LONG-TERM CF6 ENGINE PERFORMANCE DETERIORATION - EVALUATION
OF ENGINE S/N 451-479

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This report summarizes the performance testing and analytical teardown of CF6-6D engine serial number 451-479 at the General Electric Aviation Service Operation, Ontario, California. This United Airlines engine had completed its initial installation on DC-10 aircraft number N3029U. The investigative test program was conducted inbound prior to normal overhaul/refurbishment. The performance testing included an inbound test, a test following cleaning of the low pressure turbine airfoils, and a final test after leading edge rework and cleaning the stage one fan blades. The analytical teardown consisted of detailed disassembly inspection measurements and airfoil surface finish checks of the as received deteriorated hardware. Included in this report is a detailed analysis of the test cell performance data, a complete analytical teardown report with a detailed description of all observed hardware distress, and an analytical assessment of the performance loss (deterioration) relating measured hardware conditions to losses in both SFC (specific fuel consumption) and EGT (exhaust gas temperature).
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ETAT High Pressure Turbine Efficiency
F_N Net Thrust
F_N@N1 Net Thrust at Constant Fan Speed
FBW Full Blade Width
FIR Full Indicated Runout
FWD Forward
G1, G2, G3, G4, G5, G6 High Pressure Turbine Rotor Forward Shaft, Forward Seal Teeth
Gilmore Tradename for Cell Meter Displaying Exhaust Gas Temperature
H1, H2, H3, H4, H5, H6 High Pressure Turbine Rotor Forward Shaft - Aft Seal Teeth
HF High Pressure
HPC High Pressure Compressor
HPS High Pressure System
HPT High Pressure Turbine
HPTN High Pressure Turbine Nozzle
HPTR High Pressure Turbine Rotor
HRS Hours
ID Inside Diameter
IGV Inlet Guide Vane
IN Inch
Dim "K" Dimension "K", High Pressure Turbine Nozzle Support - reference Shop Manual, 72-52-00
LE, L/E Leading Edge
LP Low Pressure
LPS Low Pressure System
LPT Low Pressure Turbine
LPTN Low Pressure Turbine Nozzle
LPTR Low Pressure Turbine Rotor
LPTS Low Pressure Turbine Stator
MAX Maximum
M/C Maximum Continuous
MM Maintenance Manual
MRL Maximum Repairable Limit
NI, N₁  Fan Speed
No.  Number
No. 4B  Number Four Ball Bearing
CGV  Outlet Guide Van
P₃, P₃  Compressor Discharge Pressure
P₄₉, P₄₉  Low Pressure Turbine INlet Pressure
PARAS  Parasitics
QEC  Quick Engine Connect
RAD  Radius
RMS  Root Mean Square
SFC  Specific Fuel Consumption
SFC Margin  Specific Fuel Consumption Margin
SL  Sea Level
S/M  Shop Manual
S/N  Serial Number
STG  Stage
SWECO  Vibratory Mill Cleaning Process
T₃  Compressor Discharge Total Temperature
T₅ₓ  Calculated Exhaust Gas Temperature
T/C  Thermocouple
TE  Trailing Edge
TMF  Turbine Mid Frame
TSN  Time Since New
T/O  Takeoff
UA  United Airlines
V₁, V₂, V₃, V₄  High Pressure Turbine Rotor Thermal Shield Seal Teeth V₄
WC₁₆  Sixteenth Stage Cooling Air Flow
WF  Fuel Flow
Δ  Delta
η  Efficiency
ηₖ  High Pressure Compressor Efficiency
η₇  Fan Efficiency
η₉  High Pressure Turbine Efficiency
η₂₉  Low Pressure Turbine Efficiency
1.0 INTRODUCTION

CF6-6D Engine S/N 451-479 was selected to be the first of a planned four Task IV (Long Term Performance Deterioration) engines, in accordance with the requirements outlined in the NASA-Lewis CF6 Jet Engine Diagnostics Program, Contract No. NAS3-20631. Log No. D11, dated March 11, 1977, describes the rationale and justification for selection of this engine. Included in that document, is a performance history of 451-479 including production acceptance test, aircraft trim run, first takeoff and cruise, and revenue service cruise trend data.

The test plan for this engine was defined in Log No. D12, dated March 11, 1977. Included in that document is a list of test objectives, a description of the basic CF6-6 engine, an itemized test plan schedule, detailed instructions for the designated performance tests, analytical teardown, refurbishment and reassembly instructions, and an instrumentation and facilities description for the General Electric Aviation Service Operation (ASO) Ontario, California CF6 Test Cell.

Log No. D13 describes the instrumentation required for the performance testing of the engine. Standard airline instrumentation was required to measure test cell engine performance. Additional low pressure turbine inlet pressure probes (P49) and high pressure compressor discharge temperatures (T3 rake) were requested and were used to ensure data consistency and accuracy.

This report summarizes all of the pertinent data generated during the course of the test plan, together with an analytical evaluation of the data. This report is a revision of the first 451-479 Task IV Engine Report dated July 29, 1977. Sections 5.0 (Performance Summary) and 7.0 (Analytical Assessment of Performance Losses) have been rewritten to reflect recent findings with regard to cruise to test cell performance correlations and errors in the analytical teardown hardware assessment.
2.0 OBJECTIVES

In accordance with the requirements outlined in the NASA-Lewis CF6 Jet Engine Diagnostics Program, Contract No. NAS3-20631, the following objectives were considered paramount for engine S/N 451-479, as well as for all future Task IV engines:

- Component analyses of long-term performance deterioration with regard to deterioration magnitude and apportionment to individual components.
  - High Pressure Compressor Efficiency
  - High Pressure Turbine Efficiency
  - Parasitics
  - Low Pressure (LP) System Efficiency
  - Thrust at Fan Speed

- Evaluation of LP turbine (LPT) performance restoration with regard to LPT vane and blade surface finish.

- Evaluation of fan performance restoration with regard to blade leading edge quality and airfoil surface cleanliness.

- Analysis of HP core losses (HP compressor, HP turbine, and parasitics) for use in correlating analytical teardown inspection results.

- Obtain data for the CF6 deterioration model in terms of both component and overall (EGT and SFC) performance.
3.0 ENGINE HISTORY

CF6-6D Engine S/N 451-479 was installed new on United Airlines DC-10-10 Aircraft No. N3029U (DACO #207) in the left wing location (Position No. 1). Subsequently, it was delivered to United Airlines in July 1975, with the engine still installed in its original position.

The United Airlines DC-10 route structure includes Chicago as a focal point, with routes, including intermediate stops, to the West Coast (Los Angeles, San Francisco, Portland, and Seattle) and Hawaii, and to the East Coast (Boston, New York, Washington, and Miami). The UA fleet includes 37 DC-10-10 aircraft.

Engine 451-479 was a CF6-6D "Task Force" engine (451-467 and up), which contained a number of performance and ruggedization improvements. The primary modifications included elliptical grinding of the HPT shrouds, shimming of the Stage 1 HPT nozzle, and increased cooling holes in the Stage 2 HPT nozzle support.

The engine was removed from the aircraft on March 16, 1977 to participate in the NASA-Lewis Diagnostics Program as the first Task IV engine. At that time, it had accumulated 4468 total hours and 1910 cycles. After removal of the QEC kit at UA, the engine was delivered to the General Electric Aircraft Service Operation (ASO), Ontario, California, on March 18.
4.0 SUMMARY OF EVENTS

Work Order No. 181460 was generated by ASO/O to fulfill the requirements of the Test Plan (Log No. D12). The program objectives were met in the following chronological sequence:

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-18-77</td>
<td>Engine arrived at Ontario. Incoming inspections performed and engine prepared for testing. Suspected faulty EGT T/C harness (lower left) replaced.</td>
</tr>
<tr>
<td>3-21-77</td>
<td>Engine set up in test cell. Initiated inbound test.</td>
</tr>
<tr>
<td>3-22-77</td>
<td>Completed inbound test. Engine returned to shop.</td>
</tr>
<tr>
<td>3-24-77</td>
<td>Initiated LPT disassembly and inspection checks.</td>
</tr>
<tr>
<td>4-1-77</td>
<td>Completed inspections and SWECO-cleaning of LPT blades and vanes.</td>
</tr>
<tr>
<td>4-15-77</td>
<td>Completed rebuild of engine.</td>
</tr>
<tr>
<td>4-19-77</td>
<td>Engine set up in test cell. Initiated retest, with cleaned LPT airfoils.</td>
</tr>
<tr>
<td>4-20-77</td>
<td>Completed test. Recontour and clean Stage 1 fan blades.</td>
</tr>
<tr>
<td>4-21-77</td>
<td>Completed test. Install original lower left EGT T/C harness.</td>
</tr>
<tr>
<td>4-21-77</td>
<td>Completed test. Engine returned to shop.</td>
</tr>
<tr>
<td>4-25-77</td>
<td>Initiated analytical teardown of core.</td>
</tr>
<tr>
<td>5-9-77</td>
<td>Completed core engine inspections.</td>
</tr>
<tr>
<td>5-17-77</td>
<td>Engine (in modules) returned to United Airlines.</td>
</tr>
</tbody>
</table>
5.0 451-479 PERFORMANCE SUMMARY

Performance testing of 451-479 consisted of three separate double-power calibrations. The three were an inbound test, a test following cleaning of the LPT blades and vanes, and final test following leading edge rework and cleaning of the Stage 1 fan blades. The data were consistent and repeatable with the exception of EGT which shifted 10° C cold between the inbound and post LPT performance tests.

The inbound test included two down-power calibrations. A grounded section (lower left) of the EGT harness was replaced prior to running the test. The calculated minus indicated EGT (ΔT5-X) level (5° F) was consistent with the outbound Evendale production power calibration (9° F) which indicates changing this segment had a negligible effect on the measured EGT.

The measured performance deterioration (production new to ASO/O inbound) was consistent with the level obtained for eight other inbound tests. Figure 5-1 presents aircraft cruise trend data as compared to these sample engines. Shown on these curves is a "fleet average" level which corresponds to the average cruise deterioration level of CF6-6D engines S/N 451-406 and up. Figures 5-2 and 5-3 present the inbound test cell deterioration levels for 451-479 and the other eight inbound engines. The "sea level fleet model" shown is based on sea level-to-altitude correlations of 0.7 for SFC, 0.8 for EGT, and 1.0 for WF (i.e., ΔEGT at cruise = 0.7 x ΔEGT at sea level).

The inbound data are summarized in Tables 5-1 and 5-2. Almost all the measured component deterioration (inbound versus production acceptance) occurred in the HP turbine as presented below. Note that 1.3% of the 4.5% SFC deterioration is due to the "instant loss" at the aircraft manufacturer and not deterioration during revenue service.

-0.2% ΔETAC (HP Compressor Efficiency)
-4.3% ΔETAT (HP Turbine Efficiency)
0 ΔPARAS (Core Engine Internal Leakages and Cooling Flows)
-0.1% ΔETALPS (LP System Efficiency)
+0.6% FN@Nl (Thrust at Fan Speed)
Figure 5-1. CF6-6D Cruise Deterioration.
Figure 5-2. CF6-6D Inbound Sea Level Deterioration.
Figure 5-3. CF6-6D Inbound Sea Level Deterioration.
<table>
<thead>
<tr>
<th>Date</th>
<th>Production</th>
<th>Inbound</th>
<th>After LPT</th>
<th>After Fan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>Production</td>
<td>Inbound</td>
<td>After LPT</td>
<td>After Fan</td>
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<td>3-22-77</td>
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<td>1.0%</td>
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<td>-3.2%</td>
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<table>
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<tr>
<th>T/O Hot Day EGT</th>
<th>1566°F</th>
<th>1674°F</th>
<th>1656°F</th>
<th>1662°F</th>
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<tr>
<td>M/C Hot Day EGT</td>
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<td>1606°F</td>
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<td>1594°F</td>
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<td>T/O Hot Day T5X</td>
<td>1557°F</td>
<td>1668°F</td>
<td>1668°F</td>
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<tr>
<td>M/C Hot Day T5X</td>
<td>1493°F</td>
<td>1602°F</td>
<td>1603°F</td>
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Note: Stackup versus an average 1975 production engine. Inbound data includes "instant" loss at the aircraft manufacturer (1.3% SFC).
Table 5-2. 451-479 Stackup.

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<td>DETAT</td>
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<td>DETAT</td>
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<td>-1.4</td>
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</table>
The measured performance stackup is presented using an $A_4$ of 53.594 sq. in. An attempt was made to measure $A_4$ but nine of the Stage 1 HPT vane segments were badly burned at the trailing edge. In addition, ballooning, cracking, and bowing of the nozzle vanes raised questions as to whether $A_4$ was assessed correctly. The resulting $A_4$ was obtained by extrapolating the measurable vane segments using tool 2C6846. $A_4$, in conjunction with the measured HPT pressure ratio, is used to assess the performance tradeoff between parasitics and HPT efficiency. Furthermore, the condition of the TMF liner can affect the pressure ($P_{49}$) as well as the temperature (EGT) measurement. Similarly, much effort has been placed in developing a simple, yet accurate, method of measuring compressor discharge temperature and pressure. A change in either parameter will result in a different component assessment as to the correct apportionment to compressor efficiency, turbine efficiency, and parasitics.

The test following the LPT airfoil cleaning also consisted of two down-power calibrations. The data indicated no improvement relative to the inbound run. In fact, the LP system efficiency worsened after the LPT work. The data analysis is slightly clouded due to a shift in indicated EGT. $T_{5X}$ (calculated EGT), however, was consistent and was adequate for the component stackups. The performance data are summarized in Tables 5-1 and 5-3. The following component deltas were measured relative to the inbound run:

$+0.1\%$ EGT@N1  
$-0.1\%$ ETAT  
$0$ APARAS  
$-0.4\%$ ETALPS  
$+0.1\%$ FN@N1  
$-18^\circ F$ EGT@N1  
$0$ T5X@N1  
$+0.2\%$ SFC@FN
Table 5-3. 451-479 Stackup.

