 9. ASO/Ontario No. 2 - Test Cell Data.

	SFC Margin	Hot Day EGT	DELT5X	Based on T5X DETAC	DETAT	DPARAS	DETALPS	DFN1	Based on EGT DETAC	DETAT	DPARAS	DETALPS	DFN1
				Serviceable LPT					Serviceable LPT				
	-3.5	1610	7	0.8	-1.8	1.1	-3.5	2.0	0.8	-0.9	1.2	-2.9	2.0
	-3.4	1610	1	1.0	-2.0	0.9	-3.6	1.8	1.0	-1.4	0.9	-3.2	1.8
	-2.8	1545	3	0.8	-1.0	1.8	-3.0	1.4	0.8	-0.2	1.9	-2.5	1.4
	-2.9	1543	13	0.8	-1.6	1.6	-2.5	1.2	0.8	-0.4	1.8	-1.7	1.2
	-3.2	1605	17	0.8	-2.3	1.0	-2.4	2.1	0.8	-0.9	1.2	-1.5	2.1
	-3.4	1606	11	0.7	-1.5	1.3	-3.3	2.0	0.7	-0.4	1.4	-2.6	2.0
	-3.0	1540	15	1.1	-2.1	1.4	-2.7	1.6	1.1	-0.8	1.5	-1.9	1.6
	-2.5	1542	5	1.0	-1.4	1.5	-2.5	1.7	1.0	-0.6	1.6	-2.0	1.7
Avg	-3.1	1608/ 1543	9	0.9	-1.7	1.3	-2.9	1.7	0.9	-0.7	1.4	-2.4	1.7
				New LPT					New LPT				
	-2.8	1618	4	0.9	-1.5	1.4	-2.7	1.1	0.9	-0.7	1.5	-2.1	1.1
	-2.9	1618	8	0.9	-1.6	1.4	-2.6	1.0	0.9	-0.7	1.5	-2.0	1.0
	-2.6	1549	6	1.4	-2.4	0.9	-2.4	0.8	1.4	-1.5	1.0	-1.8	0.8
	-2.1	1550	4	1.5	-2.4	0.9	-1.8	1.1	1.5	-1.6	1.0	-1.3	1.1
Avg	-2.6	1618/ 1550	6	1.2	-1.9	1.2	-2.4	1.0	1.2	-1.1	1.3	-1.8	1.0

When assessing the total deterioration of the airline module, it must be realized that the back-to-back test was run versus the 451-507 LPT module which had been run thorugh the DACo DC-10 aircraft and engine checkout sequence. A short term performance deterioration analytical teardown assessed the 451-507 LP turbine losses to be 0.1 percent sfc. Therefore, the true deterioration of the serviceable LPT module relative to new was 0.1 percent greater, or 0.6 percent sfc.

7.3 EVENDALE PRODUCTION PROGRAM NO. 1

The Evendale Production LPT testing program consisted of two separate back-to-back tests utilizing two different CF6-6D new production engines and serviceable airline LPT modules. The first test was run in April 1978 on CF6-6D production engines S/N 451-515.

The serviceable LPT module selected was a UAL module with 12,467 hours and 5,600 cycles on the LPT rotor and stator EMU's. The module, however, had been completely refurbished prior to its use in this program. All the honeycomb (shrouds and interstage seals) had been replaced, and all the blade and vane airfoils had recently been either replaced or cleaned. But this refurbishment would not depreciate the test findings. To the contrary, the resulting performance data would help determine the ability to restore LP turbine performance to new engine levels. Table 10 presents the LPT module maintenance history (time and cycles since new/overhaul).

The test cell performance results are summarized in Tables 11 and 12. Significantly, the sfc margin got 0.7 percent worse during the installing of the new production LPT module. Examination of the component performance data explains what caused the unexpected results. The average HP turbine efficiency deteriorated by 1 percent between the two back-to-back test runs. The large HPT efficiency deterioration was verified by a "green run" teardown, in which 451-515 was analytically torn down as part of a scheduled CF6-6D quality program. The teardown results showed large HPT tip rubs which accounted for the 1 percent loss in HPT efficiency. The component performance data, therefore, were used to assess the LPT performance level. The LP system was 0.1 percent better for the new LPT module; therefore, the airline module was assessed to be 0.1 percent deficient. This figure is within the ability to measure LP system performance, and indicates that the restored airline LPT module is at essentially the same efficiency level as a new production module. Additionally, the airline module had the same flow area as the new LPT based on HPT pressure ratio.

7.4 EVENDALE PRODUCTION PROGRAM NO. 2

The second Evendale Production back-to-back LPT test was run in May 1978. The test engine was CF6-6D production engine S/N 451-516.

Table 10. Evendale Production No. 1 - Low Pressure Turbine Maintenance Record.

	Serial Number	TSN (Hours)	CSN	TSO (Hours)	CSO
TMF	51481	5,801	2,458	0	0
LPT Stage 1 Nozzle	51480	5,801	2,458	0	0
LPT Stator	51282	12,467	5,600	0	0
- Vanes		12,467	5,600	0	0
- Tip Shrouds		12,467	5,600	0	0
- Interstage Seals		12,467	5,600	0	0
LPT Rotor	51282	12,467	5,600	0	0
- Blades		12,467	5,600	0	0
- Interstage Seals		12,467	5,600	0	0
TRF	51188	12,538	5,359	0	0

Table 11. Evendale Production No. 1 - New Vs. Airline LPT.

	Based on T5X			Based on EGT		
	$\Delta\eta$	ΔEGT	ΔSFC	$\Delta\eta$	ΔEGT	ΔSFC
ΔETAC	+0.2	- 4	-0.15	+0.2	- 4	-0.15
ΔETAT	-1.2	+26	+1.01	-0.8	+17	+0.67
ΔPARAS	-0.1	- 2	-0.07	0	0	0
ΔETALPS	+0.1	- 1	-0.07	+0.4	- 3	-0.30
ΔFN at N1	-0.3	- 2	0	-0.3	- 2	0
Stacked		+17 °F	+0.7%		+8° F	+0.2%
Measured		+16 °F	+0.7%		+7° F	+0.7%

Table 12. Evendale Production No. 1 - Test Cell Data.

	SFC Margin	Hot Day EGT	DELT5X	Based on T5X DETAC	DETAT	DPARAS	DETALPS	DFN1	Based on EGT DETAC	DETAT	DPARAS	DETALPS	DFN1
				Serviceable LPT					Serviceable LPT				
	1.3	1556	-1	0.5	0.4	0.4	-0.1	0.4	0.5	0.9	0.4	0.3	0.4
	1.4	1554	-4	0.8	0.3	0.3	-0.4	0.5	0.8	0.7	0.3	-0.1	0.5
	1.4	1494	-4	0.6	0.6	0.6	-0.3	0.4	0.6	1.0	0.6	-0.0	0.4
	1.5	1492	-1	0.8	-0.2	0.1	-0.1	0.3	0.8	0.3	0.1	0.3	0.3
	1.2	1568	-10	0.5	0.3	0.4	-0.2	0.6	0.5	0.4	0.3	-0.2	0.6
	1.0	1565	-6	0.9	-0.5	-0.0	-0.3	0.5	0.9	-0.2	0.0	-0.2	0.5
	1.4	1505	-9	0.6	0.1	0.3	0.1	0.5	0.6	0.2	0.2	0.2	0.5
	1.3	1504	0	0.3	-0.0	0.5	0.2	0.3	0.3	0.6	0.5	0.5	0.3
Avg	1.3	1561/ 1499	-4	0.6	0.1	0.3	-0.1	0.4	0.6	0.5	0.3	0.1	0.4
				New LPT					New LPT				
	0.2	1569	9	0.7	-1.1	0.3	-0.1	0.1	0.7	-0.1	0.4	0.5	0.1
	0.5	1568	1	1.0	-1.2	-0.0	-0.4	0.3	1.0	-0.5	-0.0	0.0	0.3
	0.6	1504	6	0.6	-1.2	-0.1	0.0	-0.1	0.6	-0.3	0.0	0.6	-0.1
	0.7	1502	6	1.1	-1.5	-0.0	0.0	0.2	1.1	-0.6	0.1	0.6	0.2
	0.6	1570	3	0.5	-0.5	0.5	0.1	0.2	0.5	0.2	0.6	0.6	0.2
	0.5	1568	5	0.9	-1.3	0.1	0.0	0.1	0.9	-0.5	0.2	0.6	0.1
	0.8	1506	1	1.1	-1.2	0.2	0.0	0.1	1.1	-0.6	0.3	0.4	0.1
	0.8	1506	5	0.8	-0.6	0.7	0.2	0.2	0.8	0.2	0.8	0.8	0.2
Avg	0.6	1569/ 1505	5	0.8	-1.1	0.2	-0.0	0.1	0.8	-0.3	0.3	0.5	0.1

The serviceable LPT module selected was UAL module with 8246 hours and 3713 cycles on the LPT rotor and stator EMU's. Table 13 presents the maintenance history (time/cycles since new/overhaul).

The test cell performance results are summarized in Tables 14 and 15. Note that the serviceable LPT module is 0.5 percent poorer in sfc margin. Again, the component efficiency stackup is poor, although this appears to be an even tradeoff between HPT efficiency and parasitics. The calculated 0.7 percent LP system efficiency gain, however, is consistent with the measured 0.5 percent sfc improvement that is due to installing the new production LPT module. As with the previous Production Program, there was no difference between the LPT module flow areas.

Following the back-to-back tests in Evendale, the LPT module was returned to United Airlines where it was tested inbound on UAL serviceable engine S/N 451-129, refurbished with new honeycomb (tip shrouds and stationary interstage seals), and then retested on the same engine (451-129). The test cell results are summarized in Table 16 and show a 1.5 percent improvement in sfc. This is obviously suspect since this LPT module indicated only 0.5 percent sfc poorer than a new production module. In addition, EGT measured 6° F cooler, which is more in line with the expected improvement. Examination of the UAL input data shows a 1 percent difference in fuel specific gravity at the same ambient conditions. It would take a 20° F delta in fuel temperature to cause a 1 percent change in fuel specific gravity. Making a 1 percent fuel flow adjustment (see Table 16) results in a 0.5 percent improvement in sfc for the refurbished module, which agrees will with the 6° F EGT improvement. It is therefore concluded that the real sfc improvement due to restoring clearance is 0.5 percent sfc and not 1.5 percent that was measured. Table 17 shows the revised test cell summary. Note that the component results do not support the measured change in sfc.

7.5 EVENDALE DEVELOPMENT PROGRAM NO. 1

The Evendale Development LPT back-to-back program consisted of a new production LPT module test followed by three separate airline modules, all module changes occurring while the engine was hanging in the test cell. Overhead rail systems in the Development test cells let engine modules be changed while the engine is installed in the test cell. This reduces any test errors that might result from removing and reinstalling the engine. In addition, the Development test cells have an expanded capability for reading and recording additional instrumentation. The added instrumentation allows accurate diagnosis of any second-order performance effects that may arise from changing the LPT modules. The Evendale Development testing program occurred during the August-September 1978 time period.

The test engine used for the Development Program was CF6-6D engine S/N 451-111. This engine was an early vintage CF6-6D engine which had been utilized as a GE lease pool engine for the preceding four years. The total time on this engine was low - 2762 hours - because the engine, though installed numerous times, was typically kept installed for only a short period of time.

Table 13. Evendale Production No. 2 - Low Pressure Turbine Maintenance Record.

	Serial Number	TSN (Hours)	CSN	TSO (Hours)	CSO
TMF	51325	13,958	6,725	2,768	1,325
LPT Stage 1 Nozzle	51325	13,958	6,725	6,561	2,669
LPT Stator	51444	8,246	3,713	8,246	3,713
- Vanes		8,246	3,713	8,246	3,713
- Tip Shrouds		8,246	3,713	8,246	3,713
- Interstage Seals		8,246	3,713	8,246	3,713
LPT Rotor	51444	8,246	3,713	8,246	3,713
- Blades		8,246	3,713	8,246	3,713
- Interstage Seals		8,246	3,713	8,246	3,713
TRF	51450	8,800	2,694	8,800	2,694

Table 14. Evendale Production No. 2 - New Vs. Airline LPT.

	Based on T5X			Based on EGT		
	$\Delta\eta$	ΔEGT	ΔSFC	$\Delta\eta$	ΔEGT	ΔSFC
ΔETAC	-0.1	+ 2	+0.07	-0.1	+ 2	+0.07
ΔETAT	+0.9	-19	-0.76	+0.7	-15	-0.59
ΔPARAS	+1.0	+19	+0.72	+1.0	+19	+0.72
ΔETALPS	+0.7	- 4	-0.52	+0.8	- 5	-0.59
ΔFN at N1	-0.6	- 4	0	-0.6	- 4	0
Stacked		-6° F	-0.5%		-3° F	-0.4%
Measured		-6° F	-0.5%		-7° F	-0.5%

Table 15. Evendale Productuon No. 2 - Test Cell Data.

