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AD378776

PWA FR-2239
10 JAN 1967

(UNCLASSIFIED TITLE)

MONTHLY PROGRESS REPORT NO. 18
DEVELOPMENT OF A SUPERSONIC TRANSPORT AIRCRAFT ENGINE

PHASE II-C

1 DECEMBER THROUGH 31 DECEMBER 1966

CONTRACT NO. FA-SS-66-8

(Competitive Data)

Pratt & Whitney Aircraft DIVISION OF UNITED AIRCRAFT CORPORATION
FLORIDA RESEARCH AND DEVELOPMENT CENTER

DECLASSIFIED AFTER 12 YEARS. DOD DIR 5200.10

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SECTION I
SUMMARY OF PROGRESS

All of the contract requirements and program objectives have been met or exceeded with the completion of this month's testing.

Engine FX-163 has attained a maximum thrust of 58,800 pounds during a transient run and a steady-state thrust of 57,830 pounds. This engine demonstrated a takeoff TSFC of 1.74 which is 4% below the production rating. Engine testing has been accomplished with the No. 2 reverser-suppressor installed and a reduction of 5 PNdb below that predicted by the SAE method has been demonstrated which confirms the level used for the specification values.

The Preliminary Engine Model Specification for an 825 lb/sec airflow engine was given to the FAA and The Boeing Company on 16 December.

The FAA Supplementary Engine Evaluation Task Force visited FRDC on 14 and 15 December to review the SST engine and rig test results since their visit on 16 and 17 November. Numerous meetings were held with Boeing and Lockheed personnel in a continuing effort to keep engine/airframe coordination current.

The following significant achievements have been made on the JTF17A-20 experimental engines:

Total engine time	154.55 hours
Total duct heating time	27.88 hours
Time at 2000°F and above	56.65 hours
Time at 2200°F and above at cruise (M 2.7, 65,000 ft)	14.27 hours
Heated inlet time	32.34 hours
Time at cruise conditions (M 2.7, 65,000 ft)	28.59 hours

SECTION II
PROBLEM REPORT

No significant problems remained unresolved at the end of the period.

SECTION III
DESCRIPTION OF TECHNICAL PROGRESS

A. ENGINE DESIGN

1. Fan

Layouts were completed that define those items which are necessary to permit installation of the prototype JTF17A-21 fan into one of the initial experimental engines. This modification consists of prototype blades, vanes and spacing, the initial experimental engine 1st-stage disk, a new 2nd-stage disk, and a modified intermediate and inlet case. The prototype inlet bellmouth and inlet instrumentation ring are incorporated in this design. Prior to layout completion, raw material drawings were prepared and released for advance material procurement.

2. Compressor

All layouts that were required to define the incorporation of the prototype compressor into test rigs were completed.

3. Primary Combustor

The design layouts on the primary combustor and the diffuser case were completed.

The design of the alternative film-cooled transition duct was established.

4. Duct Heater

The design of the JTF17A-21 duct heater and the duct heater diffuser have been established. The duct heater diffuser case, and rear cases and liners have been defined.

5. Turbine

The design of the JTF17A-21 turbine has been established. An alternative 1st-stage blade has been designed.

The design of the turbine high spool rig for Phase III has also been defined.

6. Shafts, Bearings and Seals

The design layouts for the No. 1 and 2 bearing compartment are complete. The No. 3 and 4 compartment designs have been defined.

7. Accessory Drives

Studies were accomplished to define the modifications necessary to adapt the test stand starters and initial experimental engine gearbox arrangement for the first prototype engine.

8. Fuel System

The fuel and hydraulic system schematics were updated and redrawn for the JTF17A-21 engines in this report period.

9. Control System

Through coordination with the vendor selected for the fuel control, the specific locations were determined for all fuel connections on the control base plate for the JTF17A-21L engine.

The final configuration of the hydraulic pump and the gas generator fuel pump was decided with the selected vendors.

The design of the duct nozzle feedback system has been defined and coordination of the connection to the fuel control with the vendor was initiated. Cable routing, pulley brackets, and cable tensioners have been established.

A preliminary design of an alternative reverser interlock using cams and cam followers was completed. The associated cable routing, pulley brackets, and cable tensioner have been defined.

The design of the inlet guide vane and aerodynamic brake actuator has been established.

10. Electrical System and Instrumentation

Coordination of the low rotor speed pickup, N_1, was completed with two vendors.

Coordination of the transducer for the duct nozzle position indicator was initiated.

11. Reverser-Suppressor

Definition of the basic design of the JTF17A-21 reverser-suppressor and duct heater variable nozzle has been accomplished.

B. ENGINE TEST

	December Time, hours			Phase II-C Time, hours			
Engine	FX-161	FX-162	FX-163	FX-161	FX-162	FX-163	Total
Total	No testing in the December Report Period	No testing in the December Report Period	16.66	87.41	47.55	19.59	154.55
Heated Inlet			0	30.27	2.07	0	32.34
Cruise Condition (M = 2.7, 65,000 ft)			0	26.94	1.65	0	28.59
Duct Heater							
Total			1.68	20.43	5.77	1.68	27.88
Cruise Condition (M = 2.7, 65,000 ft)			0	6.17	0	0	6.17
Turbine Inlet Temperature							
2000°F and above			4.50	35.71	15.84	5.10	56.65
2100°F and above			1.59	26.40	15.64	1.96	44.00
2200°F and above			0.63	18.41	5.85	0.75	25.01
2200°F and above at cruise conditions (M = 2.7, 65,000 ft)			0	14.27	0	0	14.27
2300°F and above			0.03	0.59	0.38	0.03	1.00

1. Engine FX-161 - Disassembly Inspection

The engine was disassembled for inspection following the completion of the altitude inlet distortion program, reference PWA FR-2213. The engine, with the inlet instrumentation ring, is shown as it was returned to the assembly floor in figure III-B-1. All parts were inspected and reviewed in preparation for rebuild. The general condition of the parts was good.

2. Engine FX-163

Assembly was completed on 3 December, and the engine was delivered to sea level test stand A-4. See figure III-B-2. The major feature of this second build was the incorporation of the prototype design high compressor. A summary of all features included in this build is presented in PWA FR-2213.

The initial start was made on 5 December followed by a series of check runs. Operation of the gas generator and duct heater was satisfactory with engine match and performance as predicted. The prototype compressor produced a marked improvement in performance. Design rotor speeds were obtained at very near the design turbine inlet temperature. A transient maximum thrust run was made on 7 December with data automatically recorded during acceleration to and deceleration from the predicted 57K point conditions. Analysis of the data revealed that a maximum thrust of 58,800 pounds had been achieved and that this build of FX-163 with the prototype compressor was capable of demonstrating Phase II-C performance goals; see paragraph III-B-3. The engine while running is shown in figure III-B-3.

The engine was visually inspected and the parts were in good condition. See figures III-B-4 and III-B-5. A hot section inspection followed, which included X-ray and zyglo examination of the 1st-stage turbine blades. The condition of the turbine was found to be good with only four minor discrepancies as follows:

1. Four of the 24 instrumented 1st-stage turbine vanes, one temperature-instrumented and three pressure-instrumented, showed evidence of slight distress. All noninstrumented vanes were in excellent condition. See figure III-B-6.

2. Zyglo inspection of the 1st-stage turbine blades revealed a coating crack on one blade, and X-ray inspection indicated possible cracks in two other blades.

3. Three small hot spots were evident in the primary combustor, one on a scoop and two along the OD trailing edge. See figure III-B-7.

The above-mentioned four instrumented 1st-stage turbine vanes, were replaced with noninstrumented parts as a precautionary measure. In addition, a fifth pressure-instrumented vane was also replaced with a noninstrumented part. Four of the five replacements were TD Nickel.

Laboratory examination of one 1st-stage turbine blade revealed subsurface stress-rupture cracks. Blades of this type had accumulated a total of 96.0 hours of engine testing, including 87.4 hours in engine FX-161 prior to incorporation into FX-163-2. The entire stage was replaced with new blades pending more detailed examination of the remaining blades.

The small burn spots on the primary combustor were left untouched. Jet nozzle area was increased by 5% to rematch the engine to obtain design rotor speeds at design turbine inlet temperature.

Reassembly was completed on 10 December. Post-inspection check runs were completed, and on 11 December, a steady-state point at 57,830 pounds thrust and 2337°F TIT was achieved; see Performance, paragraph III-B-3. The engine is shown running in figure III-B-8.

External visual inspection of the engine revealed no evidence of damage to any parts. A hot section visual inspection of the turbine was made and revealed that all parts were in good condition. The TD Nickel vanes were unaffected by engine testing. The 1st- tage turbine blades had rubbed lightly on the outer shroud but showed no evidence of damage. The burned areas on the primary combustor had increased slightly.

Visual inspection was completed on 14 December, and reassembly was completed on 16 December with reverser-suppressor unit No. 2 installed. See figures III-B-9 through III-B-11.

On 27 December, cold and hot calibrations were completed with the reverser-suppressor in the forward thrust mode to evaluate the effect of the reverser-suppressor on performance and noise. Figure III-B-12 shows the engine running at 53,100 pounds of thrust with a TIT of 2200°F. There was no loss in performance from the reverser-suppressor when compared to running without the reverser-suppressor. The noise level at sea level takeoff conditions was 5 PNdb below that predicted by the SAE method.

The reverser-suppressor was operated into and out of the reverse thrust mode at idle conditions. There was no suppression of engine speed nor any other adverse effects. Operation into and out of reverse was smooth and without incidence. Overall operation in both the forward and reverse modes was excellent.

The duct heater light, accomplished automatically, was exceptionally smooth and without incidence.

Visual inspection revealed no evidence of distress as a result of the above running other than a few cracked Z-stiffeners in the trailing edge of four tailfeather seals. See figures III-B-13 through III-B-18.

3. Performance

On 11 December, engine FX-163-2 was run at sea level to a stabilized thrust of 57,830 pounds at a TSFC of 1.94. In addition to the maximum thrust point a duct heater lit calibration was taken, at a lower turbine inlet temperature, to define the variation of thrust with duct heater fuel/air ratio. These data, summarized in figure III-B-19, show that at the JTF17A-20 production thrust of 57,000 pounds the TSFC would be 1.74 compared to the guaranteed TSFC of 1.81.

On 27 December, nonaugmented and augmented calibrations were completed in order to evaluate the effect of the reverser-suppressor on performance and noise. There was no loss in performance from the reverser-suppressor when compared to running without the reverser-suppressor. The noise level at sea level takeoff conditions was 5 PNdb below that predicted by the SAE method.

Figure III-B-20 compares the engine match point for engine FX-163-2 with the design goal and with the match point of earlier engine builds. The high compressor in engine builds prior to engine FX-163-2 exhibited a surge line well below the design goal. The lower surge line required the engine to be run with turbine vane areas much larger than optimum to lower the operating line, reaulting in a loss in turbine efficiency and reduced rotor speeds. Engine FX-163-2 incorporated the prototype JTF17A-21 compressor which as a rig demonstrated a surge line and efficiencies better than the design goals.

Table III-B-1 compares the measured component performance of engine FX-163-2 with the predicted components for the production JTF17A-20.

Table III-B-1. Component Comparison

	FX-163-2	JTF17A-20 Production Engine
$W_a \sqrt{\theta_{T2}}/\delta_{T2}$	671	650
$N_1/\sqrt{\theta_{T2}}$	6400	6160
$N_2/\sqrt{\theta_{T3}}$	7010	7050
Gas Generator Airflow	295	283
Bypass ratio	1.27	1.30
$P_{T3}E/P_{T2}$	2.64	2.50
$P_{T3}D/P_{T2}$	2.86	2.70
P_{T4}/P_{T3}	4.76	4.77
$\eta_{\text{Fan ID}}$	0.84	0.90
$\eta_{\text{Fan OD}}$	0.78	0.82
$\eta_{\text{Comp.}}$	0.86	0.86
$\Delta P_{4-5}/P_{T4}$	0.063	0.063
Turbine Inlet Temperature - °F	2337	2300
η_T High	0.86	0.87
η_T Low	0.86	0.875
FN - lbs	57,830	57,000
TSFC	1.94	1.81
Duct Heater F/A ratio	0.064	0.060
Duct Discharge Temperature - °F	3200	3100
TSFC	1.74*	
Duct Heater F/A ratio	0.057*	
Duct Discharge Temperature - °F	3100*	

*for FN = 57,000 lb

4. Materials and Fabrication

Long-time stress rupture and creep rupture testing on candidate SST materials has been completed.

A list of candidate materials, the proposed applications in the SST design, and the limiting creep and stress design criteria are tabulated as follows:

Material	Application	Limiting Creep, %	Design Criteria Creep and Stress Rupture Temp Range, °F	High Time Specimen, hr
Astroloy (PWA 1013)	Disks	0.1	1200-1400	4745
Waspaloy Sheet (PWA 1030)	Cases	0.5	1200-1600	5113
Waspaloy Forgings (PWA 1016)	Disks, Shafts, Hubs	0.1	1100-1300	3587
Inco 718 Sheet (PWA 1033)	Ducts, Cases	0.5	1000-1200	3220
L-605 Sheet (AMS 5537)	Ducts, Liners	0.5	1400-1800	5203
Hastelloy X Sheet (AMS 5536)	Burners, Ducts	0.5	1400-1800	4761
IN-100 (PWA 658)	Blades, Vanes	1.0	1400-1800	4950
Inco 625	Duct, Liners		1200-1500	1800
TD Nickel (PWA 1035)	Vanes		1700-2100	2023
Titanium (PWA 1202)	Blades	0.1	700-900	7541
PWA 664	Blades	1.0	1400-1800	3060
A-110 (AMS 4910)	Cases	0.1	700-900	4052

The results of long-time stress rupture and creep testing of Waspaloy Sheet are plotted in figures III-B-21 and III-B-22. Results for all other alloys have been reported prior to this report.

Material	Stress Rupture Figure No.	Creep Figure No.
Astroloy (PWA 1013)	*	*
Waspaloy Sheet (PWA 1030)	III-B-21	III-B-22
Waspaloy Forgings (PWA 1016)	*	*
I-718 Sheet (PWA 1033)	*	*
L-605 Sheet (AMS 5537)	*	*
Hastelloy X Sheet (AMS 5536)	*	*
IN-100 (PWA 658)	*	*
Inco 625	*	*
TD Nickel (PWA 1035)	*	*
PWA 664	*	*
Titanium (PWA 1202)	*	*

*Testing completed. Curves in previous reports

5. Sulfidation and Oxidation-Erosion Testing

Sulfidation testing is being continued on the most promising candidate SST materials and coatings. The following is a summary of sulfidation testing conducted at accelerated test conditions of 1.0 ppm NaCl content in air, maximum sulfur content allowed (0.3%) by PWA fuel specifications 522 and specimen metal temperature of 1800°F.

Material	Coating	Protection, hr
PWA 1035 (TD Nickel)	PWA 62	1250
PWA 664	PWA 47	1350
PWA 664	PWA 64	1850
PWA 658 (IN-100)	PWA 64	1150
PWA 658 (IN-100)	*	2500
PWA 1035 (TD Nickel)	*	1350**

*PWA number has not been assigned
**Testing of specimens to date.

A graphic presentation of these data is shown in figure III-B-23. The results to date of the sulfidation testing are: (1) PWA 1035 (TD Nickel) coated with the newly developed coating showed excellent sulfidation protection after 1350 hours of total testing, (2) PWA 658 (IN-100) coated with the newly developed coating showed excellent sulfidation protection after 1350 hours of total testing, (3) PWA 658 (IN-100) and PWA 664 coated with PWA 64 showed excellent sulfidation protection after 850 hours of retesting.

Long-time oxidation-erosion testing of candidate SST materials and coatings (also other materials and coatings for comparison) continued at 1800°F specimen metal temperature. The results to date for the following materials and coatings are: (1) PWA 658 (IN-100) coated with PWA 58, and PWA 664 coated with PWA 47 showed excellent oxidation-erosion protection after 1500 hours of testing; (2) PWA 657 (SM 302) coated with PWA 45 showed excellent protection after 750 hours of testing; (3) PWA 1035 (TD Nickel) coated with PWA 62 showed excellent protection after 750 hours of testing; (4) PWA 664 and PWA 658 coated with PWA 64 showed excellent protection after 650 hours of testing. A graphic presentation of these data is shown in figure III-B-24.

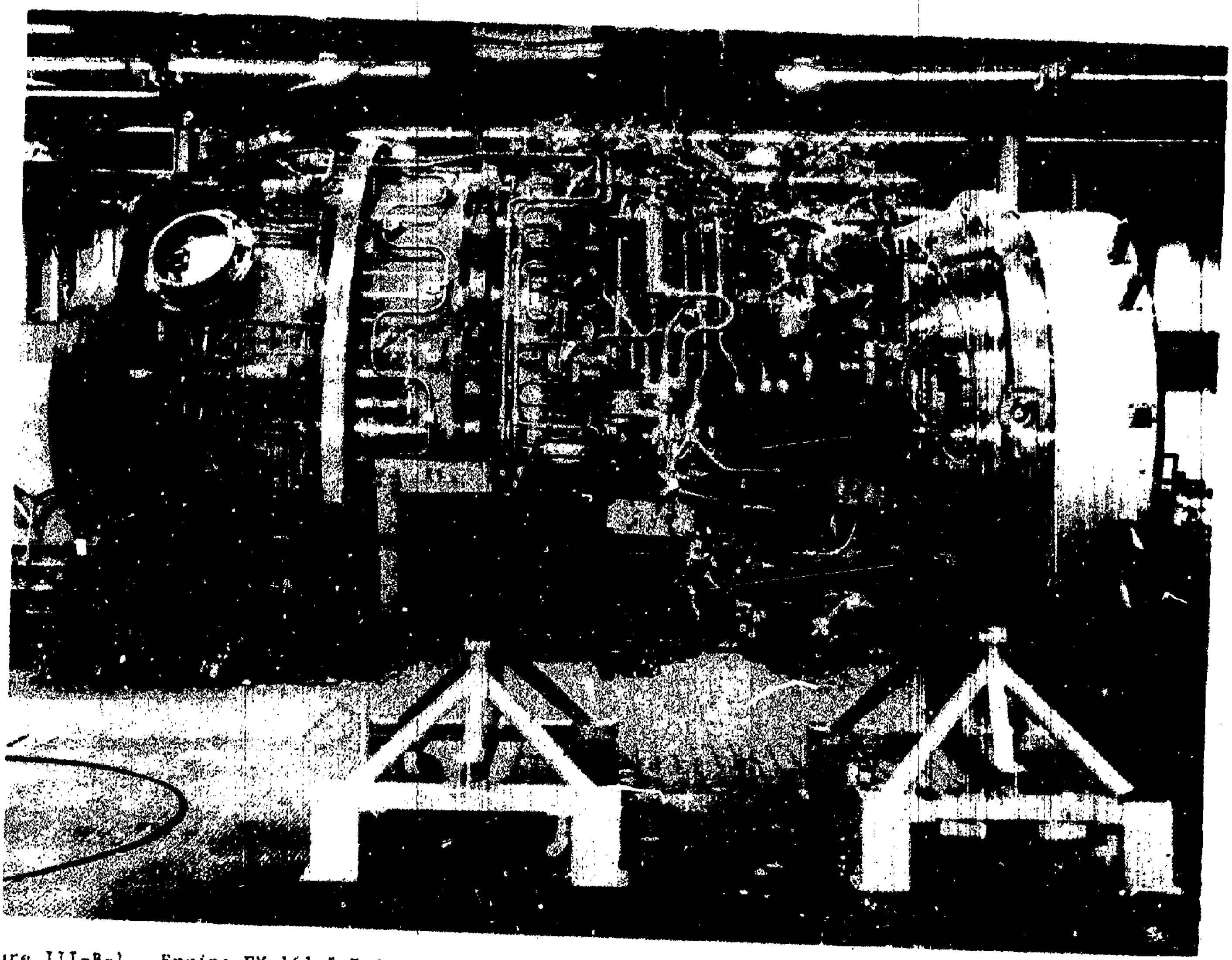


Figure III-B-1. Engine FX-161-5 Prior to Teardown

FE 65479

FE 65779

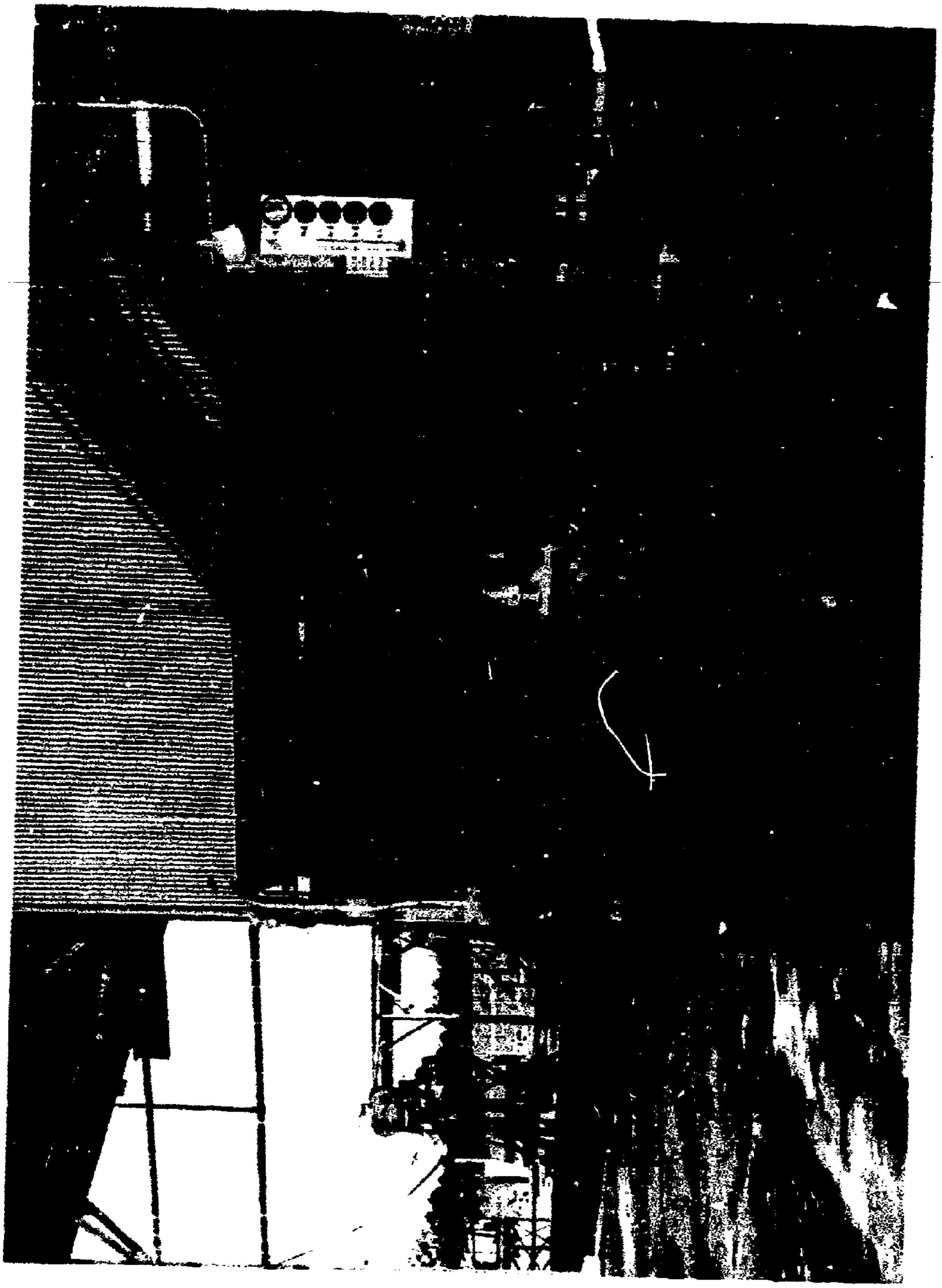


Figure III-B-2. Engine FX-163-2 in Sea Level Test Stand A-4

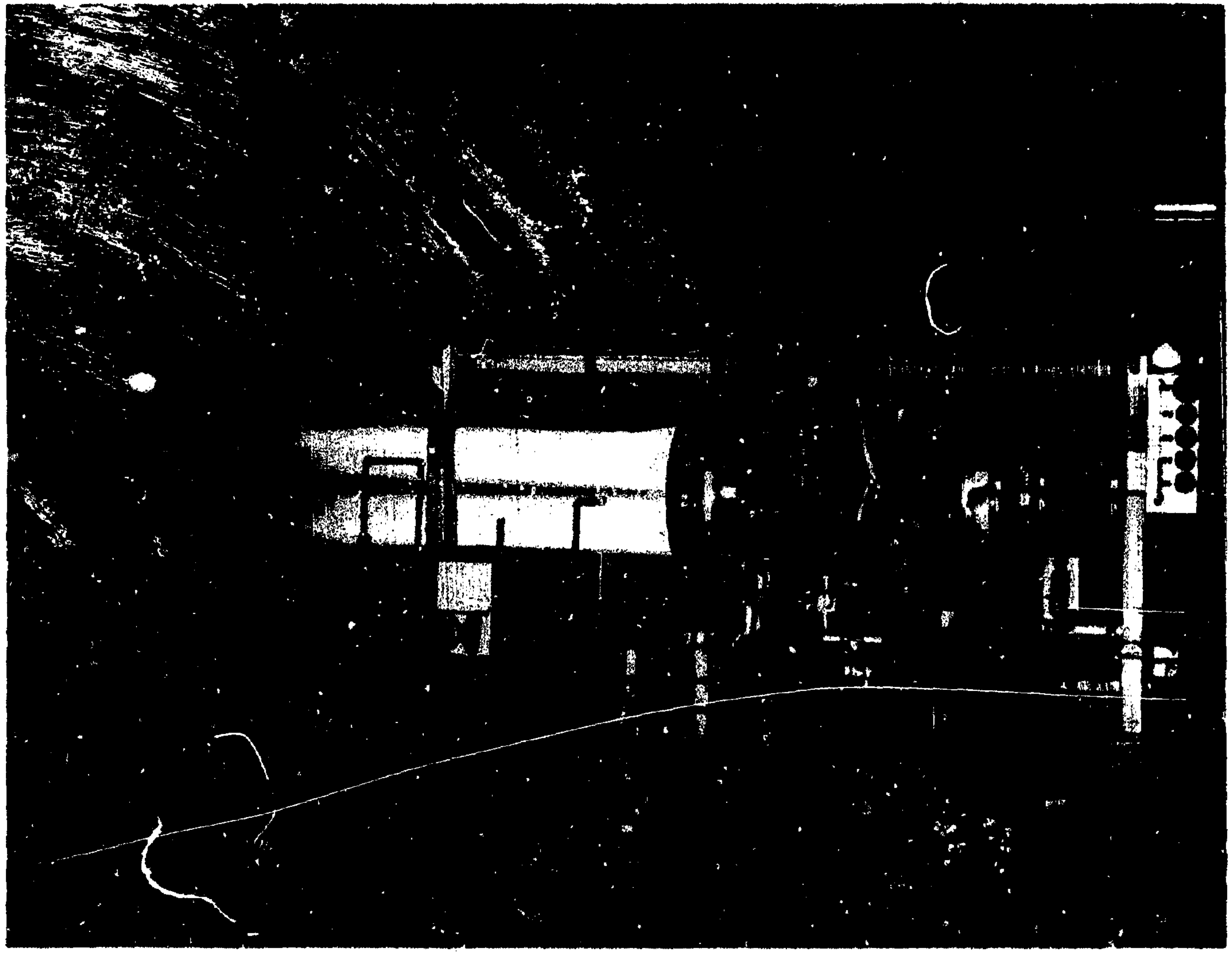
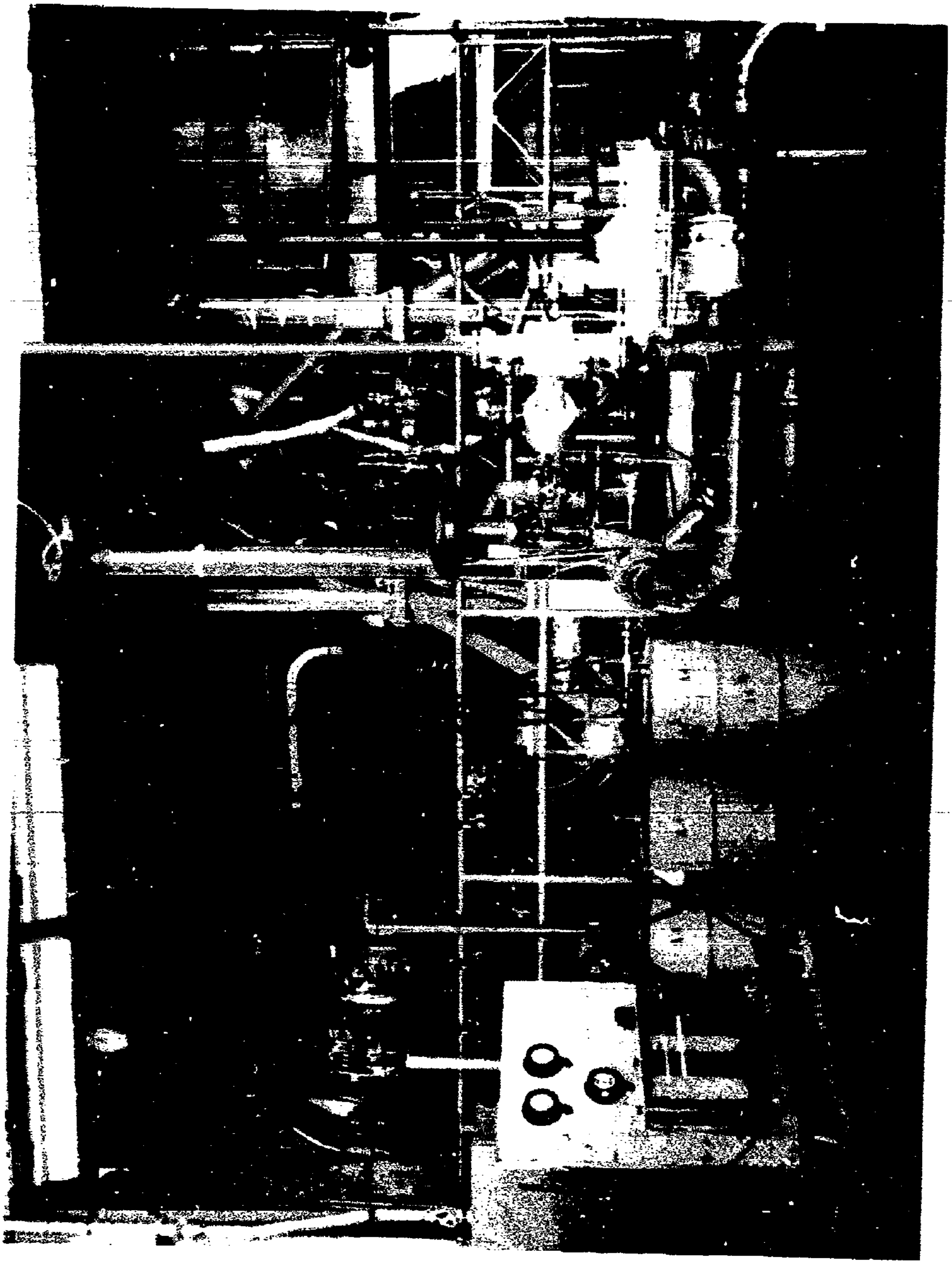


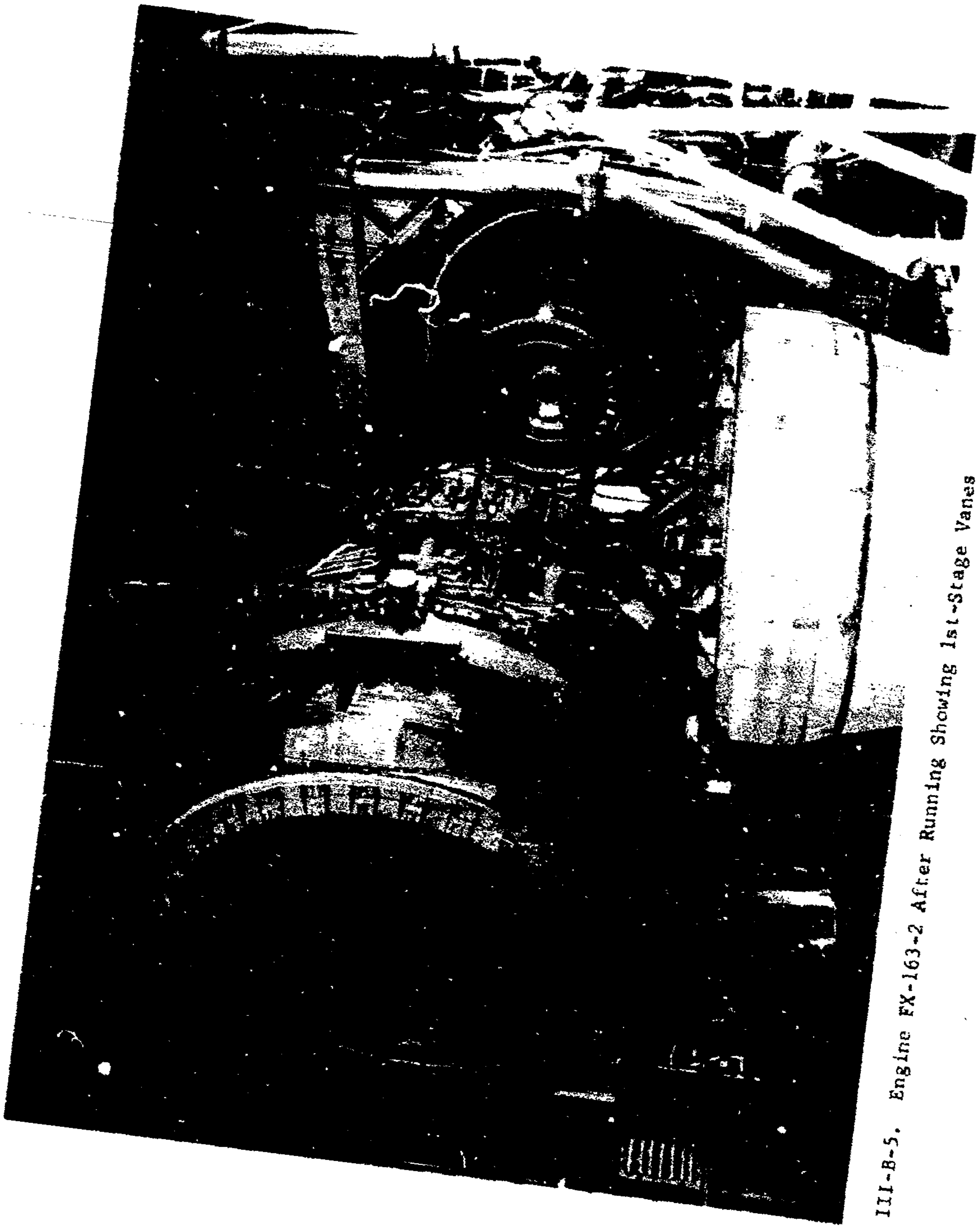
Figure III-B-3. Engine FX-163-2 Running in Test Stand A-4