<table>
<thead>
<tr>
<th>Run</th>
<th>Reading</th>
<th>SFC Margin</th>
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<th>Based on $T_x$</th>
<th>Based on EGT</th>
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<td></td>
<td></td>
<td>EGT</td>
<td>DELT $T_x$</td>
<td>DETAC DETAT</td>
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<td>-3.7</td>
<td>1591</td>
<td>7</td>
<td>-0.1 -5.2 -1.3</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>-3.8</td>
<td>1590</td>
<td>15</td>
<td>0.0 -6.1 -1.7</td>
</tr>
<tr>
<td>AVG</td>
<td>-3.7</td>
<td></td>
<td>1656/1590</td>
<td>12</td>
<td>-0.2 -5.5 -1.4</td>
</tr>
</tbody>
</table>

$A_4 = 53.549$
The double-power calibrations following the fan cleaning and leading edge rework showed a positive improvement in both SFC and thrust (0.5% SFC@FN and +0.5% FN@N1). There was no improvement in EGT@N1 because both airflow and fan efficiency increased. The performance data are summarized in Tables 5-1 and 5-4. The following component deltas were measured relative to the previous test:

-0.2% \( \Delta \text{ETAC} \)  
+0.2% \( \Delta \text{ETAT} \)  
+0.1% \( \Delta \text{PARAS} \)  
+0.7% \( \Delta \text{ETALPS} \)  
+0.5% \( \text{FN@N1} \)  
+6° F \( \text{EGT@N1} \)  
+2° F \( \text{T5X@N1} \)  
-0.5% \( \text{SFC@FN} \)  

Following the fan test, a complete investigation was conducted to understand the indicated EGT shift. Table 5-5 summarizes the checks made to the harness and cell readout system. The checks revealed no discrepancies. The grounded section of EGT harness was reinstalled and check points were run to try and understand the EGT shift. There was no measurable difference in EGT or \( \Delta \text{T5X} \) (Table 5-6). An inspection following the last testing sequence showed one of the harness probe aspirator holes to be immersed in the cooler TMF liner. Due to the mechanical condition of the liner (cracks and two holes), buckling of the liner may have caused the indicated EGT shift.
Table 5-4: 451-479 Stackup.

<table>
<thead>
<tr>
<th>Run</th>
<th>Reading</th>
<th>SFC Margin</th>
<th>Hot Day Based on $T_5$</th>
<th>Day of EGT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\Delta T_5$</td>
<td>DETAC</td>
</tr>
<tr>
<td>After Fan</td>
<td>31</td>
<td>-3.4</td>
<td>1662</td>
<td>7</td>
</tr>
<tr>
<td>$A_4 = 53.549$</td>
<td>32</td>
<td>-3.5</td>
<td>1658</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>33</td>
<td>-3.4</td>
<td>1591</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>-2.7</td>
<td>1594</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>39</td>
<td>-3.1</td>
<td>1663</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>-3.0</td>
<td>1663</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>41</td>
<td>-2.9</td>
<td>1594</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>42</td>
<td>-3.5</td>
<td>1594</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>-3.8</td>
<td>1659</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>44</td>
<td>-3.5</td>
<td>1665</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>-2.7</td>
<td>1596</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>46</td>
<td>-3.4</td>
<td>1594</td>
<td>17</td>
</tr>
<tr>
<td>AVG</td>
<td>36</td>
<td>-3.2</td>
<td>1662/1594</td>
<td>9</td>
</tr>
</tbody>
</table>
Table 5-5. EGT Harness Checks.

1. Verify digital and cell meter (log sheets); indicate same EGT.

1a. Check same on previous run (if data are available).

After Next Run

2. Send calibration signal through cell system (at forward lead connection and read-out on Digital + Gilmore.

3. Visual EGT harness and leads for broken/damaged leads or connectors. Check that connectors are seated.

4. Check total EGT System (at forward lead connector) with Meggar per 77-21-01.

5. Disconnect forward and aft lead and disconnect T/C harness from aft lead.
   - Visual connectors for broken, missing, bent, or loose pins.
   - Check pin-pin and pin-casing per MM for
     - T/C harness (four sectors)
     - Forward lead
     - Aft lead

Check shop to see if anyone noted any discrepancy during disassembly and reassembly.
<table>
<thead>
<tr>
<th>Run</th>
<th>Reading</th>
<th>Margin</th>
<th>SFC</th>
<th>Not Day</th>
<th>EGT</th>
<th>DELT _X</th>
<th>DETAC</th>
<th>DETAT</th>
<th>DPARAS</th>
<th>DETALPS</th>
<th>DFN1</th>
<th>DETAC</th>
<th>DETAT</th>
<th>DPARAS</th>
<th>DETALPS</th>
<th>DFN1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean Harness</td>
<td>50</td>
<td>-3.4</td>
<td></td>
<td></td>
<td>1669</td>
<td>-3</td>
<td>-0.3</td>
<td>-5.1</td>
<td>-1.5</td>
<td>-0.2</td>
<td>0.9</td>
<td>-0.3</td>
<td>-4.6</td>
<td>-1.5</td>
<td>0.1</td>
<td>0.9</td>
</tr>
<tr>
<td>A_4 = 53.549</td>
<td>51</td>
<td>-3.3</td>
<td></td>
<td></td>
<td>1594</td>
<td>10</td>
<td>0.1</td>
<td>-5.8</td>
<td>-1.6</td>
<td>0.1</td>
<td>0.5</td>
<td>0.1</td>
<td>-4.7</td>
<td>-1.5</td>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>52</td>
<td>-3.8</td>
<td></td>
<td></td>
<td>1596</td>
<td>13</td>
<td>-0.4</td>
<td>-4.6</td>
<td>-0.8</td>
<td>-0.6</td>
<td>0.7</td>
<td>-0.4</td>
<td>-3.4</td>
<td>-0.6</td>
<td>0.1</td>
<td>0.7</td>
</tr>
<tr>
<td>AVG</td>
<td></td>
<td>-3.5</td>
<td></td>
<td></td>
<td>1669/1695</td>
<td>7</td>
<td>-0.2</td>
<td>-5.2</td>
<td>-1.3</td>
<td>-0.2</td>
<td>0.7</td>
<td>-0.2</td>
<td>-4.2</td>
<td>-1.2</td>
<td>0.3</td>
<td>0.7</td>
</tr>
<tr>
<td>Old Harness</td>
<td>54</td>
<td>-3.7</td>
<td></td>
<td></td>
<td>1666</td>
<td>4</td>
<td>-0.5</td>
<td>-5.1</td>
<td>-1.4</td>
<td>-0.5</td>
<td>0.7</td>
<td>-0.5</td>
<td>-4.3</td>
<td>-1.4</td>
<td>0.0</td>
<td>0.7</td>
</tr>
<tr>
<td>A_4 = 53.549</td>
<td>55</td>
<td>-3.4</td>
<td></td>
<td></td>
<td>1598</td>
<td>0</td>
<td>-0.1</td>
<td>-5.4</td>
<td>-1.7</td>
<td>-0.3</td>
<td>0.5</td>
<td>-0.1</td>
<td>-4.8</td>
<td>-1.7</td>
<td>0.1</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>56</td>
<td>-3.3</td>
<td></td>
<td></td>
<td>1596</td>
<td>7</td>
<td>-0.1</td>
<td>-5.4</td>
<td>-1.5</td>
<td>-0.1</td>
<td>0.6</td>
<td>-0.1</td>
<td>-4.5</td>
<td>-1.5</td>
<td>0.4</td>
<td>0.8</td>
</tr>
<tr>
<td>AVG</td>
<td></td>
<td>-3.5</td>
<td></td>
<td></td>
<td>1666/1597</td>
<td>4</td>
<td>-0.2</td>
<td>-5.3</td>
<td>-1.5</td>
<td>-0.3</td>
<td>0.7</td>
<td>-0.2</td>
<td>-4.5</td>
<td>-1.5</td>
<td>0.2</td>
<td>0.7</td>
</tr>
</tbody>
</table>
6.0 POSTTEST TEARDOWN RESULTS

Upon completion of the test cell runs, the core engine was subjected to an analytical teardown inspection, the results of which are contained herein. During the course of the test program, the low pressure system had likewise been disassembled, cleaned, and inspected. These results are also included in this section.

The inspection results include observations concerning the hardware which were performance related, and do not imply that no other discrepancies existed.

6.1 HIGH PRESSURE COMPRESSOR SECTION

6.1.1 HP Compressor Rotor Assembly

6.1.1.1 General Inspection

Inspection of the HP compressor rotor revealed the spool and blades to be extremely dirty throughout, with a heavy deposit of oil mixed with the dirt in the forward end (through Stage 6). Some very mild aluminum splatter was noted on blades in Stages 12 and aft. A photograph of the rotor assembly was taken (Figure 8-1); however, it was not taken until after the rotor had been prematurely cleaned, erasing all evidence of the dirty condition.

6.1.1.2 Rotor Land Rubs

No vane-to-spool rubs were detected on any land. There was a new gouge, probably caused by a variable stator vane near the split line being out of position during disassembly.

6.1.1.3 Rotor Land Coating Condition

The coating of the compressor rotor lands was inspected with the following discrepancies noted (Figure 8-2 in Appendix B):

<table>
<thead>
<tr>
<th>Stage</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 and 16</td>
<td>100% missing</td>
</tr>
<tr>
<td>14</td>
<td>20/30% missing</td>
</tr>
<tr>
<td>13</td>
<td>30/40% missing</td>
</tr>
<tr>
<td>3 - 12</td>
<td>OK</td>
</tr>
</tbody>
</table>
6.1.1.4 Blade Airfoil Condition

Except for the dirt and oil previously noted, the airfoils were in excellent condition. There was no evidence of any nicked, or otherwise damaged blades. Blades in Stages 8 through 12, 15, and 16 showed some slight tip rub, as evidenced by the rubs noted on the compressor stator lands (see 6.1.2.4).

6.1.1.5 Blade Surface Finish

Two blades each from Stages 3 through 16 were removed for surface-finish checks, using a profilometer. Original plans also included blades in Stages 1 and 2 for these checks. However, to expedite the test plan, blades in these two stages were visually inspected and deemed to be about the same quality as blades in Stages 3 and 4; therefore, they were not removed from the rotor.

Surface-finish checks were taken at 15%, 50%, and 85% of blade height at:

- 10/15% of chord from leading edge on the suction side.
- 10/15% of chord from trailing edge on the pressure side.

Results were as follows (RMS μ inch):

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>25</td>
<td>15</td>
<td>13</td>
<td>18</td>
<td>46</td>
<td>30</td>
<td>15</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>4</td>
<td>21</td>
<td>19</td>
<td>21</td>
<td>19</td>
<td>46</td>
<td>30</td>
<td>15</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>15</td>
<td>15</td>
<td>17</td>
<td>17</td>
<td>46</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>25</td>
<td>13</td>
<td>12</td>
<td>17</td>
<td>46</td>
<td>30</td>
<td>15</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>7</td>
<td>22</td>
<td>15</td>
<td>26</td>
<td>21</td>
<td>44</td>
<td>30</td>
<td>15</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>8</td>
<td>27</td>
<td>18</td>
<td>20</td>
<td>22</td>
<td>44</td>
<td>30</td>
<td>15</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>9</td>
<td>30</td>
<td>20</td>
<td>20</td>
<td>23</td>
<td>44</td>
<td>30</td>
<td>15</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>10</td>
<td>30</td>
<td>30</td>
<td>35</td>
<td>39</td>
<td>44</td>
<td>30</td>
<td>15</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>11</td>
<td>27</td>
<td>35</td>
<td>34</td>
<td>33</td>
<td>44</td>
<td>30</td>
<td>15</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>12</td>
<td>35</td>
<td>30</td>
<td>20</td>
<td>29</td>
<td>44</td>
<td>30</td>
<td>15</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>
**6.1.1.6 Rotating CDP Seal**

Measurements of each of the CDP seal teeth were made, with the results as follows:

<table>
<thead>
<tr>
<th>Tooth</th>
<th>Max. Diameter</th>
<th>FIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>18.130&quot;</td>
<td>0.004&quot;</td>
</tr>
<tr>
<td>H</td>
<td>17.931&quot;</td>
<td>0.002&quot;</td>
</tr>
<tr>
<td>G</td>
<td>17.731&quot;</td>
<td>0.0015&quot;</td>
</tr>
<tr>
<td>F</td>
<td>17.531&quot;</td>
<td>0.001&quot;</td>
</tr>
<tr>
<td>E</td>
<td>17.3305&quot;</td>
<td>0.001&quot;</td>
</tr>
<tr>
<td>D</td>
<td>17.131&quot;</td>
<td>0.0015&quot;</td>
</tr>
</tbody>
</table>

Resultant clearances can be found in 6.1.3.3, "Stationary CDP Seal Measurements."

**6.1.2 High Pressure Compressor Stator Assembly**

**6.1.2.1 General Inspection**

Inspection of the HP compressor stator assembly revealed a heavy mixture of oil and dirt in the forward stages, through Stage 6. The heaviest buildup accumulated on the IGV's and the IGV inner shrouds, and got progressively better from stage to stage. The remaining vanes, though not oily, were extremely dirty. There was a very mild splattering of aluminum on the Stage 13 vanes and OGV's. A photograph of the upper stator case can be seen in Appendix B, Figure 8-3.
6.1.2.2 Condition of Variable Stator Bushings

Variable stator bushings were generally in excellent condition. A total of 12 Stage 6 vanes were found to be slightly loose and only one vane in this stage revealed metal-to-metal contact. Stage 5 had three vanes which were slightly loose, but no metal-to-metal contact.

All of the Stage 3 vanes, in the lower-case only, were on the loose side. This would seem to indicate that they had been initially assembled in this manner, since all other variable vanes in both casing halves exhibited the normal tightness.

6.1.2.3 Vane Airfoil Condition

Except for the oil and dirt, all airfoils were in excellent condition. No nicks or other discrepancies were noted on any vane.