	SFC Margin	Hot Day EGT	DELT5X	Based on T5X					Based on EGT				
				DETAC	DETAT	DPARAS	DETALFS	DFN1	DETAC	DETAT	DPARAS	DETALPS	DFN1
				Serviceable LPT					Serviceable LPT				
	-0.5	1563	9	1.9	-2.3	-0.4	-1.9	-0.0	1.9	-1.2	-0.2	-1.2	-0.0
	-0.5	1566	6	1.4	-1.5	-0.1	-2.0	-0.1	1.4	-0.6	0.0	-1.4	-0.1
	0.1	1503	6	1.6	-1.5	0.2	-1.2	0.2	1.6	-0.6	0.2	-0.7	0.2
	-0.1	1501	3	1.6	-1.4	-0.0	-1.7	-0.0	1.6	-0.7	0.0	-1.2	-0.0
	-0.4	1573	8	1.6	-2.4	-0.6	-1.4	0.7	1.6	-1.4	-0.5	-0.7	0.7
	-0.7	1574	11	1.2	-1.7	0.0	-1.5	0.5	1.2	-0.6	0.2	-0.8	0.5
	-0.2	1513	7	1.2	-1.4	0.4	-1.0	0.6	1.2	-0.5	0.4	-0.4	0.6
	-0.1	1512	5	1.5	-1.6	0.2	-1.1	0.6	1.5	-0.8	0.3	-0.6	0.6
Avg	-0.3	1569/ 1507	7	1.5	-1.7	0.0	-1.5	0.3	1.5	-0.8	0.1	-0.9	0.3
				New LPT					New LPT				
	0.1	1560	7	1.3	-0.6	1.0	-0.9	-0.5	1.3	0.3	1.1	-0.3	-0.5
	0.0	1561	10	1.3	-1.0	0.8	-0.7	-0.5	1.3	0.1	0.9	-0.0	-0.5
	0.4	1496	11	1.5	-1.2	0.6	-0.6	-0.5	1.5	-0.1	0.8	0.1	-0.5
	0.4	1496	8	1.3	-0.7	0.9	-0.8	-0.5	1.3	0.3	1.0	-0.2	-0.5
	0.0	1567	9	1.1	-0.8	1.0	-0.6	-0.1	1.1	0.2	1.1	0.1	-0.1
	0.1	1568	5	1.3	-0.7	1.0	-0.8	-0.1	1.3	0.1	1.1	-0.3	-0.1
	0.2	1503	6	1.3	-0.5	1.2	-0.8	-0.2	1.3	0.3	1.3	-0.2	-0.2
	0.2	1501	6	1.7	-1.0	1.1	-0.9	-0.2	1.7	-0.1	1.1	-0.3	-0.2
Avg	0.2	1564/ 1499	8	1.4	-0.8	1.0	-0.8	-0.3	1.4	0.1	1.1	-0.1	-0.3

Table 16. Evendale Production No. 2 - UAL Test Cell Data.

			Based on T5X						Based on EGT				
	SFC MARGIN	HOT DAY EGT	DELT5X	DETAC	DETAT	DPARAS	DETALPS	DFN1	DETAC	DETAT	DPARAS	DETALPS	DFN1
						Inbound LPT							
	-5.7	1645	-15	0.2	-1.2	0.4	-2.1	-1.4	0.2	-2.1	0.2	-2.5	-1.4
	-5.7	1642	-11	0.3	-1.3	0.4	-2.2	-1.3	0.3	-2.0	0.3	-2.4	-1.3
	-5.4	1577	-17	0.5	-1.0	0.6	-2.1	-1.3	0.5	-2.1	0.4	-2.5	-1.3
	-5.6	1579	-19	0.3	-0.9	0.6	-2.3	-1.6	0.3	-2.0	0.4	-2.8	-1.6
	-5.7	1645	- 9	0.2	-1.6	0.2	-1.9	-0.9	0.2	-2.3	0.0	-2.0	-0.9
	-5.7	1645	-10	0.4	-1.8	0.2	-1.9	-1.1	0.4	-2.5	0.0	-2.1	-1.1
	-5.6	1582	-13	0.3	-1.3	0.4	-2.2	-1.3	0.3	-2.0	0.3	-2.4	-1.3
	-5.5	1580	-13	0.4	-1.4	0.3	-1.9	-1.1	0.4	-2.3	0.2	-2.2	-1.1
Avg	-5.6	1644/ 1580	-11	0.3	-1.3	0.4	-2.1	-1.3	0.3	-2.2	0.2	-2.4	-1.3
						Inbound LPT - 1% WF*							
Avg	-4.6	1644/ 1580	-28	0.3	-0.4	0.6	-1.5	-1.3	0.3	-2.2	0.2	-2.4	-1.3
						Refurbished LPT							
	-4.5	1637	-33	0.9	0.5	1.7	-1.8	-1.6	0.9	-1.4	1.4	-2.8	-1.6
	-4.2	1565	-32	0.8	1.1	2.0	-1.9	-1.8	0.8	-0.8	1.7	-2.8	-1.8
	-4.2	1643	-42	0.4	1.2	1.8	-1.7	-1.3	0.4	-1.1	1.4	-2.9	-1.3
	-4.2	1634	-37	0.8	1.1	1.8	-1.9	-1.4	0.8	-1.0	1.4	-3.0	-1.4
	-3.9	1576	-47	0.9	1.5	2.2	-1.8	-1.2	0.9	-1.0	1.7	-3.2	-1.2
	-3.8	1571	-41	1.5	0.8	2.1	-2.0	-0.9	1.5	-1.6	1.6	-3.3	-0.9
	-4.5	1640	-42	1.5	0.7	2.1	-2.3	-1.4	1.5	-1.6	1.6	-3.5	-1.4
	-4.1	1643	-45	1.5	0.8	2.1	-2.0	-0.9	1.5	-1.6	1.6	-3.3	-0.9
	-4.2	1639	-42	1.9	0.3	2.0	-2.0	-1.3	1.9	-2.0	1.6	-3.3	-1.3
	-4.1	1568	-41	1.2	1.5	2.4	-2.2	-1.4	1.2	-0.7	1.9	-3.4	-1.4
	-4.1	1573	-48	1.1	1.6	2.3	-2.2	-1.5	1.1	-0.9	1.8	-3.6	-1.5
Avg	-4.1	1640/ 1572	-43	1.2	1.1	2.1	-2.0	-1.3	1.2	-1.3	1.6	-3.3	-1.3

* Inbound average data adjusted for a 1% fuel flow error.

Table 17. Evendale Production No. 2 - UAL Refurbished Versus Inbound LPT.

	Based on T5X			Based on EGT		
	$\Delta\eta$	ΔEGT	Δ SFC	$\Delta\eta$	ΔEGT	ΔSFC
DETAC	+0.9	-17	-0.67	+0.9	-17	-0.67
DETAT	+1.5	-32	-1.26	+0.9	-19	-0.76
DPARAS	+1.5	+28	+1.08	+1.4	+26	+1.00
DETALPS	-0.5	+ 3	+0.37	-0.9	+ 6	+0.67
DFN@N1	0	0	0	0	0	0
STACKED		-18^{o} F	- 0.5 %		-4^{o} F	+0.2
MEASURED		-21^{o} F	- 0.5 %		-6^{o} F	-0.5 %

The first serviceable LPT module selected was a National Airlines module with 13,353 hours on the LPT stator EMU and 12,367 hours on the rotor EMU. This module is different from the other six tested, in that its rotor and stator come from different engines. An important item to note is that although the LPT stator had logged over 13,000 hours, the stationary interstage seals were replaced prior to running the NASA test. Table 18 presents the LPT module maintenance history (hours and cycles since new or overhaul).

The test cell performance results are presented in Tables 19 and 20. Note that the serviceable LPT module is 0.4 percent poorer in sfc margin. Again, it is significant to note that the LPT component efficiency data do not support the measured change in sfc. Even with additional test instrumentation, overall performance measurements, together with direct substitution and back-to-back testing, are the only way to guarantee meaningful deterioration results. Even then, care must be exercised to make sure the core engine does not deteriorate as described in Section 7.3. Based on HPT pressure ratio measurements, the LPT flow area was calculated as 0.5 percent larger for the airline module.

7.6 EVENDALE DEVELOPMENT PROGRAM NO. 2

The second airline LPT module tested on CF6-6D S/N 451-111 in the Evendale Development test program was a UAL module that had 12,823 hours and 5,206 cycles on its LPT rotor and stator EMU's. This module was the only LPT tested that was not serviceable. It was a high-time module that was scheduled for a "threshold inspection" at UAL. A threshold inspection is one conducted to extend the time between mandatory shop action and also to analyze long-time parts condition. Table 21 presents the LPT module maintenance history (hours and cycles since new/overhaul).

The test cell performance results are presented in Tables 22 and 23. Note that the airline LPT module is 0.5 percent poorer in sfc margin. As in the previous LPT tests, the core component efficiencies moved around while the overall core remained relatively constant. The 1 percent increase in calculated LP system efficiency is only slightly too large for the measured 0.5 percent sfc margin gain that was due to installing the new module. But again, the purpose of conducting back-to-back tests with direct module (LPT) substitution is to evaluate component deterioration by using overall fuel-burn (sfc) measurements - not by comparing calculated component performance. Finally, note that the airline module LPT flow area was 0.3 percent larger than that of the new production module.

7.7 EVENDALE DEVELOPMENT PROGRAM NO. 3

The final serviceable LPT module tested on CF6-6D S/N 451-111 in the Evendale Development test program was the original 451-111 module. Like the total engine, it had 2762 hours and 1858 cycles on the LPT rotor and stator EMU's. This module was not included in the original test program;

Table 18. Evendale Development No. 1 - Low Pressure Turbine Maintenance Record.

	Serial Number	TSN (Hours)	CSN	TSO (Hours)	CSO
TMF	51227	14,018	7,444	3,726	1,862
LPT Stage 1 Nozzle	51159	13,917	7,388	7,526	3,995
LPT Stator	51158	13,353	6,510	13,353	6,510
- Vanes		13,353	6,510	13,353	6,510
- Tip Shrouds		13,353	6,510	Unknown	Unknown
- Interstage Seals		13,353	6,510	0	0
LPT Rotor	51342	12,367	6,829	7,450	3,725
- Blades		12,367	6,829	7,450	3,725
- Interstage Seals		12,367	6,829	7,450	3,725
TRF	51158	13,353	6,510	13,353	6,510

Table 19. Evendale Development No. 1 - New Vs. Airline LPT.

	Based on T5X			Based on EGT		
	$\Delta\eta$	ΔEGT	ΔSFC	$\Delta\eta$	ΔEGT	ΔSFC
ΔETAC	+0.4	- 8	-0.30	+0.4	- 8	-0.30
ΔETAT	+0.1	- 2	-0.08	0	0	0
ΔPARAS	+0.1	+ 2	+0.07	0	0	0
ΔETALPS	+0.1	- 1	-0.07	+0.1	- 1	-0.07
ΔFN at N1	-0.9	- 6	0	-0.9	- 6	0
ΔTFF2	-0.5%	+ 4	0	-0.5	+ 4	0
Stacked		-11° F	-0.4%		-11° F	-0.4%
Measured		-9° F	-0.4%		-6° F	-0.4%

Table 20. Evendale Development No. 1 - Test Cell Data.

	SFC Margin	Hot Day EGT	DELT5X	Based on T5X DETAC	DETAT	DPARAS	DETALPS	DFN1	Based on EGT DETAC	DETAT	DPARAS	DETALPS	DFN1
				Serviceable LPT					Serviceable LPT				
	-4.0	1649	10	-0.7	-4.4	-0.4	-0.9	-0.5	-0.7	-3.4	-0.2	-0.2	-0.5
	-4.2	1649	10	-0.7	-4.4	-0.3	-1.2	-0.8	-0.7	-3.3	-0.1	-0.5	-0.8
	-3.8	1584	10	-0.5	-4.5	-0.4	-0.9	-0.6	-0.5	-3.5	-0.2	-0.2	-0.6
	-3.7	1584	0	-0.5	-4.1	-0.3	-0.8	-0.7	-0.5	-3.5	-0.2	-0.4	-0.7
	-4.0	1647	11	-0.8	-4.5	-0.5	-1.0	-0.8	-0.8	-3.4	-0.4	-0.2	-0.8
	-4.2	1647	12	-0.8	-4.5	-0.4	-1.2	-0.9	-0.8	-3.3	-0.3	-0.4	-0.9
	-3.7	1579	11	-0.7	-4.2	-0.2	-0.8	-0.8	-0.7	-3.1	-0.1	-0.1	-0.8
	-3.9	1580	13	-0.6	-4.7	-0.5	-1.0	-0.8	-0.6	-3.5	-0.4	-0.2	-0.8
Avg	-3.9	1648/ 1582	10	-0.7	-4.4	-0.4	-1.0	-0.7	-0.7	-3.4	-0.2	-0.3	-0.7
				New LPT					New LPT				
	-3.8	1642	0	-0.4	-3.8	-0.1	-0.9	-1.8	-0.4	-3.3	-0.1	-0.5	-1.8
	-3.7	1643	6	-0.4	-4.2	-0.2	-1.1	-1.6	-0.4	-3.3	-0.1	-0.5	-1.6
	-3.5	1574	8	-0.2	-4.4	-0.3	-1.1	-2.0	-0.2	-3.5	-0.2	-0.5	-2.0
	-3.5	1574	0	-0.4	-3.9	-0.2	-0.9	-1.9	-0.4	-3.3	-0.2	-0.5	-1.9
	-3.7	1643	12	-0.4	-4.7	-0.5	-0.8	-1.5	-0.4	-3.5	-0.3	0.0	-1.5
	-3.5	1643	9	-0.4	-4.4	-0.3	-0.8	-1.4	-0.4	-3.4	-0.2	-0.1	-1.4
	-3.4	1576	11	-0.3	-4.6	-0.4	-0.6	-1.5	-0.3	-3.5	-0.3	0.1	-1.5
	-3.2	1576	10	-0.2	-4.6	-0.4	-0.6	-1.3	-0.2	-3.5	-0.3	0.1	-1.3
Avg	-3.5	1643/ 1575	7	-0.3	-4.3	-0.3	-0.9	-1.6	-0.3	-3.4	-0.2	-0.2	-1.6

Table 21. Evendale Development No. 2 - Low Pressure Turbine Maintenance Record.

	Serial Number	TSN (Hours)	CSN	TSO (Hours)	CSO
TMF	51483	8,118	3,334	5,323	2,106
LPT Stage 1 Nozzle	51483	8,118	3,334	8,118	3,334
LPT Stator	51421	12,823	5,206	12,823	5,206
- Vanes		12,823	5,206	12,823	5,206
- Tip Shrouds		12,823	5,206	12,823	5,206
- Interstage Seals		12,823	5,206	12,823	5,206
LPT Rotor	51421	12,823	5,206	12,823	5,206
- Blades		12,823	5,206	12,823	5,206
- Interstage Seals		12,823	5,206	12,823	5,206
TRF	51348	13,134	6,589	8,218	3,382

Table 22. Evendale Development No. 2 - New Vs. Airline LPT.