FE 65956



FE 65803

Figure III-B-4. Engine FX-163-2 After Running



FE 65802

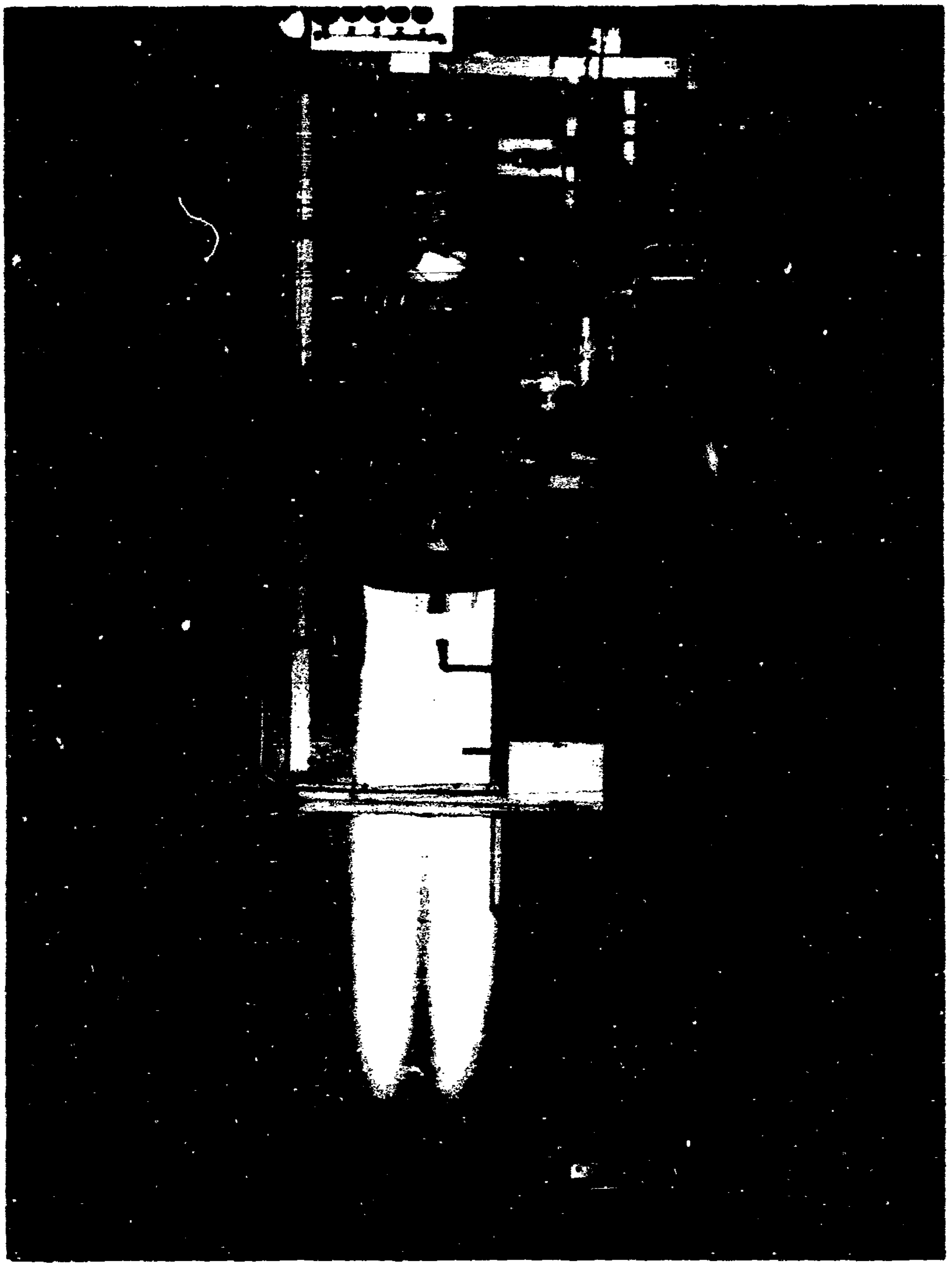
Figure III-B-5. Engine FX-163-2 After Running Showing 1st-Stage Vanes

FE 66022

Figure III-B-6. Engine FX-163-2 1st-Stage Turbine Vanes Looking Forward

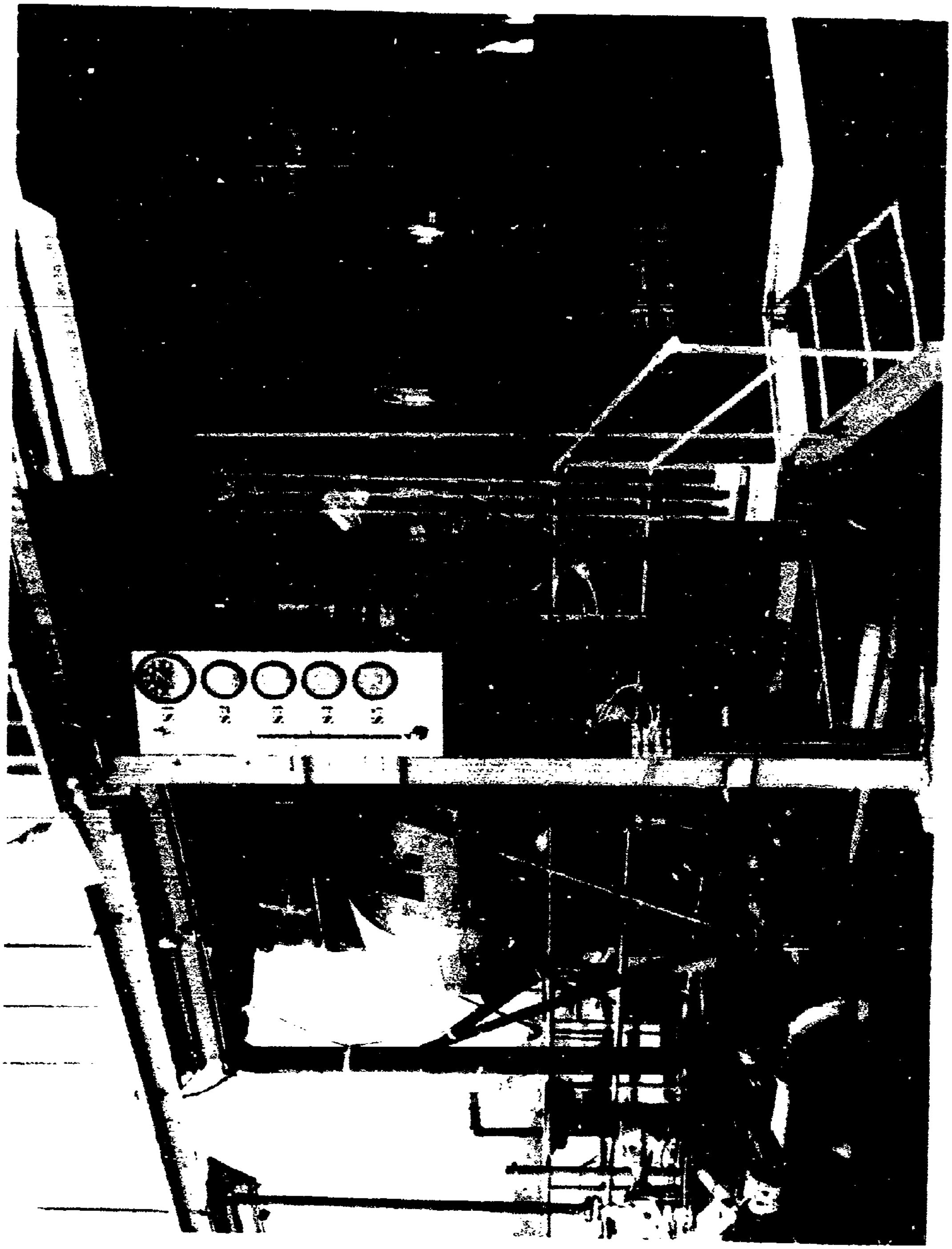
FE 65977

Figure III-B-7. Engine FX-163-2 Primary Combustor Showing Slight Burning



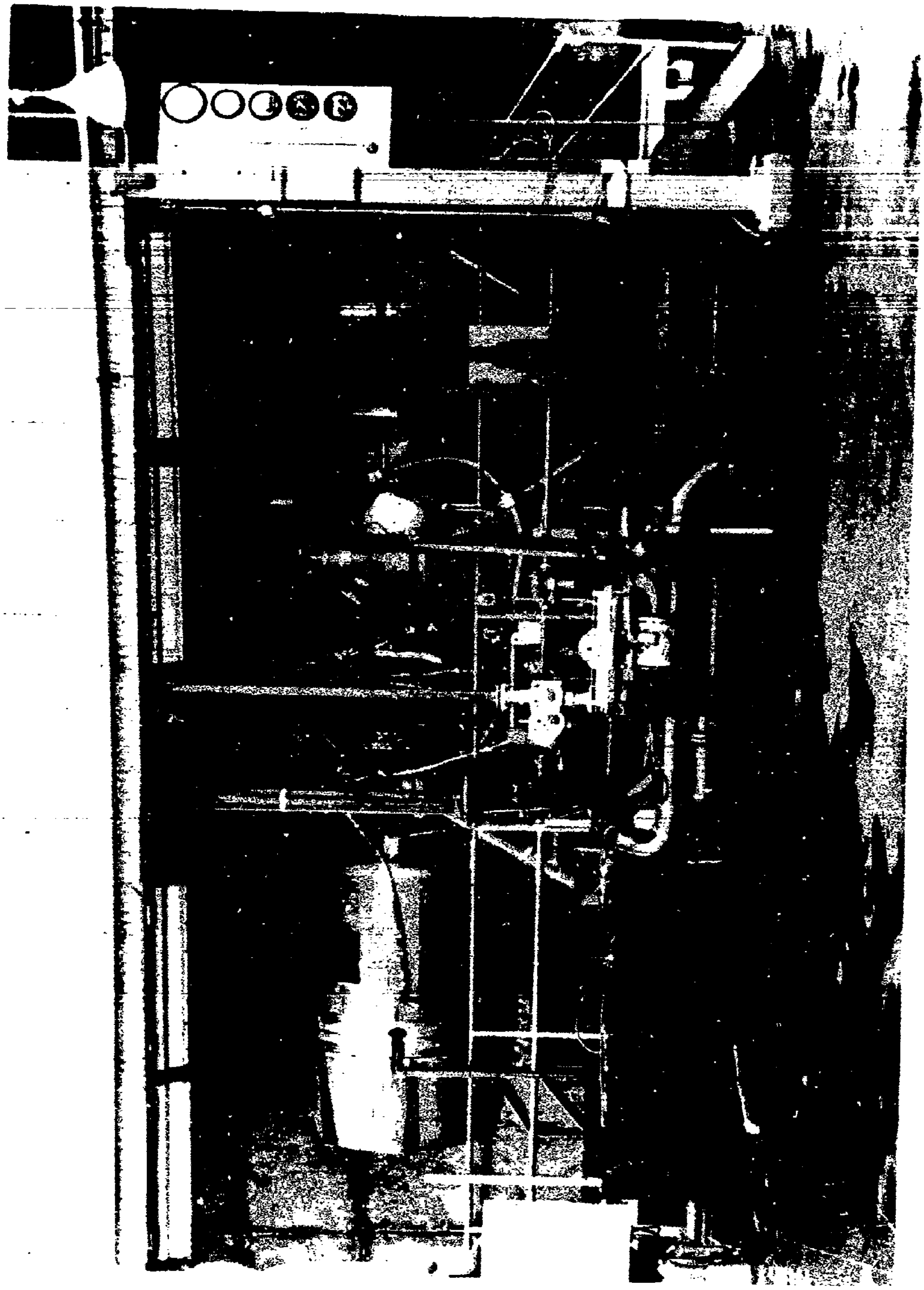
FE 66012

Figure III-B-8.. Engine FX-163-2 Operating at 57,830 lb Thrust



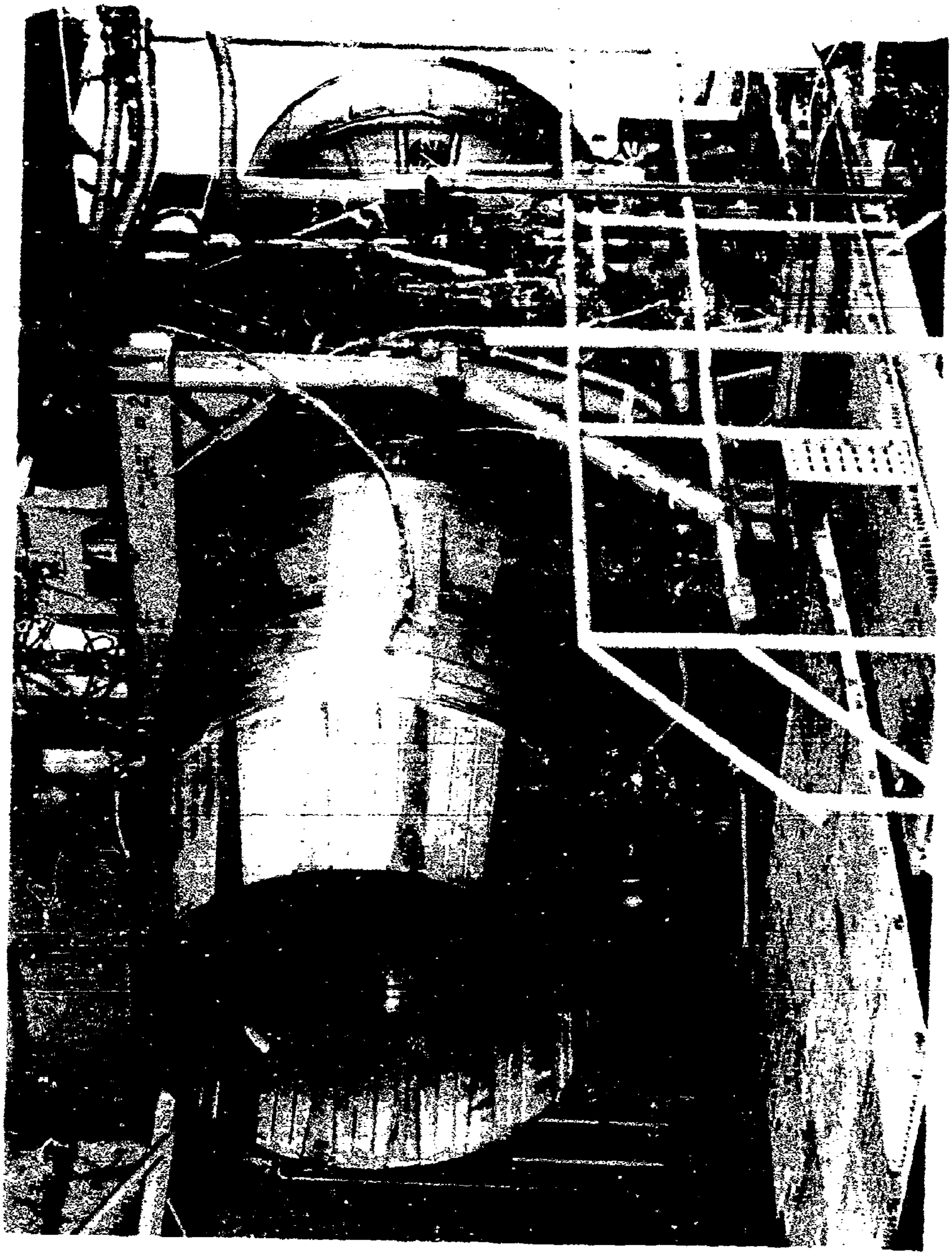
FE 66082

Figure III-B-9.. Engine FX-163-2B With Reverser-Suppressor



FE 66080

Figure III-B-10. Engine FX-163-2B With Reverser-Suppressor



FE 66083

Figure III-B-11. Engine FX-163-2B With Reverser-Suppressor

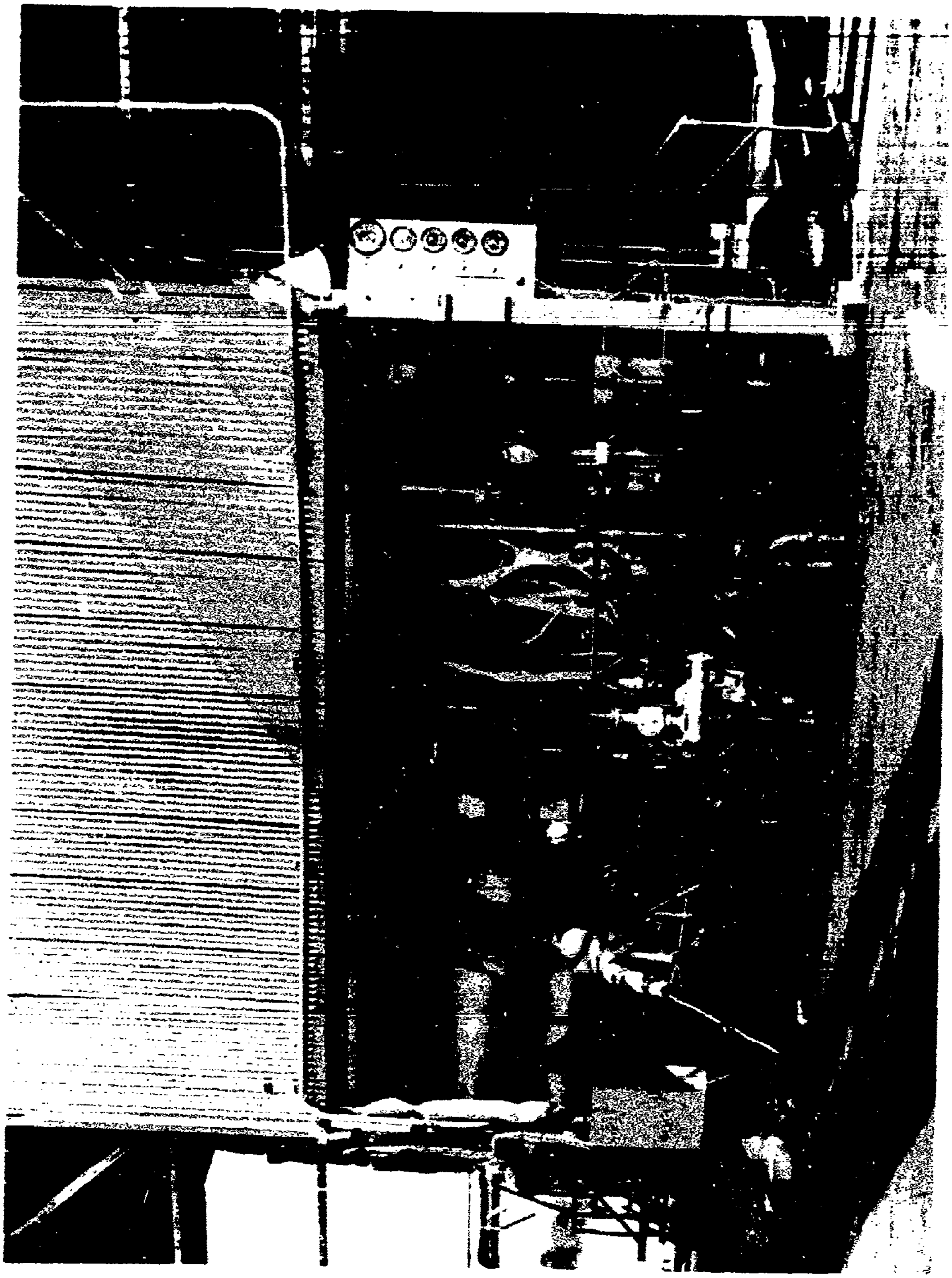


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Figure III-B-12. Engine FX-163-2B While Running With Reverser-Suppressor

FE 66505

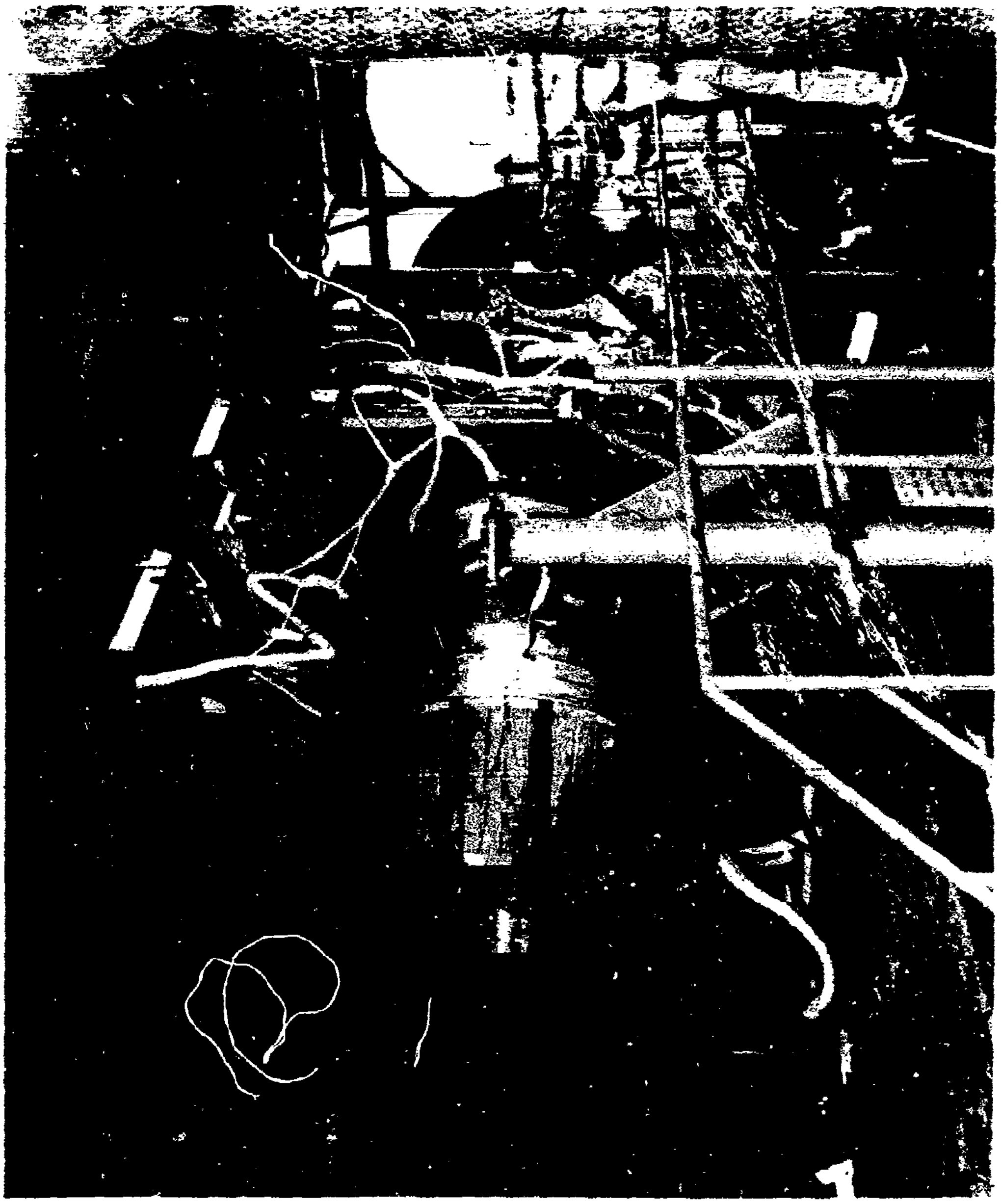


Figure III-B-13. Engine FX-163-2B After Running with Reverser-Suppressor

FE 66258

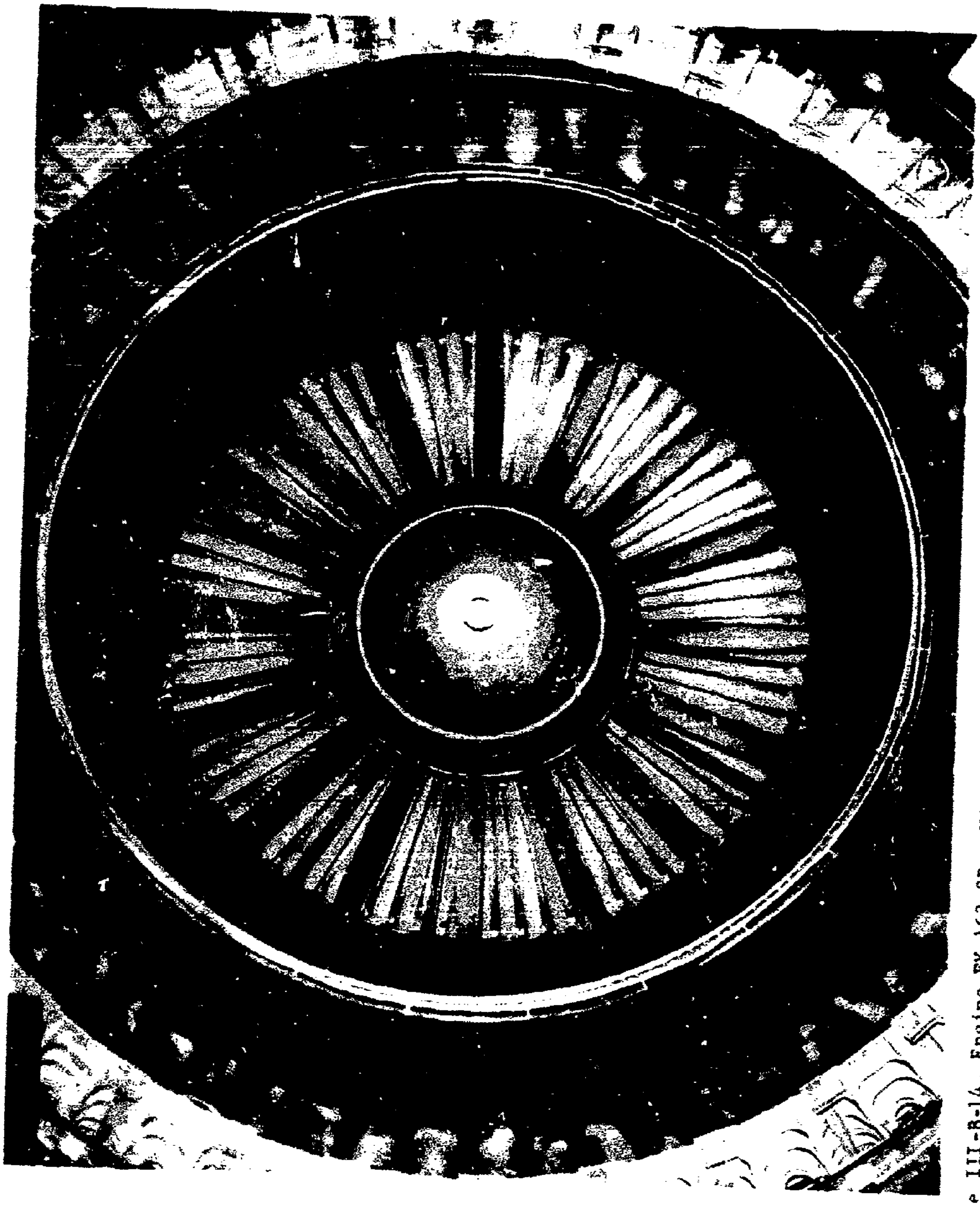


Figure III-B-14. Engine FX-163-2B - View From the Rear After Testing

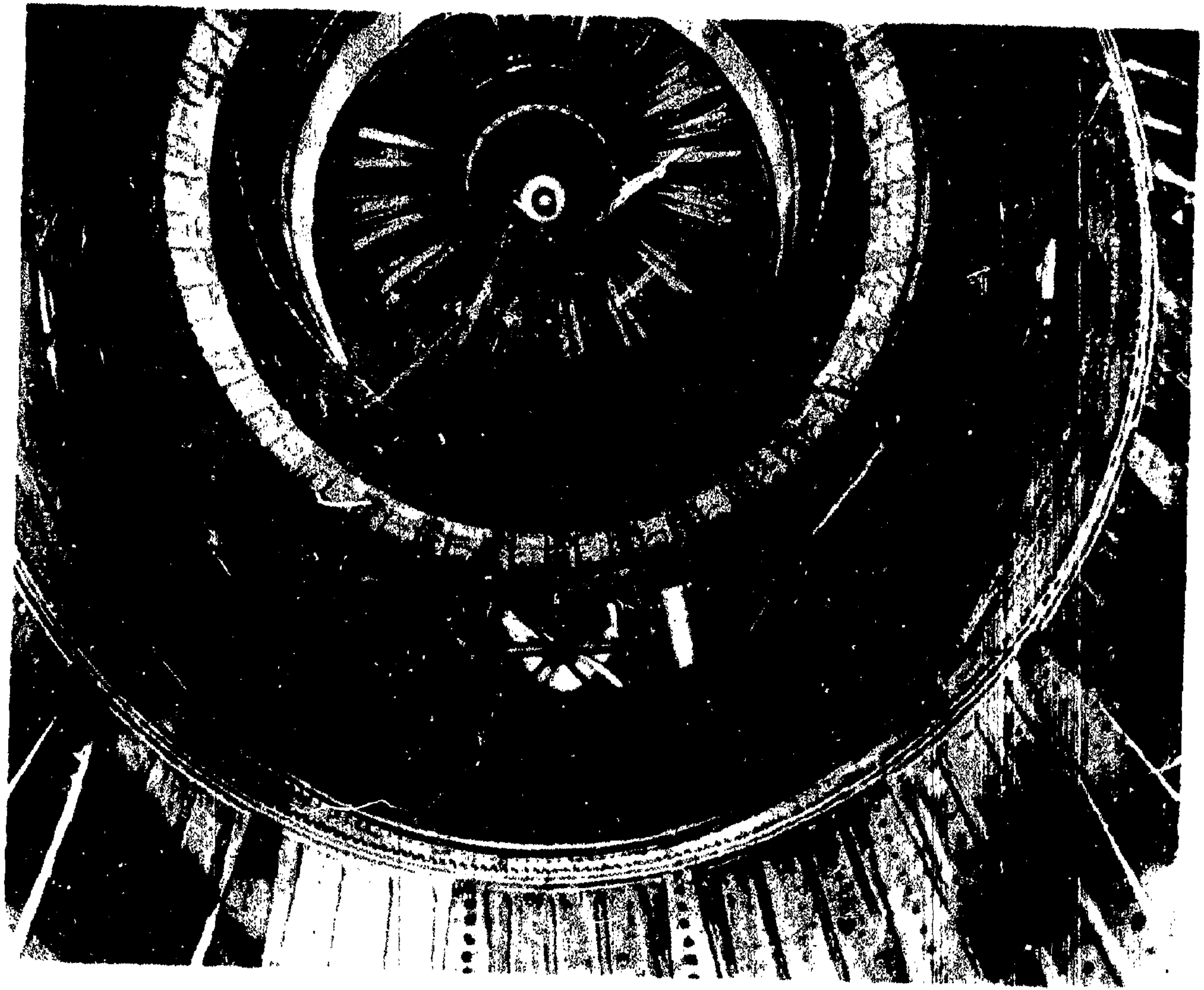
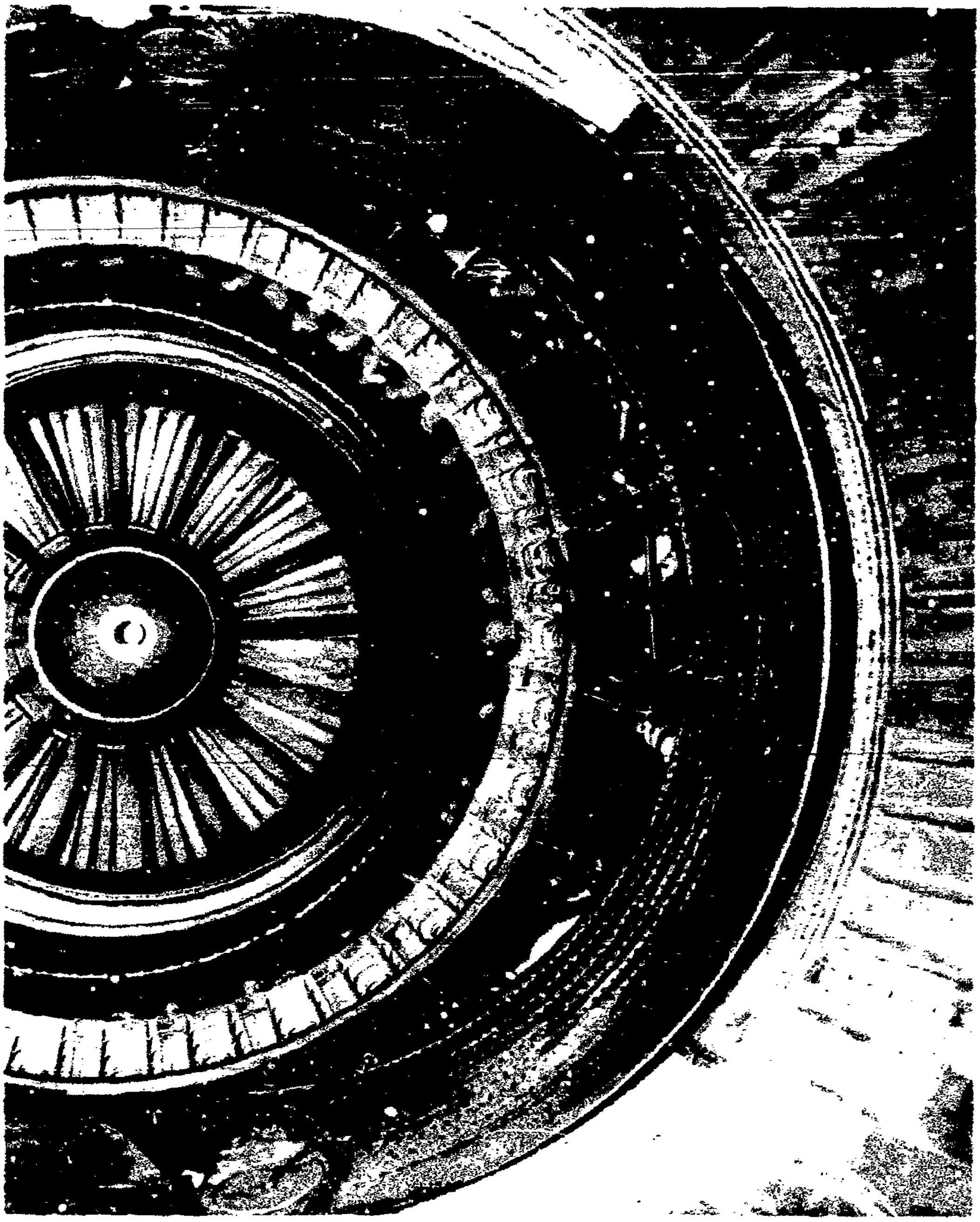