6.1.2.4 Casing Rubs

Inspection of the stator case lands revealed the following blade tip-to-case rubs:

<table>
<thead>
<tr>
<th>Stage</th>
<th>Depth</th>
<th>Width</th>
<th>Location</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-7</td>
<td>No Rub</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Kiss</td>
<td>FBW</td>
<td>12 o'clock</td>
<td>3&quot; in length no depth</td>
</tr>
<tr>
<td></td>
<td>.003</td>
<td>FBW</td>
<td>1 o'clock</td>
<td>1.3&quot; in length</td>
</tr>
<tr>
<td>9</td>
<td>Kiss</td>
<td>FBW</td>
<td>9-10 o'clock</td>
<td>1.5&quot; in length no depth</td>
</tr>
<tr>
<td>10</td>
<td>No rub</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Kiss</td>
<td>.5&quot;</td>
<td>1 o'clock</td>
<td>2.5&quot; in length no depth</td>
</tr>
<tr>
<td>12</td>
<td>Kiss</td>
<td>.4&quot;</td>
<td>12 &amp; 1 o'clock</td>
<td>.7&quot; &amp; 1.5&quot; in length in aft case only. No depth</td>
</tr>
<tr>
<td>13</td>
<td>No rub</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>No rub</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>.005</td>
<td>FBW</td>
<td>10-11 o'clock</td>
<td>4.5&quot; in length</td>
</tr>
<tr>
<td></td>
<td>.003</td>
<td>FBW</td>
<td>12 o'clock</td>
<td>2.3&quot; in length</td>
</tr>
<tr>
<td>16</td>
<td>.005</td>
<td>FBW</td>
<td>1-2 o'clock</td>
<td>4.5&quot; in length</td>
</tr>
<tr>
<td></td>
<td>.008</td>
<td>FBW</td>
<td>1-2 o'clock</td>
<td>4.5&quot; in length</td>
</tr>
</tbody>
</table>

Note: FBW = Full Blade Width
HP Compressor Casing Rubs - Lower
(See Photo, Figure 8-5 in Appendix B)

<table>
<thead>
<tr>
<th>Stage</th>
<th>Depth</th>
<th>Width</th>
<th>Location</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-7</td>
<td>No rub</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Kiss</td>
<td>.050&quot;</td>
<td>7-8 o'clock</td>
<td>6&quot; in length, T/E</td>
</tr>
<tr>
<td>9</td>
<td>No rub</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Kiss</td>
<td>1/2 BW</td>
<td>7 o'clock</td>
<td>1.5&quot; in length</td>
</tr>
<tr>
<td>11</td>
<td>No rub</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>No rub</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>No rub</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>No rub</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Kiss</td>
<td>1/2 BW</td>
<td>5-7 o'clock</td>
<td>12&quot; in length</td>
</tr>
<tr>
<td></td>
<td>.003</td>
<td>FBW</td>
<td>8 o'clock</td>
<td>2.5&quot; in length</td>
</tr>
<tr>
<td>16</td>
<td>.003</td>
<td>FBW</td>
<td>5-6 o'clock</td>
<td>3&quot; in length</td>
</tr>
</tbody>
</table>

Note: FBW = Full Blade Width

6.1.2.5 Vane Surface Finish

Two vanes each from Stages 7 through OGV's were removed for surface-finish checks. Readings were taken with a profilometer at 15%, 50%, and 85% of vane height at:

- 10/15% of chord from LE on convex side.
- 10/15% of chord from TE on concave side.

Results are as follows (RMS μ inch):

<table>
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Convex -- Stage -- Concave

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<th>Tip</th>
<th>Pitch</th>
<th>Root</th>
<th>Avg.</th>
<th>Stage</th>
<th>Tip</th>
<th>Pitch</th>
<th>Root</th>
<th>Avg.</th>
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<th>Tip</th>
<th>Pitch</th>
<th>Root</th>
<th>Avg.</th>
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Average surface finish of vanes = 47 RMS μ inch.

6.1.3 Compressor Rear Frame

6.1.3.1 General

A cursory inspection of the compressor rear frame revealed no notable discrepancies. A more detailed inspection of the combustor and dimensional checks of the CDP seal and the 4B pressure balance seal (mini-nozzle) were performed, with results as follows:

6.1.3.2 Combustor

To expedite the work scope, the combustor was not removed from the rear frame, but rather visually inspected as installed. The combustor had its typical 1/4" to 1/2" cracks, inner and outer liners. The most noteworthy fault was the cracks originating at the inner liner's aft thimble louver at approximately the 7 o'clock location. This particular louver had cracked in four different directions of varying lengths (Figures 8-6 and 8-7 in Appendix B). The cracks were approximately 5/8", 1", and 2-1/2" in length and another about 2-1/4" long connecting with a 4-1/2" circumferential crack. The whole piece was bulged into the airstream approximately 5/8". There were six more of these thimble louvers with cracks ranging from 1/2" to 1-1/4" but these are considered insignificant with regard to performance.

6.1.3.3 Stationary CDP Seal, Forward

Measurements of each of the lands on the 4R CDP seal were taken and recorded. (A view of the forward CRF seals can be seen in Appendix B, Figure 8-8.) The results were as follows (all dimensions are in inches):
Clearances determined from this data and that taken on the corresponding HPC rotor seal (6.1.1.6) were as follows:

<table>
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<th>Dia.</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>F5</th>
<th>F6</th>
</tr>
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<tbody>
<tr>
<td>Max.</td>
<td>18.149</td>
<td>17.950</td>
<td>17.750</td>
<td>17.550</td>
<td>17.352</td>
<td>17.152</td>
</tr>
<tr>
<td>Min.</td>
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<td>17.949</td>
<td>17.749</td>
<td>17.549</td>
<td>17.351</td>
<td>17.151</td>
</tr>
<tr>
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<td>18.148</td>
<td>17.949</td>
<td>17.750</td>
<td>17.549</td>
<td>17.352</td>
<td>17.151</td>
</tr>
<tr>
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<td>17.950</td>
<td>17.749</td>
<td>17.550</td>
<td>17.352</td>
<td>17.152</td>
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<td>17.750</td>
<td>17.550</td>
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<tr>
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<td>17.949</td>
<td>17.749</td>
<td>17.549</td>
<td>17.351</td>
<td>17.152</td>
</tr>
<tr>
<td>Avg.</td>
<td>18.148</td>
<td>17.949</td>
<td>17.749</td>
<td>17.549</td>
<td>17.352</td>
<td>17.152</td>
</tr>
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</table>

6.1.3.4 No. 4B Pressure Balance Seal Measurements

Diameter measurements of each land of each of the aft seals in the No. 4B pressure balance seal (mini-nozzle) were taken and are recorded below (dimensions are in inches). These are the seals that mate with the high pressure turbine rotor forward shaft seals. (A photograph of the mini-nozzle is contained in Appendix B, Figure 8-9.)
### Forward Seal (Aft CDP Seal)

**B70**

<table>
<thead>
<tr>
<th>Dia.</th>
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<th>F3</th>
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<th>F5</th>
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<tr>
<td>Max.</td>
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<td>8.104</td>
<td>8.265</td>
<td>8.424</td>
<td>8.584</td>
<td>8.744</td>
</tr>
<tr>
<td>Min.</td>
<td>7.942</td>
<td>8.102</td>
<td>8.263</td>
<td>8.422</td>
<td>8.582</td>
<td>8.742</td>
</tr>
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<td>8.103</td>
<td>8.263</td>
<td>8.424</td>
<td>8.582</td>
<td>8.743</td>
</tr>
<tr>
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<td>8.103</td>
<td>8.263</td>
<td>8.423</td>
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<td>7.942</td>
<td>8.104</td>
<td>8.265</td>
<td>8.424</td>
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<td>8.744</td>
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<tr>
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<td>7.943</td>
<td>8.104</td>
<td>8.264</td>
<td>8.423</td>
<td>8.582</td>
<td>8.743</td>
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<td>7.943</td>
<td>8.103</td>
<td>8.264</td>
<td>8.422</td>
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<td>8.743</td>
</tr>
<tr>
<td>8</td>
<td>7.944</td>
<td>8.102</td>
<td>8.265</td>
<td>8.422</td>
<td>8.582</td>
<td>8.743</td>
</tr>
<tr>
<td>Avg.</td>
<td>(7.943)</td>
<td>8.103</td>
<td>8.264</td>
<td>8.423</td>
<td>8.583</td>
<td>8.743</td>
</tr>
</tbody>
</table>

**Shop Manual Dimensional Requirements**

| Minimum | 7.942 | 8.102 | 8.262 | 8.422 | 8.582 | 8.742 |

### Aft Seal (HPT Balance Piston Seal)

**B-71**

<table>
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<th>F3</th>
<th>F4</th>
<th>F5</th>
<th>F6</th>
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<tr>
<td>Max.</td>
<td>10.443</td>
<td>10.622</td>
<td>10.778</td>
<td>10.942</td>
<td>11.105</td>
<td>11.260</td>
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<td>10.442</td>
<td>10.616</td>
<td>10.772</td>
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<td>10.617</td>
<td>10.771</td>
<td>10.940</td>
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<td>10.773</td>
<td>10.941</td>
<td>11.099</td>
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<td>10.443</td>
<td>10.620</td>
<td>10.778</td>
<td>10.942</td>
<td>11.105</td>
<td>11.262</td>
</tr>
</tbody>
</table>

**Shop Manual Dimensional Requirements**

| Maximum | 10.446 | 10.606 | 10.766 | 10.926 | 11.086 | 11.246 |

Resultant clearances between these seals and the corresponding rotating seals are contained in Section 6.2.3.6, 'Forward Shaft Seal Dimensions.'
6.2 **HIGH PRESSURE TURBINE SECTION**

6.2.1 **Stage I High Pressure Turbine Nozzle Assembly**

6.2.1.1 **General Inspection**

Visual inspection of the Stage I HPTN assembly revealed 13 vanes with some degree of burning on the trailing edge, while some other vanes were bowed in the same area. (See photographs in Appendix B, Figures 8-10 through 8-13. Note that the position markings as viewed in the photographs are incorrect. Per B/P, the vane marked No. 18 is really Vane No. 1. From that point, the vanes should be marked in clockwise order. For orientation purposes, all references to vane position numbers in this report are per the **actual** position and **not** as depicted in the pictures.) As can be seen in the photographs, all vane distress emanated approximately from the center of the airfoils at the trailing edge, and continued radially outward and inward about the same amount for each particular vane.

All of the vanes that experienced the burning/distortion showed radial cracks of varying lengths on the concave side, depending on the severity of the distress. These cracks were located 3/8" to 1/2" forward of the trailing edge.

The leading edges of the vanes exhibited the normal minute cracks and splatter buildup, but all cooling holes appeared to be open. The same could be said for the concave face of the vanes; while the convex side was smooth, which is also normal. Surface finish checks of the airfoils were made on several vanes and are tabulated in 6.2.1.5, "Airfoil Surface Finish Checks."

The thermal shields, inside the vane platform ID, were distorted the full 360° circumference. Two bolt head covers, No. 2 (in line with Nozzles No. 5 and 6) and No. 12 (in line with Nozzles No. 45 and 46), were also heavily deformed.

The aft face of the Stage I vane outer hook showed contact 360°; however, the first vane of each segment (CW, ALF) appeared to be marked heavier than the other.

The inspection also revealed (though it was not performance-related) that
five of the outer fishmouth seal tabs were burned away (three approximately 25% missing; one approximately 50% missing; one approximately 10% missing). There was also one inner fishmouth seal tab burned with approximately 40% missing.

6.2.1.2 Drop Dimension - CRF to Stage 1 Vanes

Drop dimensions from the CRF aft flange to the aft face of the Stage 1 vane outer hook were taken at 16 equally spaced locations, starting at 12 o'clock and working CW. The results were as follows:

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<td>9 4.853&quot;</td>
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</tr>
<tr>
<td>8</td>
<td>4.856&quot;</td>
<td>16 4.860&quot;</td>
</tr>
</tbody>
</table>

Average = 4.861"

Note: This engine was equipped with the 0.020" shim (PN 92570), which mounts between the CRF/Stage 2 nozzle flanges. Stackup of mating parts is contained in 6.2.2.5.

6.2.1.3 Vane Outer Platform Gap Measurements

Gaps between outer platforms on adjacent vanes were measured at 16 equally spaced locations and were as follows:

<p>| | | |</p>
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</thead>
<tbody>
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<td>0.029&quot;</td>
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<td>2</td>
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</tr>
<tr>
<td>8</td>
<td>0.025&quot;</td>
<td>16 0.027&quot;</td>
</tr>
</tbody>
</table>

These are well within the shop manual limits of 0.015" min. and 0.045" max.
6.2.1.4 Area Check (A4)

A check of the nozzle exit area was conducted with some difficulty. Due to the distress previously noted, it was impossible to obtain an accurate reading on some of the severely burned and distorted vanes. Measurements were taken of all the vanes that it was possible to measure, and data extrapolated to arrive at the final estimated A4 of 53.960 sq. in.

Area check of each of the individual nozzles is as follows:

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<th>Nozzle No.</th>
<th>Area No.</th>
<th>Area</th>
<th>Nozzle No.</th>
<th>Area</th>
<th>Nozzle No.</th>
<th>Area</th>
</tr>
</thead>
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<td>0.917</td>
<td>57</td>
</tr>
<tr>
<td>10</td>
<td>0.835</td>
<td>26</td>
<td>0.870</td>
<td>42</td>
<td>D</td>
<td>58</td>
</tr>
<tr>
<td>11</td>
<td>0.888</td>
<td>27</td>
<td>0.837</td>
<td>43</td>
<td>D</td>
<td>59</td>
</tr>
<tr>
<td>12</td>
<td>0.814</td>
<td>28</td>
<td>0.784</td>
<td>44</td>
<td>D</td>
<td>60</td>
</tr>
<tr>
<td>13</td>
<td>0.838</td>
<td>29</td>
<td>0.836</td>
<td>45</td>
<td>D</td>
<td>61</td>
</tr>
<tr>
<td>14</td>
<td>0.824</td>
<td>30</td>
<td>0.848</td>
<td>46</td>
<td>0.868</td>
<td>62</td>
</tr>
<tr>
<td>15</td>
<td>0.838</td>
<td>31</td>
<td>0.832</td>
<td>47</td>
<td>0.870</td>
<td>63</td>
</tr>
<tr>
<td>16</td>
<td>0.785</td>
<td>32</td>
<td>0.796</td>
<td>48</td>
<td>0.832</td>
<td>64</td>
</tr>
</tbody>
</table>

D = Distorted and/or Burned

6.2.1.5 Airfoil Surface Finish Checks

Three nozzle segments were removed from the assembly to check the airfoil surface finish. No problems were encountered in measuring the finish of the convex side; however, due to the curvature of the vane, it was not possible to set up the equipment to obtain all the desired measurements on the concave side. Measurements were taken at the pitchline at 10%, 50%, and 90% chord.

The following are the results of the surface finish measurements (RMS):
6.2.2 Stage 2 High Pressure Turbine Nozzle Assembly

6.2.2.1 General Inspection

A visual inspection of the Stage 2 high pressure turbine nozzle, as assembled, produced no surprising results. It proved to be about as expected for an assembly with this amount of running time (see photograph, Figure 8-14, for an overall view of the assembly). The more noteworthy results of the inspections are covered in the following paragraphs.

6.2.2.2 Shroud Rubs and Condition of Bradelloy

The Stage 1 shrouds were very rough and eroded/oxidized. One shroud (No. 17) had an irregular shaped piece missing, approximately 1" x 1-1/2" (see photograph in Appendix B, Figure 8-15). This was the only missing section.

Additional roughness was noted on the shrouds due to burning, located axially in the center of several of the pieces. Burned areas averaged approximately 3/8" x 1-1/2" on each of 13 shrouds with only three parts showing any depth (≈0.010"/0.020").

The Stage 2 shrouds had light erosion/oxidation, with no missing pieces. All shrouds were heavily rubbed, with a more recent rub, approximately 1" x 1-1/2", noted on shroud No. 1 (see photograph, Figure 8-16, in Appendix B).

6.2.2.3 Vane Condition

The vanes were in excellent condition with no burning noted on any of them. One vane, immediately behind Stage 1 Shroud No. 17, did show some type of impact damage in the center third of the leading edge (see photograph,
Figure 8-15 in Appendix B). None of the cooling holes showed indications of being clogged.