	Based on T5X			Based on EGT		
	Δη	ΔEGT	ΔSFC	Δη	ΔEGT	ΔSFC
ΔETAC	+0.3	- 6	-0.22	+0.3	- 6	-0.22
ΔETAT	-0.7	+15	+0.59	-0.2	+ 4	+0.17
ΔPARAS	0	0	0	+0.1	+ 2	+0.07
ΔETALPS	+1.0	- 6	-0.74	+1.4	- 9	-1.04
ΔFN at N1	-0.8	- 6	0	-0.8	- 6	0
ΔTFF2	-0.3	+ 2	0	-0.3	+ 2	0
Stacked		-1° F	-0.4%		-13° F	-1.0%
Measured		+2° F	-0.5%		- 8° F	-0.5%

Table 23. Evendale Development No. 2 - Test Cell Data.

	SFC Margin	Hot Day EGT	DELT5X	Based on T5X DETAC	DETAT	DPARAS	DETALPS	DFN1	Based on EGT DETAC	DETAT	DPARAS	DETALPS	DFN1
				Serviceable LPT					**Serviceable EGT**				
	-4.0	1649	-2	-0.8	-3.6	-0.3	-1.9	-0.9	-0.8	-3.1	-0.3	-1.5	-0.9
	-3.8	1647	-8	-0.6	-3.5	-0.4	-2.0	-1.0	-0.6	-3.3	-0.4	-1.8	-1.0
	-3.6	1584	-5	-0.5	-3.8	-0.5	-1.6	-0.9	-0.5	-3.4	-0.5	-1.4	-0.9
	-3.7	1585	-8	-0.4	-3.7	-0.4	-2.0	-0.8	-0.4	-3.5	-0.4	-1.8	-0.8
	-4.2	1652	0	-0.9	-3.5	-0.2	-1.8	-0.6	-0.9	-2.9	-0.1	-1.4	-0.6
	-4.1	1649	-2	-0.5	-3.6	-0.2	-2.1	-0.7	-0.5	-3.1	-0.2	-1.8	-0.7
	-4.1	1584	3	-0.7	-3.6	-0.1	-1.7	-0.7	-0.7	-2.9	-0.1	-1.2	-0.6
	-4.2	1586	-2	-0.7	-3.5	-0.2	-2.1	-0.9	-0.7	-3.1	-0.2	-1.8	-0.9
Avg	-4.0	1649/ 1585	-3	-0.6	-3.6	-0.3	-1.9	-0.8	-0.6	-3.2	-0.3	-1.6	-0.8
				New LPT					**New LPT**				
	-3.8	1642	0	-0.4	-3.8	-0.1	-0.9	-1.8	-0.4	-3.3	-0.1	-0.5	-1.8
	-3.7	1643	6	-0.4	-4.2	-0.2	-1.1	-1.6	-0.4	-3.3	-0.1	-0.5	-1.6
	-3.5	1574	8	-0.2	-4.4	-0.3	-1.1	-2.0	-0.2	-3.5	-0.2	-0.5	-2.0
	-3.5	1574	0	-0.4	-3.9	-0.2	-0.9	-1.9	-0.4	-3.3	-0.2	-0.5	-1.9
	-3.7	1643	12	-0.4	-4.7	-0.5	-0.8	-1.5	-0.4	-3.5	-0.3	-0.0	-1.5
	-3.5	1643	9	-0.4	-4.4	-0.3	-0.8	-1.4	-0.4	-3.4	-0.2	-0.1	-1.4
	-3.4	1576	11	-0.3	-4.6	-0.4	-0.6	-1.5	-0.3	-3.5	-0.3	-0.1	-1.5
	-3.2	1576	10	-0.2	-4.6	-0.4	-0.6	-1.3	0.2	-3.5	-0.3	-0.1	-1.3
Avg	-3.5	1643/ 1575	7	-0.3	-4.3	-0.3	-0.9	-1.6	-0.3	-3.4	-0.2	-0.2	-1.6

but the test had to be run prior to shipment of the engine, and it was decided to include the performance data in the report. As reported previously, this engine/module was one of the GE lease pool engines, which are characteristically installed on numerous aircraft for short periods of time. The engine deterioration may be greater than that of a similar airline engine having the same number of hours. Table 24 presents the LPT module maintenance history (hours/cycles since new/overhaul).

The test cell performance results are presented in Tables 25 and 26. Note that the serviceable module is 0.6 percent poorer in sfc margin. Also note that (1) the overall core efficiency (HPC, HPT, and parasitics) is constant, and (2) the 1 percent calculated improvement in LP system efficiency supports the measured 0.6 percent change in sfc margin that comes from installing the new production LPT module. Finally, the serviceable LPT module had a 0.9 percent larger LPT flow area, which is consistent with the other six airline modules tested in the Task II program.

7.8 SUMMARY OF PERFORMANCE RESULTS

The test results for the seven back-to-back tests are summarized in Table 27. Noter that the average sea level deterioration for the seven serviceable LPT modules is 0.6 percent.

In addition, the LPT flow area opens an average of 0.7 percent in airline service. A summary of the flow function results are presented in Table 28.

Table 24. Evendale Development No. 3 - Low Pressure Turbine Maintenance Record.

	Serial Number	TSN (Hours)	CSN	TSO (Hours)	CSO
TMF	51111	2,762	1,858	0	0
LPT Stage 1 Nozzle	51111	2,762	1,858	0	0
LPT Stator	51111	2,762	1,858	2,762	1,858
- Vanes		2,762	1,858	2,762	1,858
- Tip Shrouds		2,762	1,858	2,762	1,858
- Interstage Seals		2,762	1,858	2,762	1,858
LPT Rotor	51111	2,762	1,858	2,762	1,858
- Blades		2,762	1,858	2,762	1,858
- Interstage Seals		2,762	1,858	2,762	1,858
TRF	51111	2,762	1,858	2,762	1,858

Table 25. Evendale Development No. 3 - New Vs. Airline LPT.

	Based on T5X			Based on EGT		
	$\Delta\eta$	ΔEGT	ΔSFC	$\Delta\eta$	ΔEGT	ΔSFC
ΔETAC	+0.4	- 8	-0.30	+0.4	- 8	-0.30
ΔETAT	-0.2	+ 4	+0.17	-0.2	+ 4	+0.17
ΔPARAS	+0.1	+ 2	+0.07	+0.1	+ 2	+0.07
ΔETALPS	+1.0	- 6	-0.74	+1.1	- 7	-0.81
ΔFN at N1	+0.1	+ 1	0	+0.1	+ 1	0
ΔTFF2	-0.9	+ 6	0	-0.9	+ 6	0
Stacked		-1° F	-0.8%		-2° F	-0.9%
Measured		+5° F	-0.6%		+4° F	-0.6%

Table 26. Evendale Development No. 3 - Test Cell Data.

	SFC Margin	Hot Day EGT	DELT5X	Based on T5X DETAC	Based on T5X DETAT	Based on T5X DPARAS	Based on T5X DETALPS	Based on T5X DFN1	Based on EGT DETAC	Based on EGT DETAT	Based on EGT DPARAS	Based on EGT DETALPS	Based on EGT DFN1
				Serviceable LPT					Serviceable LPT				
	-4.1	1635	9	-0.8	-4.0	-0.3	-1.7	-1.7	-0.8	-3.0	-0.2	-1.1	-1.7
	-4.3	1637	8	-0.8	-4.0	-0.3	-2.0	-1.7	-0.8	-3.0	-0.2	-1.4	-1.7
	-4.0	1573	4	-0.5	-4.3	-0.5	-1.9	-1.9	-0.5	-3.5	-0.4	-1.4	-1.9
	-3.9	1575	3	-0.7	-4.1	-0.5	-1.7	-1.6	-0.7	-3.4	-0.4	-1.3	-1.6
Avg	-4.1	1636/1574	6	-0.7	-4.1	-0.4	-1.9	-1.7	-0.7	-3.2	-0.3	-1.3	-1.7
				New LPT					New LPT				
	-3.8	1642	0	-0.4	-3.8	-0.1	-0.9	-1.8	-0.4	-3.3	-0.1	-0.5	-1.8
	-3.7	1643	6	-0.4	-4.2	-0.2	-1.1	-1.6	-0.4	-3.3	-0.1	-0.5	-1.6
	-3.5	1574	8	-0.2	-4.4	-0.3	-1.1	-2.0	-0.2	-3.5	-0.2	-0.5	-2.0
	-3.5	1574	0	-0.4	-3.9	-0.2	-0.9	-1.9	-0.4	-3.3	-0.2	-0.5	-1.9
	-3.7	1643	12	-0.4	-4.7	-0.5	-0.8	-1.5	-0.4	-3.5	-0.3	-0.0	-1.5
	-3.5	1643	9	-0.4	-4.4	-0.3	-0.8	-1.4	-0.4	-3.4	-0.2	-0.1	-1.4
	-3.4	1576	11	-0.3	-4.6	-0.4	-0.6	-1.5	-0.3	-3.5	-0.3	-0.1	-1.5
	-3.2	1576	10	-0.2	-4.6	-0.4	-0.6	-1.3	0.2	-3.5	-0.3	-0.1	-1.3
Avg	-3.5	1643/1575	7	-0.3	-4.3	-0.3	-0.9	-1.6	-0.3	-3.4	-0.2	-0.2	-1.6

Table 27. LPT Deterioration - Summary of Results.

LPT	SFC (%) at SL
ASO/O Demonstrator	0.7
ASO/O No. 2	0.6
Production No. 1	0.1 (Refurbished)*
Production No. 2	0.5
Development No. 1	0.4
Development No. 2	0.5
Development No. 3	0.7
Average	0.6%

* Not included in average

Table 28. Low Pressure Turbine Flow Area - Summary of Results.

LPT	ΔTFF2
ASO/O Demonstrator	0 (Small TFF2)*
ASO/O No. 2	+1.7%
Production No. 1	0 (Refurbished)*
Production No. 2	0
Development No. 1	+0.5%
Development No. 2	+0.3%
Development No. 3	+0.9%
Average	+0.7%

*Not Included in Average

8.0 ANALYTICAL TEARDOWN RESULTS

Three of the LPT modules tested back-to-back with new production hardware were returned to United Airlines for an analytical teardown inspection and selected refurbishment (see Sections 7.1, 7.4 and 7.6). The performance gain due to the refurbishment was evaluated by a back-to-back testing sequence at UAL. The refurbishment consisted of installing all new honeycomb (tip shrouds and stationary interstage seals). It was thought that the new honeycomb would restore clearances to their new engine level so that the back-to-back test cell runs would evaluate the performance (sfc) loss due to increases in clearance. It could be assumed, therefore, that the remaining performance loss (as determined by the back-to-back LPT module tests) was due to airfoil surface finish.

The results of the three LPT module analytical teardown are discussed in the following paragraphs. In addition, the performance impact of these measurements are discussed and evaluated in Section 8.4 using current hardware influence coefficients. Note that all the assessed hardware conditions are compared to new engine build tolerances.

8.1 TURBINE MIDFRAME

8.1.1 General

A visual inspection of the TMF's shows them to be in good condition. No distress was noted either in the liner or in the rest of the frame.

8.1.2 TMF Forward Flange (Diameter U)

The TMF forward flange outer diameter (Diameter U) serves as the primary control of concentricity of the Stage 2 HPT nozzle support, affecting HPT blade-to-shroud clearances. Diameter U was measured at the 12 o'clock position, together with runouts of the flange in relation to the Number 5 bearing. The results (inches) were as follows:

Position	Module Serial Numbers		
	51444	51468	51421
12 o'clock	.000"	.000"	.000"
1 o'clock	-.010	.000	.005
2 o'clock	-.022	-.001	.010
3 o'clock	-.023	-.003	.005
4 o'clock	-.021	-.005	.005
5 o'clock	-.003	-.002	.006
6 o'clock	-.002	-.001	.008
7 o'clock	-.009	-.002	.005
8 o'clock	-.021	-.004	.005
9 o'clock	-.020	.000	.007
10 o'clock	-.008	.000	.007
11 o'clock	-.002	+.001	.000
Diameter at 12 o'clock	38.746	38.728	38.732
Average Diameter	38.725	38.726	38.736
FIR	.023	.006	.010

The shop manual maximum serviceable limits (average diameter) are 38.738/38.726 inches with a maximum allowable FIR of 0.020 inches.

8.1.3 LPT Pressure Balance Seal

An eight point diameter measurement of the stationary LPT pressure balance seal was made with the following results (inches):

	Module Serial Number		
Measurement	S/N 51444	S/N 51468	S/N 51421
1	19.049	19.058	19.052
2	19.049	.060	.050
3	19.054	.066	.051
4	19.053	.055	.052
5	19.052	.062	.054
6	19.051	.060	.055
7	19.050	.052	.056
8	19.050	.066	.054
Average	19.051	19.060	19.053

Shop Manual Limits 19.050 in./19.054 in.

The average clearance (C27) to the rotating seal (see Section 8.2.2) was calculated to be the following:

S/N 51444	.030 inch
S/N 51468	.036 inch
S/N 51421	.032 inch

A stack up of CF6-6D production hardware indicates a nominal clearance of 0.031 inches.

8.1.4 Stage 1 LPTN Airfoils

Six (6) Stage 1 low pressure turbine nozzles (LPTN) vane segments were removed from the TMF assembly. Surface finish measurement were made on the end vanes of each segment. The measurements were taken on each side 0.45/0.50 inch from the leading edge (LE) and from the trailing edge. Tip readings were taken 0.50 inch below the outer platform. The results of the surface finish measurements are grouped with similar measurement for the other stages of the LPT and presented in Tables 29 through 31.