Figure III-B-15. Engine FX-163-2B Reverser-Suppressor Upper Clamshell After Testing

FE 66462



FE 66463

Figure III-B-16. Engine FX-163-2B Reverser-Suppressor Lower Clamshell After Testing

Figure III-B-17. Engine FX-163-2B Left Side View of Reverser-Suppressor Exit Flaps After Testing FE 66460

Figure III-B-18. Engine FX-163-2B Right Side View of Reverser-Suppressor Exit Flaps After Testing FE 66461

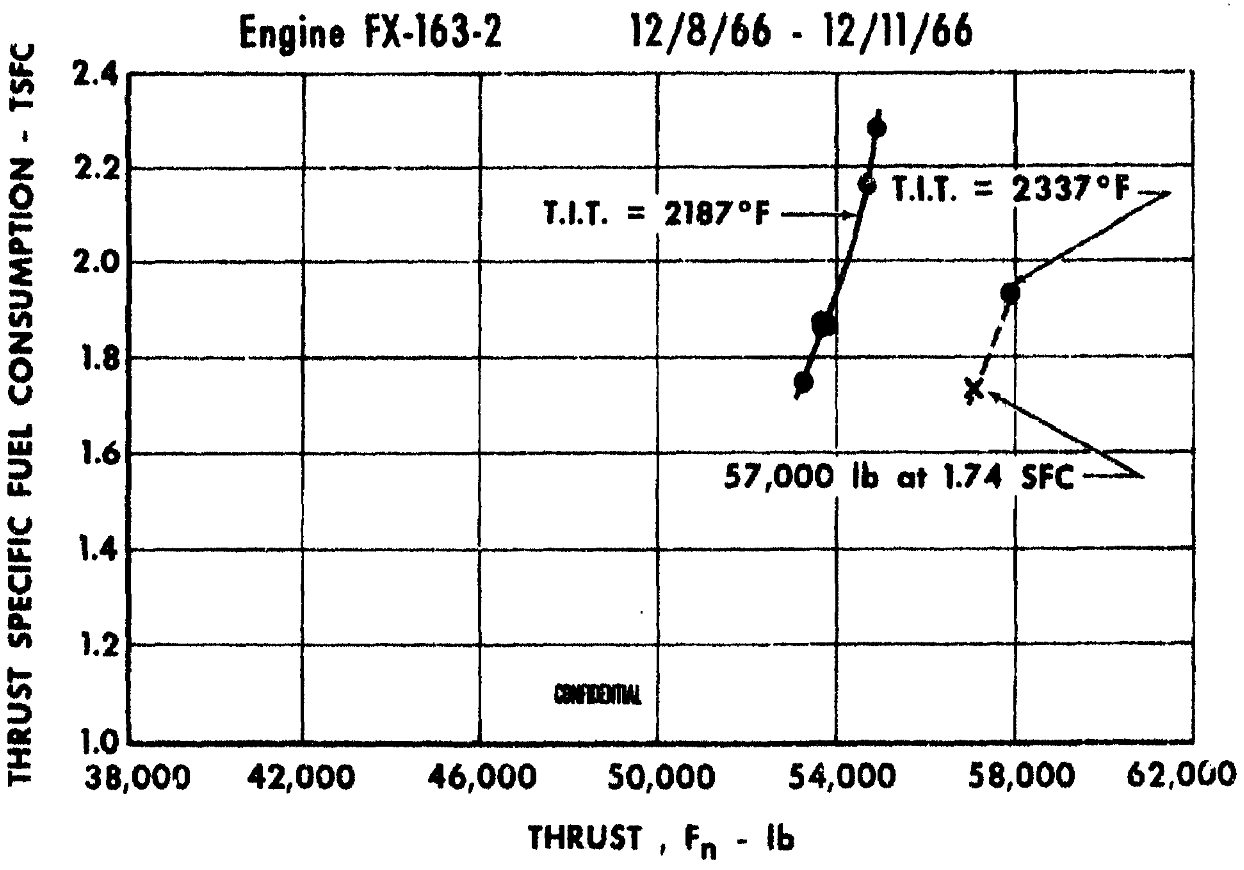


Figure III-B-19. Demonstration of JTF17A-20 Production Thrust Rating

CS 4230

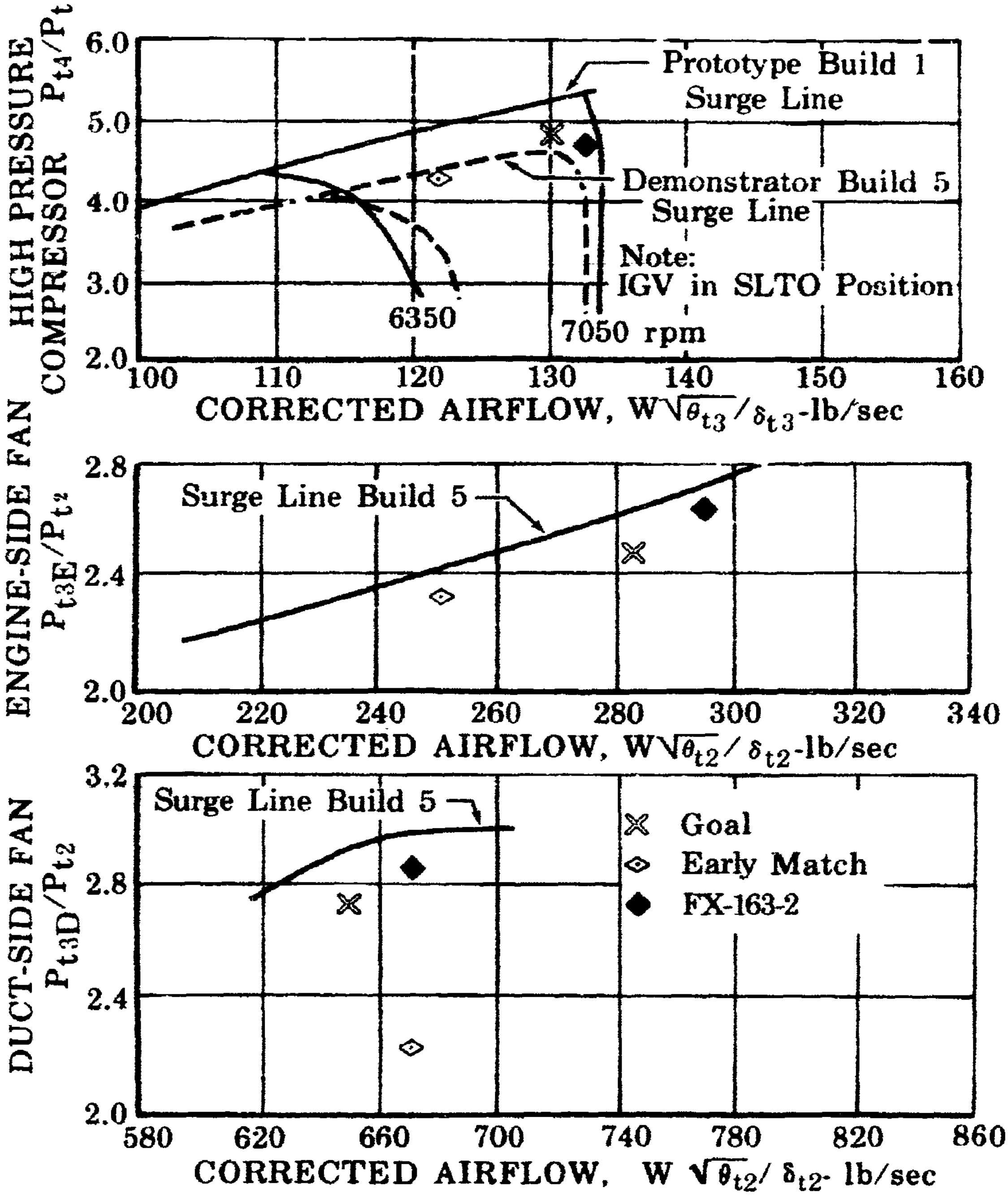
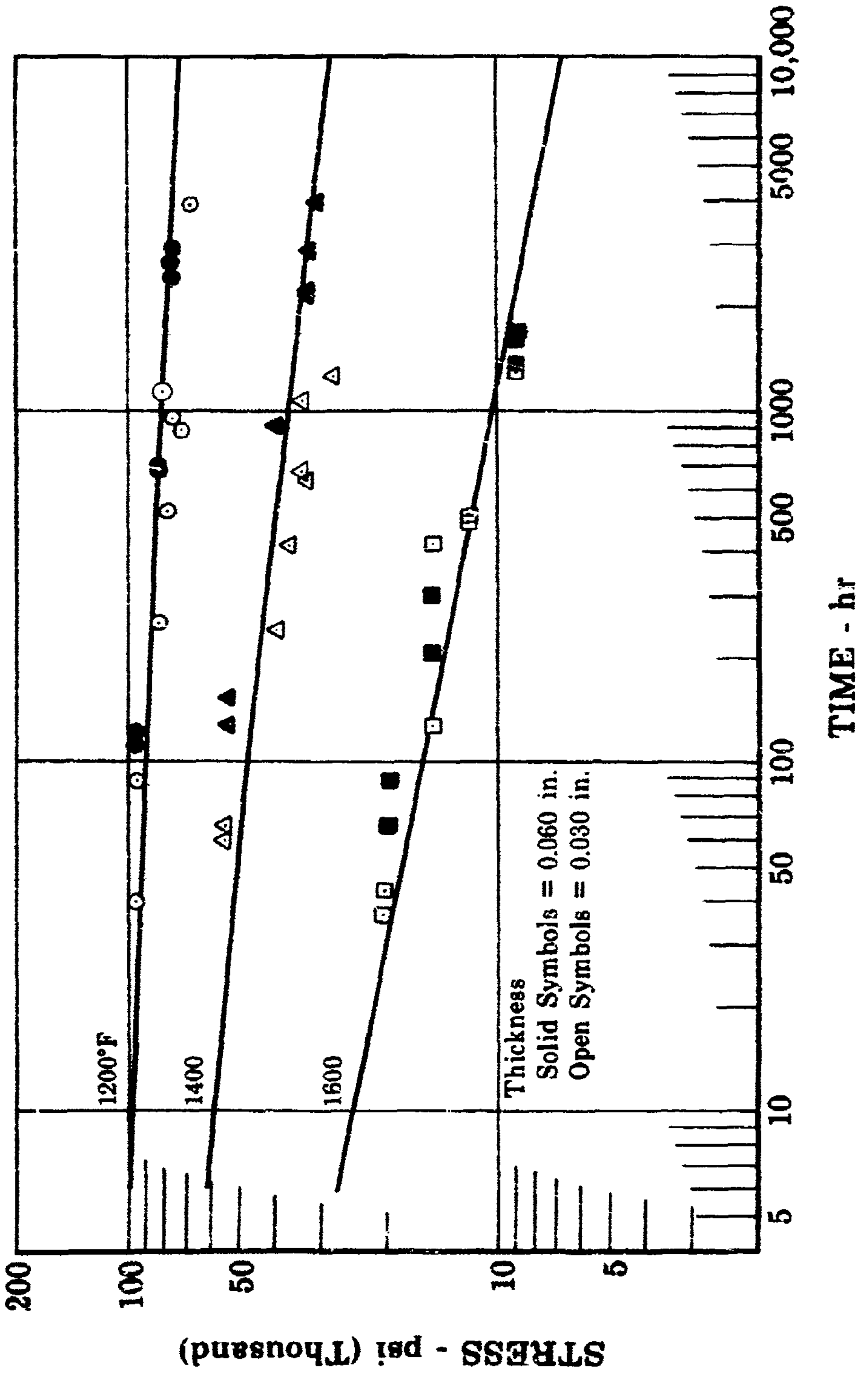


Figure III-B-20. Engine Performance Summary FD 18391B



FD 15592F

Figure III-B-21. Waspaloy Sheet (PWA 1030) Stress Rupture Test vs Design Curves

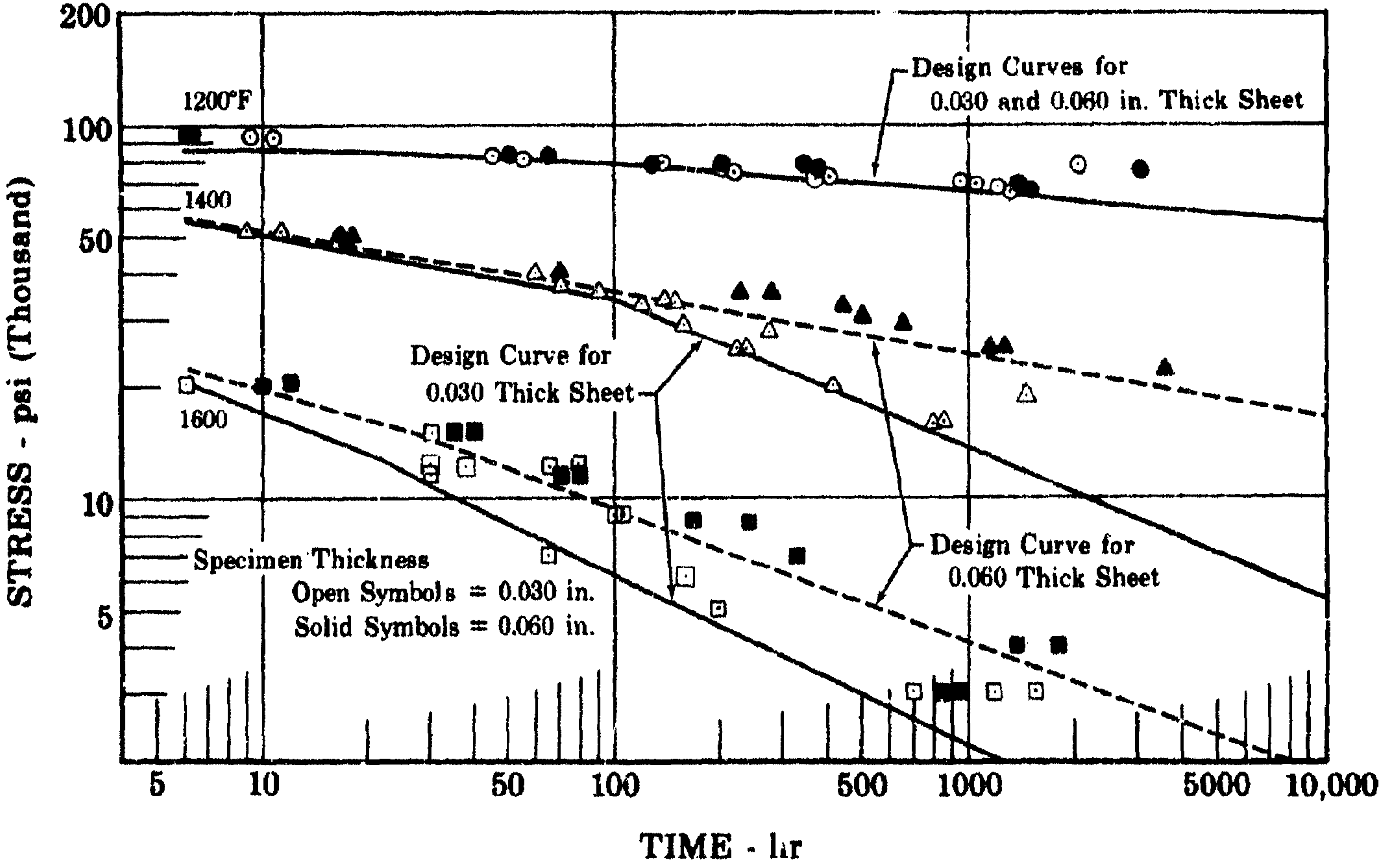


Figure III-B-22. Waspaloy Sheet (PWA 1030) 0.5% Creep vs Design Curves (Revised)

FD 15563G

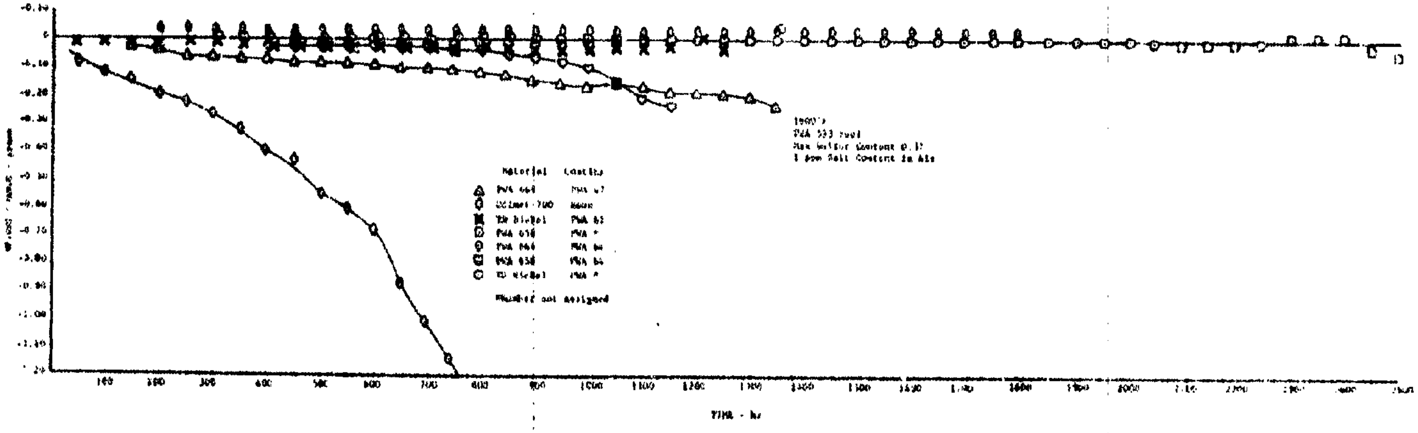


Figure III-B-23. Summary of Sulfidation Testing on Candidate Materials and Coatings

DF 47360E

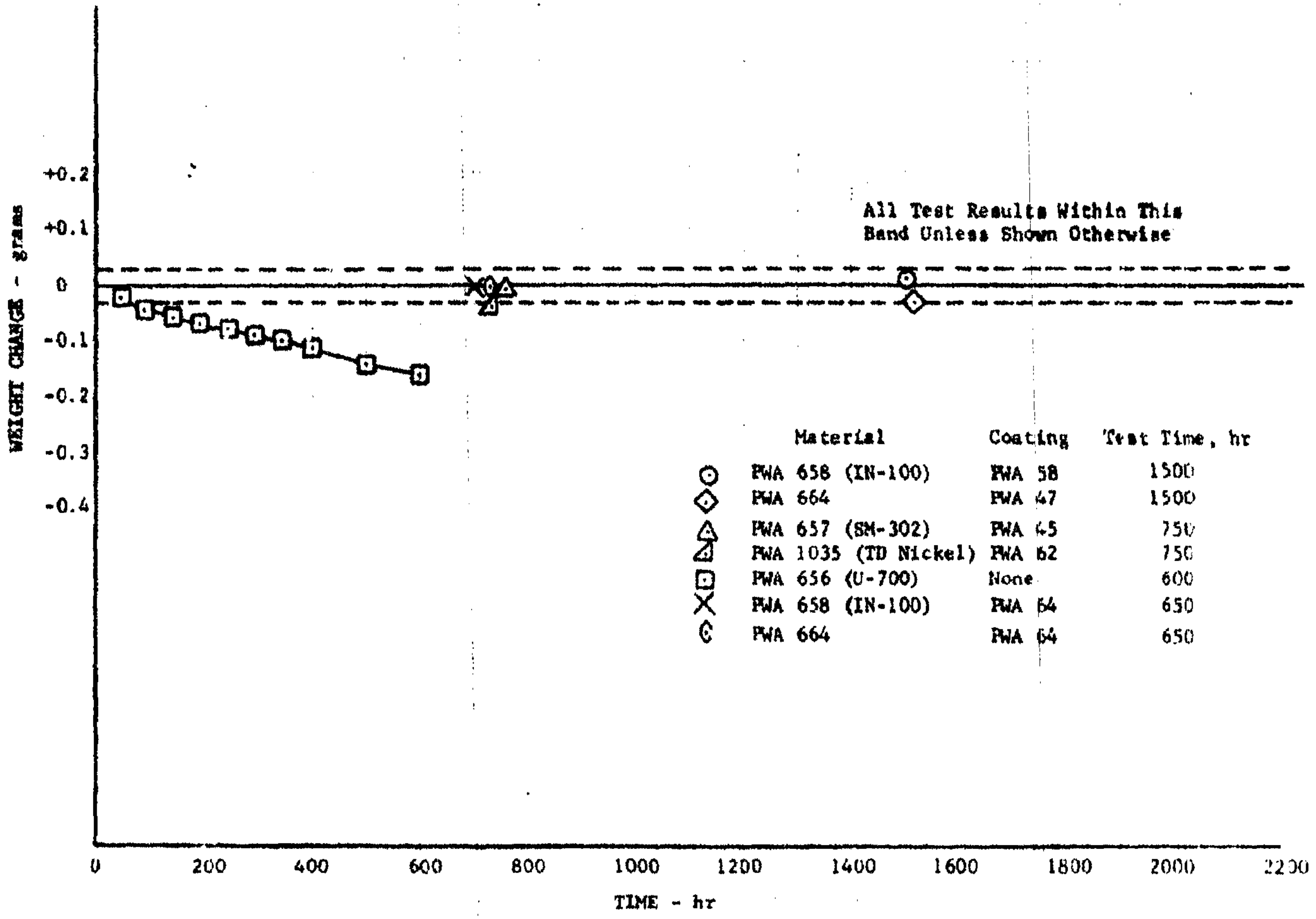


Figure III-B-24. Oxidation-Erosion Test Data Obtained at 1800°F Metal Temperature

DF 517658

C. COMPRESSOR

1. 0.6-Scale Fan Rig

	December	Phase II-C Total
Test Time	22.6 hours	584.6 hours

Build No. 12 of the 0.6-scale fan rig ran a partial performance calibration early in December. This build incorporated the redesign 1st- and 2nd-stage blades, which are a revised version of the build No. 7 blades. The 1st-stage blades are similar to the build No. 10 1st-stage blades, which were made by reoperating build No. 7 blades. The 2nd-stage blades incorporate a closed leading edge root and an opened leading edge from 30% span, relative to build No. 7.

Engine stream performance at design speed was the best demonstrated to date. A peak pressure ratio of 2.67 was reached at an efficiency of 87%, which is 4.5% higher than build No. 5. Peak efficiency at cruise was 90%. This performance is shown in the compressor map of figure III-C-1. Surge margin at cruise was lower than previous builds.

Fan stream performance was lower than build No. 5. Total airflow was down approximately 1.5% below design value at design speed. The surge point was approximately on the build No. 5 surge line. Peak efficiency was 5% below build No. 5, while cruise efficiency was the same. This performance is shown in figure III-C-2.

For the same overall rig pressure ratio, the 1st-stage blade average pressure ratio was 1.78 as compared to build No. 5 with 1.61, build No. 7 with 1.65, and build No. 10 with 1.74. The design goals of the 1st-stage blade have been reached. Analysis of data indicates that the 1st-stage vanes are stalled. This appears to be the cause of the low duct side efficiency and may be the cause of the low fan stream overall surge margin and engine surge margin at cruise.

Rig testing was terminated by failure of a 1st-stage blade approximately 3 inches above the root. Measured stresses during the test were 6000 to 7000 psi, which is well within the 10,000-psi limit for steady-state running. The fatigue failure progressed from the base of an angular oxide-discolored area approximately 0.031 in. in length at the trailing edge. The fatigue crack progressed approximately 50% through the airfoil before the failure terminated in tensile-shear. The fracture face is shown in figure III-C-3. The crack at the base of the defect from which the fatigue initiated is shown in figure III-C-4. The internal material defect was not detected by X-ray and fluorescent penetrant inspections to which the blade was subjected. Exact cause of the material defect could not be determined but may have been a lap or an internal burst during fabrication of the bar stock from which the blades were made.

Damage to the rig was moderate for this type of failure. Most of the 1st-stage blades suffered impact damage, but no other blades were broken. Approximately 10% of the 1st-stage vanes required replacement, and other vanes required minor blending. Approximately 50% of the 2nd-stage blades were reusable with only minor impact damage. Damage to the 2nd stage and exit vanes was very light with only minor blending required.

2. Full-Scale High Compressor Rig

	December	Phase II-C Total
Test Time	0.00 hours	114.50 hours

Compressor rig testing was suspended after the successful test of the first build of the prototype compressor, as documented in PWA FR-2213. New stator assemblies of engine-quality material were fabricated for an engine test of this compressor, since those of the compressor rig were made of 347 stainless steel and were not structurally adequate for engine tests.

The excellent performance of this compressor in the engine test allowed a demonstration of 57,830 pounds of thrust, corrected to standard day inlet conditions. The compressor, at the maximum thrust point, was operating at 86% efficiency and 4.76 pressure ratio with 132.5 pounds of airflow; see figure III-C-5.

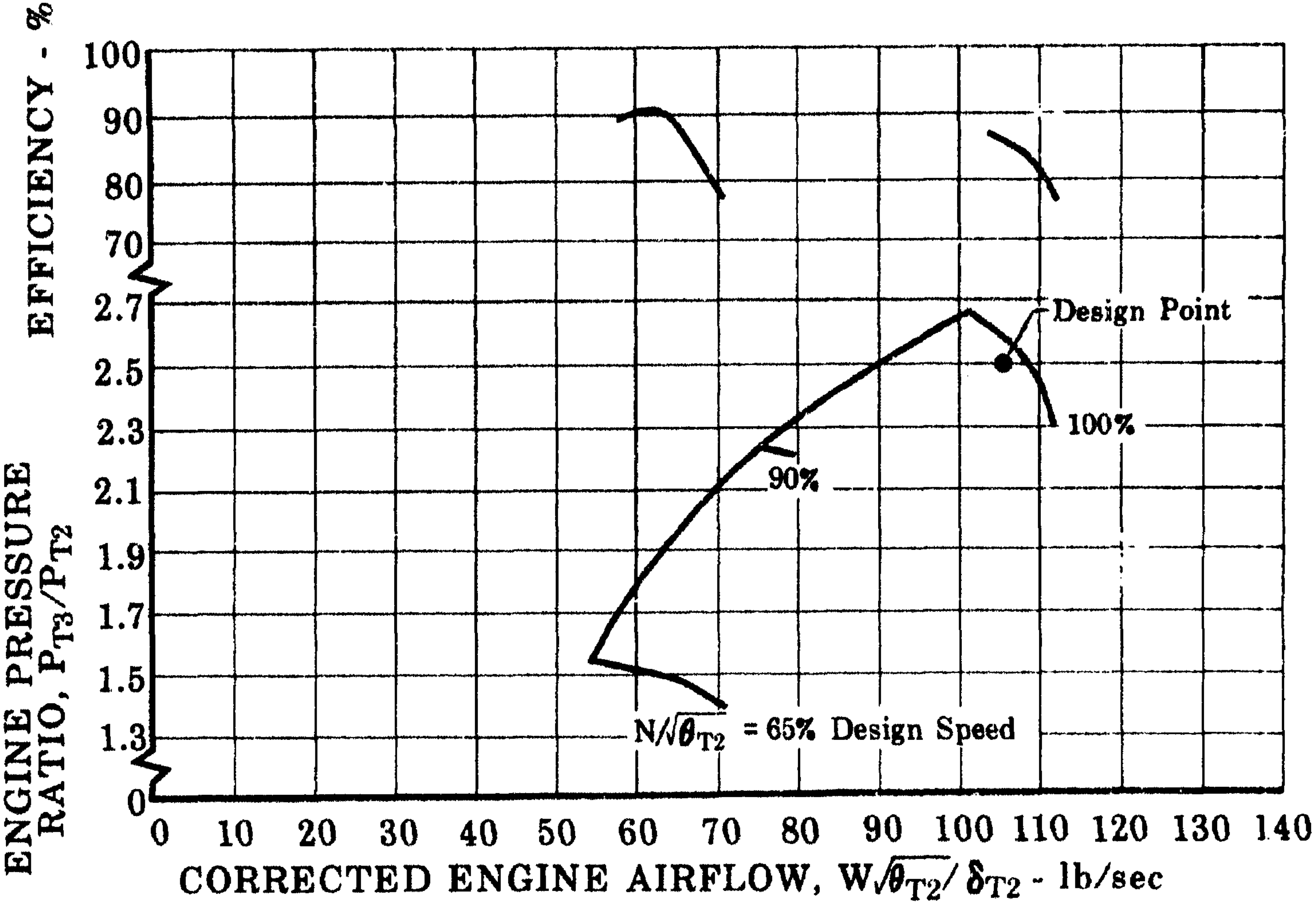
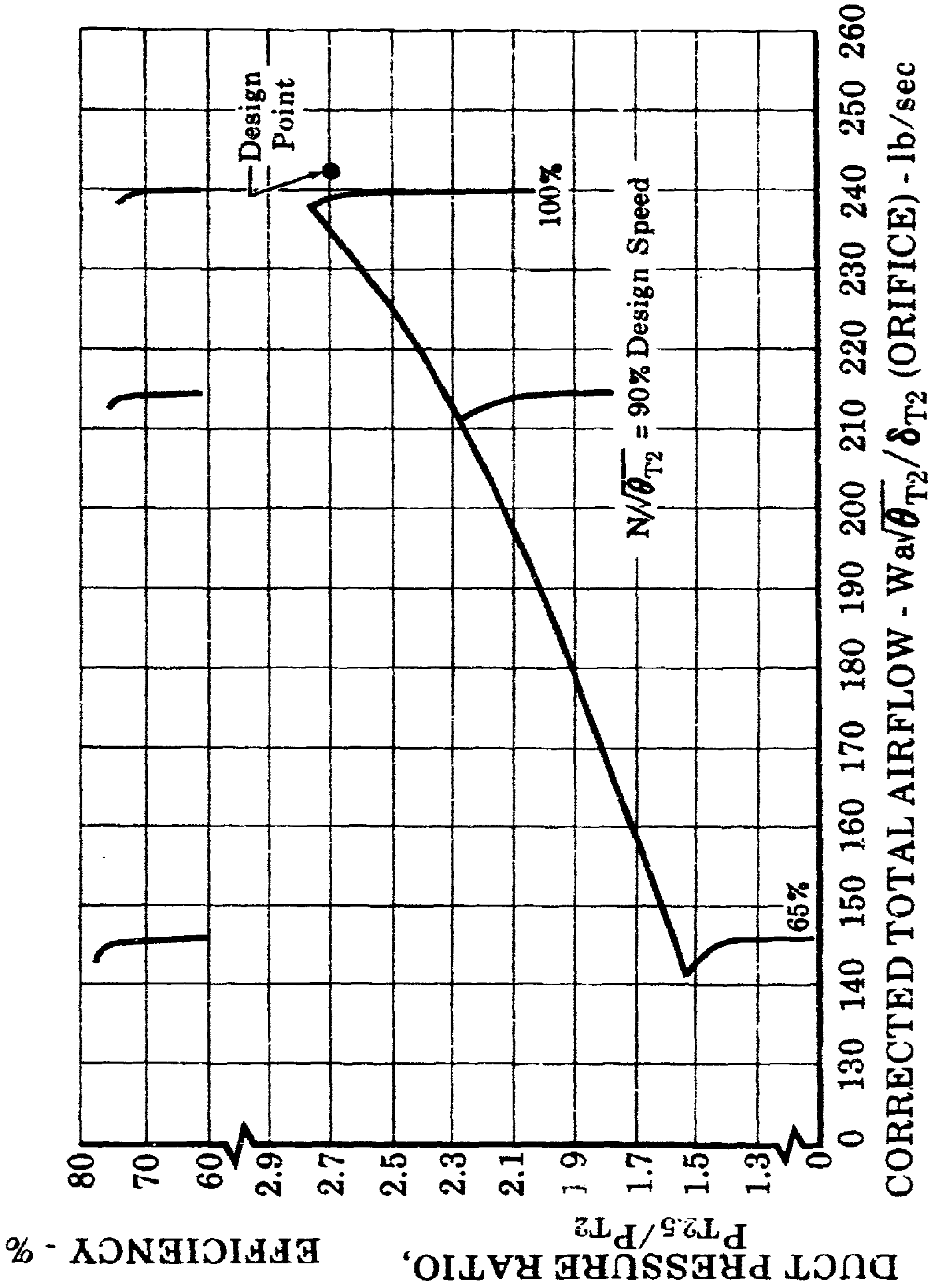


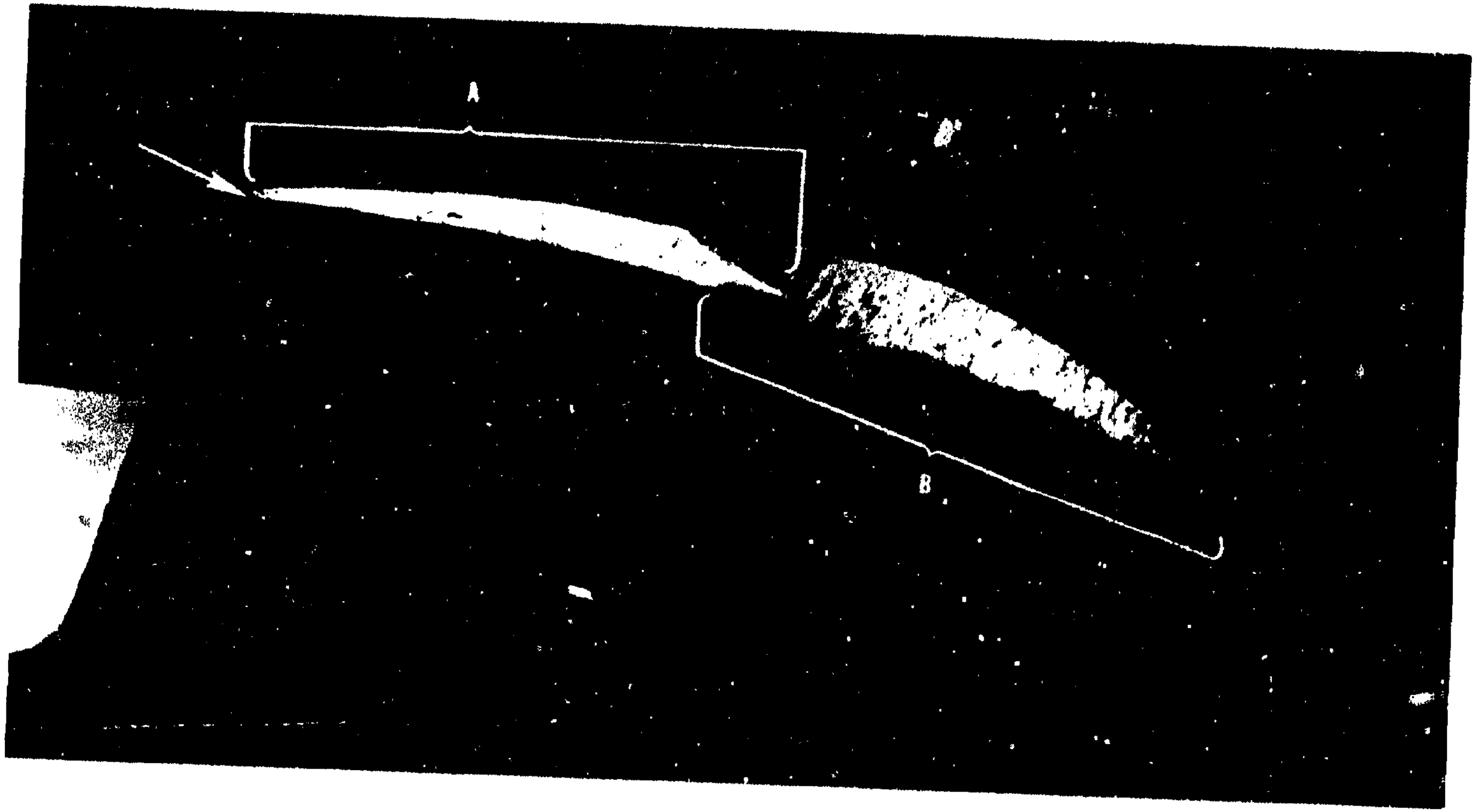
Figure III-C-1. Engine Stream Performance, Two-Stage Fan Compressor Rig, Build No. 12

FD 19267



FD 19266

Figure III-C-2. Fan Stream Performance, Two-Stage Fan Compressor Rig, Build No. 12



MAG: 2X

CLOSE-UP OF FRACTURE SURFACE SHOWING FATIGUE (BRACKET A) PROGRESSING FROM LIP (ARROW) AT TRAILING EDGE. BRACKET B INDICATES TENSILE-SHEAR PORTION OF FAILURE.