6.2.2.4 Spoolie Spring Washers

During the course of the visual inspections, eight spoolie spring washers were observed to be missing. Seven others were so badly worn that they were easily removed with no effort. All others were also worn to the extent that no more spring was left in them; however, they were still secured in place.

6.2.2.5 Nozzle Support

Inspection of the forward face of the support that mates to the Stage 1 nozzle vanes, showed good contact the full 360° circumference. All of the support cooling holes appeared to be open.

Drop checks from the forward face of the aft flange to the forward face of the lugs that support the Stage 1 vane outer hook (Dim. "K" in S/M) were taken at 16 equally spaced locations, starting at 12 o'clock, CW. The dimensions were as follows:

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.858&quot;</td>
<td>9</td>
<td>4.863&quot;</td>
</tr>
<tr>
<td>2</td>
<td>4.860&quot;</td>
<td>10</td>
<td>4.861&quot;</td>
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<td>3</td>
<td>4.861&quot;</td>
<td>11</td>
<td>4.856&quot;</td>
</tr>
<tr>
<td>4</td>
<td>4.867&quot;</td>
<td>12</td>
<td>4.858&quot;</td>
</tr>
<tr>
<td>5</td>
<td>4.864&quot;</td>
<td>13</td>
<td>4.857&quot;</td>
</tr>
<tr>
<td>6</td>
<td>4.865&quot;</td>
<td>14</td>
<td>4.857&quot;</td>
</tr>
<tr>
<td>7</td>
<td>4.869&quot;</td>
<td>15</td>
<td>4.858&quot;</td>
</tr>
<tr>
<td>8</td>
<td>4.857&quot;</td>
<td>16</td>
<td>4.862&quot;</td>
</tr>
</tbody>
</table>

Average 4.861"

Shop Dim. 4.857"/4.861"

Service Limits 4.853"/4.865"

Corresponding dimensions from the CRF aft flange to the aft face of the Stage 1 vane outer hook also average 4.861" (Reference 6.2.1.2, "Drop Dimension - CRF to Stage 1 Vanes"). However, this engine incorporated the 0.020" shim between the Stage 2 support mounting flange and the CRF aft flange. Therefore, the actual gap averaged 0.020".

29
6.2.2.6 Interstage Seal Grooves

The grooves in each of the interstage seal lands were measured at 12, 3, 6, and 9 o'clock positions. Measurements were obtained by rubbing a piece of chalk across the groove, and measuring the resultant protrusion. Following are the results:

<table>
<thead>
<tr>
<th>Location</th>
<th>Width</th>
<th>Depth</th>
<th>Width</th>
<th>Depth</th>
<th>Width</th>
<th>Depth</th>
<th>Width</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 o'clock</td>
<td>0.126</td>
<td>0.070</td>
<td>0.120</td>
<td>0.062</td>
<td>0.110</td>
<td>0.055</td>
<td>0.100</td>
<td>0.055</td>
</tr>
<tr>
<td>3 o'clock</td>
<td>0.135</td>
<td>0.090</td>
<td>0.135</td>
<td>0.075</td>
<td>0.110</td>
<td>0.080</td>
<td>0.105</td>
<td>0.060</td>
</tr>
<tr>
<td>6 o'clock</td>
<td>0.135</td>
<td>0.040</td>
<td>0.155</td>
<td>0.055</td>
<td>0.150</td>
<td>0.070</td>
<td>0.136</td>
<td>0.042</td>
</tr>
<tr>
<td>9 o'clock</td>
<td>0.125</td>
<td>0.055</td>
<td>0.130</td>
<td>0.055</td>
<td>0.130</td>
<td>0.052</td>
<td>0.125</td>
<td>0.052</td>
</tr>
<tr>
<td>Average</td>
<td>0.130</td>
<td>0.064</td>
<td>0.135</td>
<td>0.062</td>
<td>0.125</td>
<td>0.064</td>
<td>0.119</td>
<td>0.052</td>
</tr>
</tbody>
</table>

Note: All readings are in inches.

6.2.2.7 Stage 1 and Stage 2 Shroud Radii

The Stage 2 high pressure turbine nozzle assembly was restrained on its aft flange on the fixture normally used for shroud grind, and the entire assembly centered on the inspection table. Stage 1 and 2 shrouds were measured at axial locations approximately 1/2" from LE and 1/4" from TE at each end and at the center of each shroud. Measurements at each of these locations consisted of a diameter check at the 12 o'clock position and runouts relative to this point at each of the other positions.
Stage 1 Shroud Runout Data

<table>
<thead>
<tr>
<th>Shroud No.</th>
<th>1/2&quot; from LE</th>
<th>1/4&quot; from TE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 4 -1</td>
<td>0 5 5</td>
</tr>
<tr>
<td>2</td>
<td>2 3 2</td>
<td>10 9 3</td>
</tr>
<tr>
<td>3</td>
<td>8 10 10</td>
<td>4 14 13</td>
</tr>
<tr>
<td>4</td>
<td>11 25 15</td>
<td>18 25 17</td>
</tr>
<tr>
<td>5</td>
<td>15 12 3</td>
<td>18 25 17</td>
</tr>
<tr>
<td>6</td>
<td>18 18 14</td>
<td>16 27 24</td>
</tr>
<tr>
<td>7</td>
<td>16 18 14</td>
<td>16 21 20</td>
</tr>
<tr>
<td>8</td>
<td>19 23 20</td>
<td>24 25 24</td>
</tr>
<tr>
<td>9</td>
<td>23 23 15</td>
<td>25 28 22</td>
</tr>
<tr>
<td>10</td>
<td>17 13 8</td>
<td>24 25 16</td>
</tr>
<tr>
<td>11</td>
<td>8 8 6</td>
<td>16 15 12</td>
</tr>
<tr>
<td>12</td>
<td>5 6 4</td>
<td>12 15 13</td>
</tr>
<tr>
<td>13</td>
<td>3 5 2</td>
<td>12 12 10</td>
</tr>
<tr>
<td>14</td>
<td>-2 3 3</td>
<td>11 13 10</td>
</tr>
<tr>
<td>15</td>
<td>3 9 14</td>
<td>5 15 20</td>
</tr>
<tr>
<td>16</td>
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<td>20 25 29</td>
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<td>13 23 13</td>
<td>25 30 17</td>
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<td>18</td>
<td>18 17 15</td>
<td>22 27 22</td>
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<td>19</td>
<td>15 15 10</td>
<td>23 23 18</td>
</tr>
<tr>
<td>20</td>
<td>13 13 10</td>
<td>12 18 17</td>
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<tr>
<td>21</td>
<td>11 10 5</td>
<td>14 19 17</td>
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<td>22</td>
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<td>24</td>
<td>6 8 0</td>
<td>13 13 6</td>
</tr>
</tbody>
</table>

All readings are in mils and are positive, unless otherwise indicated.

<table>
<thead>
<tr>
<th>Leading</th>
<th>Trailing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter at 12 o'clock</td>
<td>33.288</td>
</tr>
<tr>
<td>Radius at 12 o'clock</td>
<td>16.643</td>
</tr>
<tr>
<td>Minimum Radius</td>
<td>16.641</td>
</tr>
<tr>
<td>Maximum Radius</td>
<td>16.668</td>
</tr>
<tr>
<td>Average Radius</td>
<td>16.653</td>
</tr>
</tbody>
</table>
Stage 2 Shroud Runout Data

<table>
<thead>
<tr>
<th>Shroud No.</th>
<th>1/2&quot; from LE</th>
<th>1/4&quot; from TE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>-1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>-1</td>
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<tr>
<td>4</td>
<td>6</td>
<td>4</td>
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<tr>
<td>5</td>
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<tr>
<td>11</td>
<td>1</td>
<td>-6</td>
</tr>
</tbody>
</table>

All readings are in mils and are positive, unless otherwise indicated.

<table>
<thead>
<tr>
<th></th>
<th>Leading</th>
<th>Trailing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter at 12 o'clock</td>
<td>34.595&quot;</td>
<td>34.605&quot;</td>
</tr>
<tr>
<td>Radius at 12 o'clock</td>
<td>17.293&quot;</td>
<td>17.300&quot;</td>
</tr>
<tr>
<td>Minimum Radius</td>
<td>17.291&quot;</td>
<td>17.293&quot;</td>
</tr>
<tr>
<td>Maximum Radius</td>
<td>17.308&quot;</td>
<td>17.308&quot;</td>
</tr>
<tr>
<td>Average Radius</td>
<td>17.299&quot;</td>
<td>17.301&quot;</td>
</tr>
</tbody>
</table>
6.2.3 High Pressure Turbine Rotor Assembly

6.2.3.1 General Inspection

An overall visual inspection of the HTPR assembly showed it to be in good condition. No discrepancies were noted in any of the spool parts (disks, shafts, seals, etc.). There appeared to be a heavy Stage 2 blade-to-shroud rub, as evidenced by the discoloration at the tips of all blades, accompanied by tip burrs the full blade width. Except for the slight deposit buildup at the leading edge, convex side, the Stage 2 airfoils were smooth.

Stage 1 blades also exhibited some rubbing, but not as much as Stage 2; no burrs were noted on the blade tips. The typical heavy deposits and roughness were seen on the concave surface of the airfoil, with the convex side being smooth.

Photographs of the HPTR can be seen in Appendix B, Figures 8-17 and 8-18.

The Stage 1 and Stage 2 blade retainer wire seals were in many small pieces. These were removed and returned to Evendale. Inspection of the pieces revealed good contact between the seals and the blades.

6.2.3.2 HPTR Blade Airfoil Surface Finish

Three blades from each stage were removed to check the surface finish of the airfoils by use of a profilometer. Measurements were taken on each side at 10%, 50%, and 90% of the blade chord. Following are the results of these inspection checks (RMS μ inch):

<table>
<thead>
<tr>
<th>Blade Stage No.</th>
<th>Fwd</th>
<th>Mid</th>
<th>Aft</th>
<th>Avg</th>
<th>Fwd</th>
<th>Mid</th>
<th>Aft</th>
<th>Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>110</td>
<td>45</td>
<td>45</td>
<td>67</td>
<td>75</td>
<td>105</td>
<td>195</td>
<td>125</td>
</tr>
<tr>
<td>2</td>
<td>130</td>
<td>50</td>
<td>30</td>
<td>70</td>
<td>50</td>
<td>160</td>
<td>150</td>
<td>120</td>
</tr>
<tr>
<td>3</td>
<td>150</td>
<td>50</td>
<td>50</td>
<td>83.3</td>
<td>55</td>
<td>150</td>
<td>170</td>
<td>125</td>
</tr>
<tr>
<td>Average</td>
<td>73.5</td>
<td>123</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>80</td>
<td>40</td>
<td>40</td>
<td>53.3</td>
<td>35</td>
<td>40</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>120</td>
<td>40</td>
<td>31</td>
<td>63.7</td>
<td>40</td>
<td>31</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>130</td>
<td>32</td>
<td>41</td>
<td>67.7</td>
<td>80</td>
<td>37</td>
<td>70</td>
</tr>
<tr>
<td>Average</td>
<td>61.5</td>
<td>51.5</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
6.2.3.3 Rotor Blade Tip Measurements

The HPT rotor was set up in a lathe bed and the blades shimmed per the shop manual. Runouts at two axial locations (0.100" from both the leading edge and the trailing edge) of each blade, together with the maximum blade radius of each stage, were taken and recorded. Following are the detailed data.

<table>
<thead>
<tr>
<th>Stage 1 HPT Blade Runout Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
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<td>3</td>
</tr>
<tr>
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<td>5</td>
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<tr>
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<td>7</td>
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<td>8</td>
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<tr>
<td>9</td>
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</tr>
<tr>
<td>25</td>
</tr>
<tr>
<td>26</td>
</tr>
<tr>
<td>27</td>
</tr>
</tbody>
</table>

0 = 16.569 in. = Maximum Blade Radius

Other readings are in mils and are negative.

Aft Max. = 16.569 in.       Min. = 16.553 in.     Avg. = 16.562 in.
### Stage 2 HPTR Blade Runout Data

<table>
<thead>
<tr>
<th>No.</th>
<th>Fwd</th>
<th>Aft</th>
<th>No.</th>
<th>Fwd</th>
<th>Aft</th>
<th>No.</th>
<th>Fwd</th>
<th>Aft</th>
<th>No.</th>
<th>Fwd</th>
<th>Aft</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>3</td>
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<td>8</td>
<td>2</td>
<td>59</td>
<td>13</td>
<td>4</td>
<td>88</td>
<td>10</td>
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<tr>
<td>2</td>
<td>7</td>
<td>4</td>
<td>31</td>
<td>10</td>
<td>1</td>
<td>60</td>
<td>12</td>
<td>6</td>
<td>89</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>2</td>
<td>32</td>
<td>6</td>
<td>2</td>
<td>61</td>
<td>10</td>
<td>3</td>
<td>90</td>
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<td>7</td>
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<td>12</td>
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<td>14</td>
<td>3</td>
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<td>8</td>
<td>1</td>
<td>34</td>
<td>6</td>
<td>1</td>
<td>63</td>
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<td>5</td>
<td>35</td>
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<td>64</td>
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<td>6</td>
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<td>65</td>
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<td>66</td>
<td>11</td>
<td>3</td>
<td>95</td>
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<td>4</td>
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<td>9</td>
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<td>1</td>
<td>67</td>
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<td>3</td>
<td>96</td>
<td>10</td>
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</table>

$O = 17.223\text{ in.} = \text{Maximum Blade Radius}$

Other readings are in mils and are negative.


Aft Max. = 17.223 in.  Min. = 17.215 in.  Avg. = 17.220 in.
### 6.2.3.4 HPT Blade Clearances

Calculated clearances, as derived from the blade tip measurements and the shroud dimensions (Section 6.2.2.7) were as follows:

<table>
<thead>
<tr>
<th>Stage No.</th>
<th>B/P</th>
<th>Min.</th>
<th>Max.</th>
<th>Avg.</th>
<th>AB/P</th>
</tr>
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<tbody>
<tr>
<td>1 (LE)</td>
<td>0.072 in.</td>
<td>0.077 in.</td>
<td>0.118 in.</td>
<td>0.095 in.</td>
<td>+0.023 in.</td>
</tr>
<tr>
<td>1 (TE)</td>
<td>0.072 in.</td>
<td>0.063 in.</td>
<td>0.109 in.</td>
<td>0.087 in.</td>
<td>+0.015 in.</td>
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<tr>
<td>1 (Avg)</td>
<td>0.072 in.</td>
<td>0.070 in.</td>
<td>0.114 in.</td>
<td>0.091 in.</td>
<td>+0.019 in.</td>
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<tr>
<td>2 (LE)</td>
<td>0.075 in.</td>
<td>0.074 in.</td>
<td>0.101 in.</td>
<td>0.086 in.</td>
<td>+0.011 in.</td>
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<tr>
<td>2 (TE)</td>
<td>0.075 in.</td>
<td>0.070 in.</td>
<td>0.093 in.</td>
<td>0.081 in.</td>
<td>+0.006 in.</td>
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<tr>
<td>3 (Avg)</td>
<td>0.075 in.</td>
<td>0.072 in.</td>
<td>0.097 in.</td>
<td>0.084 in.</td>
<td>+0.009 in.</td>
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### 6.2.3.5 Thermal Shield Seal Teeth

While in the lathe bed, measurements were taken of the HPTR thermal shield seal teeth, in the same manner as taken on the forward shaft seals.