8.2 LOW PRESSURE TURBINE ROTOR

8.2.1 General Inspection

A visual inspection of the three LPT rotor assemblies showed them to be in good condition. No discrepancies were noted on any of the spool parts. The blades were rough and dirty, typical of LPT airfoils with high running times. Figure 16 presents an overall view of a typical serviceable LPT rotor.

8.2.2 Dimensional Inspections

The rotors were set up in the LPT balance machine to obtain radii runouts of the blade tip shroud seal serrations, the air seals, and the pressure balance (P/B) seal teeth. Pi tapes were used to obtain the average diameter measurements. The results of these measurements are presented in Tables 32 through 34.

8.2.3 Airfoil Surface Finish Checks

After the dimensional inspection checks were completed, six (6) blades from each stage were removed for airfoil surface finish measurements. Tables 35 through 37 percent a tabulation of these inspections for each LPT module. All checks were taken on each side 0.10/0.15 inch from the L.E. and T.E. Tip readings were taken 0.50 inch below the blade's outer platform.

Table 29. LPTS Vane Surface Finish - LPT S/N 51444.

		CONVEX						CONCAVE			
		TIP		PITCH		VANE	STAGE	PITCH		VANE	STAGE
STAGE	NO.	LE	TE	LE	TE	AVG	AVG	LE	TE	AVG	AVG
1	1	190	170	180	190	183		110	170	140	
	2	110	120	90	150	118		140	110	125	
	3	110	205	90	100	126		140	130	135	
	4	120	130	130	120	125		100	100	100	
	5	130	120	130	120	125		130	140	135	
	6	140	130	150	180	150	138	150	230	190	138
2	1	120	110	110	80	105		110	80	95	
	2	130	170	150	90	135		90	90	90	
	3	150	140	130	110	133		150	110	130	
	4	150	150	150	90	135		140	110	125	
	5	140	120	130	80	117		100	80	90	
	6	130	250	110	80	143	128	110	90	100	105
3	1	140	100	95	90	106		100	75	88	
	2	110	130	110	90	110		90	75	82	
	3	130	90	85	80	96		100	70	85	
	4	130	140	120	90	120		110	85	98	
	5	130	80	90	90	98		120	75	97	
	6	150	100	120	90	115	108	110	85	98	91
4	1	140	100	65	100	101		60	55	58	
	2	100	70	60	50	70		40	50	45	
	3	100	100	80	50	83		70	60	65	
	4	100	90	85	55	82		55	70	62	
	5	80	90	75	80	81		60	65	63	
	6	100	80	60	60	75	82	50	60	55	58
5	1	95	80	75	100	88		60	100	80	
	2	80	140	75	50	86		130	90	110	
	3	100	80	60	50	72		50	70	60	
	4	85	50	70	85	73		50	60	55	
	5	75	100	75	80	82		95	50	72	
	6	70	90	65	45	67	78	60	80	70	75

Table 30. LPTS Vane Surface Finish - LPT S/N 51468.

		CONVEX						CONCAVE			
		TIP		PITCH		VANE	STAGE	PITCH		VANE	STAGE
STAGE	NO.	LE	TE	LE	TE	AVG	AVG	LE	TE	AVG	AVG
1	1	75	100	85	80	85		70	80	75	
	2	130	170	165	250	179		110	160	135	
	3	90	95	90	90	91		75	105	90	
	4	170	195	155	190	178		225	190	208	
							140				133
2	1	80	125	90	95	98		100	85	93	
	2	90	80	70	60	75		75	75	75	
	3	105	100	110	90	101		85	70	78	
	4	100	110	85	70	91		100	95	98	
							91				86
3	1	90	80	70	75	79		80	60	70	
	2	85	90	85	70	83		90	70	80	
	3	80	95	130	90	99		105	115	110	
	4	85	95	120	80	95		80	65	73	
							89				83
4	1	75	65	70	60	67		80	70	75	
	2	70	90	50	60	68		70	45	58	
	3	105	110	70	70	89		90	90	90	
	4	85	110	65	100	90		75	65	70	
							79				73
5	1	70	80	55	75	70		65	60	63	
	2	80	70	65	60	69		80	85	83	
	3	105	80	70	65	80		65	65	65	
	4	75	90	50	55	68		50	60	55	
							72				67

Table 31. LPTS Vane Surface Finish - LPT S/N 51421.

		CONVEX						CONCAVE			
		TIP		PITCH		VANE	STAGE	PITCH		VANE	STAGE
STAGE	NO.	LE	TE	LE	TE	AVG	AVG	LE	TE	AVG	AVG
1	1	170	125	110	140	136		145	170	158	
	2	90	130	95	100	104		110	140	125	
	3	100	100	85	125	103		145	230	188	
	4	125	120	105	80	107		115	150	132	
	5	95	120	100	80	99		185	180	182	
	6	105	165	75	90	109	110	110	170	140	154
2	1	100	210	100	85	124		120	65	93	
	2	150	125	105	125	126		165	130	147	
	3	140	140	100	135	139		150	100	125	
	4	160	155	175	75	141		120	70	95	
	5	145	140	130	110	131		120	110	115	
	6	85	115	70	100	93	126	95	70	83	110
3	1	85	60	90	50	71		95	60	78	
	2	90	90	155	55	98		125	65	95	
	3	125	80	110	70	96		75	55	65	
	4	80	65	70	65	70		75	65	70	
	5	60	60	80	90	73		85	40	62	
	6	90	100	85	50	81	81	75	65	70	73
4	1	70	65	50	55	60		50	50	50	
	2	50	70	50	40	53		65	55	60	
	3	95	60	50	50	64		60	55	57	
	4	60	80	75	55	67		50	55	53	
	5	80	125	75	55	84		40	40	40	
	6	95	75	65	65	75	67	60	70	65	54
5	1	75	130	65	45	79		165	65	115	
	2	100	95	60	75	83		50	80	65	
	3	85	70	60	75	72		75	70	72	
	4	70	105	70	45	72		65	40	53	
	5	95	120	90	95	100		85	135	110	
	6	70	120	65	50	76	80	70	70	70	81

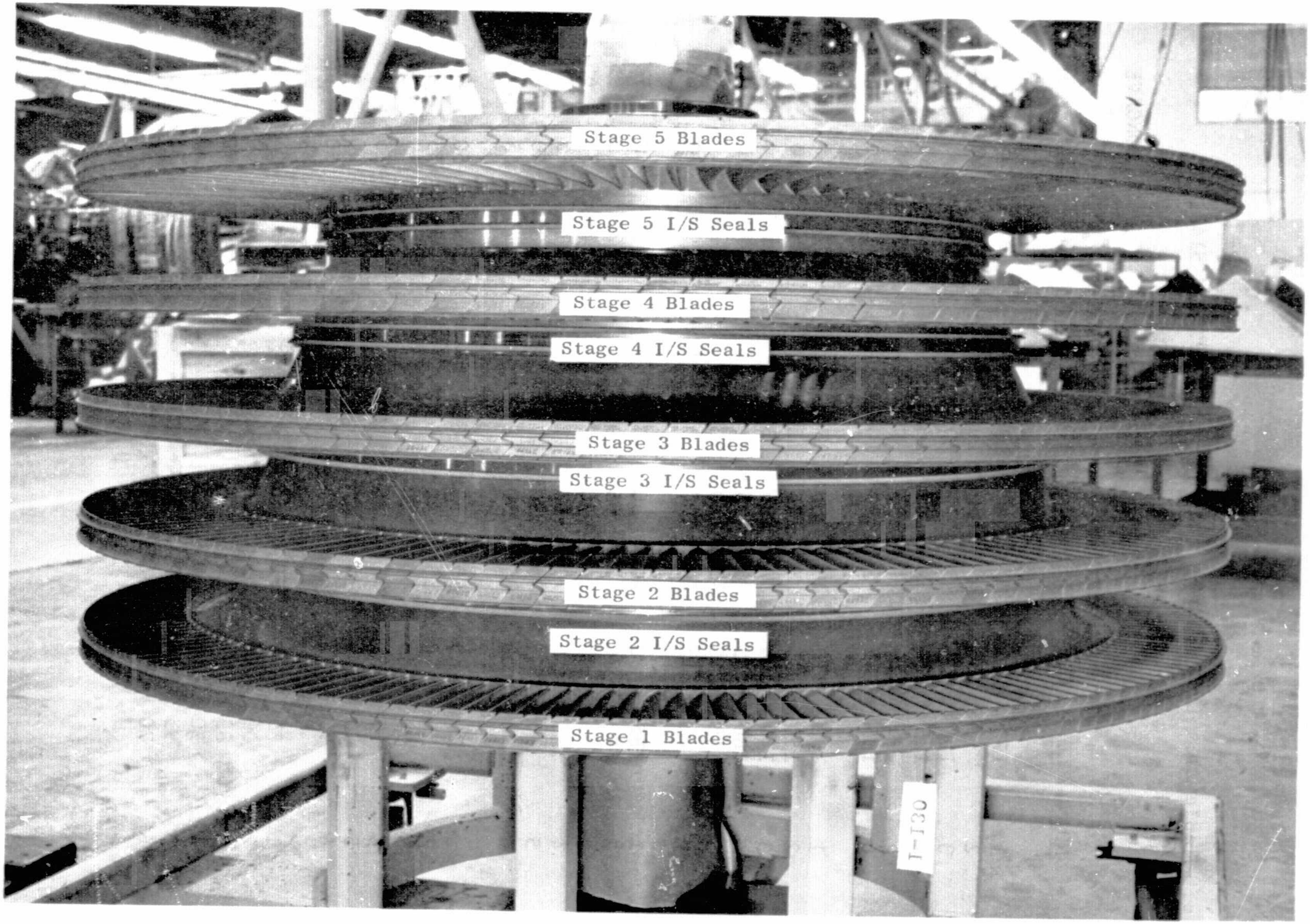


Figure 16. LP Turbine Rotor, Overall View.

Table 32. LPTR Blade Radii.

S/N 51444

	FWD		AFT	
STAGE	AVG RAD	FIR	AVG RAD	FIR
1	24.060	.010	24.120	.002
2	24.120	.002	24.111	.002
3	24.079	.005	24.106	.005
4	24.118	.010	24.117	.003
5	24.114	.008	24.112	.008

S/N 51468

	FWD		AFT	
STAGE	AVG RAD	FIR	AVG RAD	FIR
1	24.079	.006	24.124	.004
2	24.078	.003	24.114	.005
3	24.103	.002	24.109	.003
4	24.119	.010	24.116	.007
5	24.113	.010	24.110	.008

S/N 51421

	FWD		AFT	
STAGE	AVG RAD	FIR	AVG RAD	FIR
1	24.126	.005	24.131	.003
2	24.120	.008	24.117	.005
3	24.101	.003	24.099	.003
4	24.112	.010	24.110	.008
5	24.111	.010	24.107	.010

Table 33. LPTR Interstage Seal Radii.

S/N 51444

	FWD		AFT	
STAGE	AVG RAD	FIR	AVG RAD	FIR
1	18.188	.002	--	--
2	17.996	.001	18.005	.002
3	16.847	.002	16.849	.002
4	15.569	.002	15.575	.003
5	14.212	.002	14.223	.003

S/N 51468

	FWD		AFT	
STAGE	AVG RAD	FIR	AVG RAD	FIR
1	18.199	.002	--	--
2	18.004	.001	18.007	.003
3	16.851	.001	16.850	.002
4	15.567	.003	15.587	.005
5	14.226	.003	14.233	.004

S/N 51421

	FWD		AFT	
STAGE	AVG RAD	FIR	AVG RAD	FIR
1	18.201	.003	--	--
2	18.003	.004	18.007	.006
3	16.851	.004	16.853	.008
4	15.581	.002	15.583	.004
5	14.225	.004	14.232	.006

Table 34. LPTR Pressure Balance Seal Teeth Radii.

S/N 51444

TOOTH	AVG RAD	FIR
F1	18.992	.002
F2	18.992	.001
F3	18.992	.002
F4	18.992	.002
F5	18.992	.002
F6	18.992	.002

S/N 51468

TOOTH	AVG RAD	FIR
F1	18.986	.005
F2	18.986	.004
F3	18.988	.004
F4	18.987	.004
F5	18.988	.004
F6	18.988	.004

S/N 51421

TOOTH	AVG RAD	FIR
F1	18.987	.003
F2	18.987	.003
F3	18.987	.003
F4	18.987	.003
F5	18.987	.003
F6	18.989	.003

Table 35. LPTR Blade Surface Finish - LPT S/N 51444.

		CONVEX						CONCAVE			
		TIP		PITCH		BLADE	STAGE	PITCH		BLADE	STAGE
STAGE	NO.	LE	TE	LE	TE	AVG	AVG	LE	TE	AVG	AVG
1	1	85	85	95	70	84		90	110	100	
	2	95	65	75	80	79		85	105	95	
	3	95	55	95	65	78		100	110	105	
	4	85	50	90	50	69		90	115	102	
	5	135	70	75	65	87		115	75	95	
	6	100	90	100	50	85	80	105	80	93	98
2	1	90	45	55	45	59		70	65	68	
	2	75	60	90	50	69		90	75	82	
	3	95	65	70	45	69		85	60	73	
	4	80	70	80	55	71		65	70	68	
	5	95	65	75	60	74		75	50	62	
	6	80	50	60	50	60	67	85	75	80	72
3	1	60	35	65	45	51		75	80	77	
	2	110	40	45	70	66		80	60	70	
	3	75	60	65	50	63		80	55	67	
	4	75	60	70	50	69		85	55	70	
	5	80	40	60	50	57		75	60	68	
	6	70	60	55	60	61	61	75	65	70	70
4	1	75	60	55	40	58		65	50	57	
	2	60	60	35	40	49		55	55	55	
	3	55	45	45	55	50		45	45	45	
	4	65	80	50	70	66		60	50	55	
	5	65	45	50	45	51		60	50	55	
	6	70	60	55	45	58	55	60	50	55	54
5	1	60	55	65	50	58		70	55	62	
	2	65	50	60	55	57		70	60	65	
	3	55	60	65	75	64		85	55	70	
	4	75	45	55	70	61		85	70	78	
	5	90	55	95	65	76		65	75	70	
	6	65	60	55	55	59	63	65	70	67	69

Table 36. LPTR Blade Surface Finish - LPT S/N 51468.