Figure III-C-3. 0.6-Scale Fan Rig 1st-Stage Blade Showing Fracture Face

H-61317

ETCHANT: KROLL'S REAGENT MAG. 500X

PHOTOMICROGRAPH OF PLANAR SECTION THROUGH TRAILING EDGE SHOWING INTERGRANULAR CRACK (ARROWS) AT BASE OF LIP (BRACKET).

Figure III-C-4. 0.6-Scale Fan Rig 1st-Stage Blade Showing Crack FM 18306

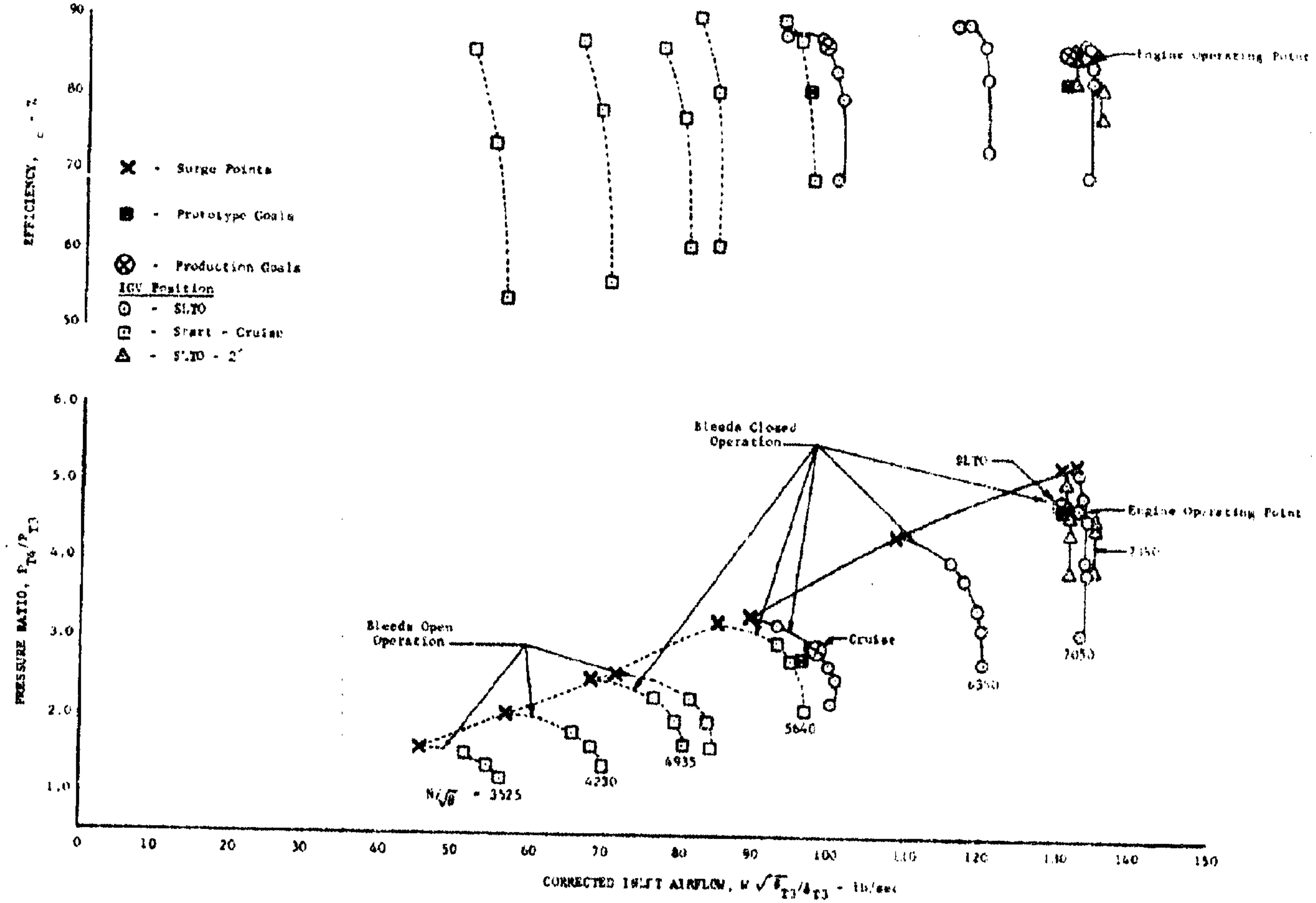


Figure III-C-5. JTF17A-21 Prototype High Pressure Compressor Rig Performance

DF 53150

D. PRIMARY COMBUSTOR

	December	Phase II-C
Full-Scale Rig Test Time	0	372 hours
Full-Annular Rig Test Time		
JTF17	0	5.36 hours
Related Technology	0	65.8 hours

Sea level testing on FX-163-2, with improved primary combustor instrumentation, has provided excellent pressure loss data for correlation with the modified JT4 annular rig data. The relationship between pressure drop $(P_{T4} - P_{T5}/P_{T4})$ and corrected airflow for the JTF17 engine and the annular primary combustor rig is shown in figure III-D-1. These results indicate that the JTF17 production goal shown in the same figure can be met.

The original combustor incorporated in FX-161 is the high time part with 87.41 hours and is still suitable for continued testing.

FD 19105

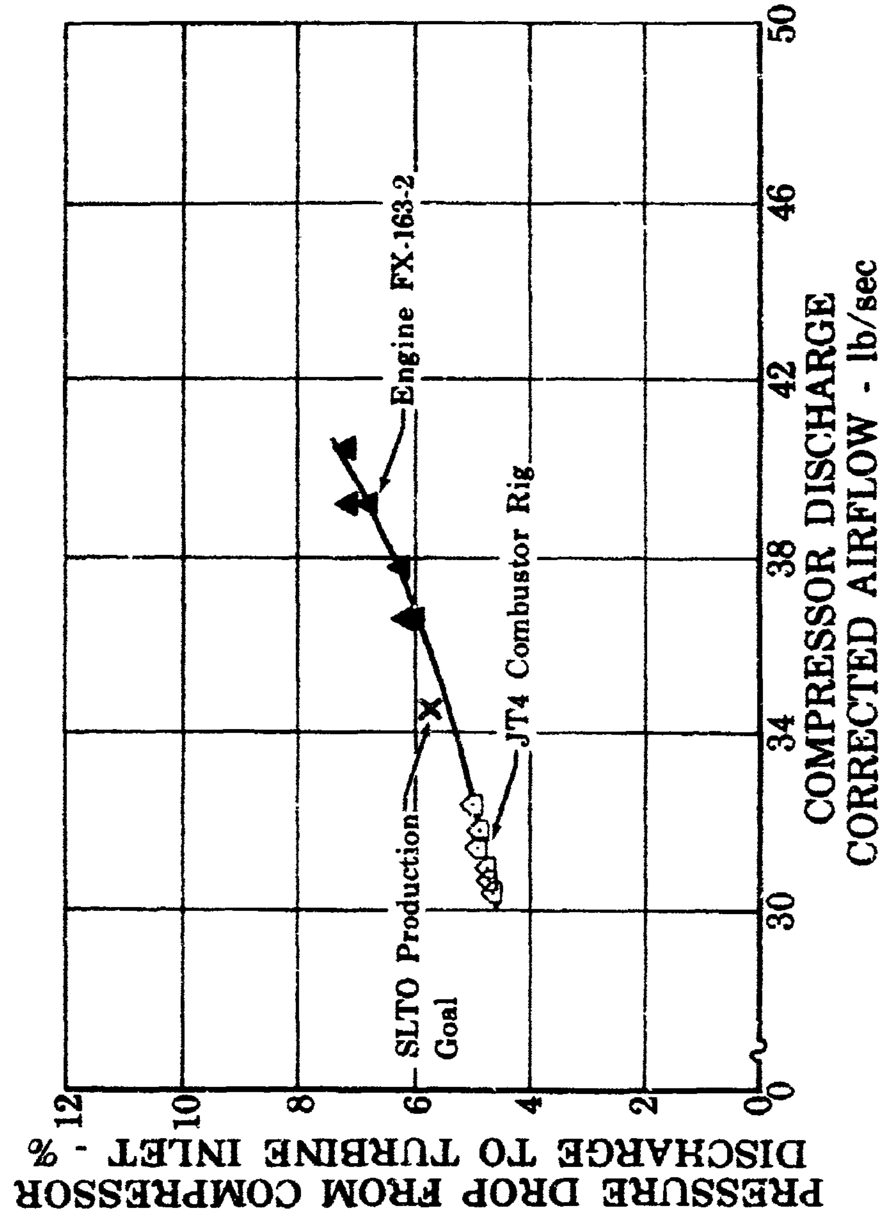


Figure III-D-1. Primary Combustor Pressure Drop

E. TURBINE

1. Thermodynamic Cascade Rig

	December	Phase II-C Total
Test Time, hours	29.36	475.31

Heat transfer tests of alternate JTF17 turbine airfoils were completed this month with testing of the 1st-stage baffle blade. A review of all 1st-stage blade test data still indicates that the P&WA two-piece Thermal Skin$_{TM}$ 1st-stage blade is the most desirable blade for use in the JTF17 engine. Test results of this blade were reported in PWA FR-2213.

F. AUGMENTOR

	December	Phase II-C Total
Full-Scale Rig Test Time	0 hours	44.97 hours

A total of 27.53 hours of engine testing has been accumulated on the duct heater (with a maximum fuel/air ratio of 0.058) in addition to the 44.97 hours previously accumulated on the full-scale annular rig, resulting in a total duct heater test time for Phase II-C of 72.50 hours.

The duct heater provided the necessary augmentation for engine FX-163-2 to exceed the JTF17A-20 production thrust of 57,000 lb. The duct heater operation was excellent throughout the entire testing of engine FX-163-2. Successful ignition was obtained on all 10 lights on FX-163-2 for a total of 78 successful lights in Phase II-C engine testing, without a single failure to light.

G. EXHAUST SYSTEM

The static pressure tap cruise test program has been completed and data are undergoing analysis. Comparison of measured-to-predicted pressure distributions on the engine plug and the reverser-suppressor clamshells and trailing edge flaps is shown in figure III-G-1. The general close agreement between the measured pressures and the theoretical pressures, which were used to establish the exhaust system pressure loads, substantiates the validity of the cruise structural design. The slightly different shroud pressure ratios indicate that a small performance improvement (approximately 0.001 C_{fp}) may be possible through revised contouring of the shroud.

The scale model reverser test program conducted to investigate reverser performance targeting and flow characteristics has been completed. Flow visualization studies indicate that acceptable reverser targeting patterns can be established with the existing reverser-suppressor design. Figure III-G-2 shows an inverted "Y" pattern which is compatible with airframe requirements. This was achieved by blocking the bottom center reverser door. Other reverse targeting patterns which may be desirable can be obtained by similar techniques.

The Boeing wing/nacelle model tests have been completed. Close agreement was obtained with previous Boeing Company tests of a similar installation. Figure III-G-3 presents a comparison of the installed and isolated exhaust system performance at Mach 0.8 and 0.5 conditions. The installed performance levels were higher than the isolated levels. The reasons for this performance improvement may result from the relative placement of the exhaust nozzle, the wing trailing edge, and the adjacent nacelle. The possibility of nacelle and wing mutual interaction contributing to improved performance warrants further investigation.

Reverser-suppressor unit No. 2 was installed on engine FX-163 in sea level test stand A-4 on 12 December. Instrumentation as described in last month's report was provided. There was no discernible effect on performance; the JTF17 meets the sea level takeoff performance goals with or without the reverser-suppressor installed. Operation in the reverse mode and all transitions into and out of reverse at idle were smooth and without incident. Visual inspection revealed no signs of distress.

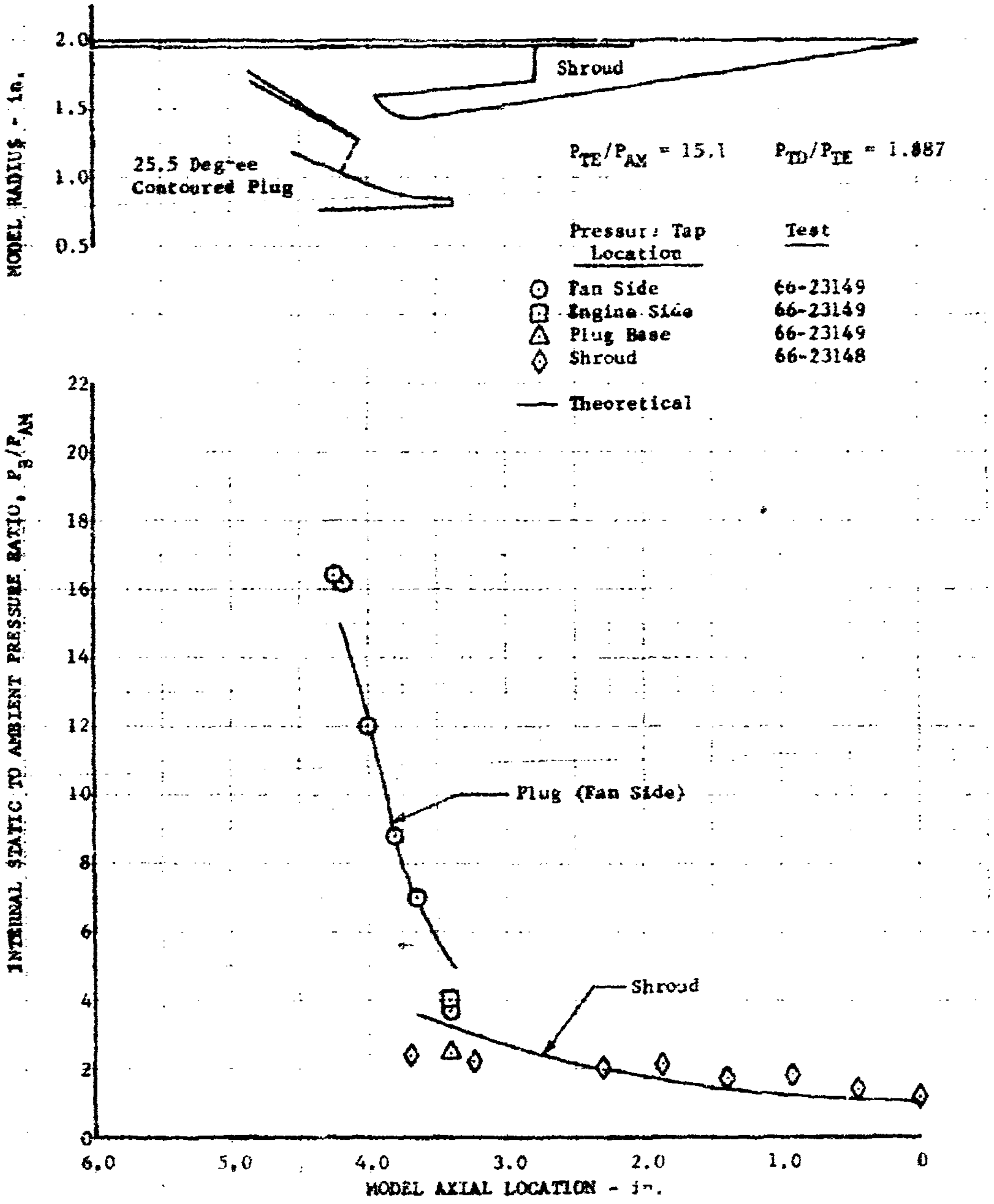
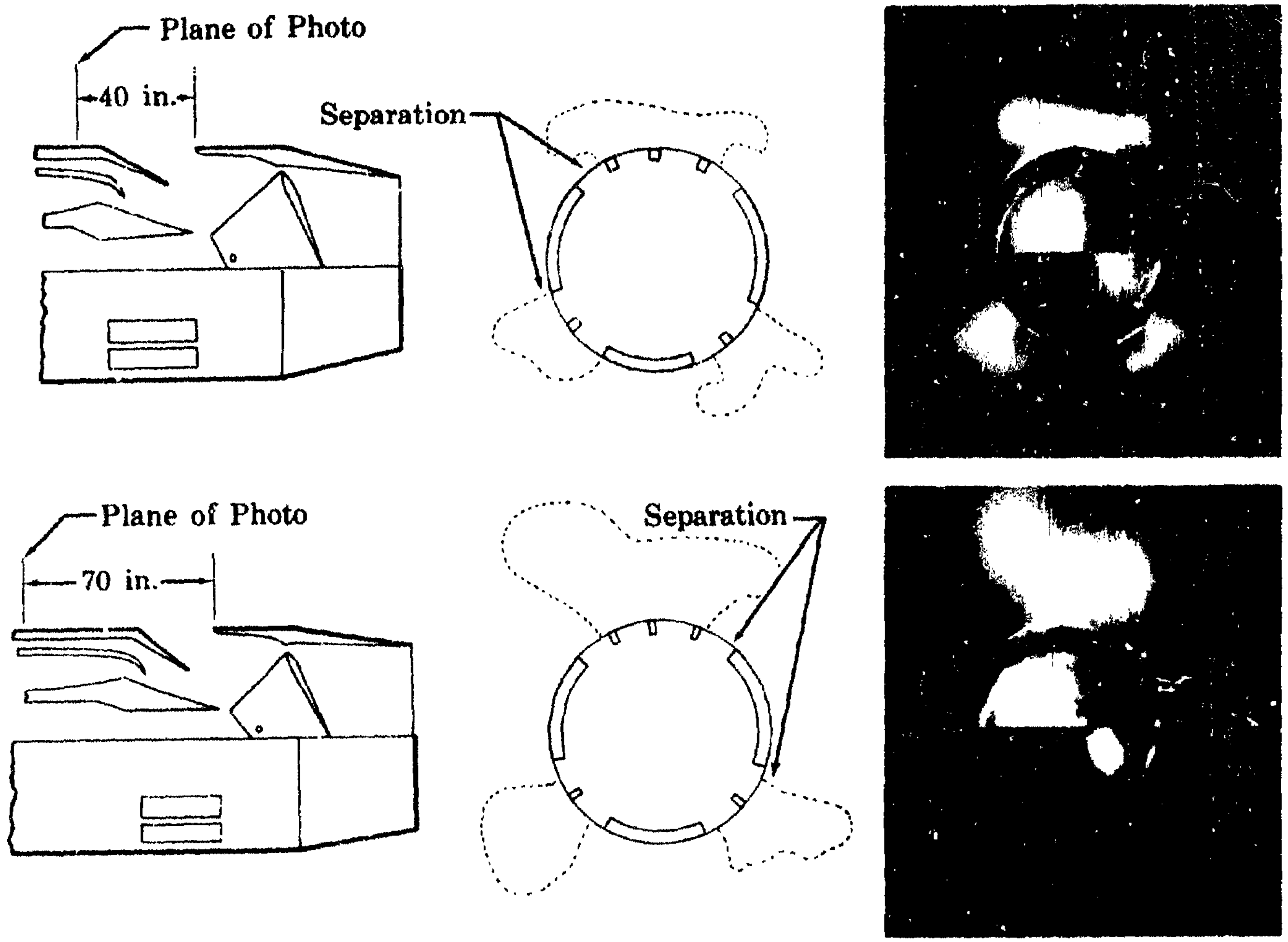


Figure III-G-1. JTF17 Exhaust System Supersonic Cruise Pressure Distributions

DF 53003

Reverser Flow Visualization Study Sealevel Static



FD 19269

Figure III-G-2. JTF17 Exhaust System Reverser Targeting

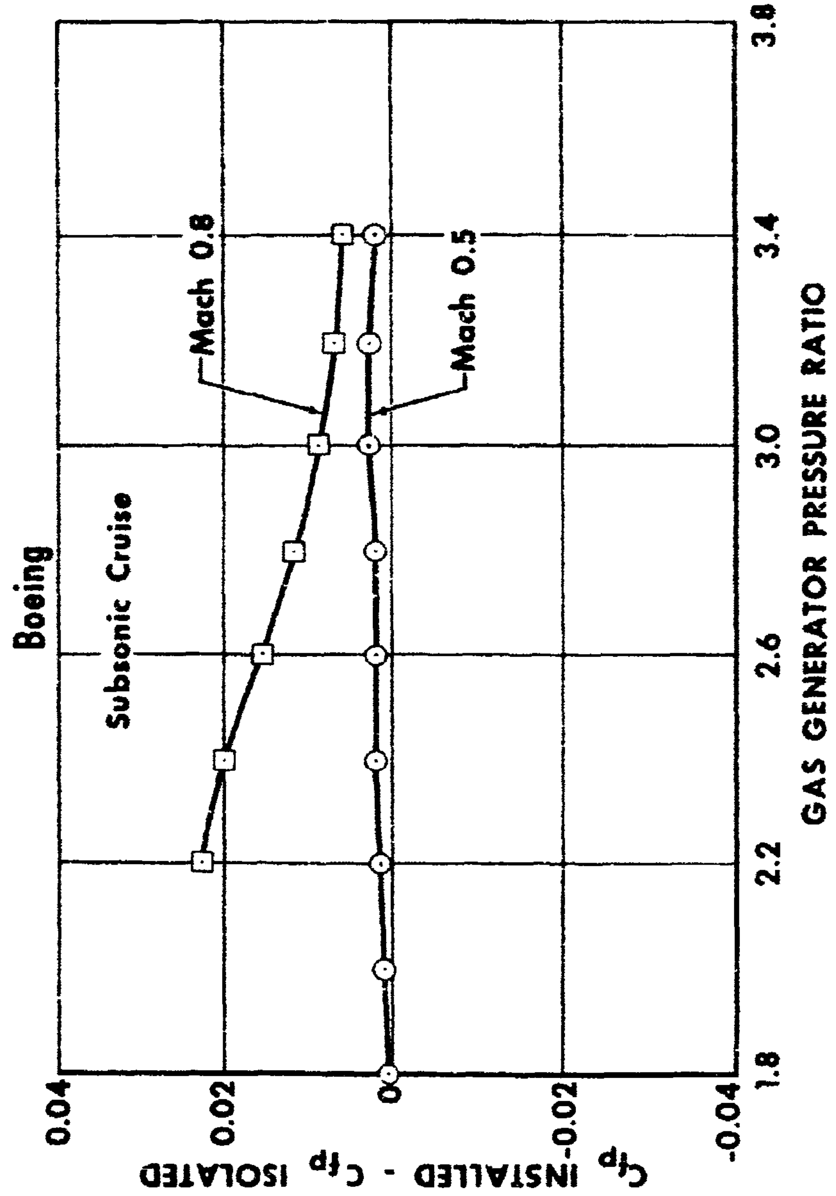


Figure III-G-3. JTF17 Exhaust System Installed Performance

H. CONTROLS

1. Initial Experimental JTF17A-20 Control System

a. Engine Gas Generator Control

The CJQ1 gas generator controls continued to operate satisfactorily on the initial experimental engines. The Build 1 (prototype) high compressor design revised the gas generator fuel requirements so that the original control schedules were still valid, thus negating the requirement for revised fuel schedule cams. The modulating inlet guide vane (IGV) schedule was changed for the new compressor to a two position schedule (start or takeoff). As a result, the inlet guide vanes were operated manually on engine FX-163-2 rather than with the gas generator control. The CJQ1 gas generator controls successfully completed the Phase II-C program with virtually no problems.

b. Duct Airflow Computer (Breadboard)

The Hamilton Standard S/N 1 breadboard computer was bench tested at FRDC and exhibited excessive hysteresis in the actual $\Delta P/P$ sensor portion of the control. The unit was returned to Hamilton Standard for investigation. The hysteresis measured during HSD tests was a maximum of 1.1% of total range,well within allowable limits. After adjustment, the unit will be returned to FRDC.

The S/N 2 unit is available at FRDC and is engine ready.

c. Duct Fuel Controls

(1) Modified JFC-51 Duct Fuel Control

The modified JFC-51 control, installed on engine FX-161, successfully completed the engine altitude test. An AA-M1 control has been assigned for the next build of engine FX-161.

(2) AA-M1 Heater Fuel and Nozzle Area Control

Bench calibration of AA-M1 control S/N D07C001 was completed, and the control is assigned to the next build of engine FX-161.

The reduced gain integrator cam, the T_{T2} bias cam, and the revised fuel flow cam were installed in AA-M1 control S/N D07C002. AA-M1 controls S/N D07C001 and S/N D07C003 also incorporate these cams.

AA-M1 control S/N D07C003 was received from Bendix, bench tested at P&WA, and delivered to engine FX-163-2. Control operation was satisfactory during the engine test. An oscillograph trace showing control system operation at maximum augmentation is presented in figure III-H-1. A tabulation of data recorded during a four-point performance calibration on engine FX-163-2 is shown in table III-H-1. These data indicate good computed total airflow control.

Table III-H-1. Engine FX-163-2 Performance

	Point 1	Point 2	Point 3	Point 4
Duct Heater Fuel Flow - lb/hr	66,034	72,430	90,369	95,955
Fan Speed - rpm	6122	6130	6170	6138
High Compressor Rotor Speed - rpm	8144	8129	8111	8114
Duct Nozzle Area - ft^2	8.85	8.89	9.30	9.32
$(P_T - P_S)/P_T$ Error - %	2.06	-0.66	0.66	2.72
Equivalent Total Airflow Error - %	0.212	-0.070	0.070	0.283

d. Quick-Fill

The breadboard quick-fill system was operated on engine FX-163-2, using various manifold pressure sense location points to determine the effect on the fill sequence. In addition, the Zone II pilot valve piston land was underlapped. The fuel manifold pressure sensor level adjustments were varied in both the Zone I and Zone II systems to determine the optimum settings. The quick-fill system performed satisfactorily by filling the duct system zone plumbing.

e. Duct Fuel Pump

The duct fuel pump for engine FX-163-2 was operated on the engine test stand at 97,000 pph fuel flow and 1130 psig discharge pressure prior to being delivered to the engine. This test was conducted to demonstrate that the pump and test facility were capable of delivering adequate fuel flow during the engine test.

During a duct heater performance calibration on engine FX-163-2 on 11 December, the fuel pump supplied 96,000 pph.

f. Ignition

The JT12, 4-joule, low tension ignition system with JTF17-type shunted gap igniters fully demonstrated the ability to meet the JTF17 prototype engine ignition requirements. The gas generator was successfully ignited 139 times, and the duct heater ignited 78 times on JTF17 experimental engines. Twenty-eight gas generator and 19 duct heater lights were achieved at simulated altitude conditions.

2. Prototype JTF17 Engine Control System

a. Unitized Fuel and Area Control

Hamilton Standard and Bendix Products Aerospace Division were in competition throughout Phase II-C for the unitized fuel and area control contract. An evaluation of the proposed controls and the capabilities of the respective companies was conducted and, in late November, both vendors were advised that Hamilton Standard has been selected. Procurement of long-lead-time parts for the control was initiated with Hamilton Standard on 1 December.

A review was held with Hamilton Standard to discuss all the requirements of the unitized fuel and area control. Hamilton Standard made an intensive study of the schematic concept and provided considerable simplification with minor control performance penalties.

Detail design was actively pursued during December with the component parts of the control being sized for maximum anticipated engine growth.

b. Digital Electronic Airflow Computer

The Hamilton Standard Division, the selected vendor for the alternate digital electronic airflow computer, proceeded with detail design and installation studies. This unit is designed to mount directly on the unitized fuel and area control and replaces the hydro-mechanical section performing the same functions.

c. EPR Control

The Eclipse Pioneer Division was selected as the vendor for the airframe-mounted electronic EPR control that is offered as optional equipment with the hydro-mechanical unitized fuel and area control.

d. FRDC Computer Studies of the JTF17 Control System

The four-engine SST aircraft cockpit simulator was revised to combine the latest detailed Boeing inlet simulation with a more detailed single engine simulation. This simulation was used to determine the effectiveness of engine airflow trim to match engine airflow to inlet airflow and to ensure that engine transient rotor speeds were compatible with the inlet dynamics.

Figure III-H-2 illustrates the inlet response to a maximum rate transient from maximum augmented to idle to maximum augmented at cruise conditions. There was little overshoot or undershoot in rotor speed, and the inlet shock was closely maintained to the desired position. For this transient, the inlet bypass doors were partially open allowing the shock to be repositioned to the steady-state desired location although engine airflow had been reset in the increased direction.

Figure III-H-3 illustrates the engine/inlet response to a duct heater blowout and a resultant power lever recycle. The shock position moved toward the engine face, which caused the inlet bypass doors to fully close; then when the power lever was retracted, the shock position moved forward. The bypass doors remained closed during the shock transition. PLA was readvanced and original operating conditions re-established after approximately 20 seconds.

e. Ignition

The General Laboratory Associates, Inc. has been selected to provide the JTF17 prototype ignition system, exciters, and harness. Champion Spark Plug Company has been selected to provide the spark igniters for the JTF17 engine. These selections were made based on the proposals received in response to the P&WA purchase specifications. The GLA system electrical schematic and installation drawing has been coordinated and found compatible with the JTF17 requirements.

f. Hydraulic Pump

Pesco Products Division of Borg-Warner Corporation was selected to provide the JTF17 prototype hydraulic pump. A suitable pump configuration and engine installation has been coordinated with Pesco.

g. Gas Generator Pump

Chandler Evans, Inc. was selected to provide the JTF17 prototype gas generator pump. Coordination of the pump requirements and engine installation has been completed with CECO.