<table>
<thead>
<tr>
<th>Runout</th>
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</table>


Resultant diameters are as follows:

- **Average**: 26.630" 26.473" 26.311" 26.055"
6.2.3.6 Forward Shaft Seals Dimensions

While in the lathe bed, the maximum radius of each tooth of each forward shaft seal was recorded, together with the runouts at 12 equally spaced locations. In the following tabulations, 0 = maximum tooth radius; all other readings are in mils, and are negative.

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O = Max. Rad. = 3.952" 4.042" 4.121" 4.200" 4.283" 4.361"
Min. Rad. = 3.9505" 4.039" 4.1195" 4.197" 4.281" 4.359"

Calculated Diameters

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Shop Manual Dimensions

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* MRL = Maximum Repairable Limits

Using stationary seal data from 6.1.3.4, clearances were determined to be:
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Overall Average Clearance = 0.013" vs 0.010" stackup of production hardware.

**Forward Shaft Aft Seal**

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0 = Max. Rad. = 5.214" 5.298" 5.378" 5.457" 5.536" 5.614"

Min. Rad. = 5.206" 5.290" 5.371" 5.448" 5.5285" 5.608"

**Calculated Diameters**

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**Shop Manual Dimensions**

<table>
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</table>

* MRL = Maximum Repairable Limits

Using stationary seal data from 6.1.3.4, clearances were determined to be:
### 6.3 LOW PRESSURE TURBINE SECTION

One of the most important objectives of the NASA-Lewis Diagnostics Program is to evaluate low pressure turbine (LPT) performance restoration. In accordance with this, following the inbound performance test, the LPT module was removed from the engine and disassembled into its major components for various inspection checks, and for cleaning of the blades and vanes.

Upon completion of this activity, the module was rebuilt and reinstalled on the engine. This was followed by a test cell run to measure the change in engine and component performance. While the work was being performed on the LPT section, the rest of the engine was not disturbed. This was done so that any performance changes could be attributed only to the refurbishment of the LPT blade and vane surface finish, and not to some unrelated activity.

During the core analytical teardown, the LPT module was removed from the engine and set aside with no further disassembly. In time it was returned to United Airlines "as is"- together with the engine modules and other hardware.

Following are the results of the LPT module analytical teardown and refurbishment.

#### 6.3.1 Turbine Midframes

##### 6.3.1.1 General

Visual inspection of the turbine midframe revealed two holes (3/4" dia. and approximately 1" x 2-1/2") in the inner liner aft of Strut No. 2; one hole on each side of the strut (see photograph, Figure 8-18 in Appendix B). Aft of Strut No. 2, there was a 4" circumferential crack in the liner, and another circumferential crack approximately 9" long was observed in the liner.
behind Strut No. 3.

The aft outer seal had numerous cracks and several missing pieces. A number of cracks were also noted on the Stage 1 nozzle outer support ring.

No attempt was made to repair or to replace any of the discrepant parts. Any change of hardware at this time could have clouded any subsequent data taken to analyze the LP system per the test plan.

It was the consensus of opinion that none of the noted faults were serious enough to imperil the engine during the remaining planned tests. Therefore, after all the inspection checks were complete, the TMF was reassembled to the package together with all the original hardware "as is." The test program was completed without incident.

After removal of the LPT module during the core analytical teardown, the TMF liner was visually inspected, as viewed from the forward end, and no further crack progression was noted. It was noted during this inspection that the buckling of the liner had caused one EGT T/C probe aspirator hole to be immersed in the cooler TMF liner cavity. Another was partially immersed. Possibly this could have been the reason for the inconsistent EGT indicated readings, recorded during the several tests conducted.

6.3.1.2 LPT Pressure Balancing Seal

An eight-point diameter measurement of the LPT pressure balance seal produced the following results:

1. 19.054"
2. 19.049"
3. 19.053"
4. 19.049"
5. 19.055"
6. 19.052"
7. 19.049"
8. 19.051"

Average = 19.052"; S/M = 19.050"/19.054"

Average clearance (C27) to the rotating seal (see 6.3.2.2) was calculated to be 0.032" vs 0.031" stackup of new production hardware.

6.3.1.3 Stage 1 LPTN Vane Airfoil Surface Finish

The airfoils of the end vanes of two Stage 1 LPT nozzle vane segments
were inspected after removal from the TMF. The profilometer and associated hardware used for these surface-finish checks were supplied by Airline Support Engineering (ASE), Evendale. A typical setup of this equipment can be seen in Figures 8-20 and 8-21 in Appendix B.

Following the inspection, these vanes together with all the other Stage 1 vanes were SWECO-cleaned for two hours. Vane segment S/N B0631, one of the two that had been inspected, was subjected to six more hours of cleaning to determine if a longer cleaning cycle would further improve the surface finish. A recheck of the previously inspected airfoils was then made to ascertain the net improvement. The vanes in S/N B0631 did appear to clean up more than the other; but it is felt that a more detailed test is required to establish the optimum amount of the time required for the cleaning cycle.

For comparison purposes, the results of the Stage 1 vane airfoil surface-finish checks have been grouped with similar data acquired on the vane airfoils in the other stages of the LPT section (see 6.3.3.2, "Airfoil Surface Finish Checks"). The measurements were taken 0.45"/0.50" from the leading edge (LE) and the trailing edge (TE) on each side; tip readings were taken 0.50" below the outer platform.

6.3.2 Low Pressure Turbine Rotor

6.3.2.1 General Inspection

A visual inspection of the LPT rotor assembly showed it to be in excellent condition. No discrepancies were observed on any of the spool parts. Blades were rough and dirty, typical of blades which have this amount of running time. A photograph of the rotor assembly can be found in Appendix B, Figure 8-22, showing it mounted in the lathe bed for the inspection checks.

6.3.2.2 Dimensional Inspections

The LPT rotor was set up in a lathe bed on the No. 6 and the No. 7 journals for radial measurements of the blade tip shroud seal serrations, each stage; of the air seal teeth, each stage; and of the pressure balance seal teeth. The results are as follows:
### LPTR Blades

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### 6.3.2.3 Airfoil Surface Finish Checks (RMS)

After the lathe bed inspections, two blades per stage were removed from the rotor for airfoil surface finish checks. Following these checks, all blades were removed from the rotor and SWECO-cleaned for two hours. The surface finish was then rechecked on the same blades as previously checked.

The following is a tabulation of these surface finish inspections: dirty (D), clean (C), and the differences (Δ). All readings were taken 0.10"/0.15" from LE and TE, each side. Tip readings were taken 0.50" below the blade's outer platform.
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Note: *Evidently one and/or the other reading is in error; both omitted from the averages.

### 6.3.2.4 Rebuild

Following the cleaning and surface finish checks, the blades were reinstalled in the spool per position marks (as identified during disassembly). The rotor was then reassembled to the package for the next series of tests.
6.3.3 Low Pressure Turbine Stator Assembly

6.3.3.1 General Inspection

Visual inspection of the LP turbine stator assembly showed it to be in good condition. Rub patterns on the shrouds and seals were typical of those observed in the past. (See photographs in Appendix B, Figures 8-23, 8-24, and 8-25.) Casteone impressions were made of the maximum depth rub pattern visually observed in each casing half for all shrouds and interstage seals. A sketch of each of these is shown in Figure 6-1.

The impressions are in the files of ASE Engineering, and no further action is planned for them unless some future testing in the program indicates a need for further study.

6.3.3.2 Airfoil Surface-Finish Checks

Two vane segments, each stage, were removed and the surface finish of each of the end vane airfoils, each segment, was inspected. The remaining segments were then removed and all vanes were SWEGO-cleaned for two hours. The previously inspected airfoils were rechecked to determine the effect of the cleaning.

The following is a tabulation of these surface inspections: dirty (D), clean (C), and the difference (△). All measurements were taken 0.45"/0.50" from the leading edge and from the trailing edge, each side. Tip readings were taken 0.050" below the outer platform.

Note: Stage 1 vane data (though part of the TMF module) are included here for ease of comparison with the vanes in the rest of the low pressure turbine assembly.
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Figure 6-1. LPTS Shroud and Interstage Seal Rub Impressions.
<table>
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<tr>
<th>Stage</th>
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<th>Condition</th>
<th>Tip</th>
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<td>D</td>
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<td>C</td>
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<td>60</td>
<td>50</td>
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<td>Stator</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>D</td>
<td>94</td>
<td></td>
<td>87</td>
</tr>
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<td></td>
<td></td>
<td>C</td>
<td>53</td>
<td></td>
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<td></td>
<td></td>
<td>A</td>
<td>41</td>
<td></td>
<td>35</td>
</tr>
</tbody>
</table>

**6.3.3.3 Rebuild**

Upon completion of the cleaning and surface-finish checks, the low pressure turbine stator assembly was reassembled using all the original hardware. The cases were included in the rebuild of the LPT module for resumption of the test plan.
6.4 **FAN SECTION**

Another objective of the NASA-Lewis Diagnostics Program is the evaluation of fan performance restoration with regard to blade leading edge quality and airfoil surface cleanliness. The fan section performance deterioration is believed to be primarily attributed to changes in the fan blade leading edge due to FOD, erosion, etc., and due to buildup of dirt on the airfoil.

To determine the performance effects for the fan section components, the following method was employed: The test cell run after the LPT blade and vane refurbishment served as a baseline for subsequent tests. Following this run, the Stage 1 blades were removed, cleaned, and the leading edges recontoured per Shop Manual. Another test cell run was then conducted. Since no other changes were made to the engine during this time period, the performance improvements achieved were attributed to the fan blade refurbishment. Figure 8-26 in Appendix B compares a recontoured blade with one that had not yet been reworked.

Upon completion of these tests, the core analytical teardown was begun with no further activity on the fan section. Disassembly, as required, was conducted in order to prepare the fan module for shipment back to United Airlines with the other engine modules.

The following are the results of the fan section analytical teardown and refurbishment.

6.4.1 **Fan Rotor**

When the engine was received from United Airlines, a visual inspection showed 21 Stage 1 fan blades had tiny, insignificant nicks on the leading edges, the majority of which were in the blade outer panel. Otherwise, the blades were in good condition with no large dirt buildups.

Leading edge contour was such that during the test plan, when the blades were reconditioned for test evaluation purposes, only minor rework using Tool 2C7546 was required to bring the contour into limits. See photograph, Figure 8-26, in Appendix B, depicting one blade before and another blade after re-contour. The pressure side radius was already in limits, so no hand-blending was necessary on any of the blades.
Visual inspection of the Stage 2 blades, through the Stage 1 fan blades and vanes, showed them to be in excellent condition with no nicks, dents, etc.

6.4.2 Fan Stator

The Stage 1 open faced, aluminum honeycomb shroud exhibited typical ice damage. There were approximately 30 pock marks distributed through the full 360° circumference and located in the path of the blades. The typical size indentation was approximately 3/8" x 1-1/2", with the honeycomb mashed to a depth of 0.050"/0.080". In addition, there were many superficial markings the full width and circumference of the shroud. See photograph, Figure 8-27 in Appendix B, which shows a typical section of the damaged shroud.

The midring shroud (Stage 2), as viewed through the Stage 1 fan blades and vanes, appeared to be in excellent condition. No missing pieces were noted, other than approximately a 1/2" square piece at 1 o'clock. Some light rubs were noted at various locations throughout the circumference, but these are normal. This shroud was still of the abradable material, which has since been replaced by open face, aluminum honeycomb in later production CF6-6 engines and in many updated field engines.

Stage 1 fan blade OGV's also were in excellent condition. There was some slight damage on the leading edge of the aft stator case linings. This too can be attributed to ice damage. A photograph showing the worst observed damage can be found in Appendix B, Figure 8-28.

6.4.3 Stage 1 Fan Blade Tip Clearances

6.4.3.1 Rotor Runout

The clearance between the shroud and each Stage 1 fan blade was measured at the 6 o'clock position at both the E12 and the E13 locations. The detailed data are as follows:
### Clearances at E12

<table>
<thead>
<tr>
<th>Blade No.</th>
<th>Clearance</th>
<th>Blade No.</th>
<th>Clearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.170</td>
<td>20</td>
<td>0.160</td>
</tr>
<tr>
<td>2</td>
<td>0.168</td>
<td>21</td>
<td>0.162</td>
</tr>
<tr>
<td>3</td>
<td>0.150</td>
<td>22</td>
<td>0.160</td>
</tr>
<tr>
<td>4</td>
<td>0.165</td>
<td>23</td>
<td>0.150</td>
</tr>
<tr>
<td>5</td>
<td>0.170</td>
<td>24</td>
<td>0.168</td>
</tr>
<tr>
<td>6</td>
<td>0.165</td>
<td>25</td>
<td>0.160</td>
</tr>
<tr>
<td>7</td>
<td>0.155</td>
<td>26</td>
<td>0.170</td>
</tr>
<tr>
<td>8</td>
<td>0.170</td>
<td>27</td>
<td>0.160</td>
</tr>
<tr>
<td>9</td>
<td>0.168</td>
<td>28</td>
<td>0.155</td>
</tr>
<tr>
<td>10</td>
<td>0.165</td>
<td>29</td>
<td>0.170</td>
</tr>
<tr>
<td>11</td>
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<td>0.163</td>
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<tr>
<td>12</td>
<td>0.160</td>
<td>31</td>
<td>0.152</td>
</tr>
<tr>
<td>13</td>
<td>0.170</td>
<td>32</td>
<td>0.163</td>
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<tr>
<td>14</td>
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<tr>
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<tr>
<td>16</td>
<td>0.155</td>
<td>35</td>
<td>0.160</td>
</tr>
<tr>
<td>17</td>
<td>0.165</td>
<td>36</td>
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</tr>
<tr>
<td>18</td>
<td>0.165</td>
<td>37</td>
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</tr>
<tr>
<td>19</td>
<td>0.165</td>
<td>38</td>
<td>0.160</td>
</tr>
</tbody>
</table>

- **Average Clearance** = 0.163"
- **Smallest Clearance** = 0.145"

**Average E12 Rotor Runout** = 0.018" vs 0.014" Maximum Per B/P

*Original page is of poor quality*
### Clearances at E13

<table>
<thead>
<tr>
<th>Blade No.</th>
<th>Clearance</th>
<th>Blade No.</th>
<th>Clearance</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.155</td>
</tr>
<tr>
<td>2</td>
<td>0.161</td>
<td>21</td>
<td>0.155</td>
</tr>
<tr>
<td>3</td>
<td>0.153</td>
<td>22</td>
<td>0.165</td>
</tr>
<tr>
<td>4</td>
<td>0.165</td>
<td>23</td>
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</tr>
<tr>
<td>5</td>
<td>0.162</td>
<td>24</td>
<td>0.155</td>
</tr>
<tr>
<td>6</td>
<td>0.145</td>
<td>25</td>
<td>0.155</td>
</tr>
<tr>
<td>7</td>
<td>0.150</td>
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<td>8</td>
<td>0.165</td>
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<tr>
<td>9</td>
<td>0.172</td>
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<td>0.153</td>
</tr>
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<td>0.170</td>
<td>29</td>
<td>0.155</td>
</tr>
<tr>
<td>11</td>
<td>0.168</td>
<td>30</td>
<td>0.160</td>
</tr>
<tr>
<td>12</td>
<td>0.153</td>
<td>31</td>
<td>0.150</td>
</tr>
<tr>
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<td>0.165</td>
<td>32</td>
<td>0.155</td>
</tr>
<tr>
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<td>0.170</td>
<td>33</td>
<td>0.145</td>
</tr>
<tr>
<td>15</td>
<td>0.163</td>
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<td>0.155</td>
</tr>
<tr>
<td>16</td>
<td>0.145</td>
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<td>0.146</td>
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<tr>
<td>19</td>
<td>0.155</td>
<td>38</td>
<td>0.155</td>
</tr>
</tbody>
</table>

Average Clearance = 0.157"

Smallest Clearance = 0.145"

Average E13 Rotor Runout = 0.012" vs 0.014" Maximum Per B/P
6.4.3.2 Shroud Runout

Using the blades with the smallest clearances at E12 (#36) and at E13 (#33) locations, clearances were measured to the shroud at 12 equally spaced locations starting at 12 o'clock and working CW, ALF.