		CONVEX						CONCAVE			
		TIP		PITCH		BLADE	STAGE	PITCH		BLADE	STAGE
STAGE	NO.	LE	TE	LE	TE	AVG	AVG	LE	TE	AVG	AVG
1	1	125	140	100	75	110		130	105	118	
	2	170	80	95	95	108		120	115	118	
	3	160	85	110	80	109		115	135	125	
	4	190	70	120	95	119		120	105	113	
	5	170	105	95	115	121		140	105	123	
	6	160	85	100	130	119	114	100	105	103	117
2	1										
	2										
	3										
	4										
	5										
	6										
3	1	120	85	80	60	86		105	90	98	
	2	100	100	70	110	95		120	100	110	
	3	120	75	110	55	90		85	75	80	
	4	115	85	80	70	88		120	95	108	
	5	120	105	90	80	99		100	75	88	
	6	110	80	55	50	74	89	80	95	88	95
4	1	120	105	75	120	105		100	80	90	
	2	85	90	70	65	78		100	105	103	
	3	95	150	55	100	100		130	85	108	
	4	60	95	40	95	73		85	110	98	
	5	50	70	35	65	55		70	120	95	
	6	140	85	60	115	100	85	120	95	108	100
5	1	80	110	125	125	108		115	130	123	
	2	105	120	150	100	119		165	105	135	
	3	105	100	120	165	123		125	110	118	
	4	160	125	130	160	144		150	140	145	
	5	75	70	170	100	104		130	110	120	
	6	110	120	115	115	115	119	145	75	120	127

Table 37. LPTR Blade Surface Finish - LPT S/N 51421.

		CONVEX						CONCAVE			
		TIP		PITCH		BLADE	STAGE	PITCH		BLADE	STAGE
STAGE	NO.	LE	TE	LE	TE	AVG	AVG	LE	TE	AVG	AVG
1	1	180	175	130	100	146		160	160	160	
	2	170	125	120	175	148		165	90	128	
	3	150	115	115	150	132		160	130	150	
	4	120	90	160	105	119		150	135	143	
	5	175	150	135	150	152		155	145	150	
	6	180	120	150	80	133	138	130	90	110	140
2	1	90	50	70	55	66		75	85	80	
	2	95	55	60	50	65		80	70	75	
	3	65	50	65	55	59		70	55	62	
	4	95	70	70	55	73		95	75	85	
	5	90	95	65	75	81		90	110	100	
	6	60	65	60	60	61	68	90	60	75	80
3	1	80	60	60	40	60		110	100	105	
	2	105	70	50	65	70		100	85	93	
	3	70	50	60	40	55		75	65	70	
	4	105	70	55	60	73		70	85	77	
	5	65	45	60	65	59		80	75	78	
	6	85	70	50	40	61	63	70	70	70	82
4	1	70	65	45	60	60		80	70	75	
	2	95	80	55	70	75		90	70	80	
	3	95	65	60	100	80		80	75	78	
	4	85	60	55	75	69		50	95	72	
	5	85	65	55	50	64		90	100	95	
	6	70	95	60	85	78	71	95	75	85	81
5	1	85	120	85	70	90		90	80	85	
	2	60	50	65	50	56		105	95	100	
	3	80	75	60	65	70		100	95	97	
	4	70	75	70	90	76		150	70	110	
	5	95	120	80	80	94		130	95	112	
	6	110	105	55	80	88	79	110	90	100	101

8.3 LOW PRESSURE TURBINE STATOR

8.3.1 General Inspection

A visual inspection of the three LPT stator assemblies showed them to be in good condition. As expected, the vanes were rough and dirty with the worst conditions in the forward stages. Rub patterns on the shrouds and interstage seals were typical of other CF6-6D engines (see NASA CR-135381, "Long Term CF6 Engine Performance Deterioration - Evaluation of Engine S/N 451-479" and NASA CR-159390, "Long-Term CF6 Engine Performance Deterioration - Evaluation of Engine S/N 451-380"). Impressions were made of the maximum depth rub pattern for each stage of shrouds and interstage seals. Figure 17 presents an overall view of a typical serviceable LPT stator case including shrouds and interstage seals.

8.3.2 Airfoil Surface Finish Checks

Six vane segments from each stage were removed and airfoil surface finish measurements were taken for the end vane of each segment. Tables 29 through 31 tabulate the surface finish data. All measurements were taken on each side 0.45/0.50 inch from L.E. and T.E. Tip readings were taken 0.50 inch below the vane's outer platform.

8.4 ANALYTICAL ASSESSMENT OF PERFORMANCE LOSSES

The detailed analytical teardown inspection measurements were evaluated for the three LPT modules using influence coefficients listed in Table 38. The coefficients are based on current "best estimates" of hardware effects on LPT performance and may be updated based on information gathered during this program. The performance stackup (Table 39) relative to new LPT performance levels, is based on the analytical teardown inspections summarized in Section 8.1 through 8.3. The analytical teardown data for the three modules is averaged since all three indicated approximately the same level of sfc deterioration from new (see Sections 7.1, 7.4 and 7.6).

The first obvious conclusion is that the sfc assessed from hardware data is over two times the measured 0.6 percent sfc deterioration for the three LPT modules. In additon, almost three-fifths of the assessed loss was due to blade and vane airfoil surface finish. Previous studies of the performance effects of LPT airfoil surface finish have indicated that the current influence coefficients are much too large (see NASA CR-135381 and NASA CR-159390).

The clearance effects (0.4 percent) are much more in line with the back-to-back test results described in Sections 7.1 and 7.4 where the clearances were restored by replacing the tip shrouds and stationary interstage seals. These tests show an average gain of 0.4 percent for the two tests, which tends to indicate that the clearance influence coefficients are correct. If the remaining 0.2 percent sfc deterioration is due to the airfoil surface finish, then the influence coefficients for that condition must be reassessed.

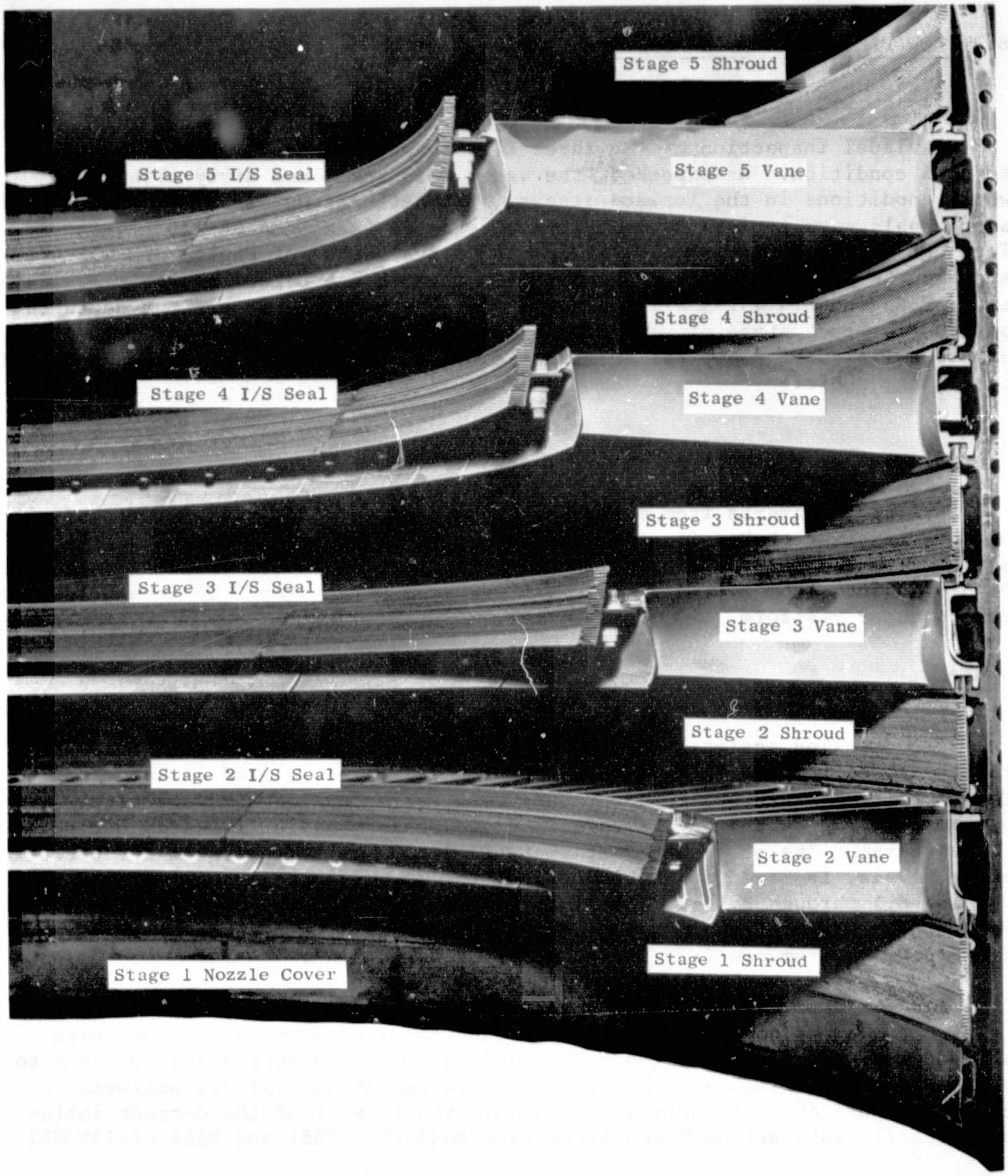


Figure 17. LP Turbine Stator Assembly, End View of Shroud and Seal Rubs.

Table 38. CF6-6 LPT Influence Coefficients.

LPT	DESCRIPTION	*F EGT	% SFC T/O	% SFC CR
Airfoils	60 μ in. surface finish blades and vanes *			
Stage 1	= 0.41% η2t	3.0	0.31	0.26
Stage 2	= 0.29% η2t	2.1	0.22	0.18
Stage 3	= 0.18% η2t	1.3	0.13	0.11
Stage 4	= 0.10% η2t	0.7	0.07	0.06
Stage 5	= 0.02% η2t	0.1	0.01	0.01
	1.00% η2t	7.2	0.74	0.62
Shrouds	40 mils tip seal clear			
Stage 1	= 0.28% η2t	2.0	0.21	0.18
Stage 2	= 0.20% η2t	1.4	0.15	0.13
Stage 3	= 0.15% η2t	1.1	0.11	0.09
Stage 4	= 0.11% η2t	0.8	0.08	0.07
Stage 5	= 0.06% η2t	0.4	0.04	0.04
	0.80% η2t	5.7	0.59	0.51
Interstage Seals				
Rotating	20 mils clear			
Stage 1				
Stage 2	= 0.25% η2t	1.8	0.19	0.16
Stage 3	= 0.14% η2t	1.0	0.10	0.09
Stage 4	= 0.10% η2t	0.7	0.07	0.06
Stage 5	= 0.05% η2t	0.4	0.04	0.03
	0.54% η2t	3.9	0.40	0.34
Bal. Piston Seal	51 mils = 0.1% WC16 to LP from HP	2	0.25	0.2

*Pressure (concave) surface values weighted at 1/4
Suction (convex) surface values weighted at 3/4

Table 39. LPT Performance Assessment.

	$\Delta\eta$	EGT	SFC
LP Turbine			
Rotor Clearance	.36%	2.3°F	.27%
Stage 1 (+27 mils)	.19		
2 (+16 mils)	.08		
3 (+14 mils)	.05		
4 (+ 9 mils)	.02		
5 (+13 mils)	.02		
I/S Seal Clearance	.17%	1.1°F	.13%
Stage 2 (+ 8 mils)	.10		
3 (+ 4 mils)	.03		
4 (+ 6 mils)	.03		
5 (+ 5 mils)	.01		
Blade Airfoil Surface Finish	.37	2.3°F	.27%
Stage 1	.23		
2	.06		
3	.05		
4	.02		
5	.01		
Vane Airfoil Surface Finish	.40	2.5°F	.30%
Stage 1	.24		
2	.11		
3	.04		
4	.01		
5	0		
TOTAL	1.30%	8.2°F	.97%

9.0 CONCLUSIONS

As a result of the NASA CF6 Jet Engine Diagnostics Program, the level of long-term LPT performance deterioration in the CF6-6D engine is now understood. The average sea level sfc loss for the six airline modules tested was 0.6 percent. (The refurbished module described in Section 7.3 is not included in the averages.) This level is significantly lower than had been expected when the program was defined late in 1977. However, the level is consistent with the current unrestored outbound sea level test cell deterioration level of 2.2 percent sfc. Note that the 0.6 percent sfc deterioration at sea level is equivalent to 0.4 percent sfc deterioration and 0.8 percent LPT efficiency loss at altitude cruise conditions.

The test results for the seven back-to-back tests are summarized as 0.6 percent sea level sfc loss, two-thirds (0.4 percent) is due to rotor blade and interstage seal clearance. This was assessed based on analytical teardown measurements of three of the above LPT modules at United Airlines and confirmed by back-to-back testing of two of the LPT modules with restored clearances (new honeycomb). The remaining one third (0.2 percent) is due to airfoil surface finish degradation.

A prime discovery is that there appears to be no correlation between deterioration and time since new or overhaul. The LPT appears to deteriorate during its initial installation and then remain relatively constant until the next LPT overhaul/repair. In addition, there is no correlation with the quality of test engine or location of the test, as all three locations and four test engines yielded approximately the same level of LPT deterioration.