FD 19277

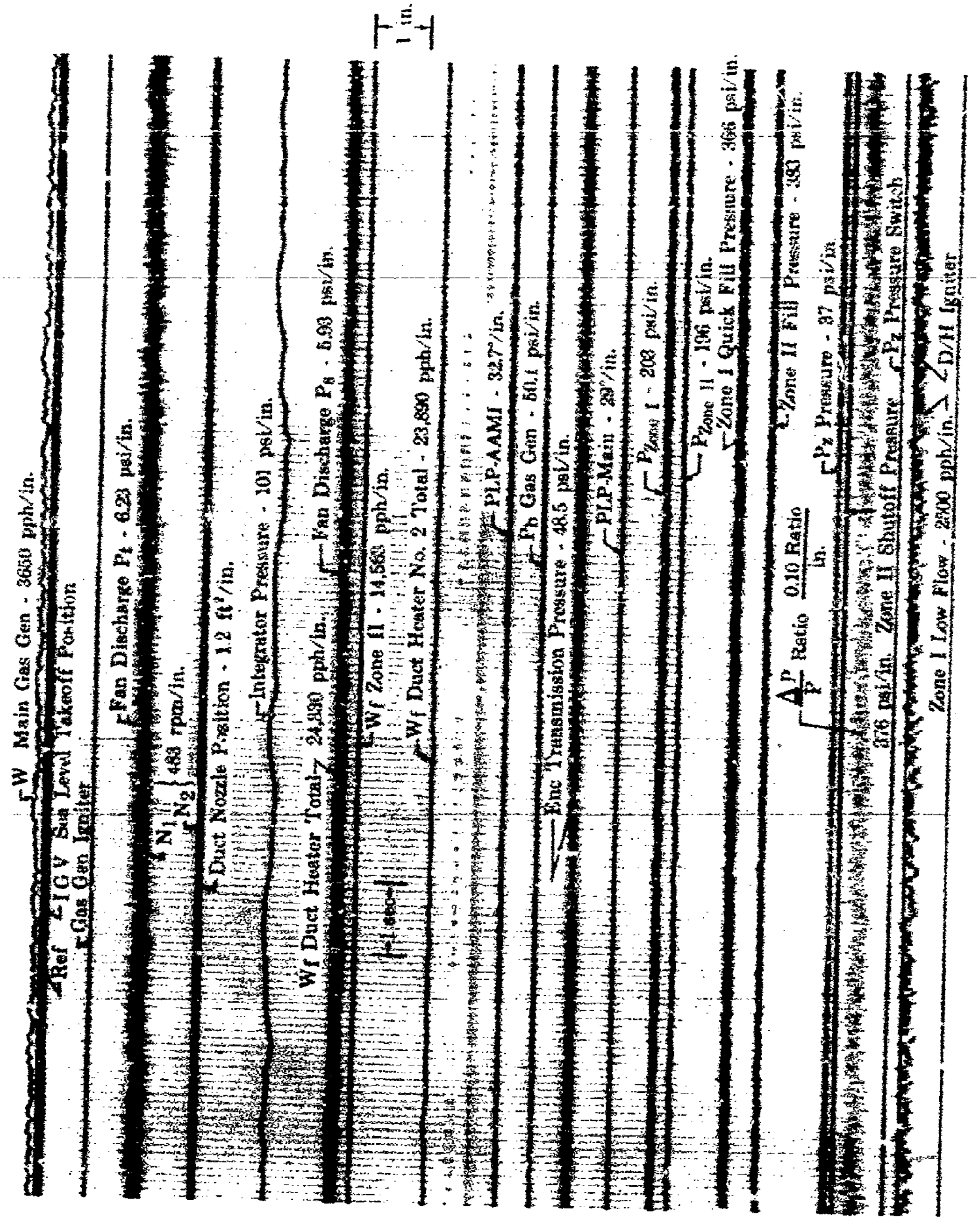


Figure III-H-1. JTF17 Control System Operation at Maximum Augmentation on FX-163-2

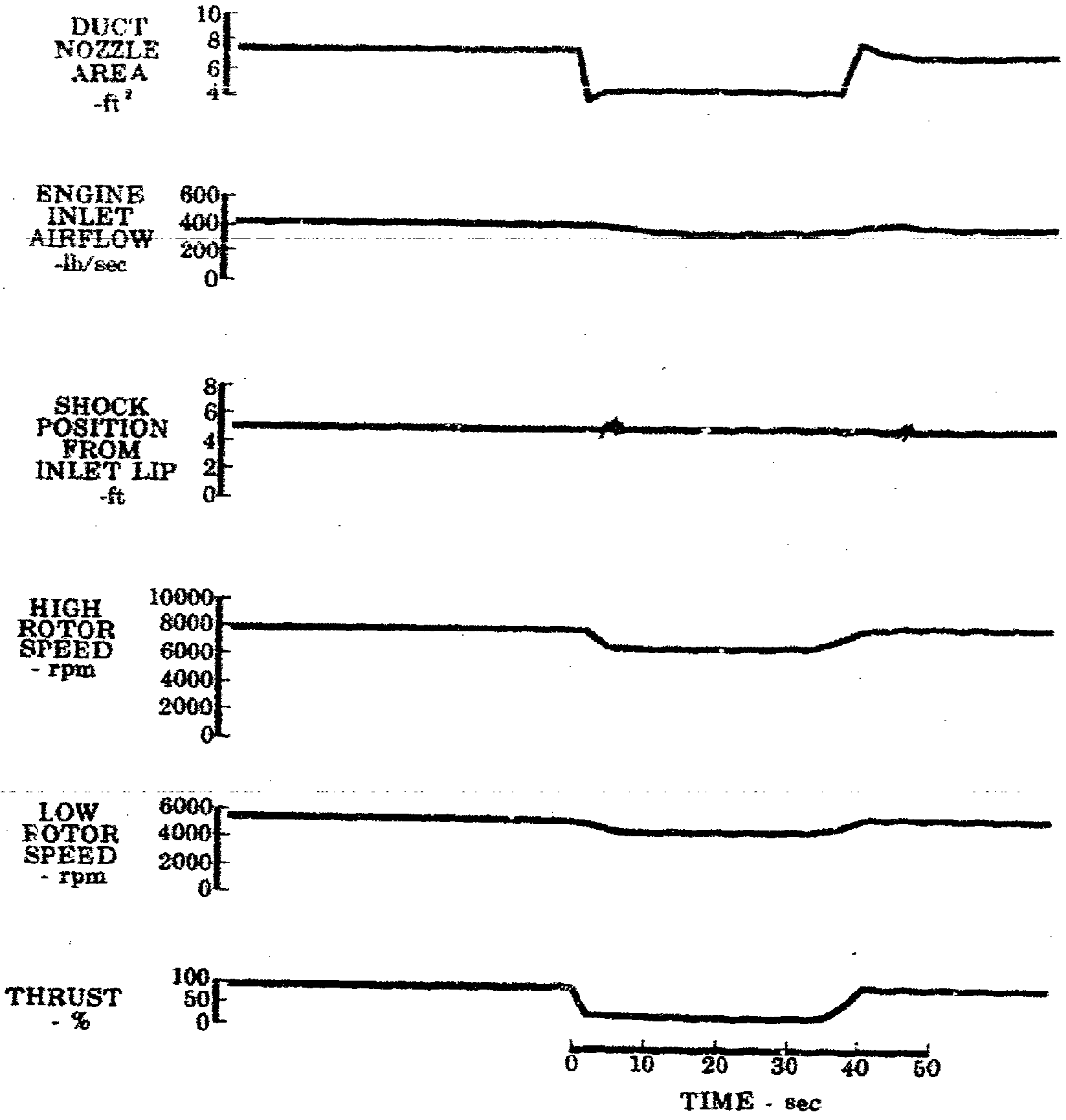


Figure III-H-2. JTF17 Response to PLA Modulation from Maximum Augmented to Idle to Maximum Augmented at Cruise FD 19276

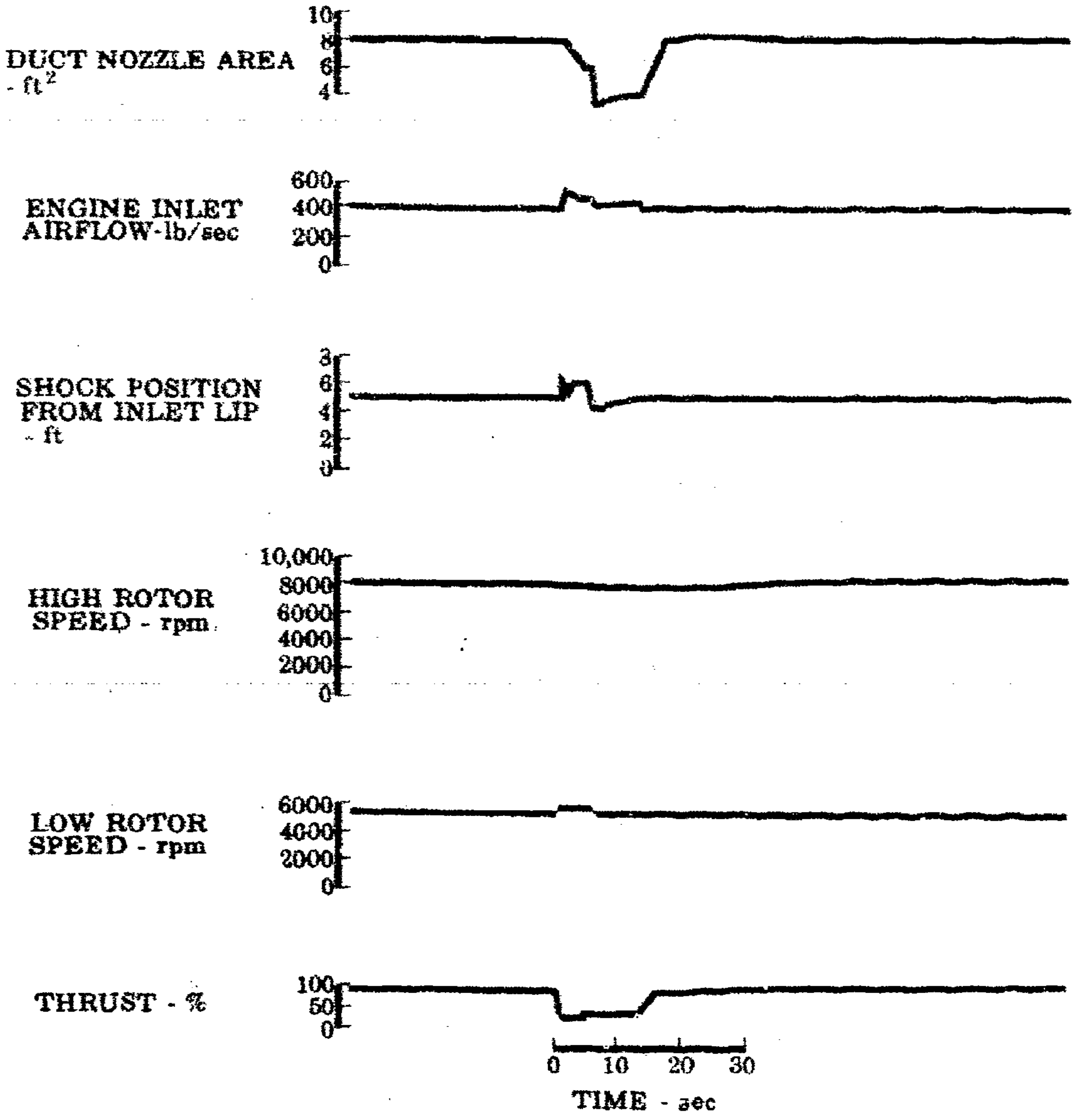


Figure III-H-3. JTF17 Response to Duct Heater Blowout and FLA Recycle at Cruise

FD 19268

1. BEARINGS AND SEALS

No rig development testing has been accomplished on bearings and seals during this report period.

J. FUELS AND LUBRICANTS

1. Fuels

Fuel coker tests on aviation kerosene have continued to confirm that fuel delivered to FRDC is meeting the purchase specification requirements. This monitoring also confirms that the thermal stability is maintained during storage and delivery to the experimental JTF17 engines.

December activities included attendance at the ASTM Committee D-2 on Petroleum Products and Lubricants Meeting at Houston, Texas. FRDC representation was included at the Technical Division J, Section I Panel on Supersonic Fuel meeting.

2. Lubricants

Laboratory tests were continued on candidate lubricants to ensure conformance to specification requirements.

K. INLET SYSTEM COMPATIBILITY

1. Engine/Inlet Compatibility

The JTF17 engine/inlet cockpit dynamic simulator was demonstrated to the FAA. This detailed engine/inlet dynamic simulation includes flight crew provisions for cruise trim and adjustment of engine pressure ratio (EPR), inlet spike position, and bypass door position. See figure III-K-1. Extensive analysis of automatic and manual engine/inlet modes of operation is proceeding with the JTF17 engine/inlet cockpit dynamic simulator.

A JTF17 engine and control digital dynamic simulation for the U.S. Air Force Aero-Propulsion Laboratory is complete and has been transmitted.

The improved IBM system 360, JTF17 digital dynamic simulations for both airframe manufacturers are near completion. A UNIVAC system 1108, JTF17 digital dynamic simulation is being prepared for engine control studies by Hamilton Standard.

The Lockheed California Company has completed an updated inlet simulation for the P&WA engine/inlet compatibility study.

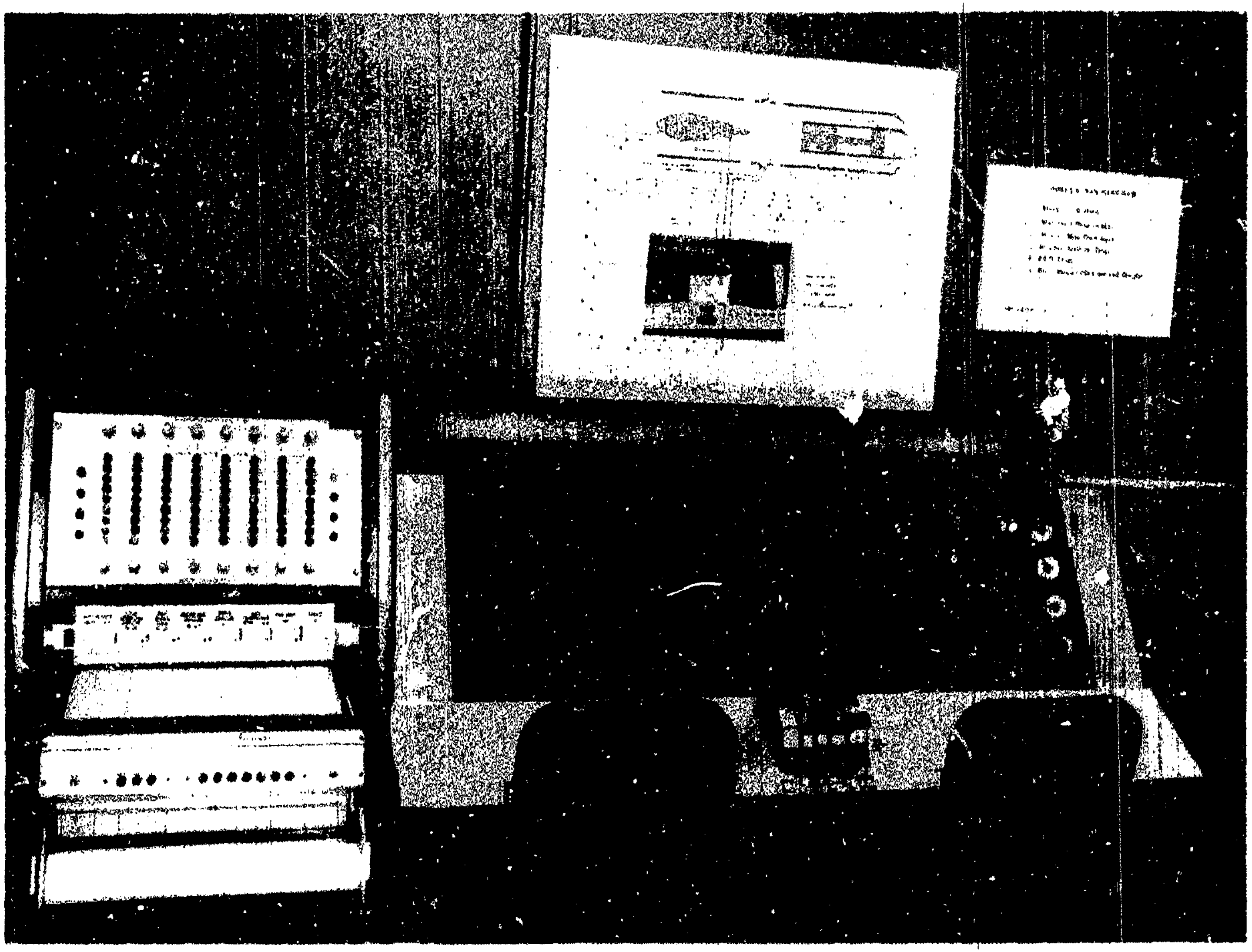


Figure III-K-1. JTF17 Engine/Inlet Cockpit Dynamic Simulator

FE 66358

L. NOISE

The resonant liner test section, described in PWA FR-2213, was tested in the East Hartford reverberation chamber. The test section was constructed as shown in figure III-L-1 to simulate the first 29 in. of the fan duct that is shown in figure III-L-2. For the first section to be tested, the acoustic treatment was uniform over the entire surface of the model.

Analytical studies indicate that even greater attenuations are possible if certain variations are made to sections of the walls and flow splitter. As an example, a system of patches, each treated to attenuate different frequencies, would increase the overall attenuation. For a second method, the downstream section of the duct could be designed for the lower sound pressure level because of the attenuation by the upstream section.

Preliminary analysis of the data obtained from the reverberation chamber tests indicates that present test section treatment, together with changes in blade-vane spacing, will meet the prototype design goal of 12 db fan noise attenuation. Figure III-L-3 shows the effect of velocity on attenuation from the resonant liner with a treated flow splitter. The net effect is an increase in overall attenuation as the velocity increases to 400 ft/sec, which was the design point. Figure III-L-4 shows the beneficial effect on attenuation of adding a treated flow splitter as compared to no flow splitter. This too results in broader spectral attenuation, and consequently better overall sound suppression.

Initial tests to determine the reflection of rearward propagated fan noise because of a density gradient in the fan discharge duct were completed. Results to date and analytical studies by Dr. Ingard indicate that significant reduction in fan noise may be expected when the temperature ratio across the burner is greater than 4 to 1.

The study program for evaluating psycho-acoustic reactions to jet noise with impressed "pure tones" has been delayed.

The acoustical analysis of the single jet noise models referred to in PWA FR-2213 has been completed and is summarized in figure III-L-5 through III-L-10. The final analysis of the data recorded during this test series continues to substantiate the selection of the 4-lobe, 50% penetration, long-length mixing nozzle as the optimum configuration to be incorporated in the prototype engine design. The nozzle performance and reduction in jet noise level for this configuration, presented in figure III-L-5, clearly show that the indicated reduction in jet noise can be achieved with virtually no loss in nozzle performance in a properly designed exhaust nozzle system.

During the above-mentioned series of tests, several models with noncoplaner, coannular center bodies were evaluated. A comparison of the 4-lobe, 75% penetration, long-length mixing nozzle with noncoplaner center bod exhibited a 2.5 PNdb reduction in jet noise level over a similar [illegible] without a center body. This reduction in jet noise may be attributed [illegible] coannular mixing phenomenon of the basic JTF17 exhaust system which has shown a 3 PNdb reduction in jet noise from the level predicted by the SAE method.

Acoustical data recorded during the recent full-scale demonstration of maximum thrust on engine FX-163 without a reverser-suppressor showed a reduction in noise level of 3 PNdb, figure III-L-11, relative to the noise level predicted by the SAE method. Figure III-L-12 shows the octave band sound pressure levels recorded during engine FX-163 maximum steady-state thrust point and the corresponding levels from the SAE prediction method. It is apparent from these data that the maximum difference in sound pressure level occurs in the center octave bands and reflects the relatively short potential cone which is characteristic of the noncoplaner coaxial system used in the basic JTF17 exhaust nozzle design. With reverser-suppressor unit No. 2 installed on the engine, there was a 5 PNdb reduction in noise level below that predicted by the SAE method. (Reference figure III-L-11.) No discernible effect on performance was evident. The JTF17 engine meets the sea level takeoff performance goals with or without the reverser-suppressor installed.

Full-scale testing of a J58 engine with the 4-lobe mixing nozzle and blow-in-door ejector installed, has been completed. An extensive run program was scheduled that evaluated the acoustical performance of the nozzle over a relative jet velocity range of from 1600 to 2700 ft/sec. The acoustical data and nozzle performance are shown in figures III-L-13 and III-L-14, respectively. These data, when compared to predicted levels, show a maximum of 4.5 PNdb attenuation with no loss in nozzle performance.

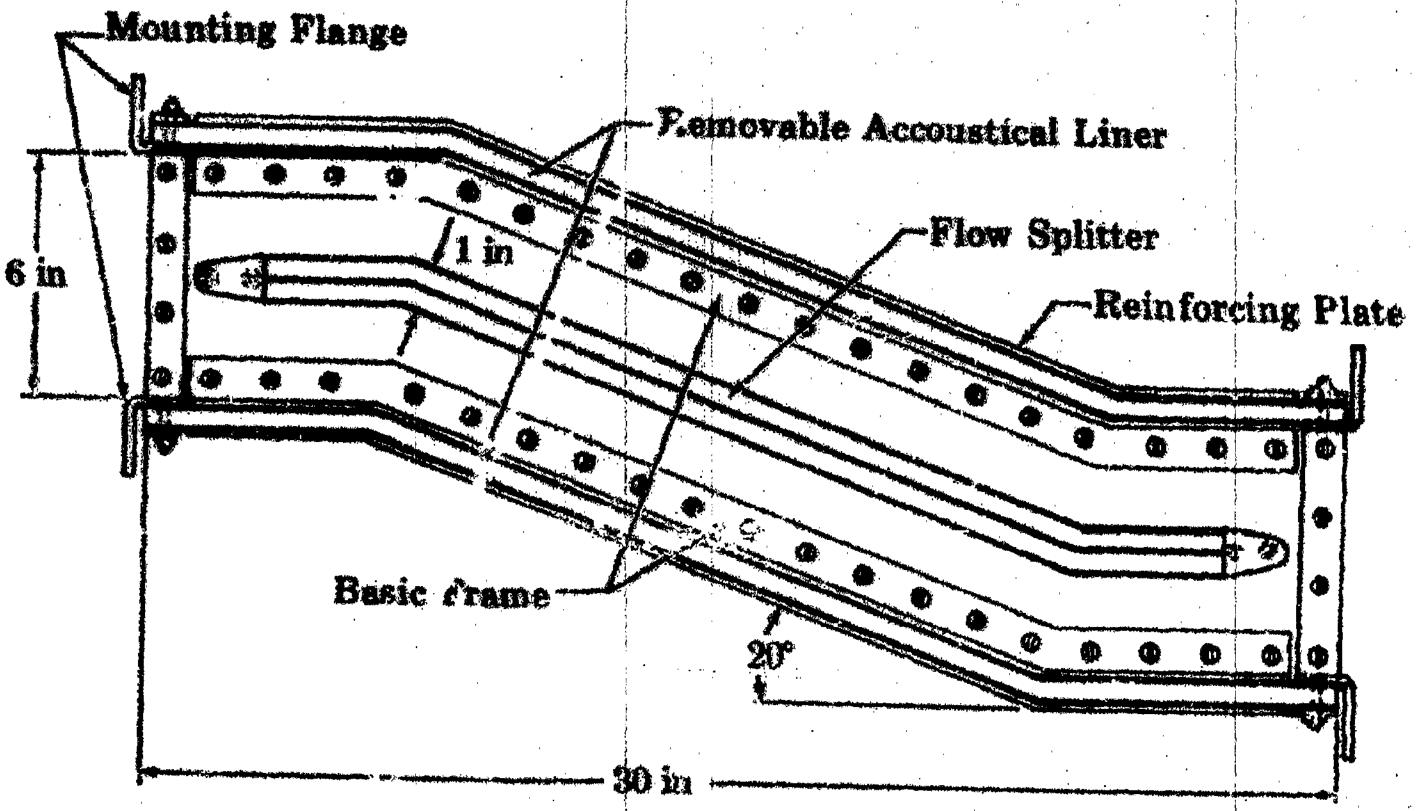


Figure III-L-1. Cross-Section of Liner Absorption Test Unit

FD 13828

Growth Version

Zone A: Flow Splitter, 2 Walls, and Struts Treated
Zone B: Flow Splitter and 2 Walls Treated

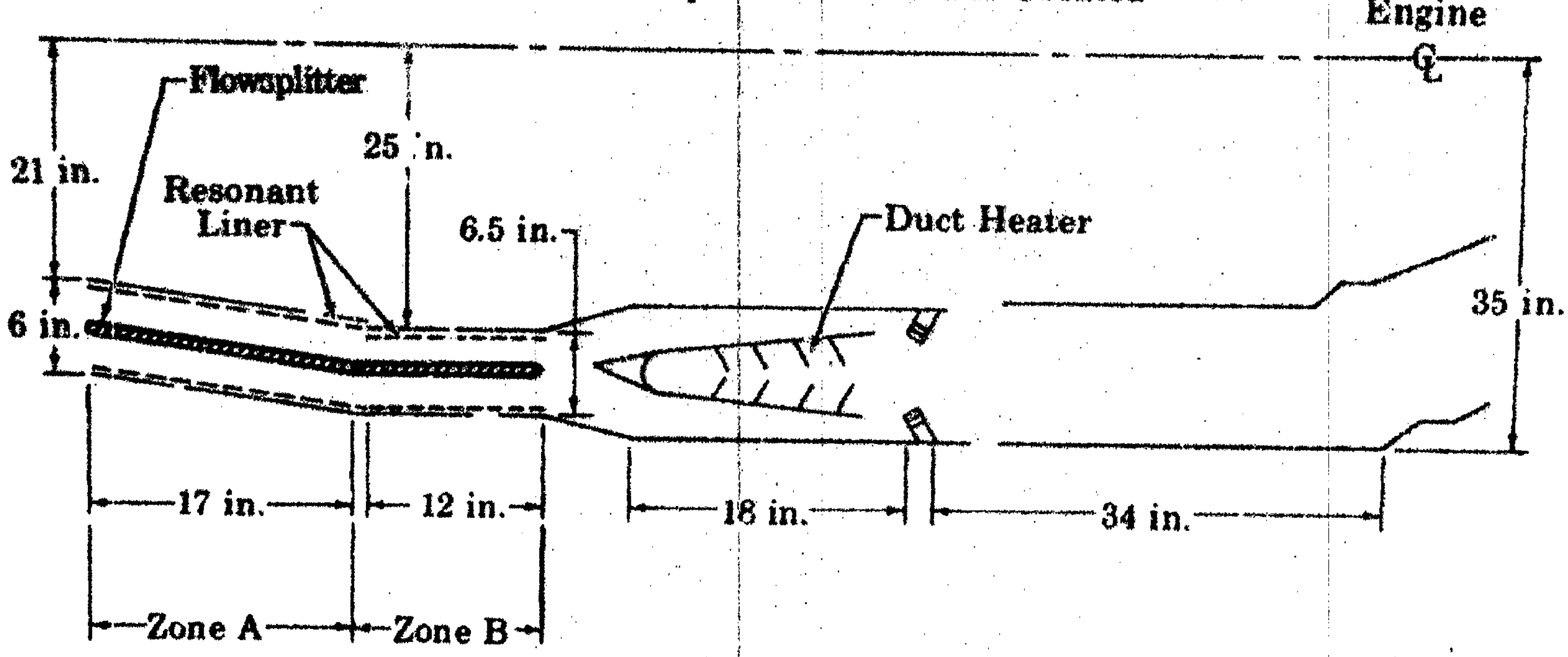


Figure III-L-2. Fan Noise Absorption Liners

FD 19062A

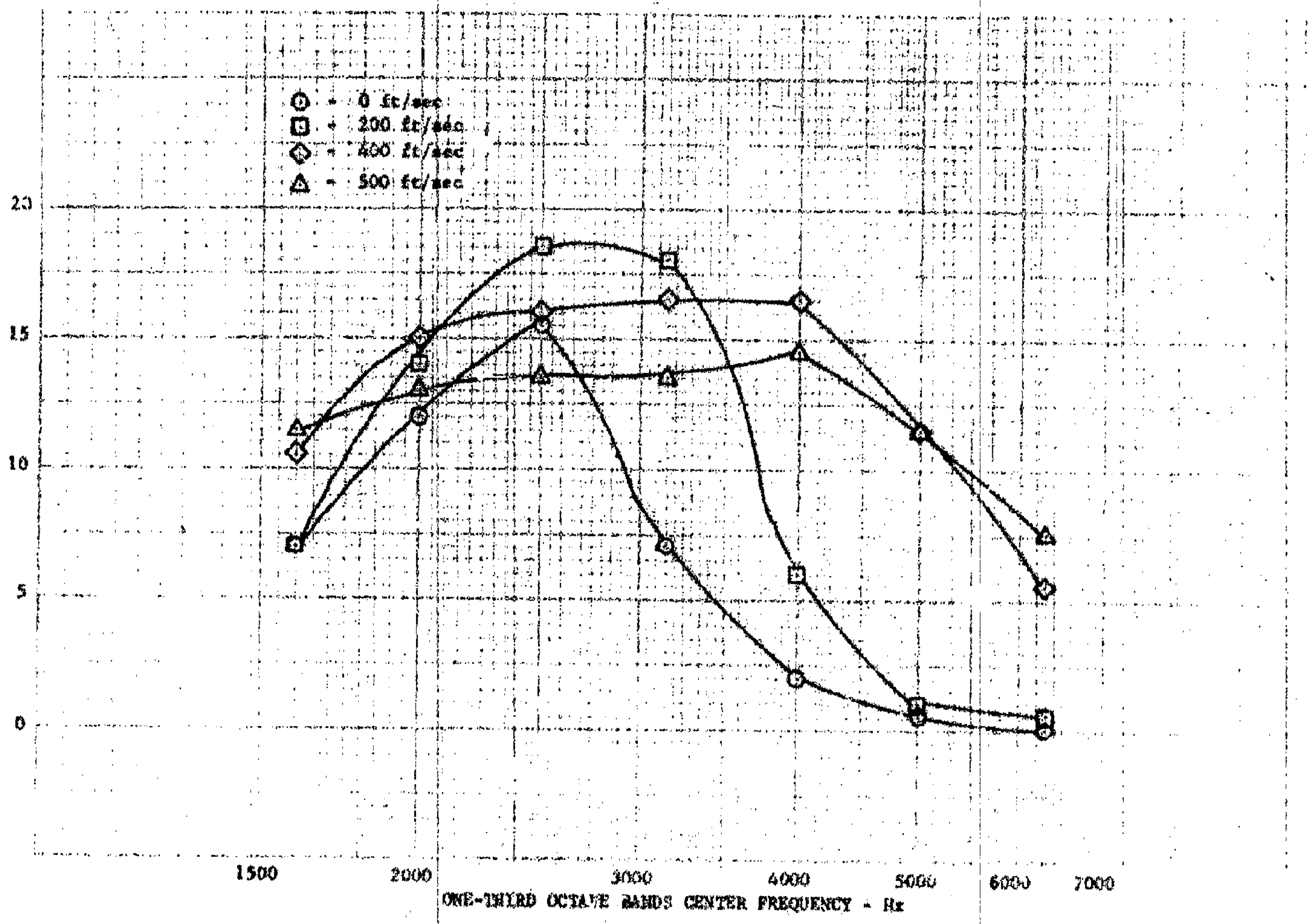


Figure III-L-3. SST Resonant Liner Duct-Effect of Velocity on Attenuation-Prototype Design DF 53148