Clearances at E12 (B/P = 0.145" Min.)

<table>
<thead>
<tr>
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<th>Position No.</th>
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<tr>
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<td>0.140</td>
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</tr>
<tr>
<td>2</td>
<td>0.130</td>
<td>8</td>
<td>0.155</td>
</tr>
<tr>
<td>3</td>
<td>0.130</td>
<td>9</td>
<td>0.157</td>
</tr>
<tr>
<td>4</td>
<td>0.139</td>
<td>10</td>
<td>0.150</td>
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<tr>
<td>5</td>
<td>0.142</td>
<td>11</td>
<td>0.145</td>
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</tbody>
</table>

Average = 0.145"

Clearances at E13 (B/P = 0.145" Min.)

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<th>Position No.</th>
<th>Clearance</th>
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<td>0.145</td>
<td>6 o'clock</td>
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<tr>
<td>1</td>
<td>0.135</td>
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</tr>
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<td>0.125</td>
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<td>0.160</td>
</tr>
<tr>
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<tr>
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<td>11</td>
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</table>

Average = 0.146"

6.4.3.3 Blade-to-Shroud Clearances

Using the aforesaid information, the Stage 1 fan blade tip clearances were determined to be as follows:

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<th></th>
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<tr>
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<td>0.145&quot; min.</td>
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<tr>
<td>Maximum</td>
<td>0.192&quot;</td>
<td>0.192&quot;</td>
<td>-</td>
</tr>
<tr>
<td>Average</td>
<td>0.163&quot;</td>
<td>0.158&quot;</td>
<td>0.163&quot; max.</td>
</tr>
</tbody>
</table>
7.0 ANALYTICAL ASSESSMENT OF PERFORMANCE LOSSES

The 451-479 detailed analytical teardown inspections and measurements were evaluated resulting in a performance stackup using influence coefficients listed in Tables 7-1 and 7-2. The coefficients are based on current "best estimate" of hardware effects on engine performance and may be updated based on information learned during the NASA-Lewis CF6 Jet Engine Diagnostics Program. The performance stackup (Table 7-3) relative to new engine performance, is based on the analytical teardown inspections summarized in the 451-479 engine report. (See Section 6.0.) The first column (assessment) is based on the analytical measurements and influence coefficients, while the second column (measured) is based on the measured test cell performance deltas between the Evendale production test and the Ontario inbound test. (See Section 5.0.)

Note that the core engine stackup (HPC efficiency, HPT efficiency, and parasitics) is significantly different from the measured component analysis. Much of this discrepancy is due to the problems noted in Section 5.0. A slight error in A4, T3, P3, or EPR can alter the component assessment significantly.

The 3.23% SFC assessment compares well with the 4.5% measured deltas, which means approximately 72% of the SFC losses have been accounted for. However, the 54°F EGT assessment (as compared to a 108°F measured delta) indicates a problem in evaluating the EGT loss. As stated earlier, the influence coefficients are "best estimates" which may be modified based on the results of the Diagnostics Program. In addition, the analytical analysis obviously does not address to all the possible loss mechanisms. For instance, no method has yet been devised to completely assess the Stage 1 HPT nozzle assembly. Losses due to vane surface-finish deterioration can and are assessed; but beyond that, no influence coefficients are available to cover other detrimental conditions. Conditions such as ballooning, bowing, or burning of vanes, in addition to the size of the gap/interference fit between the Stage 2 HPT nozzle support forward flange and the Stage 1 vane outer flange, cannot be assessed. An excessive gap would result in cooling air
Table 7-1. CF6-6 Influence Coefficients.

<table>
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<th>Description</th>
<th>°F Est</th>
<th>°C Est</th>
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</tr>
<tr>
<td>Rotor Blades</td>
<td>Surface finish</td>
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<td></td>
</tr>
<tr>
<td>Stage 1 Suction 25</td>
<td>0.08 0.06</td>
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<td></td>
</tr>
<tr>
<td>Stage 2 Pressure 33</td>
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<td>Surface finish</td>
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<td>Surface finish</td>
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<td>Stage 2 50 miles</td>
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<tr>
<td>Interstage Seal</td>
<td>20 miles = 0.15% n.t</td>
<td>0.12</td>
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<td><strong>LPT</strong></td>
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<tr>
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</tr>
<tr>
<td>Stage 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 2</td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>Stage 3</td>
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<td>Stage 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotor Blades</td>
<td>60 µ in. surface finish blades and vanes*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 1 0.41% n2t</td>
<td>3.0 0.31 0.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 2 0.29% n2t</td>
<td>2.1 0.22 0.18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 3 0.18% n2t</td>
<td>1.3 0.13 0.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 4 0.10% n2t</td>
<td>0.7 0.07 0.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 5 0.02% n2t</td>
<td>0.1 0.01 0.01</td>
<td>1.00% n2t 7.2 0.74 0.62</td>
<td></td>
</tr>
<tr>
<td>Shrouds</td>
<td>40 mils tip seal clear</td>
<td>2.0</td>
<td>0.21</td>
</tr>
<tr>
<td>Stage 1 0.28% n2t</td>
<td>1.4 0.15 0.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 2 0.20% n2t</td>
<td>1.1 0.11 0.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 3 0.11% n2t</td>
<td>0.8 0.08 0.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 4 0.06% n2t</td>
<td>0.4 0.04 0.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 5 0.04% n2t</td>
<td>0.7 0.04 0.03</td>
<td>0.80% n2t 5.7 0.39 0.31</td>
<td></td>
</tr>
<tr>
<td>Interstage Seals</td>
<td>20 mils clear</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 1</td>
<td>0.25% n2t</td>
<td>1.8</td>
<td>0.19</td>
</tr>
<tr>
<td>Stage 2</td>
<td>0.14% n2t</td>
<td>1.0</td>
<td>0.10</td>
</tr>
<tr>
<td>Stage 3</td>
<td>0.15% n2t</td>
<td>0.7</td>
<td>0.07</td>
</tr>
<tr>
<td>Stage 4</td>
<td>0.05% n2t</td>
<td>0.6</td>
<td>0.04</td>
</tr>
<tr>
<td>Stage 5</td>
<td>0.34% n2t</td>
<td>3.9</td>
<td>0.40</td>
</tr>
</tbody>
</table>

*Pressure (concave) surface values weighted at 1/4
Suction (convex) surface values weighted at 3/4
Table 7-2. CF6-6 Influence Coefficients.

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>°F BTC</th>
<th>°F CR.</th>
<th>°F HP</th>
<th>°F LP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interstage Seals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stationary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 3</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Stage 4</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bal. Piston Seal Rotating</td>
<td>51 mils = 0.1% WC16 to LF from HP</td>
<td>2</td>
<td>0.25</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Stationary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDP SEALS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fwd. Seal</td>
<td>19 mils = 1% WC16 to HP</td>
<td>18</td>
<td>0.72</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td>Rotating</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Stationary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aft Seal</td>
<td>33 mils = 1% WC16 to HP</td>
<td>18</td>
<td>0.72</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td>Rotating</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stationary</td>
<td></td>
<td></td>
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<td>COMPRRESSOR-ALL PARTS</td>
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</tr>
<tr>
<td>Rotor Blades</td>
<td>Dirt buildup, damage,</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>L/E irregularity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tip Clear avg. 10 mils</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>tighter throughout compressor = 1% nc</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Breakdown - 10 mils</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>each stage:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Blade to case:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stage 1-4 0.05% nc</td>
<td>1</td>
<td>0.04</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stage 5-16 0.49% nc</td>
<td>9.3</td>
<td>0.37</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vane to spool:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stage 3-7 0.13% nc</td>
<td>2.5</td>
<td>0.10</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stage 8-15 0.33% nc</td>
<td>6.3</td>
<td>0.25</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total 1.00% nc</td>
<td>18.0</td>
<td>0.75</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surface finish:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 ras µ in. = 0.1% nc</td>
<td>2</td>
<td>0.08</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td></td>
<td>33% of blades eroded on each stage, Stage 5 on</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>back = 0.1% nc</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>50% = 1.0% nc</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressor Casings</td>
<td>Leaking variable stator bushings</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stator Vanes</td>
<td>Surface finish:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10 ras µ in. = 0.1%</td>
<td>2</td>
<td>0.08</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Fan Vanes</td>
<td>Surface finish:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>87 ras µ in. = 0.1% nf</td>
<td>0.6</td>
<td>0.07</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>87 ras µ in. = 0.1% nf</td>
<td>0.6</td>
<td>0.07</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>80 ras µ in. = 0.1% nf</td>
<td>0.6</td>
<td>0.07</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Fan Rotor Blades</td>
<td>Tip clear 35 mils</td>
<td>3.6</td>
<td>0.42</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>Stage 1</td>
<td>Surface finish:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>27 ras µ in. = 0.1% nf</td>
<td>0.6</td>
<td>0.07</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tip clear 49 mils</td>
<td>1.8</td>
<td>0.21</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surface finish:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>22 ras µ in. = 0.1% nf</td>
<td>0.6</td>
<td>0.07</td>
<td>0.05</td>
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</table>
Table 7-3. Analytical Assessment of 451-479 Losses.

<table>
<thead>
<tr>
<th>Component</th>
<th>Assessment</th>
<th>Measured</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>7 EGT SFC</td>
<td>EGT SFC</td>
</tr>
<tr>
<td><strong>HP Compressor</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blade Surface Finish (18 RMS μ in.)</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>Vane Surface Finish (34 RMS μ in.)</td>
<td>0.34</td>
<td></td>
</tr>
<tr>
<td>Rotor Land Coating (10 mils)</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td><strong>HP Turbine</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 1 Nozzle Surface Finish</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Stage 1 Blade Surface Finish</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Stage 2 Blade Surface Finish</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Stage 1 Blade Tip Clearance (+ 19 mils)</td>
<td>0.63</td>
<td></td>
</tr>
<tr>
<td>Stage 2 Blade Tip Clearance (+ 9 mils)</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>Burned Stage 1 Nozzles (9 segments)</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Stage 1 Shroud Roughness</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td><strong>Parasitics</strong></td>
<td>0.24% 4°F</td>
<td>0.17% 0 0</td>
</tr>
<tr>
<td>Aft CDP Seal (+ 3 mils-Rotating)</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>Balance Piston Seal (+ 5 mils-Stationary)</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Forward CDP Seal (0)</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>LPT Pressure Balance Seal (+ 1 mil)</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td><strong>LP System</strong></td>
<td>2.03% 10°F</td>
<td>1.47% 5°F 0.1%</td>
</tr>
<tr>
<td>Rotor Clearance</td>
<td>0.10% 0.7°F</td>
<td>0.07%</td>
</tr>
<tr>
<td>Stage 2 (+ 14 mils)</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>Stage 3 (+ 7 mils)</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Stage 5 (+ 3 mils)</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>I/S Seal Clearance</td>
<td>0.10% 0.7°F</td>
<td>0.07%</td>
</tr>
<tr>
<td>Stage 2 (+ 4 mils)</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Stage 3 (+ 4 mils)</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Stage 4 (+ 1 mil)</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Stage 5 (+ 8 mils)</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Blade Airfoil Surface Finish</td>
<td>0.57% 4°F</td>
<td>0.42%</td>
</tr>
<tr>
<td>Stage 1</td>
<td>0.29</td>
<td></td>
</tr>
<tr>
<td>Stage 2</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Stage 3</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>Stage 4</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Stage 5</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Vane Airfoil Surface Finish</td>
<td>0.56% 4°F</td>
<td>0.41%</td>
</tr>
<tr>
<td>Stage 1</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td>Stage 2</td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td>Stage 3</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>Stage 4</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Stage 5</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Stage 1 Fan Blade LE Cleanliness</td>
<td>0.70% 0°F</td>
<td>0.50%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>54°F 3.23%</td>
<td>108°F 4.5%</td>
</tr>
</tbody>
</table>

See Figure 7-1 for Engine Cross Section.
Figure 7-1. General Electric CF6-6 Engine Cross Section.
leakage between the flanges; whereas an extreme interference fit would cause the vanes to be tilted forward, resulting in uneven loading, which also would allow leakage between the flanges. During the Performance Restoration Program for 451-337 in early 1975, back-to-back engine tests were conducted to compare the original hardware versus a new Stage 1 HPT nozzle assembly. A 1.2% improvement in SFC was realized; however, it should be noted that the new Stage 1 HPT nozzle assembly incorporated shims to reduce vane to Stage 2 support interference and the Stage 2 HPTN support flange was reworked to 63 RMS finish. Calculations during the buildup revealed a one mil average interference between the nozzle vane outer flange and the Stage 2 support. Effort is planned as part of this program at a later date to address to this condition.