A second significant discovery resulting from the LPT back-to-back tests was that the LPT flow area (TFF2) opens an average of 0.7 percent in airline service. While this has little effect on fuel-burn, it does affect other performance parameters; the area change has been included in the current CF6-6D long-term deterioration model.

And finally, the component efficiency results emphasize the advantages of back-to-back testing with direct module (LPT) substitution. In many of the tests, the calculated core efficiencies (HPC, HPT, and parasitics) varied for no explainable reason. The back-to-back tests, however, allowed a direct assessment of the LPT deterioration (or restoration) by measuring the overall change in engine sfc (fuel burn).

APPENDIX A - QUALITY ASSURANCE REPORT

INTRODUCTION

It is the fundamental precept of the Aircraft Engine Group to provide products and services that fulfill the Product Quality expectations of customers and maintain leadership in product quality reputation, in conformance to the policy established by the Executive Office.

The Quality System as documented in Aircraft Engine Group Operating Procedures provides for the establishment of Quality assurance requirements through the design, development, manufacture, test, delivery, application and post-delivery servicing of the product. These instructions and Operating Procedures clearly delineate the cross-functional responsibilities and procedures for implementing the system, which includes coordination with cognizant FAA/AFPRO functions prior to issue and implementation.

The Quality Organization implements the Quality System requirements in each of their assigned areas of responsibility, providing design review participation, quality planning, quality input to Manufacturing planning, quality assurance and inspection, material review control, production testing and instrument calibration.

The Aircraft Engine Group has additional Manufacturing facilities, and Overhaul/Service Shops such as the one at Ontario, California. These various facilities are termed "satellite" plants or locations. They are not considered vendors or suppliers for quality control purposes and have the same status and requirements they would have if located in the Evendale Manufacturing Facility.

The Field Service representatives are a key part of our Quality Organization, providing inputs into all areas concerning Product Quality. Quality Service representatives have access to all levels of management and are in a position to ensure that quality standards are maintained on our products operating in the field.

Our representatives stationed at United worked directly with Engineering and United personnel monitoring this program to assure objectives were accomplished, helping to bring the program to a successful conclusion.

The specific requirements for this contract were accomplished at the following locations:

1. Production Assembly and Engine Test - Evendale
2. Development Assembly and Engine Test - Evendale
3. Ontario Service Shop - Ontario
4. United Airlines Maintenance Operation Center - San Francisco

A summary of activities for each location is included in this report.

QUALITY SYSTEMS

Quality Systems for Evendale and Ontario are constructed to comply with Military Specifications MIL-Q-9858A, MIL-I-45208A, and MIL-C-45662A, and with Federal Aviation Regulations FAR-145 and (where applicable) FAR-21. The total AEG Quality System has been accepted by NASA-LeRC for fabrication of engines under prior contracts.

Inherent in the system is the assurance of conformance to the quality requirements. This includes the performance of required inspections and tests. In addition, the system provides change control requirements which assure that design changes are incorporated into manufacturing, procurement, and quality documentation, and into the products.

Engine parts are inspected to documented quality plans that define the characteristics to be inspected, the gages and tools to be used, the conditions under which the inspection is to be performed, the sampling plan, laboratory and special process testing, and the identification and record requirements.

Work instructions are issued for compliance by operators, inspectors, testers, and mechanics. Component part manufacture provides for laboratory overview of all special and critical processes, including qualification and certification of personnel, equipment, and processes.

When work is performed in accordance with work instructions, the operator/inspector records that the work has been performed. This is accomplished by the operator/inspector stamping or signing the operation sequence sheet to signify that the operation has been performed.

Control of part handling, storage, and delivery is maintained through the entire cycle. Engines and assemblies are stored in special dollies and transportation carts. Finished assembled parts are stored so as to preclude damage and contamination, openings are covered, lines are capped, and protective covers are applied as required.

A buildup record and test log is maintained for the assembly, inspection, and test of each major component or engine. Component and engine testing is performed according to documented test instructions, test plans, and instrumentation plans. Test and instrumentation plans were submitted to NASA for approval prior to the testing.

Records essential to the economical and effective operation of the Quality Program are maintained, reviewed, and used as a basis for action. These records include inspection and test results, nonconforming material findings, laboratory analysis, and receiving inspection.

Nonconforming hardware is controlled by a system of material review at the component source. Both a Quality representative and an Engineering representative provide the accept (use-as-is or repair) decision. Nonconformances are documented, including the disposition and corrective action if applicable to prevent recurrence.

CALIBRATION

The need for product measurement is identified and the design, procurement and application of measuring equipment specified at the start of the product cycle. Measuring devices used for product acceptance and instruments used to control, record, monitor, or indicate results of, or readings during, inspection and test are initially inspected, calibrated, and periodically reverified or recalibrated.

Documented procedures are used to define methods of calibration and verification of characteristics which govern the accuracy of the gage or instrument. Provisions are made for procurement of instrument calibration capability as a part of instrument system acquisition.

Frequency of recalibration is specified and measuring gages and instruments are labeled to indicate the period of use before recalibration is necessary. Records are maintained for each gage or instrument which lists the identification, serial number, calibration frequency, procedure, and results of each calibration.

Recalibration periods (frequency of calibration) are prescribed on the basis that the gages and instruments are within calibration tolerance limits at the end of the recalibration period. The results of recalibration are analyzed to determine the effectiveness of the recalibration period, and adjustments are made to shorten or lengthen the cycle when justified.

Standards used to verify the gages and instruments are traceable to the National Bureau of Standards.

QUALITY ASSURANCE FOR INSTRUMENTATION

Items defined as Standard Instrumentation (items appearing on the engine parts lists) will have Quality Assurance Control to the same degree as other engine components. Instrumentation on engines for Revenue Service will be subject to the test and inspection criteria identified in the applicable Shop Manual.

Items defined as "Test Instrumentation" (standard test instrumentation as identified in the applicable engine manual GEK 9266 for CF6 test section 72-00) will be subject to the same controls required for measuring and test equipment. This instrumentation is periodically reverified by the technician and recalibrated, at a prescribed frequency, against standards traceable to the National Bureau of Standards.

Items identified as "Special Instrumentation" (non-parts list or non-Tech Manual instrumentation supplied for this program) will have Quality Assurance Control consistent with the stated objectives of this program.

The instrumentation used for obtaining data for this contract fulfillment has not affected the engine operations or performance.

APPENDIX B - ACTIVITY SUMMARY BY LOCATION

PRODUCTION ASSEMBLY

In Production Assembly, the standard engine build procedures were used to insure compliance to Quality Systems. These procedures and practices are approved under FAA Production Certificate 108. The operating procedures utilize an Engine Assembly Build Record (EABR) and an Engine Assembly Configuration Record (EACR). These documents, incorporated into an Engine Record Book, serve as a historical record of the compliance to the Assembly Procedure, a record of critical assembly dimensions, and a record of the engine configuration. Work performed is claimed by the applicable inspector or assembler. (Samples of the EABR and EACR cards are provided in Figures B-1 and B-2 respectively.)

Production Assembly releases the engine to Test and upon successful completion of the required test, performs the necessary work and inspection in preparation for shipment to the customer.

PRODUCTION ENGINE TEST

In Production Engine Test, the engine is inspected and prepared for test per Engine Test Instruction (ETI) Number C15. The test for Task II was defined in Quality Control Inspection (QCI TE-CF6-2253).

Limits and restrictions of Production Test Specifications were applied during the testing of engines under this contract. The safety of the test crew and engine is ensured by conducting ETI C-18 CF6 cell check sheets prior to the performance of the test.

The engine performance data and safety parameters are recorded by automatic data recording (ADR). The data systems, test cell, thrust frame, fuel measuring systems, are calibrated on a periodic basis by specialized technicians. During testing, the ADR system is continually monitored by test engineers to ensure the quality of the data being recorded.

ONTARIO SERVICE SHOP

At the Ontario facility, a Quality Control Work Instruction (QCWI DF015) was written and coordinated with NASA LeRC. The QCWI provided instructions on these specific items as applicable to the CF6 diagnostic program.

Assembly/Disassembly Control
Rework Control
Workscope Definition
Nonconformance
Quality Planning
Auditing

GT 6331 (6/72)

ENGINE ASSEMBLY BUILD-UP RECORD

DATE ISSUED ________ ENGINE SERIAL NO. 451-507 ASSEMBLY SERIAL NO. ________ PAGE 02 OF 04

WORK STAT.	ENGINE MODEL	ASSEMBLY DWG. NO.	ASSEMBLY NAME	PROCEDURE TITLE	PROCEDURE DATE	REV. NO.
MSG56	CF6-6D			FAN FRAME SUB-ASSY		
07-14-77						

DATA IDENTIFICATION	OPER NO.	OPERATION INSTRUCTIONS	GREEN	FINAL	EPR	C/I
	036	TORQUE INLET GEARBOX MOUNTING BOLTS	A 4245	A		0
	037	DROP C 1.193 / 1.193 / 1.193 REF DIM 1.200	I J-38			0
		DIFF .002 / .002 / .001 REF LIMIT &- .002	I J-38			0
		DROP C / / REF DIM 1.200		I		0
		DIFF / / REF LIMIT &- .002		I		0
NO2BHBF	038	FIR OF NO 2 BRG HOUSING BORE .008 LIMIT MAX .010	I J-38	I		0
NO3BHBF	041	FIR OF NO 3 BRG HOUSING BORE .006 LIMIT MAX .008	I J-38	I		0
	043	ASSURE PROPER NO 3 BRG AND RECORD BRG S/N SGA 01833	A 4245			0
	047	TORQUE NO 3 BRG BOLTS	A 4245			0
	056	TORQUE 2 SCREWS TO 25 IN LB AND ASSURE SCREW HEADS ARE				0
		.001-.020 BELOW FLANGE	A 4245			0
	059	CHECK NO 2 BRG HOUSING SEATING	A N/D			0
	061	PLUG GAGE INTO ID OF SEAL NUT	A N/D			0
	064	TORQUE NO 1 BRG HOUSING BOLTS	A N/D			0
NO2FIR	065	RECORD MAX FIR LIMIT .010 FIR MAX	A N/D			0
	071	CHECK FOR .060 CLEARANCE BETWEEN TUBES AND FRAME	A N/D			0
	075	CHECK NO 2 BRG SEATING	A N/D	A		0
	076	TORQUE NO 2 BRG BOLTS	A N/D	A		0

Figure B-1. EABR Card.

c-2

PART TRANSFERS

DRAWING NUMBER	NOMENCLATURE	VENDOR CODE	SERIAL NO.	INSP. STAMP	DATE	TOTAL TIME	PENALTY	FUNCT. FAULT	TRANSFERRED FROM	REASON

QCI & SPECIAL CHECKS

REEN RELEASE
D RELEASE
INAL RELEASE
PR RELEASE

SPECIAL NOTES TO BE CLEARED

NOTE	ENTERED BY	DATE	CORRECTION MADE	ENTERED BY	DATE	CLEARED INSP	CLEARED DATE

Figure B-1. EABR Card (Concluded).

1556

ENGINE ASSEMBLY CONFIGURATION RECORD

BOOK/ENG. NUMBER	WORK STATION	DATE ISSUED	WORK-STATION DESCRIPTION	MODEL	SUB-ASSY.	DRAWING NO.	S/A SERIAL NO	PAGE
451-507	MSG56	09-02-77	FAN FRAME S/A	CF6-6				1

RQD. DATA	G. E. DRAWING NUMBER	ALT	R/W	NOMENCLATURE	PART POSITION NUMBER	QTY.	VSE	VENDOR CODE	RQD	PART SERIAL/HEAT LOT NO	RQD	CURE DATE
BR	MIL-L-25681C			50-50 MOLY	00000025 B	A/R		XXXXX		XXXXXXXX		
NEW MAJ	9155M67P01			NO 3 BEARING	01100	1	*	52676 SGA	S	SGA 01833		
BR	MS9217-06			BOLT-STA S	01121	17		XXXXX		XXXXXXXX		
BR	R584P05SL			BOLT BRG 3+4	01122	12		XXXXX		XXXXXXXX		
BR	MS9208-10			BOLT STA S	01123	20		XXXXX		XXXXXXXX		
BR	MS9321-09			WASHER	01130	20		XXXXX		XXXXXXXX		
BR	9607M05P08			PKG PREFOR	01152	1		XXXXX		XXXXXXXX		
*** MAJ	9654M23P04			NO 3 BRG SEAL	01153	1	*	11512 LAM	S	LAM 01269		
							*	18734 BES	S			
BR	R149P09A			PKG PREFOR	01155	1		XXXXX		XXXXXXXX		
***	9654M03G05			SEAL COMP INLE	01156	1	*	07482 PMB	S	PMB 40502		
RIW	9009M78G27			G/B ASSY INLET	03000	1		XXXXX	S	FIA 00203		
BR	R1394P015			BOLT	03020	12		XXXXX		XXXXXXXX		
BR	AN960C416L			WASHER	03030	12		XXXXX		XXXXXXXX		
	9065M44G01			TUBE LUBE	44900	1		XXXXX		XXXXXXXX		
	9064M10G01			MANFD LUBE	44901	1	*	96593 TUPR		XXXXXXXX		
	9065M45G02			MANIFOLD	44902	1		XXXXX		XXXXXXXX		
BR	9064M12P01			BRACKET	44910	1		XXXXX		XXXXXXXX		
BR	MS9208-07			BOLT	44921	3		XXXXX		XXXXXXXX		
66	CONTINUED ON NEXT PAGE WORKSTATION MSG56											

GT-6336

Figure B-2. EACR Card.

OPERATION RECORD					
START	FINISH	ASSY. BADGE	ASSEMBLER NAME	DATE	REMARKS
1	29	4245	J.E. Jones	23 Sept 77	Various Operations
30	100	4245	J.E. Jones	26 Sept. 77	not Disturbed
					See orig. B/U Sheet
					J.E.Jo. 9-26-77
101	120	4245	J.E. Jones	26 Sept. 77	

SIGN OUT LAST OPERATION IN HEAVY BLACK LINES

INSPECTION OPERATION RECORD					
START	FINISH	INSP. BADGE	INSPECTOR NAME	DATE	REMARKS

SIGN OUT LAST OPERATION IN HEAVY BLACK LINES

Figure B-2. EACR Card (Concluded).