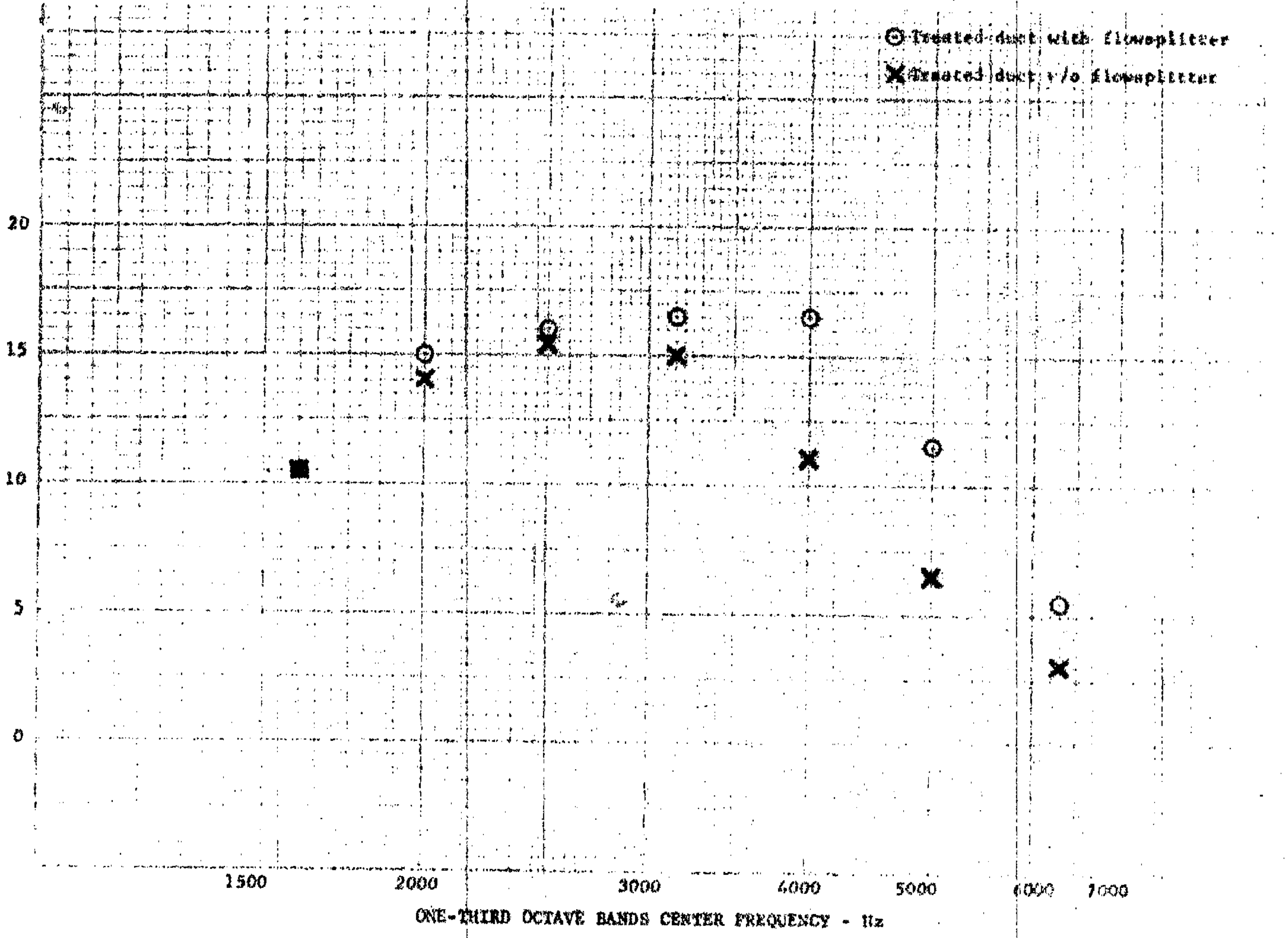
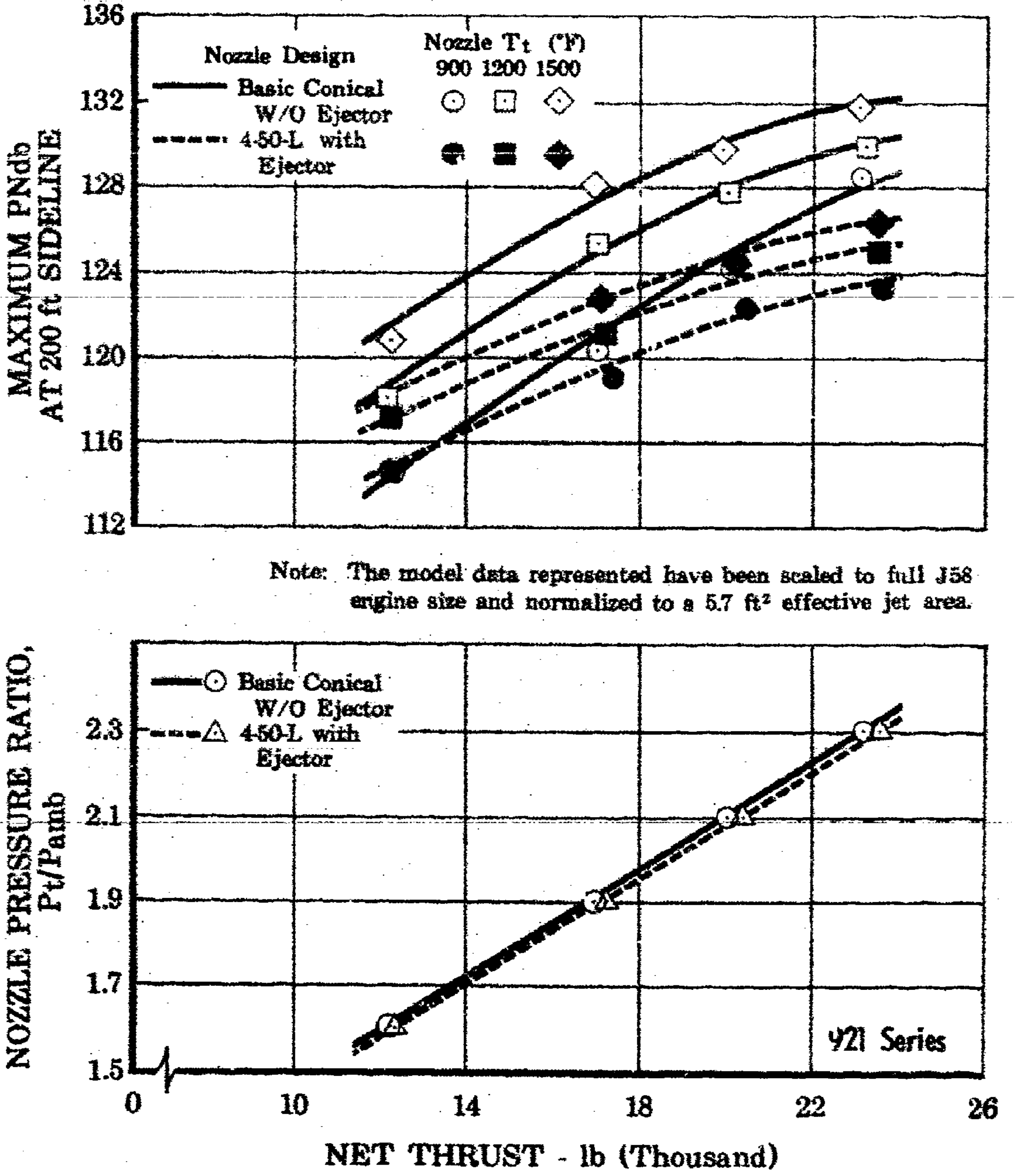


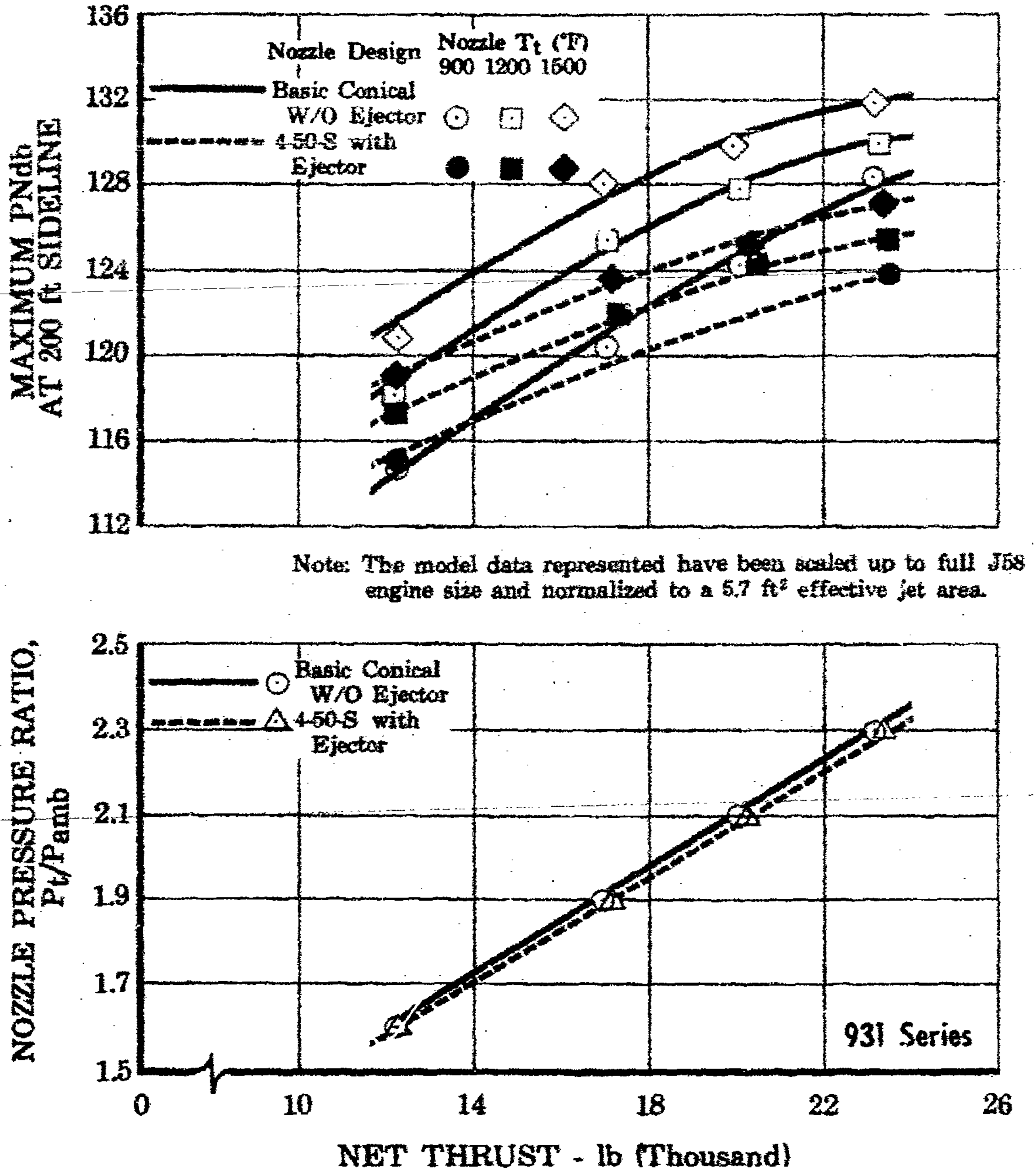
Figure III-L-4. SST Resonant Liner Duct-Effect of Flow Splitter on Attenuation
Flow Velocity = 400 ft/sec

DF 53149



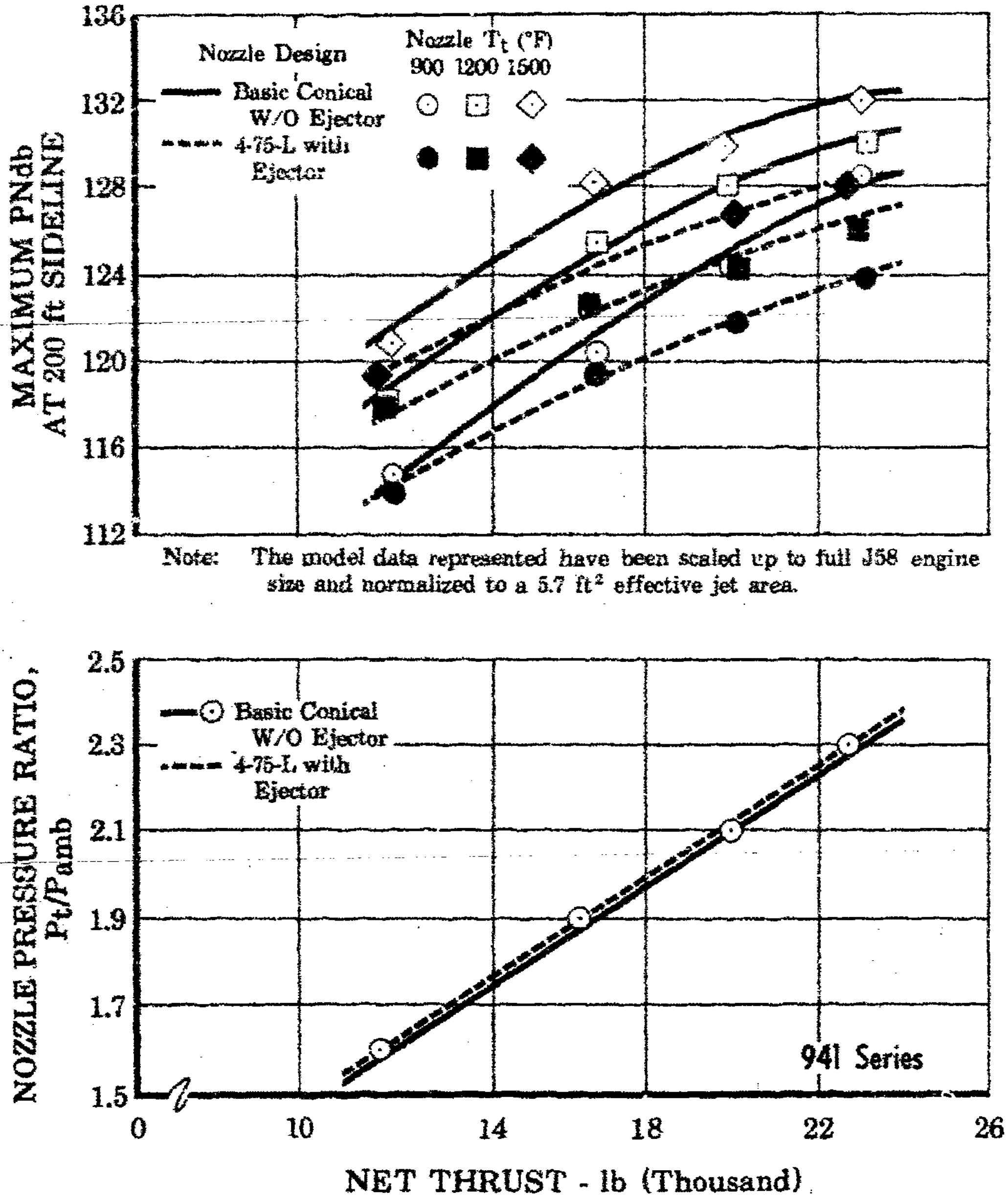
Note: The model data represented have been scaled to full J58 engine size and normalized to a 5.7 ft² effective jet area.

Figure III-L-5. Performance of Turbojet Mixing Nozzle Models - 921 Series FD 19265



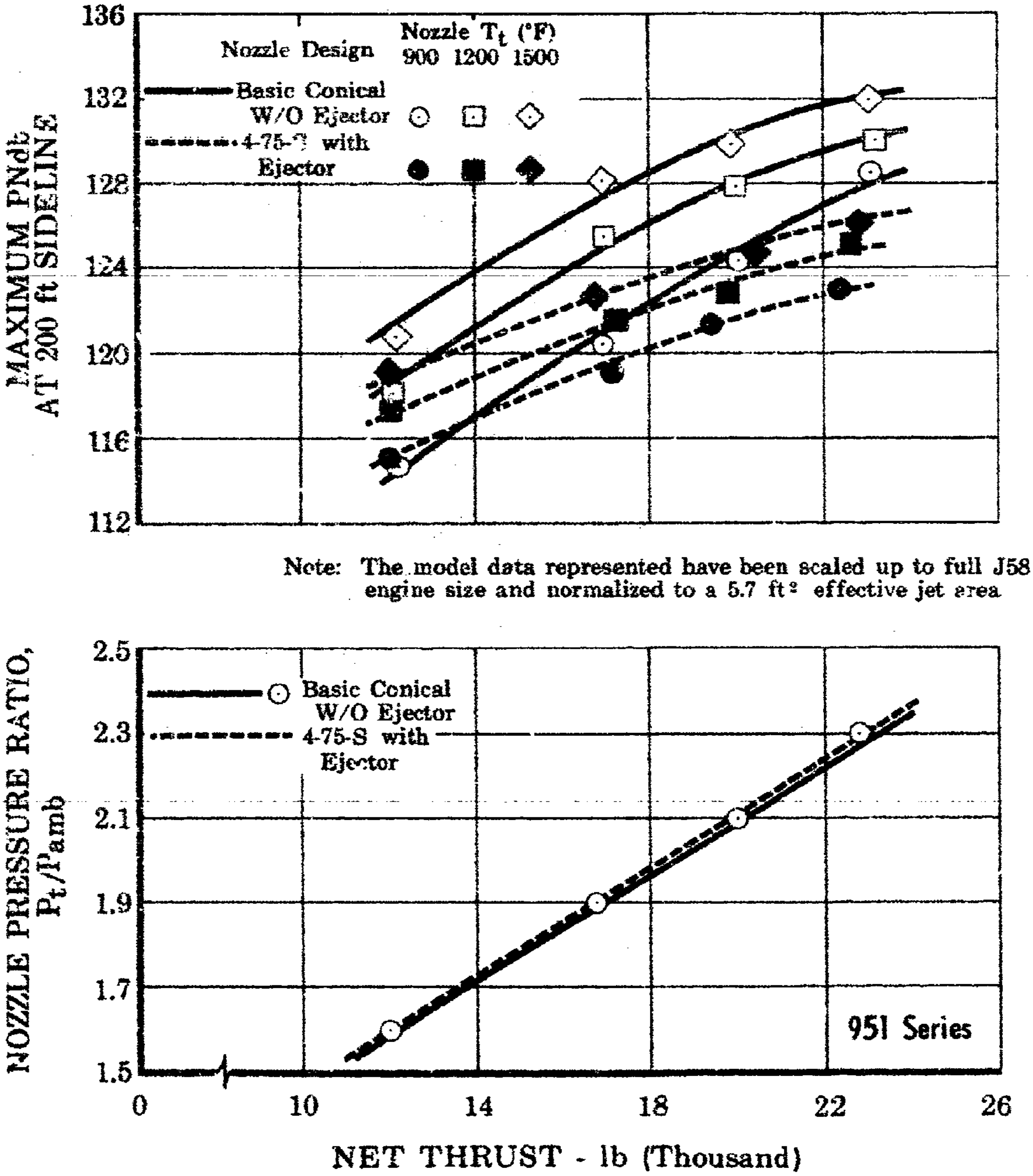
Note: The model data represented have been scaled up to full J58 engine size and normalized to a 5.7 ft² effective jet area.

Figure III-L-6. Performance of Turbojet Mixing Nozzle Models - 931 Series FD 19264



Note: The model data represented have been scaled up to full J58 engine size and normalized to a 5.7 ft² effective jet area.

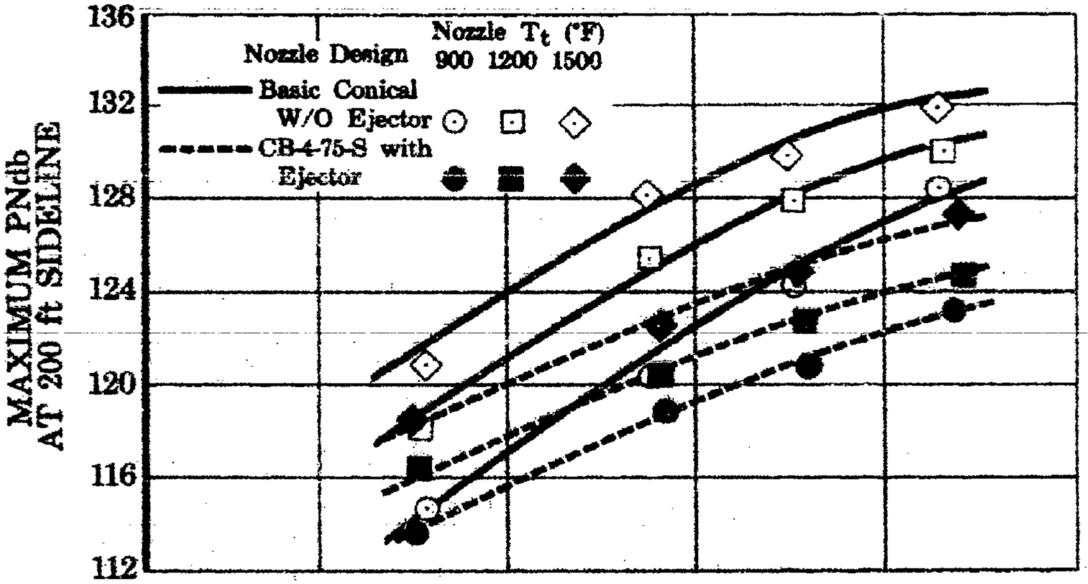
Figure III-L-7. Performance of Turbojet Mixing Nozzle Models - 941 Series FD 19263



Note: The model data represented have been scaled up to full J58 engine size and normalized to a 5.7 ft² effective jet area

Figure III-L-8. Performance of Turbojet Mixing Nozzle Models - 951 Series

FD 19262



Note: The model data represented have been scaled up to full J58 engine size and normalized to 5.7 ft² effective jet area.

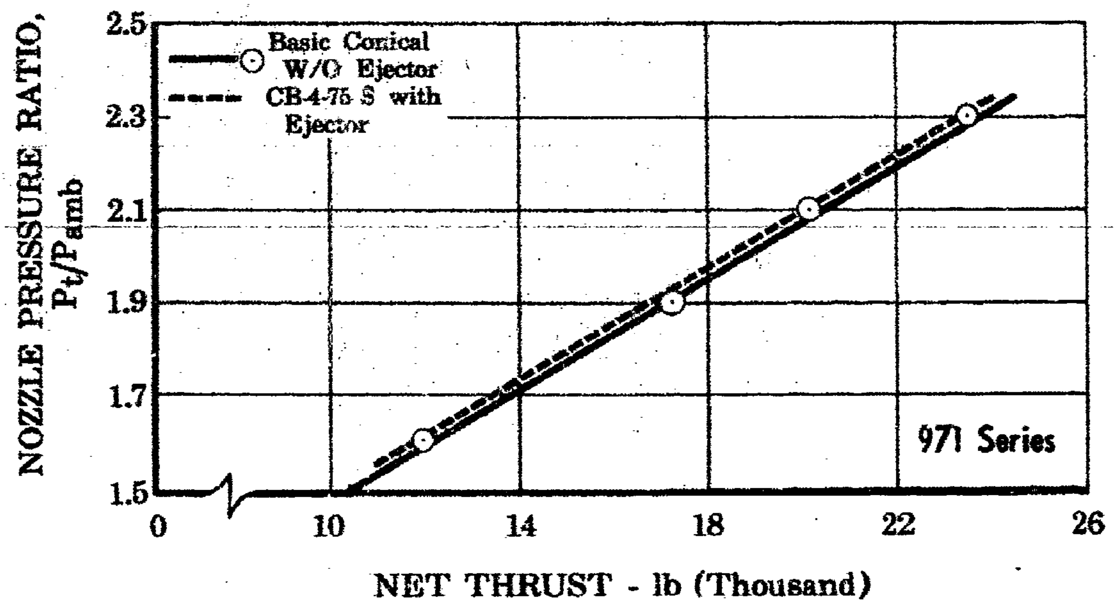
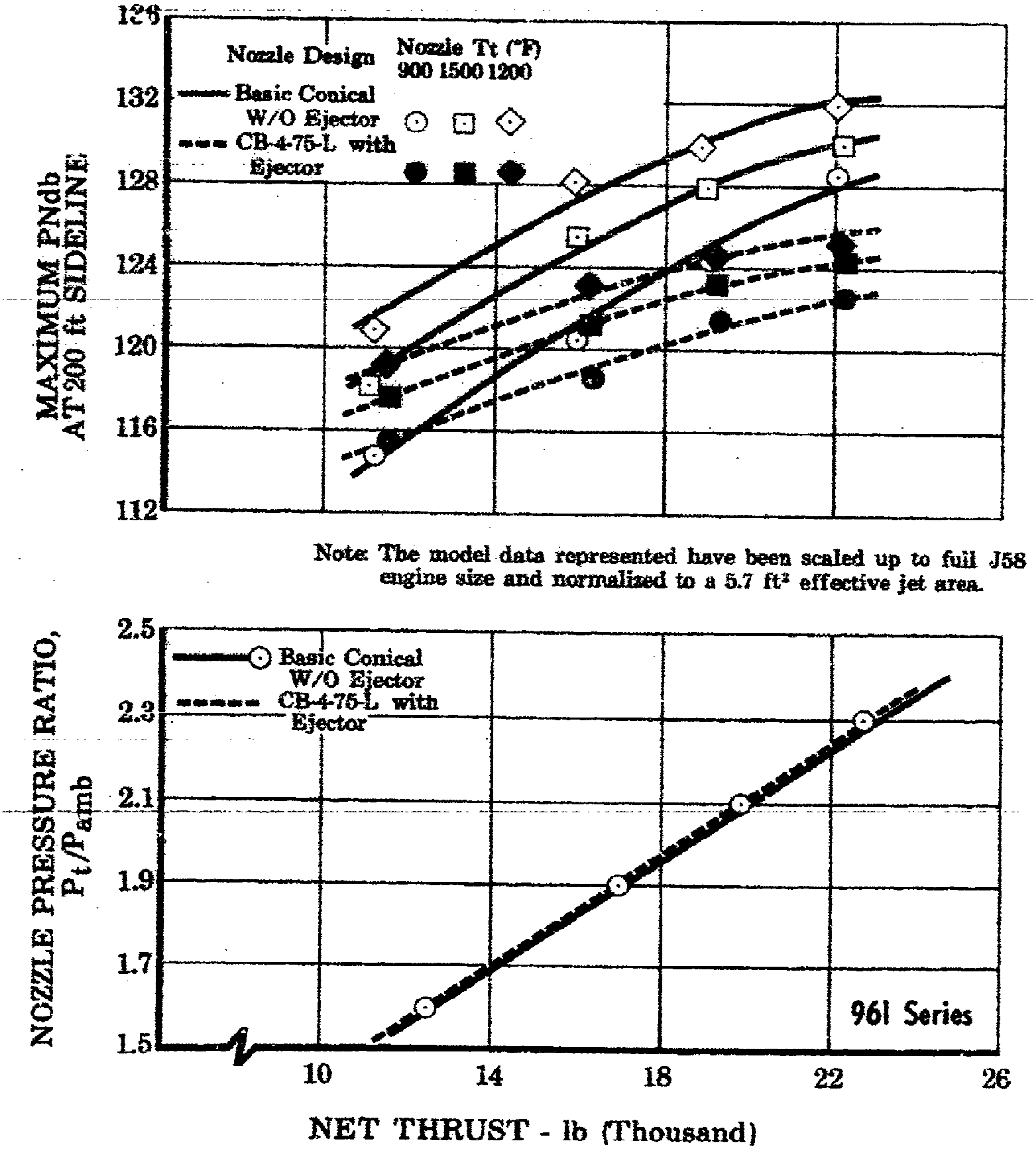
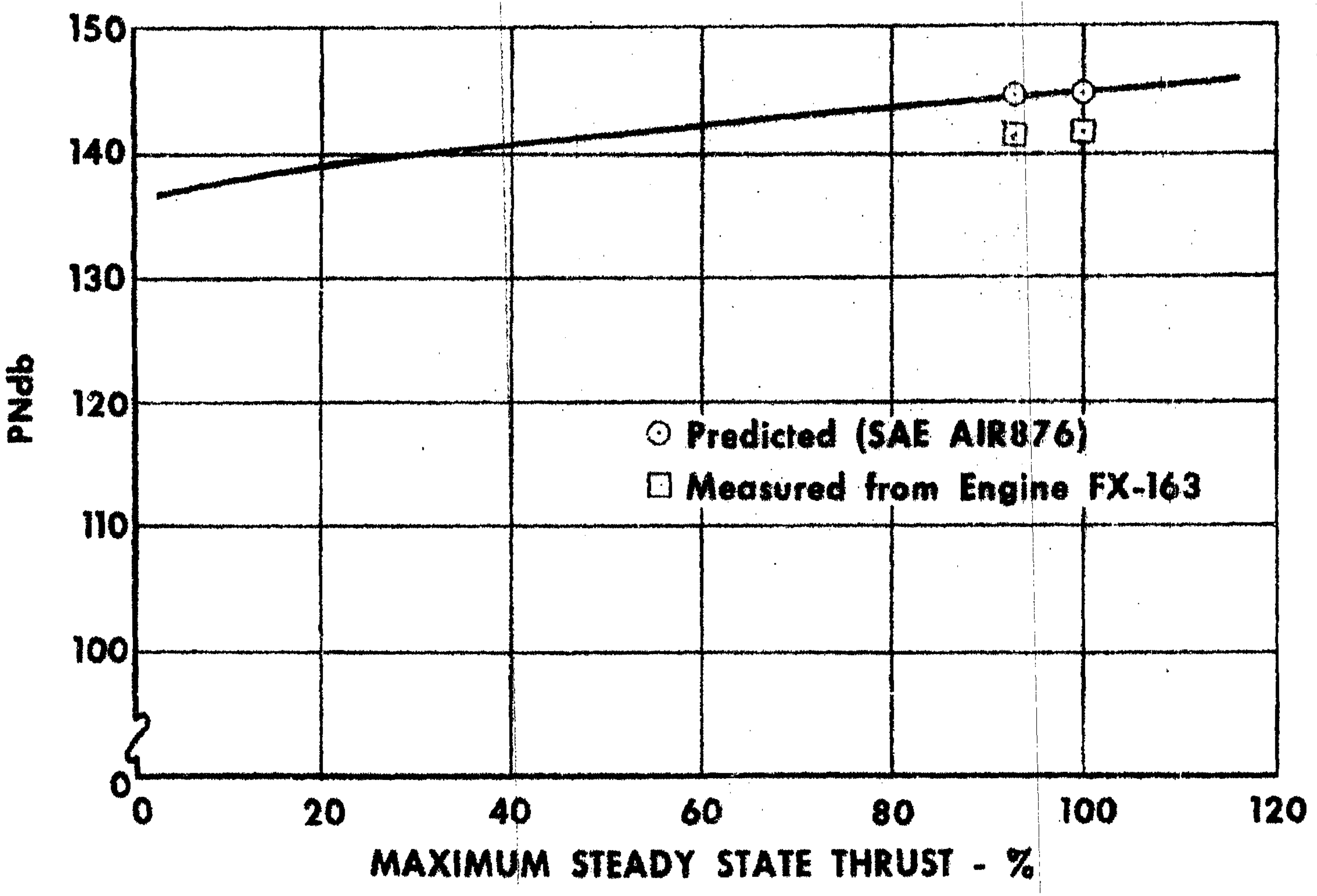


Figure III-L-9. Performance of Turbojet Mixing Nozzle Models - 971 Series FD 19261



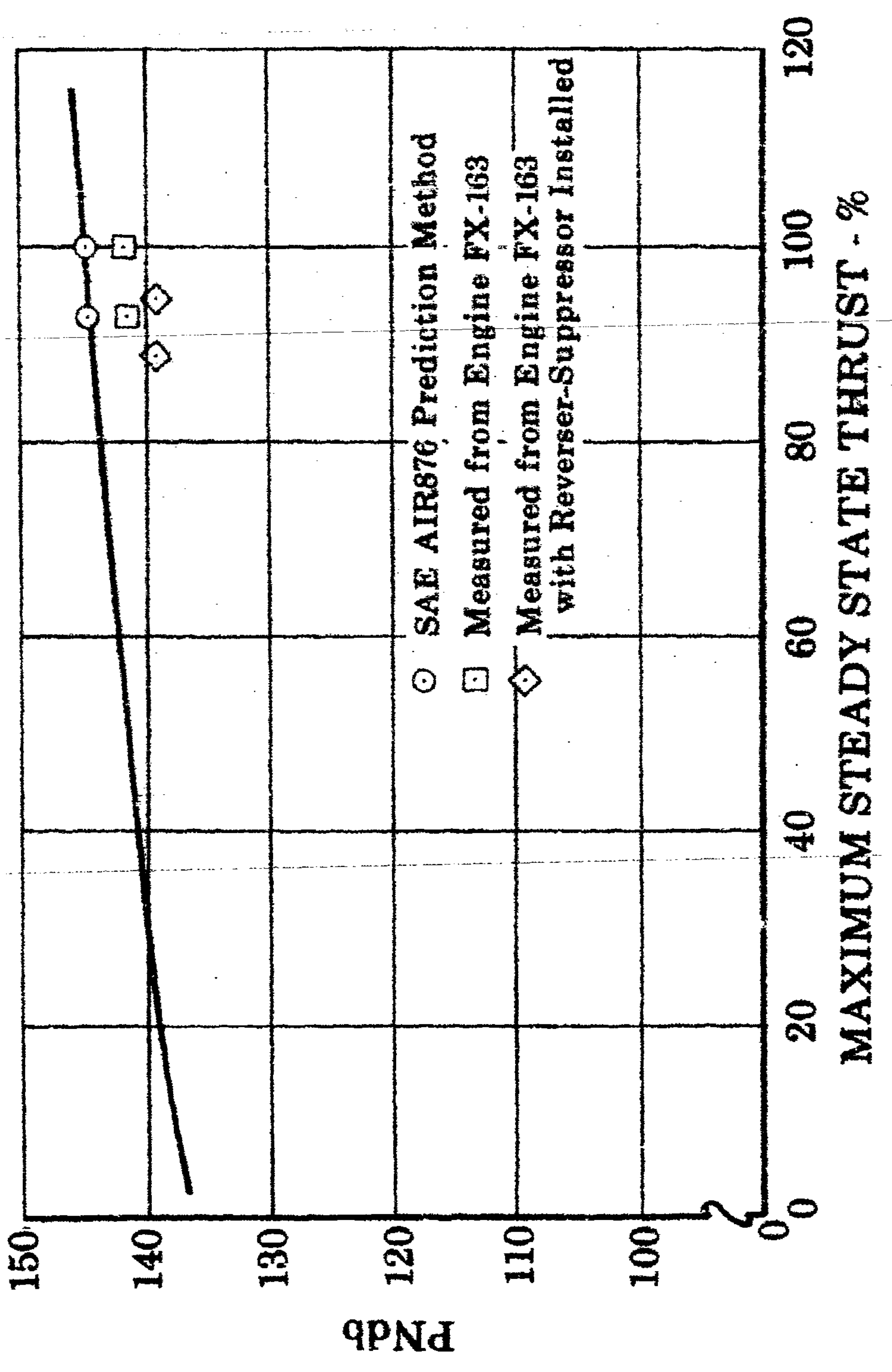
Note: The model data represented have been scaled up to full J58 engine size and normalized to a 5.7 ft² effective jet area.