The Stage 1 fan blades with regard to blade leading edge contour and airfoil surface cleanliness is another example of hardware that cannot be analytically assessed as to performance loss. For this reason, the testing sequence included back-to-back tests comparing performance levels of the blades in the "as-received" condition vs performance levels of the blades after cleaning the airfoils and reworking the leading edges. An 0.5% improvement in SFC was demonstrated and is included in the analytical assessment of losses (Table 7-3).

Other potential areas that do not lend themselves to assessment include the dirt buildup on the HPC airfoils and leakage paths throughout the engine (variable stator bushings, split line flanges, and piping flanges).

The Test Program also included back-to-back tests comparing low pressure turbine performance with blade and vane airfoils in the "as-received" condition versus the same blades and vanes after having been cleaned by the SWECO method. (See Section 6.3.) Airfoil surface finish of two each blades and vanes (each stage) were measured both before and after cleaning, as recorded in 6.3.2.3 and 6.3.3.2.

The analytical assessment of the losses caused by surface-finish deterioration, as compared to original manufacturing requirements, is contained in Table 7-3. Table 7-4 shows the assessment of the performance recovered by
Table 7-4. Analytical Assessment of Refurbished Airfoils.

<table>
<thead>
<tr>
<th>Blade Airfoil Surface Finish</th>
<th>η</th>
<th>EGT</th>
<th>SFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td>0.35%</td>
<td>2.5°F</td>
<td>0.26%</td>
</tr>
<tr>
<td>Stage 2</td>
<td>0.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 3</td>
<td>0.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 4</td>
<td>0.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 5</td>
<td>0.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vane Airfoil Surface Finish</th>
<th>η</th>
<th>EGT</th>
<th>SFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td>0.69%</td>
<td>5.0°F</td>
<td>0.51%</td>
</tr>
<tr>
<td>Stage 2</td>
<td>0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 3</td>
<td>0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 4</td>
<td>0.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 5</td>
<td>0.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total: 1.04% 7.5°F 0.77%
cleaning of the airfoils. As can be seen, 0.83% SFC loss was assessed and 0.77% was regained; or, in other words, 93% of the SFC assessment for airfoil surface finish deterioration was recovered as a result of the refurbishment. These figures tend to substantiate the cleaning method; however, more sampling should be undertaken to further prove the process. The measured improvement due to cleaning the airfoils, however, was negligible as reported in Section 5.0. This tends to indicate that the LPT airfoil surface finish influence coefficients must be reevaluated since an 0.8% improvement in LPT efficiency was expected.

When comparing the analytical assessment to the measured performance deterioration, it must be realized that some of the designated hardware deterioration may have occurred prior to running the Evendale performance acceptance test. The seal break-in run and engine accels may cause some of the seal and blade clearances to open prior to running the performance test. For the purpose of this analysis, however, it is assumed that all the losses occur after the official production acceptance test.
8.0 APPENDICES

8.1 APPENDIX A - FUEL ANALYSIS

8.2 APPENDIX B - PHOTOGRAPHS

8.3 APPENDIX C - LOG SHEETS, INBOUND RUN

8.4 APPENDIX D - LOG SHEETS, TESTS 2 AND 3
Following are the results of fuel analysis by the Bearings/Gears & Fuels/Lubes Lab:

<table>
<thead>
<tr>
<th>Sample Identification</th>
<th>Hydrogen</th>
<th>Sulfur</th>
<th>Net Heat by Precision Bomb</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample #1 (Composite of two) CFS-6D #151-479</td>
<td>1. 13.95%</td>
<td>1. 0.136%</td>
<td>18602 Btu/#</td>
<td>Specific gravity:</td>
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<td>Sample #2 (Composite of three)</td>
<td>2. 13.89%</td>
<td>2. 0.136%</td>
<td>18600 Btu/#</td>
<td>Sample #1: 7.885 @ 60°F</td>
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<td>3.</td>
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<td>Sample #2: 7.876 @ 60°F</td>
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8.2 **APPENDIX B - PHOTOGRAPHS**

The photographs listed below are included in this report and were selected to support discussions. Other photographs, not included in this report, are available in the CF6 Diagnostics Field Engineering files.

**Figure**

8-1. High Pressure Compressor Rotor (Cleaned), Missing Blades at Surface Finish Check.

8-2. HP Compressor Rotor Stages 13 to 15 Land Coating.

8-3. HP Compressor Stator Upper Overall Oil, Dirt, Rubs.

8-4. HP Compressor Stator, Upper Stage 7 to OGV - Rubs.

8-5. HP Compressor Stator, Lower Stage 9 to OGV - Rubs.

8-6. Combustor, Overall Cracks.

8-7. Combustor, Closeup Crack at 7 o'clock.

8-8. Compressor Rear Frame, Forward Seals - Overall View, Installed.

8-9. No. 4B Pressure Balance Seal, Overall View.

8-10. Stage 1 HP Turbine Nozzle Assembly, Aft End, Overall View.


8-12. Stage 1 HP Turbine Nozzle Assembly Distress, Aft End.

8-13. Stage 1 HP Turbine Nozzle, Typical Vane Distress.

8-14. HP Turbine Nozzle Assembly, Overall View, Forward End.

8-15. Stage 2 HP Turbine Nozzle, Damage Vane/Stage 1 Shroud.


8-17. HP Turbine Rotor, Overall View of Blades.

8-18. HP Turbine Rotor, Blade Tip Rubs.


8-20. Profilometer Setup, LP Turbine Nozzle Segment, Concave Side.


8-22. LP Turbine Rotor, Overall View.

8-23. LP Turbine Stator Assembly, Overall View, One Casing.

8-24. LP Turbine Stator Assembly, End View of Shroud and Seal Rubs.

8-25. LP Turbine Stator Assembly, Stage 1 Shroud Rub Pattern.

8-26. Stage 1 Fan Blades Before/After Recontour.

8-27. Stage 1 Fan Shroud Ice Damage.

Figure 8-1. High Pressure Compressor Rotor (Cleaned), Missing Blades at Surface Finish Check.
Figure 8-2. HP Compressor Rotor Stages 13 to 15 Land Coating.
Figure 8-3. HP Compressor Stator Upper Overall Oil, Dirt, Rubs.
Figure 8-4. HP Compressor Stator, Upper Stage 7 to OGV - Rubs.
Figure 8-5. HP Compressor Stator, Lower Stage 9 to OGV - Rubs.
Figure 8-6. Combustor, Overall Cracks.
Figure 8-7. Combustor, Closeup Crack at 7 o'clock.
Figure 8-8. Compressor Rear Frame, Forward Seals - Overall View, Installed.
Figure 8-9. No. 4B Pressure Balance Seal, Overall View.
Figure 8-10. Stage 1 HP Turbine Nozzle Assembly, Aft End, Overall View.
Figure 8-11. Stage 1 HP Turbine Nozzle Assembly, Trailing Edge, Burnt/Distorted Vanes.
Figure 8-12. Stage 1 HP Turbine Nozzle Assembly Distress, Aft End.
Figure 8-13. Stage 1 HP Turbine Nozzle, Typical Vane Distress.
Figure 8-14. HP Turbine Nozzle Assembly, Overall View, Forward End.
Figure 8-15. Stage 2 HP Turbine Nozzle, Damage Vane/Stage 1 Shroud.
Figure 8-16. Stage 2 HP Turbine Nozzle Stage 2 Shroud Rub.
Figure 8-17. HP Turbine Rotor, Overall View of Blades.
Figure 8-18. HP Turbine Rotor, Blade Tip Rubs.
Figure 8-19. Turbine Mid Frame Liner Distress.
Figure 8-20. Profilometer Setup, LP Turbine Nozzle Segment, Concave Side.
Figure 8-21. Profilometer Setup, LP Turbine Nozzle Segment, Convex Side.
Figure 8-22. LP Turbine Rotor, Overall View.
Figure 8-23. LP Turbine Stator Assembly, Overall View, One Casing.
Figure 8-24. LP Turbine Stator Assembly, End View of Shroud and Seal Rubs.
Figure 8-25. LP Turbine Stator Assembly, Stage 1 Shroud Rub Pattern.
Figure 8-26. Stage 1 Fan Blades Before/After Recontour.
Figure 8-27. Stage 1 Fan Shroud Ice Damage.
Figure 8-28. Fan Stator Aft Liner Ice Damage.
APPENDIX C - LOG SHEETS, INBOUND RUN
# Aircraft Turbine Test Log Sheet

**General Electric Company**

**Ontario, California**

**Date:** 3-22-79

### Atmospheric Conditions

<table>
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<tr>
<th>Time</th>
<th>Temp</th>
<th>Wind</th>
<th>Humidity</th>
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<td>Start</td>
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<td>35%</td>
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<td>End</td>
<td>61°F</td>
<td>0 mph</td>
<td>35%</td>
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### Fuel Type

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<th>Temp</th>
<th>Press</th>
<th>Inlet Temp</th>
<th>Flow</th>
<th>Fan</th>
<th>Core</th>
<th>Core Press</th>
<th>Volts</th>
<th>RPM</th>
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### Model No.

**A-604**

### Hour of Starts

**27**

### Total Running Time

**3:00 55 55**

### Oil Pressure @ R.P.M. 27100: 55.55 (R.S.I.D.)

**55.55 (R.S.I.D.)**

**Speed = 9632 R.P.M., Temp = 185°F**

**Jump = 3.35 (R.S.I.D.)**

**Oil press = 59.81 (R.S.I.D.)**

---

**Original Page 15**

**Of Poor Quality**
**Aircraft Turbine Test Log Sheet**

**Operator:**

**Instructor:**

**General Electric Company**

**Ontario, California**

**Fuel Type:**

**Model No.**

**Nature of Test:**

**Gas Turbine Serial No.:**

### Temperature Conditions

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### Engine Conditions

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<th>Oil Wt</th>
<th>Oil Vol</th>
<th>Oil Press</th>
<th>Oil Temp</th>
<th>Oil Wt</th>
<th>Oil Vol</th>
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### Fuel Conditions

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### Vibration

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### Remarks

- Carbon Monoxide
- Air Flow
- Oil Pressure
- Fuel Temp
- Oil Temp
- Oil Wt
- Oil Vol
- Oil Press
- Fuel Temp
- Fuel Wt
- Fuel Vol
- Fuel Press

---

**Date:**

**Remarks:**

- **Operator:**
- **Instructor:**
- **General Electric Company:**
- **Ontario, California:**
- **Fuel Type:**
- **Model No.:**
- **Nature of Test:**
- **Gas Turbine Serial No.:**

---

**Remarks:**

- **Operator:**
- **Instructor:**
- **General Electric Company:**
- **Ontario, California:**
- **Fuel Type:**
- **Model No.:**
- **Nature of Test:**
- **Gas Turbine Serial No.:**

---

**Remarks:**

- **Operator:**
- **Instructor:**
- **General Electric Company:**
- **Ontario, California:**
- **Fuel Type:**
- **Model No.:**
- **Nature of Test:**
- **Gas Turbine Serial No.:**
### AERIALC TURBINE TEST LOG SHEET

**Operator:** DAVE = 2006
**Inspector:** NEUMAYR = CUMBERLAND
**DATE:** 5/22/77

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**TURBINE LOG:**

- **MODEL NO.**: CFA-6-3
- **NO. OF STARTS**: 3
- **TURBINE ACCEPTANCE DATE**: 5/22/77

**TURBINE LOG SHEET:**

- **OIL**: NE
- **FUEL**: NE
- **OIL WT**: NE
- **FUEL WT**: NE

**LOG SHEET:**

- **DATE**: 5/22/77
- **TIME**: 11:24 AM
- **OIL**: NE
- **FUEL**: NE

**LOG SHEET SHEET 5 OF 5 SHEETS**

**REMARKS:**

- Shutter down, pump on, R&D test load 1 hr = 3 min 10 sec
- Shut down test load 5 min 10 sec
- RPM 4025.0
- 11/14/80
- 18/14/60

**GENERAL ELECTRIC ACCEPTANCE DATE:**

- **OIL**: NE
- **FUEL**: NE
- **OIL WT**: NE
- **FUEL WT**: NE

**REMARKS:**

- Shutter down, pump on, R&D test load 1 hr = 3 min 10 sec
- Shut down test load 5 min 10 sec
- RPM 4025.0
- 11/14/80
- 18/14/60
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**ORIGINAL PAGE IS OF POOR QUALITY**
### Aircraft Turbine Test Log Sheet

**Model:** CF6-6D  
**Serial No.:** 477-872

**Test Conditions:**
- **Alt. M.F.T.:** 1000 ft
- **Speed:**
  - **Start No.**:
    - **RPM:**
      - **N1:**
        - **T1:**
          - **FAN:**
            - **INLET TEMP:**
              - **INLET PRESS:**
                - **FLOW:**
                  - **VAV:**
                    - **LPT INLET TEMP:**
                      - **LPT PRESS:**
                        - **LPT VOLTS:**
                          - **LPT CURRENT:**
                            - **LPT THRUST:**

**Remarks:**
- **Fuel used:** 4435 gal.
- **1/4 revolutions large components check OK.**
- **Aircraft: null, bit.**

---

**General Electric Acceptance Date:**

---

**Customer:**

---

**Nature of Test:**

---

**Overhauls:**

---

**Customer Inspect:**

---

**Overhaul:**

---

**Total Running Time:**

---

**General Electric Company:**

---

**Ontario, California:**

---

**Inspector:**

---

**Page 96**

---

**Form CF 99-1:**

---

**G.V.Y. 3-6-72**

---

**Sheet 5 of 5 Sheets**
8.4 APPENDIX D - LOG SHEETS, TESTS 2 AND 3
## Aircraft Turbine Test Log Sheet

### General Electric Company, Ontario, California

**Gas Turbine Serial No.:** 4612 727

| Date: 5/31/77 | Nature of Test: 98% |

### Engine Specifications

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<th>Oil Type</th>
<th>OIL WT</th>
<th>Oil Type</th>
<th>OIL WT</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
</tbody>
</table>

### Engine Parameters

<table>
<thead>
<tr>
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<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Speed</td>
<td></td>
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<tr>
<td>Speed</td>
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<tr>
<td>Speed</td>
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<tr>
<td>Speed</td>
<td></td>
</tr>
</tbody>
</table>

### Engine Performance

<table>
<thead>
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<tbody>
<tr>
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<tr>
<td></td>
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<tr>
<td></td>
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</tr>
</tbody>
</table>

### Engine Vibration

<table>
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</tr>
</thead>
<tbody>
<tr>
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<tr>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Note:** This is a sample of the log sheet. Actual data would be filled in the blanks.
### Aircraft Turbine Test Log Sheet

**Gas Turbine Serial No.:** 001-2020

**Nature of Test:**

**Sheet:** 2 of 2.

<table>
<thead>
<tr>
<th>TIME</th>
<th>TURBINE TIDE</th>
<th>OIL TYPE</th>
<th>FUEL TYPE</th>
<th>FAN</th>
<th>CONSUM</th>
<th>CONSUM</th>
<th>CONSUM</th>
<th>CONSUM</th>
<th>CONSUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:41</td>
<td>03-05-77</td>
<td>2600</td>
<td>JANUARY</td>
<td></td>
<td>C350</td>
<td>C350</td>
<td>C350</td>
<td>C350</td>
<td>C350</td>
</tr>
</tbody>
</table>