Instrumentation Control (Safety)
Measuring and Test Equipment
Engine Test
Witnessing
Records
Failure Recording

To document the condition of the engine hardware, photographs were taken of the LPT shrouds and seals, representative HPT blades, LPT blades, compressor rotor, stator case, fan inlet guide vanes, CDP seal, HPT seals and shrouds, HPT rotor, HP nozzles. These photographs were of high quality and are available for review.

Work orders were written to provide work direction for Engine Test, Prep-to-Test inspections and for assembly and disassembly instructions. Inspections as requested were witnessed by the designated DCAS representative.

Examples of the work documents as issued to the Test and Assembly personnel are presented in figures:

- Figure B-3 - Test Operating Requirements
- Figure B-4 - Prep-to-Test & Test Check-Off Sheet
- Figure B-5 - Instrumentation Check Sheet
- Figure B-6 - Inspection Check List
- Figure B-7 - Work Order (HPCR)
- Figure B-8 - HPCR Inspection Sheet

DEVELOPMENT ASSEMBLY

In Development Assembly the requirements of the AEG Quality System were implemented through the standard integrated Assembly and Inspection Procedures. These procedures are very similar to Production Engine Assembly Procedures. The specific requirements for buildup and disassembly are identified by work request issued by Evaluation Engineering. The Development Assembly Operation is monitored by Development Assembly Quality to insure compliance to the approved Quality System.

DEVELOPMENT ENGINE TEST

The Development Engine Testing is conducted by specific functions of Engineering organizations; in this case, Evaluation Engineering. The Quality interface with Evaluation Engineering and Development Test is through the Development Assembly Quality Function.

Specific test instructions are defined by Work Requests which are initiated by the Evaluation Engineering Function.

Each test cell is periodically calibrated per AEG Operating Procedures. The test cell operation is responsible for conducting the prescribed test and

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AMENDMENT NO.

PERFORMANCE TESTS

5.1 INBOUND TEST

THE FOLLOWING SEQUENCE OF TESTING IS REQUIRED FOR THE CF6-6 TASK III ENGINE. THE TESTING WILL BE CONDUCTED IN THE ASO-ONTARIO CF6 TEST CELL WITH A LIGHTWEIGHT BELLMOUTH AND THE STANDARD CF6-6 ACCEPTANCE TEST COWLING CONFIGURATION.

1. INSTALL ENGINE IN THE CF6 TEST CELL AND SET UP PER CF6 SHOP MANUAL, 72-00-00 TESTING.

2. CHECK VARIABLE STATOR VANES COLD RIG, BUT DO NOT ADJUST UNLESS VSV TRACKS OUTSIDE OF THE OPEN LIMIT BY MORE THAN ONE DEGREE DURING ENGINE OPERATION. NO ADJUSTMENT IS TO BE MADE WITHOUT THE CONCURRENCE OF ASE ENGINEERING.

3. INSTALL INSTRUMENTATION AS DEFINED BY THE INSTRUMENTATION PLAN FOR THE TASK III ENGINES.

4. CONDUCT THE FOLLOWING PERFORMANCE TEST:

   a. PERFORM NORMAL PREFIRE CHECKS INCLUDING A LEAK CHECK.

   b. START ENGINE AND STABILIZE FOR FIVE MINUTES AT GROUND IDLE.

   c. SET THE FOLLOWING TWO STEADY-STATE DATA POINTS AND TAKE FULL DATA READINGS AFTER FOUR MINUTES STABLIZIATION:

POWER SETTING	CORRECTED FAN SPEED
50%	76.42% (2623 rpm)
75%	90.11% (3093 rpm)

NOTE: PERFORM FULL FUNCTIONAL TEST

   d. SLOW DECEL TO GROUND IDLE, AND ANALYZE THE TWO POINTS TO DETERMINE IF THE ENGINE CAN BE SAFETY OPERATED TO TAKEOFF POWER WITHOUT EXCEEDING ANY LIMITS (N2, EGT, VSV). ALSO ASCERTAIN THAT ALL INSTRUMENTATION, INCLUDING THE RECORDER, IS FUNCTIONING PROPERLY.

   e. SET THE FOLLOWING STEADY-STATE DATA POINTS AND TAKE TWO BACK-TO-BACK DATA READINGS AFTER FOUR MINUTES STABILIZATION. THE ENGINE SHOULD BE OPERATED AT MAXIMUM CONTINUOUS POWER FOR A MINIMUM OF SIX MINUTES PRIOR TO SETTING THE FOLLOWING POINTS. TAKE ONE DATA READING AFTER SIX MINUTES.

Figure B-3. Performance Tests.

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AMENDMENT NO.

POWER SETTING	CORRECTED FAN SPEED
TAKEOFF	100.30% (3443 rpm)
MAXIMUM CONTINUOUS	98.70% (3388 rpm)
MAXIMUM CRUISE	95.85% (3290 rpm)
75%	90.11% (3093 rpm)

f. SHUT DOWN FOR A MINIMUM OF 30 MINUTES AND THEN REPEAT STEPS b AND e.

5.2 SPECIAL INSTRUCTIONS:

THE FOLLOWING SPECIAL INSTRUCTIONS APPLY FOR TESTING THE CF6-6D TASK III ENGINE:

1. GENERAL ELECTRIC-EVENDALE PERSONNEL WILL BE ON SITE AND WILL ASSURE DATA QUALITY BEFORE THE ENGINE CAN BE RELEASED FROM THE TEST CELL.
2. OBTAIN A FUEL LHV SAMPLE BETWEEN THE DUAL-PERFORMANCE POWER CALIBRATIONS. A BOMB CALORIMETER WILL BE USED TO OBTAIN THE LHV.
3. NO PERFORMANCE DATA IS TO BE TAKEN WHEN VISIBLE PRECIPITATION EXISTS OR THE RELATIVE HUMIDITY EXCEEDS ~~XXXX~~ 85%.
4. PRESSURE TRANSDUCERS, FUEL METERS, AND THE THRUST LOAD CELL MUST BE WITHIN FAA CALIBRATION LIMITS AND THE CALIBRATIONS ~~XE~~TRACEABLE TO THE NATIONAL BUREAU OF STANDARDS.
5. AFTER FIRST INBOUND PERFORMANCE RUN, CLEAN FAN BLADES USING MCK. PERFORM ANOTHER SINGLE PERFORMANCE TEST.

RLA:mjs

Figure B-3. Performance Tests (Concluded).

W/O ______________________

ENGINE S/N ______________________

CF6
PREP TO TEST
&
TEST CHECKOFF SHEET

FORM NO. CF6-TEST-1
2/3/78
Page 4 Of 8
Revision 21

STEP	OPERATION	MECH. SIGNATURE DATE	INSP	INSP DATE
	TEST CELL Engine mount bolts placed correctly, secured and lockwired. Front mount bolts stretch .006"/.008". Left bolt stretch ·006" 6-22-78 Right bolt stretch .008"	✓ S. Sakie	GE 72 ASO	6-22-78
2.	Check accessory gearbox customer pads for proper installation of gear shaft plugs. ✓	✓ Morano	GE 72 ASO	6-22
3.	Check all engine mounts for proper installation and lockwired. ✓	S. Sakie	GE 21 ASO	6-22
4.	Check all required vibration pickups for installation, leads connected to their respective amplifier, lockwire. Check cooling air to T.R.F. pickup. Hookup. ✓	S. Sakie	GE 72 ASO	6-22
5	Check throttle operation and for positive fuel shutoff in zero position of fuel shutoff lever.	Morano	GE 72 ASO	6-22
6.	Check both ignition systems for operation of plug.	Morano	GE 72 ASO	6-22
7.	Check air starter piping, secure clamp and lockwire. ✓	Morano	GE 72 ASO	6-22
8.	All electrical connections secure and lockwired.	Morano	GE 72 ASO	6-22
9.	Check to see that specific gravity setting on M.F.C. is ~~.76~~ set .77 per book — if JP4 fuel is used. ✓	Morano	GE 72 ASO	6-22
10	Visually check inlet instrumentation shoes/probes for condition and security. Check sensing holes for obstructions. ✓	X	GE 72 ASO	6-22
X	See engineer rework instruction for steps __________ recorded on back of this page. Void sign-off for steps __________ and modify per instruction on back of this page.	X	X	

Figure B-4. CF6 Prep-to-Test and Test Checkoff Sheet.

ENGINE S/N 451-507

W/O 182960

CF6-6D-50

INSTRUMENTATION CHECKLIST

FORM NO. CF6- TEST-3
12/12/73
Page 1 of 4
Revision 1

ITEM	OPERATION	MECH	INSP	DATE
1.	Check air starter for proper servicing.	✓ Moore	GE 72 ASO	6-22-78
2.	Vibration: 3 Pick-ups (Lockwire)	✓		6-22
	A. ~~Compressor~~ turb rear frame horizontal Location: Aft 2 bolt holes of #8 strut (1st strut below 9/o/c split line)	[signature]	GE 72 ASO	
	B. Turbine ~~rear~~ MID frame horz. Location: 9 o/c, second & third bolt holes fwd. of T.R.F. flange "V"	✓ [signature]	GE 72 ASO	6-22
	C. Fan rear stator case horizontal Location: 3 o/c fourth bolt above the upper ignition exciter.	✓ N/A	GE 72 ASO	6-22
	D. No. one bearing - horizontal Location: 4 o/c no. 4 fan exit strut below stator actuator.	✓ [signature]	GE 72 ASO	6-22
	Variable stator vane position ind. Location: Transducer bracket at approx. 3 o/c on comp. front casing. Check rig marks: Ref. LAASS T.R. #CF6-50/082 Synchronize indicator to read zero ± 0.005 volts full open - record full closed 4.74 Volts. Lockwire.	✓ Moore	GE 72 ASO	6-22
4.	Variable bleed valve position ind. Location: Transducer bracket at V.B.V. - Bellcrank at 9 o/c position. Check rig plate alignment bar is centered in shaft cover "V" notch - synchronize indicator to read 5.0 ± 0.02 volts. Record full open________ Lockwire.	✓ N/A	GE 72 ASO	6-22

Figure B-5. CF6-6D,-50 Instrumentation Checklist.

CF6-6D, -50
INSPECTION CHECKLIST

FORM NO. Q.C.-232
3/10/76
Page 2 Of 3
Revision 3

ITEM	AREAS INSPECTED	CLEAN	NORMAL	CONTAM-INATED	INCOMING INSP/DATE	PREP TO TEST INSP/DATE	PREP TO SHIP INSP/DATE
2.	Starter magnetic plug					GE 18 ASO 6/21	
	Starter valve filter					NA	
	Explain on squawk sheet, the condition of any filter that is contaminated. All filters are to be clean prior to re-installation. Report any abnormal contamination to Q.C. Engineering.						
3.	Inlet area for "FOD" & loose or missing hardware, overall condition.					GE 18 ASO 6/21	
R 4.	Incoming check blocker doors; open ☐ closed ☐ (Check one). If received with blocker doors open, close them.					X	X
5.	Fan stator case & frame not including accessory gearbox area.					GE 18 ASO	
6.	High pressure compressor stator & related plumbing - right hand side.					GE 18 ASO	
7.	High pressure compressor stator & related plumbing - left hand side.					GE 18 ASO 2/21/78	
8	Compressor rear frame - right half to forward side of fire-seal.					GE 18 ASO	
9.	Compressor rear frame - left half to forward side of fireseal.					GE 18 ASO	
10.	Compressor rear frame - right half aft of fireseal.					GE 18 ASO	
11.	Compressor rear frame - left half aft of fireseal.					GE 18 ASO	
12.	Low pressure turbine module - right half.					GE 18 ASO	
13.	Low pressure turbine module - left half.					GE 18 ASO	
14.	Low pressure exhaust including turbine reverser or conical nozzle.					GE 18 ASO	
15. R	Prep to ship; If received with blocker doors open, close them.				X	X	

Figure B-6. CF6-6D,-50 Inspection Checklist.

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REASSEMBLY

After all inspection checks are completed, rebuild the LPT module per the SM.

3. CORE ENGINE INSPECTIONS

Disassemble the engine as necessary to obtain the required data on the noted EMU's. Disassembly will be performed per the following sequence of events; visually inspect EMU's to H.M.M.

NOTE 1: Photographs (detailed and overall) will be taken of each sub-assembly prior to its disassembly, with particular emphasis on deteriorated parts, or any unique condition. MODULE PHOTOGRAPHS NOT REQUIRED KZA 5/17/78

NOTE 2: Prior to removal of the Stage 1 HPTN assembly, obtain drop checks from the aft face of the CRF outer flange to the aft face of Stage 1 HPTN vane outer platforms in 8 equally spaced locations. At each location, obtain drops to both ends of each segment (16 individual readings)

DCAS INSP.

NOTE 3: Record inspection requirements on sheets supplied by Evendale engineer.

B. Split core engine away from fan module and route core to S/N Remove HPT module.

C. Position-mark and remove Stage 2 HPTR blades. Remove second stage nozzle.

D. Remove second stage nozzle, preserve the stage 2 blade retainer seal wire for engineering inspection.

E. Comply with Note 2 above (drop checks). Then remove the Stage 1 HPTN assembly.

F. Position-mark, then remove the 4B pressure balance seal (mini-nozzle).

G. Remove the CRF.

H. Remove the HPCS cases.

I. Send the HPC rotor to the rotor area.

4. HIGH PRESSURE TURBINE ROTOR (REFERENCE 72-53-00)

A. Install the rotor in the Runout Fixture. Shim the blades per the SM, and measure each Stage 1 and 2 blade tip at 0.1 inch from the leading and trailing edges as follows:

DCAS INSP

1. Measure and record the radius of blade No. 1 0.1 inch from the LE of each stage.

Figure B-7. Example of Work Order.