Figure III-L-10. Performance of Turbojet Mixing Nozzle Models - 961 Series FD 19196



GS 4286

Figure III-L-11. Reduction in Jet Noise Provided by JTF17 Coannular Nozzle



FD 19251

Figure III-L-12. Reduction of Jet Noise Provided by JTF17 Coannular Nozzle

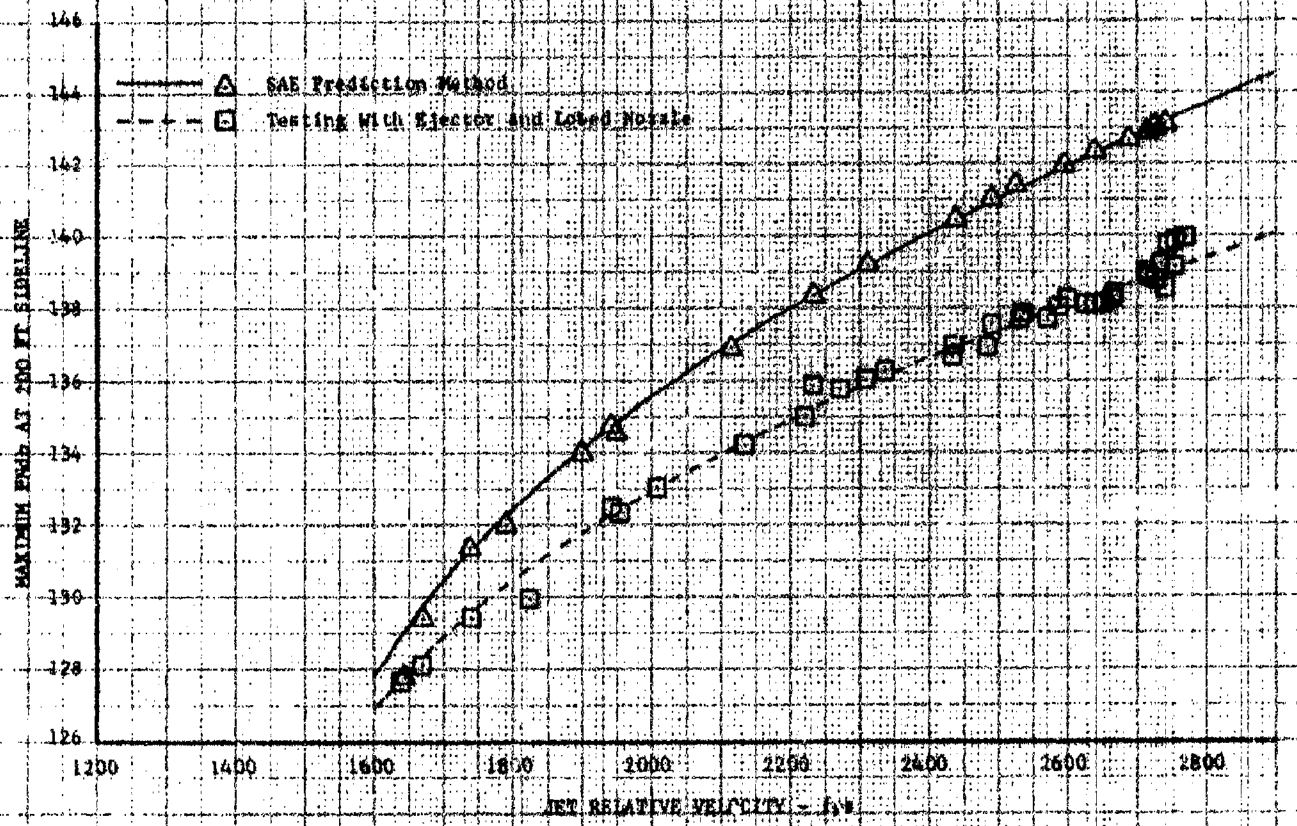


Figure III-L-13. Acoustical Performance of Full-Scale Turbojet Mixing Nozzle

DF 53151

DF 53152

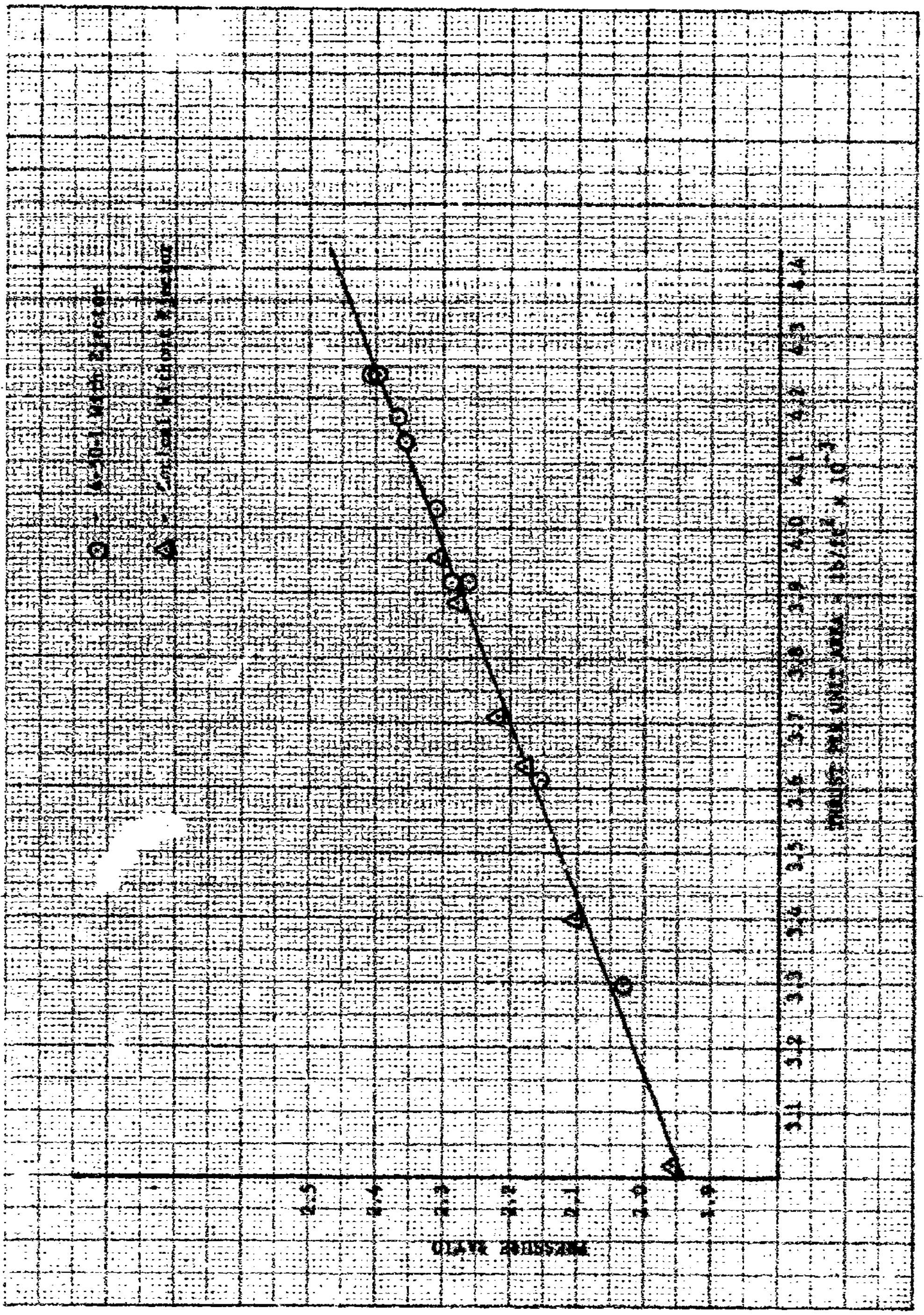
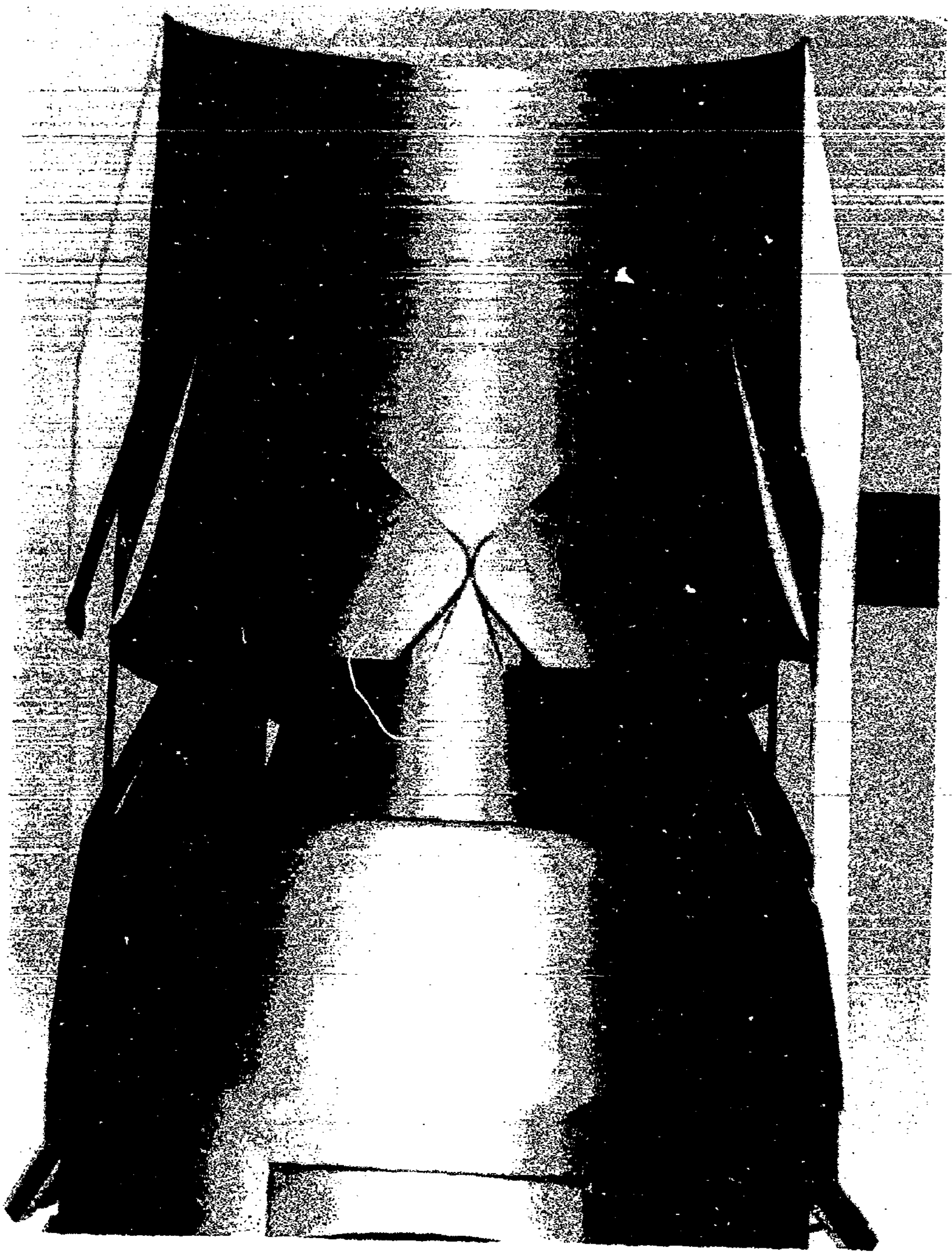


Figure III-L-14. Nozzle Performance of Full-Scale Turbojet Mixing Nozzle

M. MOCKUPS

All work on the full-scale mockup was completed prior to the FAA evaluators visit this period.

A workable 1/4-scale mockup of the 4-lobe noise suppressor was fabricated during this period and was used to demonstrate the concept to the FAA. A full side view of the model in the suppression mode with tertiary ram scoop doors open is shown in figure III-M-1. Figure III-M-2 is a 3/4 rear view showing the tertiary doors and the trailing edge of the top and bottom suppression flaps. The trailing edge of all 4 suppression flaps can be seen in the full rear view shown in figure III-M-3.



FE 65879

Figure III-M-1. Workable 1/4-Scale Mockup of 4-Lobe Noise Suppressor - Side View

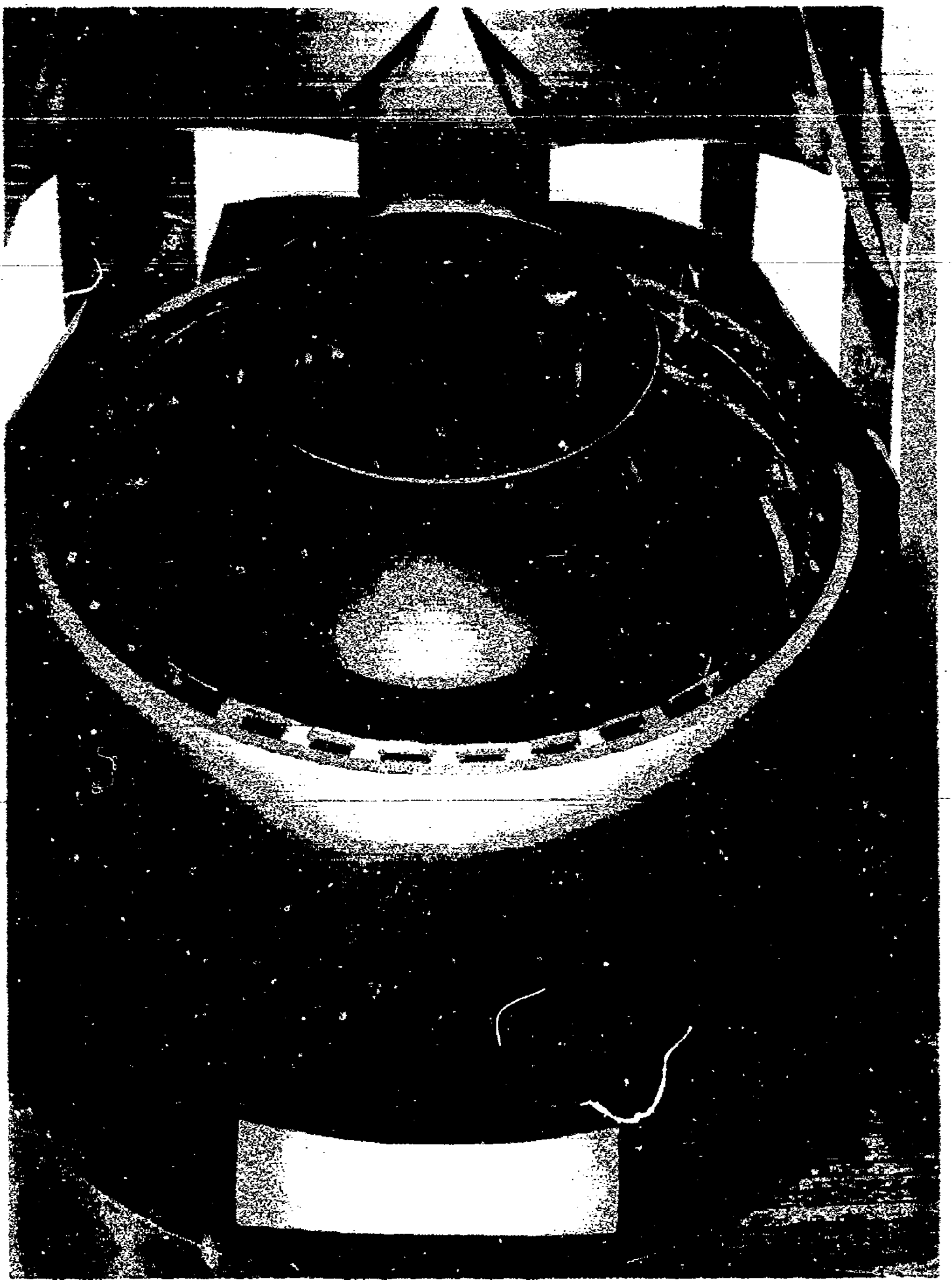


Figure III-M-2. Workable 1/4-Scale Mockup of 4-Lobe Noise Suppressor - 3/4 Rear View

FE 65886

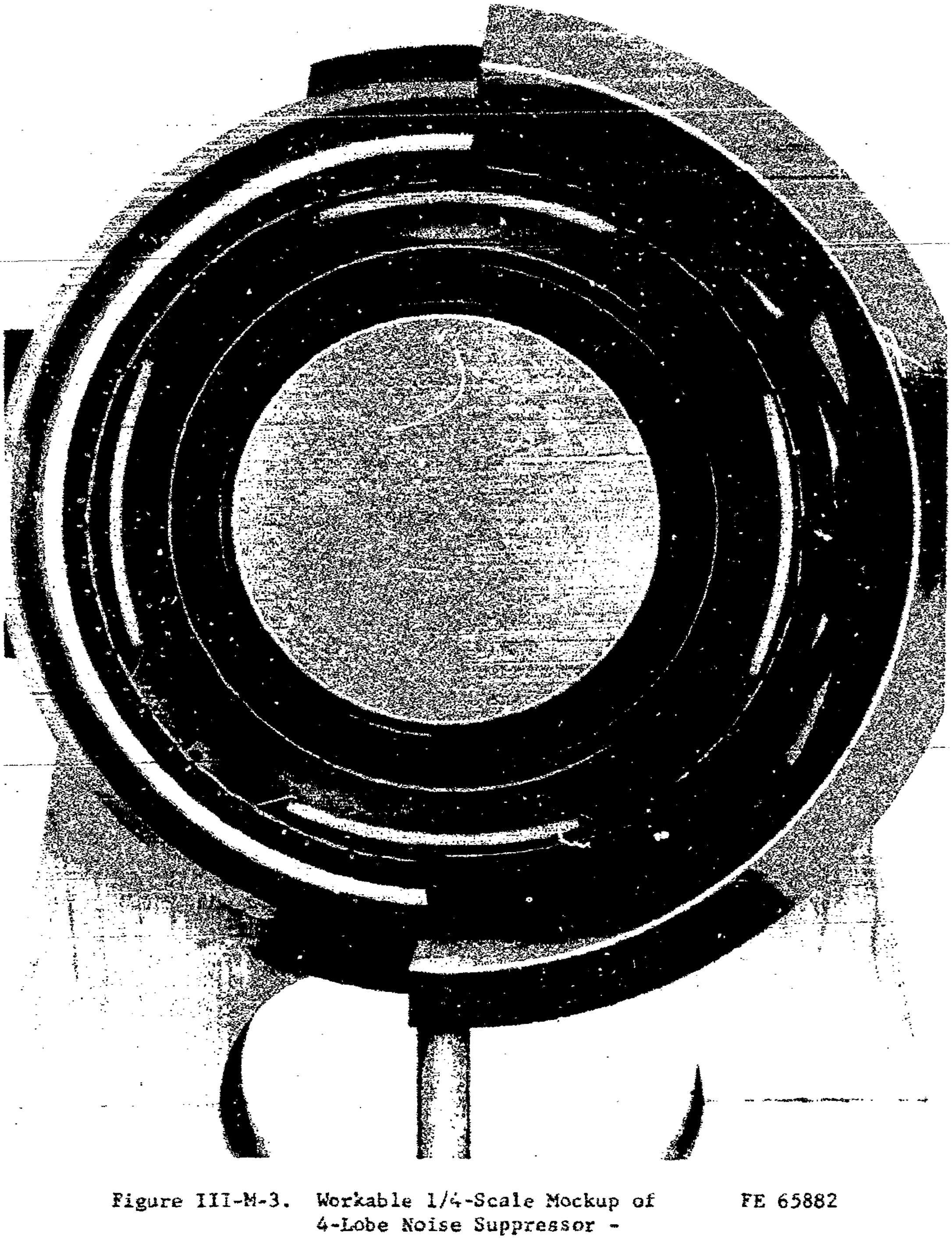


Figure III-M-3. Workable 1/4-Scale Mockup of 4-Lobe Noise Suppressor - Rear View FE 65882

N. COORDINATION

1. General

FRDC JTF17 performance engineers visited Boeing on 5 and 6 December and Lockheed on 7 December for increased-size airplane and engine discussions.

FRDC performance and installation engineering personnel visited Boeing and Lockheed on 8 and 9 December, respectively, for presentations of distorted inlet fan rig and engine test results, as well as the latest JTF17A-21 prototype engine high compressor rig test results.

Messrs. W. L. Gorton, FRDC General Manager, and B. N. Torell, Chief Engineer, visited the FAA, Washington, D. C., on 12 December, for SST program discussions.

The FAA Supplemental Engine Evaluation Team visited FRDC on 14, 15 December, to review the JTF17 Phase II-C engine and rig testing accomplishments subsequent to their November visit. All engine objectives have been met.

Phase II-C Evaluation Supplementary Report, PWA FR-2193, dated 15 December, was transmitted to the FAA, Washington, on schedule. This report summarizes FRDC powerplant progress from 6 September to 15 December, including Phase II-C engine and major component overall test results.

JTF17 Failure Mode and Effect Analysis material, which included block diagrams, component FMEA, and fuel and control FMEA was provided to American Airlines as requested.

A JTF17 engine simulation program, which included the JTF17 engine and control dynamic simulation deck, basic logic flow diagram of the propulsion system, engine control block diagrams and constants, and engine control schedules and functions, was transmitted to the Air Force Aero-Propulsion Laboratory, as requested.

2. JTF17A-21L Engine

Proposed P&WA Spec. 2698 revisions, resulting from FAA-P&WA Phase III contract negotiations, were forwarded to LCC for their review and approval.

A preliminary drawing of a "four lobe" suppressor nozzle, designed to provide an additional noise suppression of 3 PNdb at maximum augmented thrust, was generated and transmitted to Lockheed for their consideration in engine studies associated with their increased TOGW airplanes. This reverser-suppressor, which is conical in shape, is four inches greater in diameter at the front end, and weighs approximately 350 lb more than the current JTF17A-21L reverser-suppressor.

To supplement data previously supplied, additional engine disk failure data and analyses were transmitted to LCC, per their request, to aid them in completing their FAA-requested reliability studies.

Performance decks for several increased airflow study engines were transmitted to LCC for their use in optimization studies on possible increased TOGW airplanes. Applicable dimensions and weights were also provided. Extremely close and active coordination continues in efforts to achieve an optimum airplane/engine combination.

In response to a Lockheed request a design study was conducted to determine the engine-driven compressor-oil pump gearbox envelope growth, associated with increased horsepower requirements. A layout depicting the increased size gearbox was generated and transmitted to LCC.

As a variation of the above, LCC has advised P&WA that they are currently conducting additional studies of their environmental control system, in an effort to define a system in which the engine-driven compressor can be removed from the engine. The feasibility of these systems depends in part on possibility of revising the current engine air bleed concept. Initial design studies of the required engine bleed system were conducted.

LCC has again requested relocation of the engine front mount attach points. The relocation is a result of continuing mount system optimization studies. Preliminary engine design studies were conducted to determine structural and weight effects on the engine. LCC have provided drawings and additional mount and maneuver load data to aid in these studies.

A drawing, depicting a reduced drag wing/reverser-suppressor mate-up configuration, was received from Lockheed. This results in a slightly revised upper reverser-suppressor blow-in-door configuration. The drawing has been reviewed and estimates of performance effects have been forwarded to LCC for input into their drag versus thrust trade-off studies.

3. JTF17A-21B Engine

Proposed P&WA Spec. 2710 revisions, resulting from FAA-P&WA Phase III contract negotiations, have been approved by Boeing.

At Boeing's request a performance deck and applicable dimensions for a study engine, JTF17A-21B-1, sized at 825 lb/sec airflow and 1.1 bypass ratio was provided. This engine will provide (1) a significant improvement in overall airplane performance at the current TOGW, (2) improved transonic thrust margin, and (3) a significant reduction in the noise level. This engine has the potential of reducing sideline noise to a level well below the present FAA objectives. Copies of the preliminary specification for this engine, PWA Engine Specification No. 2716, dated 9 December 1966, have been transmitted to the FAA, Washington, D. C. for their review.

The latest revised copy of P&WA duct heater nozzle attachment layout has been transmitted to Boeing to further assist them in their independent thrust reverser design studies. Boeing has advised that the planned coordination meeting in December should be deferred until completion of their design and mockup work, after the end of Phase II-C.

FRDC supplied Boeing, per their request, information concerning the effect of prolonged operation at high temperature on the properties of oil, and on the JTF17 engine bearings and lubricated components.

FRDC transmitted to Boeing, per their request, a complete set of FRDC noise test equipment facilities photographs. FRDC also provided Boeing with two high temperature duct heater discharge (pressure and temperature reading) probes, and instructions for use in the Boeing SST propulsion system noise test program being conducted at the Boardman, Oregon test facility. FRDC offered the services of an instrumentation engineer, if they so desired.

Airplane nacelle model test coordination has been extensive. A preliminary review of the Boeing and FRDC wing-nacelle test results indicates very good agreement. A reverser targeting study indicates that the inverted "Y" pattern of flow, suggested by the airframe company, can be achieved with the prototype engine design.

O. MAINTAINABILITY

The design layout to improve the maintainability characteristics of the JTF17 engine by revising the fan stator assembly attachment, as reported in PWA FR-2213, has been completed. This redesign resulted in a 41% reduction in the number of bolts that have to be removed in order to disassemble the fan stator assembly and still retain support at the front mount.

To supplement the maintainability-maintenance endeavors, P&WA has prepared two additional documents: (1) JTF17 Installed Engine Diagnostic Inspection Plan, PWA FR-2233 and (2) a preliminary document, PWA JT9D/SST Turbine Engine Overhaul Test Cell Requirements. The following will summarize each of the documents.

The JTF17 engine diagnostic inspection analysis included the following categories:

1. In-Flight Monitoring

Gas generator parameter monitoring for malfunction analysis through gas generator comparisons and mechanical trends is the basic method of in-flight monitoring. The detailed procedure and techniques, as outlined in P&WA Gas Turbine Operation Information Letters No. 14, 15, 16, and 18, were reviewed. Current airline practice and operating procedures were reviewed with P&WA Flight Operation Engineering and airline field service representatives. Engine trend curves are established by a circular slide rule provided by P&WA for each particular engine and used by flight crews.

2. Flight Line Investigation

Flight line techniques that were investigated included oil analysis, borescope inspection, sonic analysis and radiography.

The Lube Rater system was reviewed, the details of which are contained in P&WA Report NaFL-65-3 entitled "Extension of Synthetic Oil Drain Periods in Aircraft Gas Turbine Engines," dated 10 February 1965. The spectrometric oil analysis program as used by commercial and military operators has been reviewed. Chip detectors and popout oil filters of the visual as well as recording variety have been investigated, and vendors have been contacted for the best equipment for this application.

Mockups have been made to determine the feasibility of the borescope provisions. Investigation work has been done with equipment manufacturers for borescopes with zoom lenses, polaroid and movie camera attachments, as well as closed circuit television attachments.

A survey was made of the various airlines as well as independent laboratories currently using radioisotopes for diagnostic work. Radiographs taken during the engine test phase of the JTF17 program demonstrated the feasibility as well as the effectiveness of this technique.

The current work on a sonic analyzer being evaluated by TWA, Eastern and National Airlines was reviewed with our service representatives. Several acoustical tapes were made on the JTF17 during the test program to evaluate this technique.

3. Engine Heavy Maintenance

Techniques to determine serviceability of either subassemblies or detailed parts include conventional radiography, ultrasonic, eddy current, fluorescent penetrant, and infrared inspection. Current techniques and practices were reviewed with Materials Development Laboratory and Nondestructive Test (NDT) personnel in such areas as spin, hot spin, wink zyglo, eddy current, and ultrasonic defect detection programs. A method has been developed by P&WA to measure wall thickness of turbine blades and vanes by eddy current. An infrared inspection method for the detection of alloy segregation in titanium hubs and disks has been developed and recommended for production use.

A literature survey has shown that there are new NDT techniques which are being investigated such as color radiography, neutron radiography, olfactronics, lasers, microwaves, and ultrasonic imaging.

Pratt & Whitney Aircraft recognized that the airline operators were already involved in planning for shop and test facility modifications to support a forthcoming generation of large subsonic and supersonic aircraft, and therefore provided a preliminary document, PWA JT9D/SST Turbine Engine Overhaul Test Cell Requirements. Drawings representing modifications to existing facilities as well as new construction details were included to provide the operator with data for comparison of JT9D and JTF17 requirements. The printed information was hand-carried and discussed directly with responsible planning personnel at PAA, AAL, TWA, and UAL, and the response from these major carriers was most favorable.

To illustrate the degree of effort and depth of information, the table of contents from PWA JT9D/SST Turbine Engine Overhaul Test Cell Requirements is reproduced below:

CONTENTS

P. VALUE ENGINEERING

Value Engineering cost studies completed during the month of December include:

1. Boeing engine vs Lockheed engine cost changes with varying fuel flow and bypass ratio
2. Updated controls and valves cost estimate
3. Updated engine cost estimate
4. Flange study summary of form rolled and welded rings, contoured flash butt-welded rings and rectangular flash butt-welded rings.

During this report period, Value Engineering also:

1. Investigated feasibility of using titanium honeycomb for noise suppression liners
2. Reviewed use of angle gaskets for Haskell seals in main fuel drain valve and found them not acceptable for this application
3. Completed Phase II-C Final Report for Value Engineering.

A total of 17 Value Engineering proposals remain pending at this time, with a total potential cost reduction of $36,087 per engine.

Seven new Value Engineering proposals have been initiated, but the potential savings have not yet been established.

Q. CONFIGURATION MANAGEMENT

Design of the prototype engine is continuing with incorporation of coordinated interfaces. Detail changes required on some interface items are being coordinated with the airframe manufacturers as design of the engine and airframe progresses. All proposed changes are being transmitted by Field Survey Layouts with a log of dates of transmittal and acceptance or rejection by the airframe manufacturer. The basic configuration of the engine is unaffected by these changes.

R. QUALITY ASSURANCE

Chem-milling of airfoil sections has proved to be a quick and accurate method for producing masters in size ranges needed for blade and vane wall thickness measurement. These masters permit setting of eddy current equipment so that close measurement of actual thickness is possible.

S. RELIABILITY

1. Design Reviews

Reliability review of all layouts describing the prototype engine and reliability engineering layout review sheets indicating areas that merit further study have been completed.

2. Failure Mode and Effect Analysis

The third edition of the Failure Mode and Effect Analysis has been completed and is included in this report as Appendix A. This edition contains FMEA Sheet II which includes the hazard classification, design philosophy to preclude failure and the design philosophy to reduce hazard for each failure mode. Minor revisions have been made to FMEA Sheet I to reflect the latest design decisions.

3. Service Data Analysis

Detailed analysis of Service Department data on causes of inflight shutdowns, premature engine removals, and parts discrepancies is continuing. The areas investigated in detail during this month are:

1. JT3C No. 4-1/2 Bearing Seal Wear
2. JT4A Fuel Nozzle Inlet Tee Cracking
3. JT4A Rear Compressor Bore Tube Wear
4. JT8D Oil Pressure Regulating Valve Loosening

4. Special Reliability Studies

A study of "strip stock" versus "forged foot" compressor stators has been completed. A survey of premature engine removals of the JT3C, JT3D, JT4A, and JT8D engines from 1961 through 1965 shows that forged stators have greater reliability than strip stock stators. The failure rates were calculated to be 0.0006 failures/one thousand hours for forged stators and 0.0014 failures/one thousand hours for strip stock stators.

A study to determine exhaust gas temperature variations of first run production engines and the exhaust gas temperature deterioration experienced by overhauled engines has been completed. This information was used in studies of hot section parts life.

5. Parts History Survey

A parts history survey of 1st- and 2nd-stage fan blades was made for Project Test Engineers to identify the high test time blades.

6. Statistical Analysis of Outliers

A Monte Carlo simulator was written to evaluate efficiencies of methods for detecting outliers in JTF17 performance data. The results will show the relative performance of Thompson's "T", Anscombe's "C", Fisher's "F" and Grubb's detection techniques with small samples.

7. Dead Band

The final version of the dead band study (PWA Report FR-1897) was completed during this report period and the report is included herein as Appendix B.

SECTION IV
AIRLINE COMMENTS

No Airline comments were received during this report period.

SECTION V
STATE-OF-THE-ART

There has been no significant State-of-the-Art information received during this report period.

APPENDIX A

JTF17 FAILURE MODE & EFFECT ANALYSIS

APPENDIX A

JTF17 FAILURE MODE AND EFFECT ANALYSIS

The following pages represent the results of a detailed Failure Mode and Effect Analysis (FMEA) and design philosophy to reduce hazards. The FMEA is shown on sheet I, while the design philosophy to reduce hazards is shown on sheet II for each failure mode.

The following abbreviations have been used:

F.O.D.	Foreign object damage
I.F.S.	Inflight shutdown
P.E.R.	Premature engine removal
A.F.	Augmentor failure

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
1 FRONT MOUNT 1.0.0	Provide Airframe attachment points for the engine.						
Mount Ring 1.1.0	Transmit thrust and reverser loads and a portion of vertical and side loads to the airframe.	1. Yielding	None	Increased vibration, ground inspection.	Possible deflection of case relative to blades causing blade rub.	Possible I.F.S. and P.E.R. for parts replacement.	Reduce rpm or shut down engine as vibration level dictates.
		2. Cracks	None	Ground inspection, inspection at overhaul.	None	P.E.R. for parts replacement.	None
Case 1.2.0	Transmit thrust and reverser loads and a portion of vertical and side loads to the mount ring and provide support for 1st-stage shroud case and stator.	1. Yielding	None	Increased vibration, ground inspection.	Possible deflection of case relative to blades causing blade rub.	Possible I.F.S. and P.E.R. for parts replacement.	Reduce rpm or shut down engine as vibration level dictates.
		2. Cracks	None	Ground inspection. Inspection at overhaul.	None	P.E.R. for parts replacement.	None

Sheet #

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
1 FRONT MOUNT 1.0.0	Provide Airframe attachment points for the engine.							
Mount Ring 1.1.0	Transmit thrust and reverser loads and a portion of vertical and side loads to the airframe.	1. Yielding	X				Combined stresses from engine, maneuver, and gust loads were limited to 0.2% of the yield strength or 67% of the ultimate strength, whichever is lower. In weld areas, the maximum stress will be equal to or less than 80% of the 0.2% yield strength. This criteria, based on our commercial engine experience, ensures no permanent set at limit load conditions and no failures at ultimate load conditions. Ground handling attachment points are provided to prevent overloading during maintenance.	
		2. Cracks	X				The engine mount ring cross section is trapezoidal in shape. This configuration allows for thermal expansion while providing maximum structural strength. The trapezoidal design was chosen because the conventional "U" cross section ring structure used on the JT3D and JT4 was unsatisfactory in the J58 application, while the selected shape performed satisfactorily.	Forward location makes ring easily accessible for visual inspection.
Case 1.2.0	Transmit thrust and reverser loads and a portion of vertical and side loads to the mount ring and provide support for 1st-stage shroud case and stator.	1. Yielding	X				Thickness is selected for blade containment requirement and stresses are therefore well below the yield point under normal operating conditions.	Same as 1.1.0
		2. Cracks	X				One piece forged construction, fully machined.	