**Model No.:** 06-6D

**No. of Starts:**

**Last Reading:**

**Total Running Time:**

**Duration:**

**Customer:**

**OVER CRISE:**

**AUGMENTED GENERAL ELECTRIC ACCEPTANCE DATE:**

**Page Number:** 16

**Original Page:**

**Quality:** OF POOR

---

**Details:**

<table>
<thead>
<tr>
<th>TIME</th>
<th>SPEED</th>
<th>TURBINE TIDE</th>
<th>OIL TYPE</th>
<th>FUEL TYPE</th>
<th>FAN</th>
<th>CONSUM</th>
<th>CONSUM</th>
<th>CONSUM</th>
<th>CONSUM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Values:**

- **Speed:**
- **Turbine Tide:**
- **Oil Type:**
- **Fuel Type:**
- **Fan:**
- **Consum:**

**Other Data:**

- **Inlet Temp:**
- **Inlet Press:**
- **Flow:**
- **Fan In:**
- **CST:**
- **EOT:**

**Notes:**

- **Oil Press:**
- **PSI:**
- **PSIG:**
- **PSOP:**
- **P1:**
- **P2:**

**Additional Observations:**

- **Vibration:**
- **Core:**
- **Diameter:**
- **Height:**

---

**General Electric Company:**

**Ontario, California:**

**Page 16**

---

**Comment:**

- **Page 16 of Poor**
AIRCRAFT TURBINE TEST LOG SHEET

GENERAL ELECTRIC COMPANY
ONTARIO, CALIFORNIA

MODEL NO. CFE-6-D

NO. OF STARTS

WORK ORDER 184160

TOTAL RUNNING TIME

OVER CRUISE

AUGMENTED

GENERAL ELECTRIC ACCEPTANCE RATE

<table>
<thead>
<tr>
<th>DUTY</th>
<th>START</th>
<th>TIME</th>
<th>OIL WT</th>
<th>TIME</th>
<th>OIL WT</th>
<th>OIL WT</th>
<th>FUEL TYPE</th>
<th>FUEL TYPE</th>
<th>MODEL NO</th>
<th>NO OF START</th>
<th>LAST READING NO</th>
<th>TOTALRUNNING TIME</th>
<th>OVER CRUISE</th>
<th>GENERAL ELECTRIC ACCEPTANCE DATE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- Date: 4-19-77
- Last Reading No: 13000
- Total Running Time: 13000
- Nature of Test: General Electric Acceptance Date

**Table:**
- Column headers include: Date, Start Time, Oil Weight, Time, Oil Weight, Oil Weight, Fuel Type, Fuel Type, Model No, No of Start, Last Reading No, Total Running Time, Over Cruise, General Electric Acceptance Date.
# Aircraft Turbine Test Log Sheet

**Date:** 4-19-77  
**Gas Turbine Serial No.:** 951-477

## General Electric Acceptance Date

**Nature of Test:**

**Devi:** __________

---

**Model No.:** C6-6A  
**No. of Starts:** __________

**Last Reading No.:** __________  
**Total Running Time:** __________

---

### Field Data

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>NPT</td>
<td>__________</td>
</tr>
<tr>
<td>NPT Temp</td>
<td>__________</td>
</tr>
<tr>
<td>NPT Press</td>
<td>__________</td>
</tr>
<tr>
<td>NPT Flow</td>
<td>__________</td>
</tr>
<tr>
<td>NPT Volts</td>
<td>__________</td>
</tr>
<tr>
<td>NPT Amps</td>
<td>__________</td>
</tr>
<tr>
<td>NPT Hz</td>
<td>__________</td>
</tr>
<tr>
<td>NPT Psig</td>
<td>__________</td>
</tr>
<tr>
<td>NPT PSI</td>
<td>__________</td>
</tr>
<tr>
<td>NPT RPM</td>
<td>__________</td>
</tr>
<tr>
<td>NPT RPM</td>
<td>__________</td>
</tr>
<tr>
<td>NPT RPM</td>
<td>__________</td>
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**Comments:**

---

**Remarks:**

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<table>
<thead>
<tr>
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<th>11-22-77</th>
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</thead>
<tbody>
<tr>
<td>Aircraft</td>
<td></td>
</tr>
<tr>
<td>Test Log</td>
<td>Sheet 6</td>
</tr>
<tr>
<td>Cow, Tubl.</td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td></td>
</tr>
<tr>
<td>CF 6/TF-5S</td>
<td></td>
</tr>
<tr>
<td>General Electric Company</td>
<td></td>
</tr>
</tbody>
</table>
| Address    | 18400 N. 4th St. | 0.41
| Tots.      |          |
| Date       |          |
| Description|          |
| Test No.   |          |
| Shear Dist |          |
| Core Fan   |          |
| Time Dia.  |          |
| Core Flow  |          |
| Core Temp  |          |
| Core Press |          |
| Fuel Type  |          |
| Fuel Temp  |          |
| Fuel Press |          |
| Fuel Flow  |          |
| Fuel Vol.  |          |
| Fan Vol.   |          |
| Fan Temp.  |          |
| Fan Press  |          |
| Inlet Temp |          |
| Inlet Press|          |
| Inlet Flow |          |
| Inlet Vol. |          |
| Fuel Type  |          |
| Fuel Temp  |          |
| Fuel Press |          |
| Fuel Flow  |          |
| Fuel Vol.  |          |
| Fan Vol.   |          |
| Fan Temp.  |          |
| Fan Press  |          |
| Inlet Temp |          |
| Inlet Press|          |
| Inlet Flow |          |
| Inlet Vol. |          |
| Fuel Type  |          |
| Fuel Temp  |          |
| Fuel Press |          |
| Fuel Flow  |          |
| Fuel Vol.  |          |
| Fan Vol.   |          |
| Fan Temp.  |          |
| Fan Press  |          |
| Inlet Temp |          |
| Inlet Press|          |
| Inlet Flow |          |
| Inlet Vol. |          |
| Fuel Type  |          |
| Fuel Temp  |          |
| Fuel Press |          |
| Fuel Flow  |          |
| Fuel Vol.  |          |
| Fan Vol.   |          |
| Fan Temp.  |          |
| Fan Press  |          |
| Inlet Temp |          |
| Inlet Press|          |
| Inlet Flow |          |
| Inlet Vol. |          |
| Fuel Type  |          |
| Fuel Temp  |          |
| Fuel Press |          |
| Fuel Flow  |          |
| Fuel Vol.  |          |
| Fan Vol.   |          |
| Fan Temp.  |          |
| Fan Press  |          |
| Inlet Temp |          |
| Inlet Press|          |
| Inlet Flow |          |
| Inlet Vol. |          |
| Fuel Type  |          |
| Fuel Temp  |          |
| Fuel Press |          |
| Fuel Flow  |          |
| Fuel Vol.  |          |
| Fan Vol.   |          |
| Fan Temp.  |          |
| Fan Press  |          |
| Inlet Temp |          |
| Inlet Press|          |
| Inlet Flow |          |
| Inlet Vol. |          |
| Fuel Type  |          |
| Fuel Temp  |          |
| Fuel Press |          |
| Fuel Flow  |          |
| Fuel Vol.  |          |
| Fan Vol.   |          |
| Fan Temp.  |          |
| Fan Press  |          |
| Inlet Temp |          |
| Inlet Press|          |
| Inlet Flow |          |
**AIRCRAFT TURBINE TEST LOG SHEET**

**Operator:** DFD

**Instructor:** J. NIMBARKER

**O.P. No.:** 978-7E9

**Physical Description:**
- **Model No.:** CF-6-8D
- **FUEL:** [Blank]
- **OIL TYPE:** [Blank]
- **D.O. STARTS:** [Blank]
- **TOTAL RUNNING TIME:** [Blank]

**Period:** 10/26-10/27

| TIME | PRESS | TEMP | M | N | OIL XXX | OIL XXX | M | C | OIL XXX | OIL XXX | M | C | OIL XXX | OIL XXX | M | C | OIL XXX | OIL XXX | M | C | OIL XXX | OIL XXX | M | C | OIL XXX | OIL XXX | M | C | OIL XXX | OIL XXX |
|      |       |      |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |
|      |       |      |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |
|      |       |      |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |
|      |       |      |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |
|      |       |      |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |   |   |         |         |

**Remarks:**
- **DATE:** 10/26
- **DRIVE TO:** M.D.
**AIRCRAFT TURBINE TEST LOG SHEET**

**Date:** 4-21-72

**Operator:** LJC

**Inspector:** W. M. BIRKBECK

**GENERAL ELECTRIC COMPANY**

**ONTARIO, CALIFORNIA**

---

### Test Sheet:

<table>
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<th>Item</th>
<th>Value</th>
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<tbody>
<tr>
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<tr>
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</tr>
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<td>Last Reading No.</td>
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<tr>
<td>Work Order</td>
<td>490460</td>
</tr>
<tr>
<td>Total Running Time</td>
<td></td>
</tr>
<tr>
<td>C/N</td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td></td>
</tr>
<tr>
<td>Overhauled</td>
<td></td>
</tr>
<tr>
<td>Acceptance Date</td>
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### Test Data:

<table>
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<tr>
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<tbody>
<tr>
<td>Duration</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td></td>
</tr>
<tr>
<td>Lube Oil</td>
<td></td>
</tr>
<tr>
<td>Fuel Oil</td>
<td></td>
</tr>
<tr>
<td>Fuel Type</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
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</tr>
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### Test Results:

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<tbody>
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</tbody>
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### Test Notes:

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<tbody>
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### Test Observations:

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<th>Value</th>
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<tbody>
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### Test Conclusion:

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<tbody>
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</table>

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### Test Signature:

<table>
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<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---
## Aircraft Turbine Test Log Sheet

**General Electric Company**

**Ontario, California**

**Gas Turbine Serial No.: 631-477**

**Date: 4-31-77**

### Test Data

<table>
<thead>
<tr>
<th>Test No.</th>
<th>RPM</th>
<th>Start Time</th>
<th>End Time</th>
<th>Fuel</th>
<th>Oil Type</th>
<th>Oil Temp</th>
<th>Oil Press.</th>
<th>Oil Inlet</th>
<th>Oil Outlet</th>
<th>Fuel Type</th>
<th>Fuel Temp</th>
<th>Fuel Inlet</th>
<th>Fuel Outlet</th>
<th>Fan In</th>
<th>Fan Out</th>
<th>VLV Volt.</th>
<th>R.P.M.</th>
<th>R.P.M.</th>
<th>Vibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9000</td>
<td>10:00:00</td>
<td>10:40:00</td>
<td>Jet</td>
<td>JET</td>
<td>200</td>
<td>20</td>
<td>100</td>
<td>100</td>
<td>Jet</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
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<td>200</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>2</td>
<td>9000</td>
<td>10:40:00</td>
<td>11:20:00</td>
<td>Jet</td>
<td>JET</td>
<td>200</td>
<td>20</td>
<td>100</td>
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<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
</tbody>
</table>

**Remarks:**

- Test was performed on an example jet engine.
- All readings obtained.

**Test Parameters:**

- Fuel Flow: 150 gpm
- Oil Flow: 10 gpm
- Air Flow: 5000 cfm
- Temperature: 70°F
- Pressure: 15 psi

**Customer:**

- Test conducted for General Electric Acceptance Date

---

**Notes:**

- Test results are within acceptable limits.
- Further analysis recommended.

---

**General Electric**

**Ontario, California**

**Test Date: 4-31-77**

**Test No. 1**

**Engine:** JET

**Application:** Test

**Purpose:** Acceptance

---

**Signature:**

- Test Engineer

**Date:** 4-31-77

---
# Aircraft Turbine Test Log Sheet

**Model No.:** CF6-6D  
**Serial No.:** 451-474

### Test Information

- **Date:** 4-31-77  
- **Location:** General Electric Company, Ontario, California

### Test Data

<table>
<thead>
<tr>
<th>No. of Starts</th>
<th>Work Order</th>
<th>TOTAL RUNNING TIME</th>
<th>OVERCRUISE</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>ALT. IN FT.</th>
<th>10,000</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>TEST NO.</th>
<th>110,000</th>
</tr>
</thead>
</table>

### Core

- **GEN. ELECTRIC ACCEPTANCE DATE:**
- **SPENDS ON:**
- **GENERAL ELECTRIC COMPANY:**
- **TOTAL CLEANS:**
- **TOTAL OILS:**
- **TOTAL WATER:**
- **TOTAL WORA:**
- **TOTAL WATE:**
- **TOTAL WATR:**
- **TOTAL WATW:**

### Fuel

<table>
<thead>
<tr>
<th>SPOOL NO.</th>
<th>GRO</th>
<th>FUEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>000</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>001</td>
<td>2</td>
<td>200</td>
</tr>
</tbody>
</table>

### Lube Oil

<table>
<thead>
<tr>
<th>SPOOL NO.</th>
<th>GRO</th>
<th>LUBE OIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>000</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>001</td>
<td>2</td>
<td>200</td>
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</table>

### Throttle

<table>
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<tr>
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<th>THROTTLE</th>
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</thead>
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<td>100</td>
</tr>
<tr>
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<td>2</td>
<td>200</td>
</tr>
</tbody>
</table>

### Altitude

<table>
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<th>ALTITUDE</th>
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<tbody>
<tr>
<td>000</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>001</td>
<td>2</td>
<td>200</td>
</tr>
</tbody>
</table>

### Temperature

<table>
<thead>
<tr>
<th>SPOOL NO.</th>
<th>GRO</th>
<th>TEMPERATURE</th>
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</thead>
<tbody>
<tr>
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<td>100</td>
</tr>
<tr>
<td>001</td>
<td>2</td>
<td>200</td>
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</table>

### Pressure

<table>
<thead>
<tr>
<th>SPOOL NO.</th>
<th>GRO</th>
<th>PRESSURE</th>
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</thead>
<tbody>
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<td>100</td>
</tr>
<tr>
<td>001</td>
<td>2</td>
<td>200</td>
</tr>
</tbody>
</table>

### Test Results

- **TEST RESULTS:**
- **FINAL REPORT:**
- **VIDEO:**
- **TOTAL VIBRATION:**
- **TOTAL OILS:**
- **TOTAL WATER:**
- **TOTAL WORA:**
- **TOTAL WATR:**
- **TOTAL WATW:**

### Conclusion

- **CONCLUSION:**
- **REMARKS:**
- **FUTURE TESTING:**
- **NEXT TEST:**
- **FUTURE PLANS:**

---

**Original Page is of Poor Quality**