ESN 4[illegible] 507

DATE ____________

STAGE 1 HPTR BLADE RUNOUT DATA

RUNOUTS TAKEN AT .100" FROM LE AND TE OF EACH BLADE

No.	FWD.	AFT	No.	FWD	AFT	No.	FWD.	AFT	No.	FWD	AFT
1	.000	000	28	-.003	+.005	55	-.001	000	82	+.002	+.007
2	+.002	+.003	29	-.003	+.001	56	-.002	+.001	83	-.001	+.005
3	-.003	+.001	30	000	+.005	57	000	+.003	84	000	+.008
4	+.001	+.006	31	-.004	+.003	58	-.001	+.006	85	-.001	+.005
5	-.002	-.001	32	000	+.008	59	-.001	+.002	86	+.001	+.007
6	+.003	+.005	33	-.004	-.001	60	-.002	+.004	87	+.001	+.007
7	-.002	-.001	34	000	+.004	61	-.002	+.002	88	-.001	+.008
8	+.002	+.005	35	-.002	+.001	62	000	+.005	89	-.002	+.008
9	-.003	-.001	36	000	+.005	63	000	+.003	90	-.003	+.008
10	-.001	+.005	37	-.008	-.003	64	+.001	+.005	91	+.001	+.006
11	-.004	-.002	38	-.002	+.004	65	000	+.001	92	-.002	+.006
12	000	+.005	39	-.004	006	66	-.001	+.005	93	+.003	+.003
13	-.002	-.003	40	-.002	+.006	67	000	-.001	94	000	+.002
14	+.001	+.004	41	-.004	+.002	68	-.001	+.004	95	000	+.006
15	-.002	000	42	-.001	+.007	69	000	-.001	96	-.002	+.007
16	+.001	+.004	43	-.002	+.002	70	+.002	+.004	97	-.001	+.008
17	-.004	-.002	44	-.001	+.005	71	-.001	000	98	-.006	+.007
18	+.002	+.003	45	-.006	+.002	72	+.002	+.005	99	-.001	+.006
19	-.001	-.001	46	-.004	+.004	73	000	+.001	100	-.004	+.006
20	+.002	+.005	47	+.001	+.003	74	+.003	+.008	101	000	+.010
21	-.002	-.004	48	+.002	+.005	75	+.001	-.001	102	-.003	+.009
22	+.001	+.002	49	-.003	+.002	76	+.003	+.005	103	-.002	+.008
23	-.002	-.001	50	+.002	+.006	77	000	000	104	-.004	+.008
24	+.002	+.004	51	-.002	000	78	+.002	+.007	105	-.005	+.008
25	-.002	+.001	52	+.002	+.006	79	+.002	+.001	106	-.008	+.006
26	000	+.005	53	+.001	+.001	80	+.002	+.006	107	-.006	000
27	-.004	+.001	54	000	+.005	81	+.001	+.001	108	-.008	+.002

READINGS ARE IN MILS

RADIUS AT #1 = FWD 16.560" AFT = 16.566

FWD. MAX = 16.563 MIN = 16.552 AVG. = 16.559

AFT MAX = 16.576 MIN = 16.562 AVG = 16.570

Figure B-8. HPTR Inspection Sheet.

for insuring the safe operation of the test cell and test vehicle. The engine performance data were taken by an Astrodata system. This system is certified for accuracy per procedure in Attachment A.

UNITED AIRLINES

A portion of the Diagnostics Program was performed at the United Airlines Maintenance Operation Center at San Francisco, California. The technical guidance and leadership on the program was provided by GE Airline Service Engineering function. United provided a Technical Program Manager to coordinate activities between GE and United.

Activities such as the assembly and testing were monitored by Field Service personnel who report to the GE Quality Organization.

On-Site Engineering coverage/inspection was provided by Evendale as required for the success of this program. Limits and requirements of the Overhaul Manuals were applicable during the testing and assembly work on this program. The United Airlines Maintenance Operation Center's procedures and practices are approved by the FAA and controlled under the FAA Certification Station Number 11.

APPENDIX C - DIGITAL DATA SYSTEM(S) QUALITY CERTIFICATION

1.0 SCOPE

The purpose of this practice is to document the means which are used to certify the accuracy and precision of the Steady State Data Systems utilized in the development test facilities at the General Electric Company, Evendale and Peebles, Ohio.

2.0 INTRODUCTION

Performance test data acquisition and processing systems in the development test facilities at Evendale and the Peebles Test Operations will consist of one of the following systems as a function of the specific test facility.

a. ASTRODATA - Consists of an analog to digital data acquisition system for D.C. analog signal and frequency measurements and a pressure acquisition system for measurement of pressure measurements. A dedicated central on-line computer provides on-line conversion of test data to engineering units, parameter averaging with error analysis and rejection capability and performance calculations.

b. MODCOMP SYSTEM - These systems utilize the same fundamental analog, frequency and pressure acquisition technique as described for the Astrodata systems. A dedicated central on-line computer is utilized for test data processing, providing on-line conversion of test parameters to engineering units, parameter averaging with error analysis and rejection capability, performance calculations and inter-active graphics for engineering data analysis.

c. DYMEC SYSTEM - Consists of a central controller with analog to digital conversion and local sub-systems which provide signal multiplexing and signal conditioning to acquire data from various test facilities. Digital data from the central controller is processed on-line via an on-line central computer, thereby, providing the same data processing capabilities as the Astrodata and Modcomp systems.

Calibration practices described below apply in all cases to each of the above three (3) systems.

3.0 DEFINITIONS

3.1 IC & SL - Instrumentation Calibration and Standards Laboratory.

3.2 D.S.O. - Data Systems Operations.

3.3 CYCLIC CALIBRATION - Calibrations which are performed on a scheduled, periodic basis.

3.4 ON-LINE CALIBRATION - Calibrations which are performed during acquisition of test data.

4.0 POLICY

4.1 The Steady State Data Systems utilized for test data acquisition and processing in the Development Test and Evaluation test facilities are subject to the Instrumentation Calibration and Control requirements of AEG Operating Procedure #379.12 so that conformance with DOD Specification #MIL-C-45662A, "Calibration System Requirements," are achieved.

4.2 A number of subsidiary practices exist to provide more detailed, working level directions on the operations necessary to achieve the desired end result, which is complete system accuracy in the data handling systems.

4.3 All performance Steady State Data Systems shall be calibrated in compliance with established practices and certification shall be traceable to the National Bureau of Standards. Required documentation shall be maintained for a minimum of three years.

5.0 INSTRUCTIONS AND PROCEDURES

5.1 PRESSURE.

5.1 1 BAROMETER.

A certified Ruska, Model DDR 6000 Barometers are interfaced to the Steady State Data Systems to enable automatic acquisition of barometric pressure. Cyclic Calibrations of these barometers are calibrated by IC & SL per instruction CPX-1.0.

5.1.2 PRESSURE ACQUISITION SYSTEM.

Cyclic calibrations are performed (instruction ID.00.005, ID.00.006, ID.00.007) by D.S.O. by applying known pressure levels as measured against a certified C.E.C. air dead weight tester or Texas Instrument Precision Pressure Gauge. This data is recorded in the same manner as test data for each 10% of the appropriate pressure transducer range.

On-line verification of transducer stability are obtained by dedicating one input channel of each transducer to barometric presuure and one input to a known pressure level. Automatic analysis of these measured values versus expected are made for each test data point with data printout flags should tolerances be exceeded.

In addition, transducer outputs are automatically corrected for any variations in excitation voltage and/or zero offset.

5.2 FREQUENCY.

Cyclic calibrations per D.S.O. practice ID.00.009 are performed by comparing the system readout with that of a certified counter when both are reading a common output frequency of an audio oscillator.

On-line system verification is obtained by reading the input of a certified crystal controlled oscillator at each test data point.

5.3 THRUST.

5.3.1 Cyclic calibrations are performed by IC & SL and D.S.O. of all thrust stands per practices C.P.-F-3.3 and ID.00.082.

5.3.2 On-line verification is provided by automatic monitoring and error testing of excitation voltages, zero force tare values and bridge to bridge variations on the working load cell. (ID.00.082).

5.4 D.C. VOLTAGES.

Cyclic calibrations are performed per practice ID.00.009. Known voltage levels from a certified voltage standards are programmed to each multiplexor, read by the system and compared to expected values.

On-line/automatic calibrations are performed during engine operation. Each multiplexor has a dedicated offset and calibration channel. The offset channel being a shorted input and the calibration channel being connected to a certified voltage standard. These channels are recorded concurrently with engine test data. Measured test data are subsequently corrected for any measured variations in system offset and/or gain.

In addition, two additional channels are dedicated as "confidence channels." One channel is shorted to measure corrected offset and the second channel is connected to a second certified voltage standard to measure corrected system gain.

5.5 TEMPERATURE.

Working thermocouples are fabricated from precision grade wire, further calibrations per practice ID.00.036 are performed by GE. Calibration data are reviewed by engineering to determine if corrections to measured temperatures are required; if required, the calibration data are stored in the data system and on-line corrections performed.

Copper alloy reference blocks are utilized for all thermocouple inputs to the data system. Indicated temperatures are corrected for junction temperature by the computer. Reference junction temperature is determined by reading the output of one of the reference block channels which is referenced to a certified 32° F ice point reference. A secondary certified ice point reference is also read from each reference block and compared to the primary reference to assure required confidence.

The ice point reference units are certified on a cyclic basis per practice ID.00.083.

6.0 CONTROL.

6.1 All calibration data are reviewed by engineering personnel and retained on file for a minimum of three (3) years.

Calibration techniques and practices are reviewed at least on an annual basis.

6.2 Computer software has been developed to enable automatic analysis, error testing and flagging of all on-line calibration and system confidence parameters during engine test operations. Copies of this data with appropriate identification such as; engine number, test data, test cell and engine data reading number are retained on file by D.S.O.

7.0 CYCLIC CALIBRATION INTERVALS. (Figure C-1)

7.1 PRESSURE - 3 months.

7.2 FREQUENCY - 3 months.

7.3 THRUST - 3 months, or as specified by engineering, whichever is shorter.

7.4 TEMPERATURES.

7.4.1 Thermocouples, when fabricated.

7.4.2 Ice point reference units - 2 months.

7.5 D.C. VOLTAGES - 3 months.

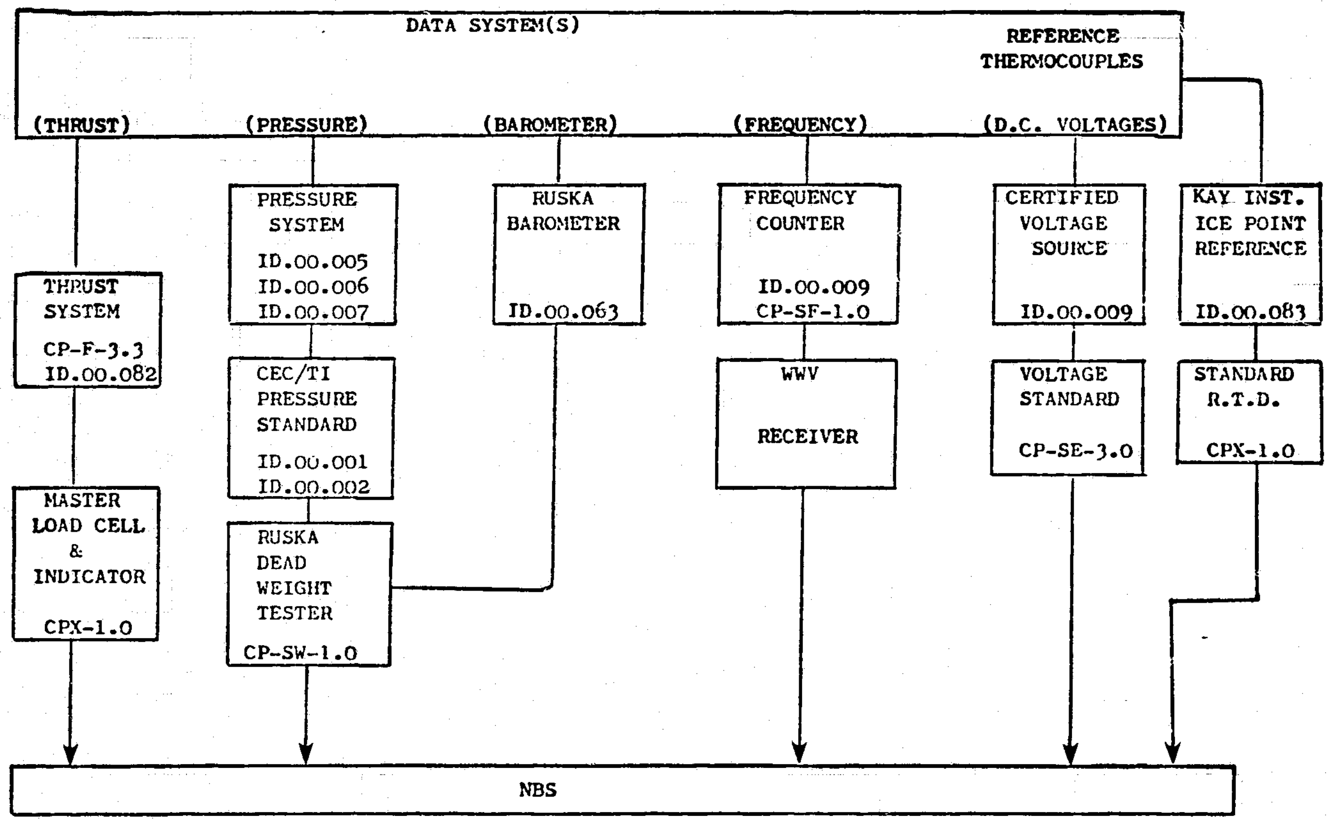

Figure C-1. Development Test and Evaluation Steady State Data Systems Traceability.