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
2 FAN 2.0.0							
Stators 1st and 2nd 2.1.0	Direct air from rotor to rotor at proper angles.	1. Damage from foreign objects striking blades.	Decrease in performance proportional to extent of damage. Flow distortion to aft stages.	Engine surge. Increased vibration. Reduced thrust. Ground inspection.	Performance loss and possible surge.	Possible P.E.R. for parts replacement.	Avoid high power settings or rapid transients if engine surges.
		2. Cracks	None	Ground inspection. Inspection at overhaul.	None	Possible P.E.R. for parts replacement.	None
		3. Airfoil breakage.	F.O.D. to aft components. Vibration increasing with additional damage if engine is not shut down.	Engine surge, increased vibration, reduced thrust, ground inspection.	Performance loss. Downstream F.O.D. to high compressor and aft components.	Possible I.F.S. and P.E.R. for parts replacement.	Shut down or reduce rpm as engine vibration level dictates.
Blade Tip Shrouds (Stationary) 2.2.0	Form flowpath and provide stator attachment.	1. Cracks	None	Ground inspection. Inspection at overhaul.	None	Possible P.E.R. for parts replacement.	None
		2. Excessive Blade Rub	Blade and shroud case damage. Decrease in surge margin.	Noisy rundown. Engine surge. Increased vibration. Ground inspection.	Reduced surge margin.	Possible P.E.R. for parts replacement.	Avoid high power settings or rapid transients if engine surges.
Seals 2.3.0	Limit interstage air leakage.	1. Hard Rub	Increased clearance resulting in higher interstage air leakage.	Reduced thrust.	Performance loss.	None	None
		2. Breakage	Same as 1 above, plus F.O.D. to aft components.	Reduced thrust. Increased vibration. Ground inspection.	Performance loss plus possible downstream damage.	Possible I.F.S. and P.E.R. for parts replacement.	Reduce rpm or shut down engine as vibration level dictates.
1st & 2nd Integral Disk & Hub 2.4.0	Supports rotating blades, seals, spacers, counterweights.	1. Yielding	Blade rub on shrouds. Some loss in surge margin.	Noisy rundown. Engine surge. Increased vibration. Ground inspection.	Reduced surge margin.	Possible P.E.R. for parts replacement.	Avoid high power settings or rapid transients if engine surges.

Sheet II

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification				Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
			I	II	III	IV		
2 FAN 2.0.0								
Stators 1st and 2nd 2.1.0	Direct air from rotor to rotor at proper angles.	1. Damage from foreign objects striking blades.	X	X			Space provided for blade flexing without contacting vanes. Vanes fixed at both ends for increased damping.	Area accessible for visual inspection at transit inspection.
		2. Cracks		X			Glass peened [illegible] increase fatigue life.	
		3. Airfoil breakage.			X		Vanes are forged and mechanically attached to the supporting cases to obtain beneficial damping.	Inner and outer vane end attachments provide positive retention of broken airfoil to prevent foreign object damage to blading.
Blade Tip Shrouds (Stationary) 2.2.0	Form flowpath and provide stator attachment.	1. Cracks	X				One piece forged rings, retained at both ends, for increased damping.	
		2. Excessive blade rub		X			Blade tip clearance sized for thermals plus worst maneuver condition. Shrouds are separate from front mount case to eliminate feedback of mount deflections.	Area accessible for visual inspection at transit inspection.
Seals 2.3.0	Limit interstage air leakage.	1. Hard rub		X			Clearances are sized to prevent hard rub.	Seal configuration with serrated surface behaves like an abradable surface to dissipate heat and reduce damage. If titanium blades rub, danger of fire is eliminated by not using titanium for stationary blade tip shrouds.
		2. Breakage			X		Continuous ring configuration of seal will reduce FOD by preventing entry into gas path.	
1st & 2nd Integral Disk and Hub 2.4.0	Supports rotating blades, seals, spacers, counterweights.	1. Yielding		X			Yield margins of 13% over maximum deteriorated speed and 3% over maximum overspeed due to control malfunction. Radial stress in the disk web is restricted to the average tangential stress. Radial stress between bolt holes will not exceed 90% of the average tangential stress. Allowable tangential stress is equal to yield factor times 0.2% yield strength of the material divided by the yield margin squared. Low cycle fatigue for disks is 20,000 engine acceleration cycles or 17,000 engine thermal cycles.	

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
		2. Cracks	None	Inspection at overhaul	None	None	None
		3. Loss of Disk lug.	Loss of Blades. Severe unbalance and vibration.	Engine surge. Increased vibration. Reduced thrust. Ground inspection.	Severe F.O.D. to aft components.	I.F.S. and P.E.R. for overhaul.	Shutdown
		4. Fracture	Severe F.O.D. of high compressor and turbine. Severe unbalance and performance loss. Cases cannot contain this level of energy.	Rpm drop. Increased vibration. Loss of thrust.	Severe vibration and loss of failed parts through cases.	I.F.S. and P.E.R. for overhaul. F.O.D. from projectiles.	Shutdown
1st Disk Hub Spline 2.4.1	Transmits turbine torque to fan rotor.	1. Wear	None	Inspection at overhaul.	None	None	None
Tiebolts 2.4.2	Axial clamping of low rotor, maintain axial pinch on rim spacer, transmit torque to fan 2nd rotor.	Bolt Breakage	Bolt could become F.O.D. and cause downstream damage. Increased vibration. If a number of bolts fail, the axial pinch on the rim spacer is lost, and the fan rotor critical speed may be in engine running range.	Increased vibration. Ground inspection.	Increased vibration. Possible F.O.D. to aft parts.	Possible I.F.S. and P.E.R. for parts replacement.	Reduce rpm or shut down as engine vibration level dictates.
Rim Spacer 2.4.3	Stiffen the low rotor.	1. Yield	Stiffness and critical speed margin reduced. Fan disk and blades may experience vibration.	Increased vibration.	Fan rotor critical speed may be in engine running range.	Possible I.F.S. and P.E.R. for inspection and parts replacement.	Reduce rpm or shut down as engine vibration level dictates.

Sheet II

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
		2. Cracks		X			All surfaces of the disks are glass-bead peened to improve fatigue resistance. The 1st-stage hub spline, and the dovetail slots of both disks are treated per specification PWA 60 graphite varnish to prevent surface galling. The bolt holes in the hubs are polished per PWA 99 and are located in the disk support cone, which operates at a low stress level to improve fatigue resistance. The relatively compact configuration of the fan disks results in low thermal gradients.	Failure can be minimized by periodic borescope and visual inspection of disks and hubs to preclude progression.
		3. Loss of disk lug.			X		The disk cross section shapes were determined primarily by disk and blade vibration requirements and by weight optimization. For the first stage, a compact thick cross section for rim torsional stiffness is required. The truss system has been carefully designed to balance out all forces and moments to assure there is no rotation of the disk rims. This is achieved by making the 1st-stage disk cross section slightly asymmetrical and by careful location of the axial spacer on the second stage. Stress levels are based on formulae developed from existing PWA engines.	The 10% blade loss capability of the design will reduce the effects of this failure mode. Vibration monitoring and ground inspection at transit inspection will prevent escalation of this failure.
		4. Fracture				X	A burst margin of 28% over maximum deteriorated speed was designed into the fan disks.	Rotor planes occupy short axial length which permits maximum allowance for installation of critical aircraft components.
1st Disk Hub Spline 2.4.1	Transmits turbine torque to fan rotor.	1. Wear	X				Lubricant is used to reduce wear and galling, double piloted hub provides uniform loading of spline by reducing misalignment.	
Tiebolts 2.4.2	Axial clamping of low rotor, maintain axial pinch on rim spacer, transmit torque to fan 2nd rotor.	Bolt breakage		X			Bolts are sized to limit moment stress from 10% blade loss in any one stage to 0.2% of material yield stress and to keep strain energy produced by a 10% blade loss in any one stage within the strain energy absorption capability of the bolts. Hydraulic stretch at assembly eliminates torsional stresses in the bolts.	Redundancy of bolts is provided. Vibration monitoring will prevent escalation of failure.
Rim Spacer 2.4.3	Stiffen the low rotor.	1. Yield		X			Rim spacer, disks and disk support cones were analyzed and designed as a loaded truss system. Rim spacer is sized to withstand loads of surge and 10% blade loss in any one stage. Axial pinch is generated by disks swinging together as centrifugal load increases. The maximum effective stress, which includes tangential axial, and local bending stresses, is below the yield strength at all conditions.	Axial pinch will tend to retain spacer. Continuous ring configuration will limit spacer movement and failure propagation.

Sheet 8

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
		2. Cracks	None	Inspection at overhaul.	None	None	None
		3. Fracture	Loss of rotor stiffness, F.O.D. to blades and vanes.	Increased vibration. Ground inspection.	Fan rotor critical speed may be in engine running range. F.O.D. to aft components.	I.F.S. and P.R.R. for overhaul.	Shutdown.
Blades 1st & 2nd Stage Fan 2.5.0	Compression of 100% of engine airflow.	1. Loose blades due to shroud wear.	Reduced vibration damping.	Noisy rundown. Ground inspection.	None	Replace blades with worn shrouds.	Recommend inspection when noisy rundown noted.
		2. Foreign Object damage without breakage.	Decrease in performance proportional to extent of damage. Flow distortion to aft stages. Reduced surge margin.	Engine surge. Increased vibration. Reduced thrust. Ground inspection.	Performance loss and possible surge.	Inspect and repair damaged blades.	Avoid high power settings or rapid transients if engine surges.
		3. Excessive growth.	Blade and shroud case damage. Some loss in surge margin.	Noisy rundown. Engine surge. Increased vibration. Ground inspection.	Reduced surge margin.	Possible P.R.R. for parts replacement.	Avoid high power settings or rapid transients if engine surges.
		4. Cracks	None	Ground inspection.	None	Replace cracked blades.	None
		5. Blade breakage	Excessive vibration with additional damage if engine is not shutdown.	Increased vibration. Reduced thrust. Ground inspection.	Damage to outer shrouds and other fan blades and vanes with possible F.O.D. to aft components. (Detached blades should exit through fan duct)	Possible I.F.S. and P.R.R. for parts replacement.	Reduce rpm or shut down engine as vibration level dictates.
Blade Locks 2.5.1	Prevent forward and aft movement of blade.	1. Cracks	None	Inspection at overhaul.	None	None	None
		2. Ring or lug breakage.	Blades may move axially and rub vanes. Blade and vane damage if engine is not shut down.	Increased vibration. Ground inspection.	F.O.D. to aft components if blade and vane damage occurs.	Possible I.F.S. or P.R.R. for parts replacement.	Reduce rpm or shut down engine as vibration level dictates.

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JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
		2. Cracks		X			The LCF design life of the spacer is in excess of 20,000 cycles.	
		3. Fracture				X	Burst margin based on tangential stress in over maximum deteriorated speed.	The rotor is designed to withstand the loss of 10% of the blades in any one stage without complete failure thus limiting the damage. The case wall thickness is selected to provide blade containment and prevent external damage, thus limiting damage from this failure mode.
Blades 1st & 2nd Stage Fan 2.5.0	Compression of 100% of engine airflow.	1. Loose blades due to shroud wear.		X			Shrouds have optimum notch angle, sufficient bearing area and hardfaced contact surfaces. The two shrouds used will double contact area and reduce wear.	Area is accessible for visual and borescope inspection.
		2. Foreign Object damage without breakage.	X	X			Blades are sized for FOD and surge loads. Double shrouds increase torsional stiffness and contact angles are set to prevent disengaging. Axial space is provided for deflection so that the load can be distributed to adjacent blades.	Axial space provided between blades and vanes will reduce contact and damage propagation.
		3. Excessive growth		X			Blades are designed to a life limit of 30,000 hours without unacceptable growth.	If titanium blades rub, danger of fire is eliminated by not using titanium for stationary blade tip shrouds.
		4. Cracks			X		Blades are peened and attachments are undercut to reduce stress concentrations.	Area is accessible for visual and borescope inspection.
		5. Blade breakage			X		Double shrouds used for torsional stiffness, blade incidence control to limit flutter and foreign object damage. Blade disk systems are designed with 10% frequency margin over 2E excitation frequency. Blades are peened and attachments are undercut to reduce stress concentrations.	The rotor is designed to withstand the loss of 10% of the blades in any one stage without complete failure thus limiting the damage. The case wall thickness is selected to provide blade containment and prevent external damage.
Blade Locks 2.5.1	Prevent forward and aft movement of blade.	1. Cracks	X				Rings are fully machined with radii sized to reduce stress concentrations.	Area is accessible for visual and borescope inspection.
		2. Ring or lug breakage.			X		Ring is secured by multiple rivets. Lug stresses are extremely low. Thicknesses sized for FOD.	Continuous ring configuration used will reduce the possibility of this failure mode releasing blades. If the ring should crack the mating parts will carry the load of a broken lock. Double shrouds will also tend to prevent blade release.

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
3 INTER-MEDIATE CASE 3.0.0	Provide support structure for primary gas generator. Provide section of fan and compressor flowpath. Provide No. 1 and 2 bearing support.						
Outer Struts (Fan Section) 3.1.0	Provide support for gas generator.	1. Cracks	None	Inspection at overhaul.	None	None	None
		2. Cracks and separation.	Dependent upon severity. Vary from no effect to loss of function.	Increased vibration, ground inspection.	Varies from vibration to partial loss of gas generator support.	Possible I.F.S. and P.R.R. for inspection and repair.	Reduce rpm or shut down engine as vibration level dictates.
		3. Buckling	Loss of alignment.	Increased vibration, ground inspection.	Fan blade rub against case, possible F.O.D. to high compressor and aft parts.	Possible I.F.S. and P.R.R. for inspection and repair.	Same as 2 above.
Inner Struts (Compressor Section) 3.2.0	Provide support for main rotor bearing compartment.	1. Cracks	None	Inspection at overhaul	None	None	None
		2. Cracks and separation.	Dependent upon severity. Vary from no effect to loss of bearing support.	Increased vibration, ground inspection.	Possible shift of blades into vanes with rub damage and F.O.D. to aft parts.	Possible I.F.S. and P.R.R. for inspection and repair.	Reduce rpm or shut down engine as vibration level dictates.
Bearing Support Cones 3.3.0	Provide support for main rotor bearing compartment plus separate compartment pressure zones.	1. Cracks	None	Inspection at overhaul	None	None	None
		2. Buckling	Bearing misalignment.	Increased vibration, ground inspection.	Possible shift of blades into vanes with rub damage and F.O.D. to aft parts.	Possible I.F.S. and P.R.R. for inspection and repair.	Reduce rpm or shut down engine as vibration level dictates.
Fan Exit Stator 3.4.0	To direct fan discharge air at proper angles.	1. Cracks	None	Inspection at overhaul	None	None	None
		2. Breakage	Aerodynamic performance loss.	Reduced augmentation, ground inspection.	F.O.D. to duct heater system.	Possible A.F. and/or P.R.R. for inspection and parts replacement.	Adjust augmentation zone fuel management.

Sheet II

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
INTERMEDIATE CASE 3.0.0	Provide support structure for primary gas generator. Provide section of fan and compressor flowpath. Provide No. 1 and 2 bearing support.							
Outer Struts (Fan Section) 3.1.0	Provide support for gas generator.	1. Cracks	X				Struts are butt welded to integral machined contoured standups. All welds loaded in simple tension or compression.	
		2. Separation		X	X		Same as 1.	Separation of one strut will not result in the failure of remaining struts as multiple struts are used to distribute loads and provide redundant support.
		3. Buckling		X	X		30% buckling margin used to size strut wall thickness.	Same as 3.1.0.2
Inner Struts (Compressor Section) 3.2.0	Provide support for main rotor bearing compartment.	1. Cracks	X				Same as 3.1.0-1 plus load from bearing supports is not taken at strut leading and trailing edge.	
		2. Separation		X	X		Same as 1.	Same as 3.1.0.2
Bearing Support Cones 3.3.0	Provide support for main rotor bearing compartment plus separate compartment pressure zones.	1. Cracks	X				Minimum welding used, no fillet welds. Thickness is set by manufacturing limitations, not stress limited.	
		2. Buckling		X	X		Not a limiting factor, buckling stresses are extremely low.	Bearings are designed to withstand an increase in load and vibration comparable to a 10% blade loss in any one stage
Fan Exit Stator 3.4.0	To direct fan discharge air at proper angles.	1. Cracks	X				Stator vanes are forged construction and peened for increased fatigue life.	
		2. Breakage		X			Stator vanes are forged construction, mechanically retained at both ends and peened for increased fatigue life.	

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
HIGH PRESSURE COMPRESSOR 4.1.							
Variable Inlet Guide Vanes 4.1.0	Provides proper air entry for SLTO, start & cruise and to brake r[illegible]ion slows rotor speeds.						
Airfoils 4.1.1	Directs air at selected angle.	1. Breakage	F.O.D. downstream, performance loss	Increased vibration, reduced thrust, borescope inspection.	Decrease in engine performance depending on propagated damage.	Possible I.F.S. and/or U.E.R. for parts replacement.	Reduce rpm or shut down engine as vibration level dictates.
Actuators 4.1.2	Provide power to drive torque tubes.	Hydraulic (fuel) pressure loss (Line Breakage)	Vanes migrate to cruise if failure occurs at SLTO. Pneumatic system provides power to brake.	Small thrust reduction at SLTO with cruise vane position. Possible loss of restart capability if fuel supply is cut off by leakage. Ground inspection.	Performance reduction at SLTO if in cruise position.	Inspect and repair.	None
Actuator Linkage to Torque Tube 4.1.3	Transmits actuator motion to sync. ring.	Structural failure causing disconnect	Redundancy provided; remaining side will operate system except in high Mach No., low altitude transient regions of envelope.	Slow response to controls.	Slow response to controls.	U.E.R. for inspection and part replacement.	Avoid transient regions, request inspection.
Torque Tube Drive Spline 4.1.4	Same as 4.1.3 above.	Same as 4.1.3 above.	Same as 4.1.3 above.	Same as 4.1.3 above.	Same as 4.1.3 above.	Same as 4.1.3 above.	Same as 4.1.3 above
Torque Tube 4.1.5	Drives vanes to proper settings.	Breakage of one tube.	Same as 4.1.3 above.	Same as 4.1.3 above.	Same as 4.1.3 above.	Same as 4.1.3 above.	Same as 4.1.3 above
Link-Torque Tube to IGV Sync. Ring 4.1.6	Translates motion from torque tube to IGV sync. ring.	Breakage of one link.	Same as 4.1.3 above.	Same as 4.1.3 above.	Same as 4.1.3 above.	Same as 4.1.3 above.	Same as 4.1.3 above.
IGV Torque Tube Roller Bearing 4.1.7	Provides a pivot for torque tube rotation.	Seizes	Partial or complete loss of function.	Various parameters may be out of normal limits. Slow rpm response to power lever.	Slow response to controls or no response to controls.	Possible I.F.S. and U.E.R. for inspection and parts replacement.	Shutdown if required. Request inspection.

Sheet #

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification				Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
			I	II	III	IV		
4. HIGH PRESSURE COMPRESSOR 4.0.0								
Variable Inlet Guide Vanes 4.1.0	Provides proper air entry for SLTO, start & cruise and in brake position slows rotor speeds.							
Airfoils 4.1.1	Direct air at selected angle.	1. Breakage		X			Vanes are of forged construction and are peened to increase fatigue resistance. Selection of a mid chord pivot point results in minimum stress in the airfoils and attachments.	Mechanical retention of both ends of airfoil is provided.
Actuators 4.1.2	Provide power to drive torque tubes.	Hydraulic (fuel) pressure loss (Line Breakage)			X		Integral ferrule lines are used to supply actuator.	Failsafe design will migrate vanes to cruise position if hydraulic pressure is lost at SLTO setting. Electrical switch provided to indicate vane position.
Actuator Linkage to Torque Tube 4.1.3	Translates actuator motion to sync. ring.	Structural failure causing disconnect	X				Linkage is sized to maintain loads within material capabilities. Stress levels are consistent with existing commercial engines.	Redundancy is provided. All components in the variable inlet guide vane actuation linkage are sized so that operation is possible with one actuator only or with one linkage system only.
Torque Tube Drive Spline 4.1.4	Same as 4.1.3 above.	Same as 4.1.3 above.	X				Same as 4.1.3	Redundancy is provided as stated in 4.1.3.
Torque Tube 4.1.5	Drives vanes to proper settings.	Breakage of one tube.	X				Same as 4.1.3.	Redundancy is provided as stated in 4.1.3.
Link-Torque Tube to IGV Sync. Ring 4.1.6	Translates motion from torque tube to IGV sync. ring.	Breakage of one link.	X				Same as 4.1.3.	Redundancy is provided as stated in 4.1.3.
IGV Torque Tube Ball Bearing 4.1.7	Provides a pivot for torque tube rotation.	Seizes		X			Ball bearing configuration is used to improve misalignment capabilities. Bearing is shielded to prevent wear caused by contaminates.	

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JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
Balance Weights 4.2.0	To balance rotor.	Loss of rivet.	Possible loss of balance weight which could cause ingestion damage.	Increased vibration, borescope inspection.	Engine vibration and possible performance loss.	Possible I.F.S. and P.E.R. for inspection and parts replacement.	Reduce rpm or shut down engine as vibration level dictates.
Hubs 4.3.0	Rotor support.	1. Crack	None	Inspection at overhaul	None	None, replace at overhaul.	None
		2. Fracture	Rotor will cease to rotate due to rubbing of blades and vanes.	Increased vibration, reduced thrust, reduced rpm, inspection at overhaul.	Loss of rotation. Major secondary damage to compressor and turbine.	I.F.S. and P.E.R. for overhaul.	Shutdown.
Blade 4.4.0	Air compression	1. Foreign Object Damage	Depends on severity of damage, any of above could occur.	Borescope inspection.	Depends on severity, any of above could occur.	Possible I.F.S. or P.E.R. according to severity.	Depends on severity, any of above could occur.
		2. Loose airfoil shrouds (one stage only)	Reduced vibration damping.	Inspection at overhaul.	Noisy rundown	None. Replace at overhaul.	Request inspection.
		3. Abrasion of tip.	Increased tip clearance.	Reduced thrust.	Some loss in performance.	None. Replace at overhaul.	None
		4. Cracks	None	Inspection at overhaul.	None	None, replace at overhaul.	None
		5. Partial airfoil separation	Damage to adjacent parts, increased compressor unbalance.	Borescope inspection.	None	None, replace at overhaul.	None
		6. Complete airfoil separation	Major failures of parts downstream, excessive unbalance.	Decreased rpm, reduced thrust, increased vibration, borescope inspection.	Loss in performance, excessive vibration.	Possible I.F.S. and P.E.R. for overhaul.	Reduce rpm or shut down engine as vibration level dictates.

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JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
Balance Weights 4.2.0	To balance rotor.	Loss of rivet	X				Rivet carries no load during engine operation and two rivets secure each weight.	
Hubs 4.3.0	Rotor support.	1. Crack	X				Holes in hub are polished to increase fatigue life. Stress concentration points are minimized by large radius corners and shot peened surfaces.	
		2. Fracture			X		Material thickness of hub selected for 10% blade loss in any one stage.	Blade and vane engagement will occur and prevent disk rub and large rotor misalignment.
Blade 4.4.0	Air compression.	1. Foreign object damage	X	X			All blades have retention tangs and first high compressor blade row has part span shrouds and tangs for ingestion resistance. Fan stages will tend to centrifuge debris into the duct.	Same as 4.4.0.6
		2. Loose airfoil shrouds (one stage only)		X			Shrouds have optimum notch angle, sufficient bearing area and hardfaced contact surfaces.	
		3. Abrasion of tip		X			Tip clearance sized for worst maneuver loads plus thermals. Honeycomb shrouds greatly reduce blade tip abrasion.	Same as 4.4.0.6
		4. Cracks		X			Airfoils are forged and peened.	Same as 4.4.0.6
		5. Partial airfoil separation			X		Airfoils are designed to be flutter resistant, are of forged construction and are peened to increase fatigue life. Clearance is provided for surge deflections without blade to vane contact.	Same as 4.4.0.6
		6. Complete airfoil separation			X		First blade row has part span vibration damper and increased chord length for ingestion resistance. All blades are forged construction, have large radius at root attachment and are peened. Anti gallant is used on all blade attachments to eliminate stress concentrations from galling. Attachments on first two stages are undercut to reduce this source of stress concentrations.	The blade containment design philosophy for the compressor is similar to that of the fan. The difference is mainly in having more walls, the compressor case walls plus two duct walls, to prevent penetration of the nacelle area. Borescope holes provided for inspection of all compressor blades at phased inspection (cowl open).

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
Bladelock 4.4.1	Retain blades in disk.	Shear	See complete airfoil separation.	See complete airfoil separation.	See complete airfoil separation.	See complete airfoil separation.	See complete airfoil separation.
Blade Tip Shroud 4.4.2	Abradable air sealing surface.	1. Excess wear.	Possible performance loss, efficiency and surge margin, depending upon severity.	Reduced thrust, increased TSFC.	Performance loss, inefficient operation.	None. Replace at overhaul.	Close fuel management, possible retrim of engine for surge margin.
		2. Fatigue cracks.	Sections of shroud could break off but should not cause noticeable damage or decrease in performance.	Inspection at overhaul.	None	None	None
Stator Vane 4.5.0	Direct air from rotor at proper angle for following rotor.	1. Partial separation.	Vane could turn sideways, block airflow and excite rotor, decrease in performance. possible rotor flutter damage.	Reduced thrust, borescope inspection.	Performance loss.	P.E.R. for inspection and parts replacement.	None
		2. Complete separation.	F.O.D. downstream, performance loss.	Increased vibration, reduced thrust, borescope inspection.	Decrease in engine performance depending on propagated damage.	Possible I.F.S and P.E.R. for overhaul.	Reduce rpm or shut down engine as vibration level dictates.
Disk 4.6.0	Supports rotating blades, seals, spacers, counterweights.	1. Cracks	None	Inspection at overhaul.	None	None. Replace at overhaul.	None
		2. Rim lug structural failure.	Extensive damage to surroundings and parts downstream. Excessive rotor unbalance.	Increased vibration, reduced thrust. borescope inspection.	Damage to engine cases.	Possible I.F.S. and P.E.R. for overhaul.	Reduce rpm or shut down engine as vibration level dictates.
		3. Fracture	Severe damage of high compressor stage. Severe unbalance and performance loss. Cases cannot contain this level of energy. Possible failure of hub and bearings.	Decreased rpm. Increased vibration. Loss of thrust, borescope inspection.	Severe vibration and loss of failed parts through case.	I.F.S. and P.E.R. for overhaul. Possible F.O.D. from projectiles.	Shutdown.

Sheet 3

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
Bladelock 4.4.1	Retain blades in disk.	Shear		X			Lock is not of bent construction, load is pure shear, stress levels are extremely low. Redundancy provided in that each blade is retained by two locks either of which can suffice and the first stage has midspan shrouds which help to retain blades.	Rotor is designed to withstand a 10% blade loss in any one stage thus limiting the effects of this failure mode.
Blade Tip Shroud 4.4.2	Wearable air sealing surface.	1. Excess wear		X			Blade tip clearance sized for thermals plus worst maneuver loads. Durability is substantiated by extensive J58 experience.	
		2. Fatigue cracks		X			Honeycomb is brazed to a backing plate to limit cracking.	
Stator Vane 4.5.0	Direct air from rotor at proper angle for following rotor.	1. Partial separation			X		Each vane is mechanically attached at both ends. Both ends are guided cantilever design to reduce deflection. Forged construction is used.	Positive retention of vane ends will reduce FOD to blading.
		2. Complete separation			X		Each vane is mechanically attached at both ends. Both ends are guided cantilever design to reduce deflection. Forged construction is used.	Positive retention of vane ends will reduce FOD to blading.
Disk 4.6.0	Supports rotating blades, seals, spacers, counterweights.	1. Cracks		X			After machining to the final configuration, the disks are vibratory barrel finished. The disk is vibrated in an abrasive slurry to assure smooth, notch-free surfaces in critical areas, such as bolt holes. The edges of the holes are rounded by the slurry and small imperfections are smoothed to prevent stress concentrations.	Borescope and X-Ray inspection will reduce this hazard. Overspeed protection is provided in main fuel control. Rotor planes occupy short axial length which permits maximum allowance for installation of critical aircraft components.
		2. Rim lug structural failure			X		Disk rim configuration accounts for disk and blade vibratory interactions and uses stress levels consistent with existing PWA engines.	The 10% blade loss capability of the design will reduce the effects of this failure mode to some extent.
		3. Fracture				X	The average tangential stress in the compressor is 13% below the yield and 32% below the burst limit. The disks for the high compressor are made of forged PWA 1016 (modified) Waspaloy material. The PWA 1016 disks used on the J58 engine demonstrated very high toughness and resistance to the thermal cycling experienced with supersonic engine transient thermal gradients. After rough shapes are machined they are sonic tested for inclusions and foreign deposits. They are then spin tested in the semifinished configuration at sufficient speed to prove that the disk has the minimum strength required for the material.	Same as 1

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JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
Spacer 4.6.1	Rotor spacing and support.	1. Cracks	None	Inspection at overhaul.	None	None. Replace at overhaul.	None
		2. Fracture	Contact between blades and stationary vanes.	Increased vibration, decreased rpm, reduced thrust. Inspection at overhaul.	Vibration increase.	Possible I.F.S. and P.E.R. for overhaul.	Reduce rpm or shut down engine as vibration level dictates.
Bore Tube 4.6.2	Provides path for cooling air flow.	1. Wear	None	Inspection at overhaul.	None	None. Replace at overhaul.	None
		2. Cracks	None	Same as 1 above.	None	None. Replace at overhaul.	None
		3. Extensive cracking	May cause increase in disk temperature and disk creep.	Increased vibration, noisy rundown.	Increased vibration.	Possible I.F.S. and P.E.R. for inspection and parts replacement.	Reduce rpm or shut down engine as vibration level dictates.
Interstage Air Seal Land and Diaphragm 4.7.0	Prevent interstage air recirculation.	1. Buckle	Excessive wear of knife edge seals and lands, leakage.	Higher TSFC, reduced thrust.	Performance loss.	Possible I.F.S. and P.E.R. for inspection and parts replacement.	Reduce rpm or shut down engine as vibration level dictates. Close fuel management, request inspection.
		2. Structural failure.	Crack propagation within diaphragm with possible section breakoff. Loss of function.	Inspection at overhaul, noisy rundown.	F.O.D. to aft parts.	P.E.R. for inspection and parts replacement.	None
Knife Edge Seals 4.8.0	Prevent interstage air recirculation.	Rub, wear and fracture.	Same as 1 above.	Same as 1 above.	Same as 1 above.	Same as 1 above.	Same as 1 above.
Tiebolts 4.9.0	Maintain axial tightness of rotor.	1. Preload relaxation	Loose rotor stack, possible vibration.	Inspection at overhaul, vibration increase.	None	Repair at overhaul.	None
		2. Cracks	None	Inspection at overhaul.	None	None. Replace at overhaul.	None
		3. Fracture	Possible rotor vibration.	Increased vibration.	Possible slight increase in engine vibration if only one bolt fails. More vibration if a number of bolts fail.	Possible I.F.S. and P.E.R. for inspection and parts replacement.	Reduce rpm or shut down as engine vibration level dictates.

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JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
Spacer 4.5.1	Rotor spacing and support.	1. Cracks		X			Holes are polished and surface peening is used to reduce concentrations and increase life.	Radioisotope inspection provides method of installed detection.
		2. Fracture				X	Barreled design provides large radius design to reduce bending stresses. Knife edge seals are separate from spacers to prevent failure propagation.	Multiple tiebolts will help to retain spacer pieces and reduce or eliminate downstream damage. Blade and vane engagement will limit rotor misalignments and prevent disk contact with stationary parts.
Bore Tube 4.6.2	Provides path for cooling air flow.	1. Wear	X				Both tube and mating surface are hardfaced and polished.	
		2. Cracks	X				Supported at both ends, extremely low stresses. Fully machined forgings with a single butt weld in a low stress area.	Radioisotope inspection provides method of installed inspection.
		3. Extensive cracking		X			Configuration limits crack propagation.	Vibration monitoring will detect this failure. Low ΔP will prevent large change in cooling air temperature.
Interstage Air Seal Land and Diaphragm 4.7.0	Prevent interstage air recirculation	1. Buckle		X			Conical configuration used to resist buckling.	
		2. Structural failure.		X			Configuration and stress levels proven in J58.	
Knife Edge Seals 4.8.0	Prevent interstage air recirculation.	Rub, wear and fracture.		X			Clearance allowed for thermals plus worst maneuver loads. Configuration of seal provides support in the event of cracking.	
Tiebolts 4.9.0	Maintain axial tightness of rotor.	1. Preload relaxation		X			Bolts are preloaded to 90% of the 0.2% yield strength at assembly to ensure preload without relaxation.	
		2. Cracks		X			Bolts are supported at each disk to damp vibration and are fully machined to increase resistance to cracking.	
		3. Fracture	X	X	X		Tiebolts are designed to withstand bending moments created by a 10% blade loss in any one stage while continuing to transmit turbine torque. Hydraulic stretch assembly is used to eliminate torsional stresses.	In the event of multiple bolt failure, blade and vane engagement will limit the effects by braking the rotor and preventing large misalignments. Vibration monitoring will detect this failure.

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
5 PRIMARY COMBUSTOR DIFFUSER 5.0.0							
Compressor Exit Vanes 5.1.0	Straighten airflow to primary combustor.	1. Cracks	Negligible flow angle change.	Inspection at overhaul.	None	Parts replacement or repair.	None
		2. Breakage	Possible F.O.D. to combustor section, reduced combustion efficiency.	Increased vibration, decreased rpm.	Possible F.O.D. to turbine section.	Possible I.F.S. and P.E.R. for parts replacement or repair.	Reduce rpm or shut down engine as vibration level dictates.
Seal Support 5.2.0	Supports last compressor stage knife edge seal face.	Cracks	Misalignment of seal, increased last compressor stage leakage.	Inspection at overhaul.	Slight thrust decay.	Parts replacement or repair.	None
Combustor Support 5.3.0	Axial anchorage for combustor dome section.	Broken strut, anchor pin breakage.	Distortion & overheating of combustor. Possible F.O.D. to combustor section.	Increased EGT, increased vibration, reduced rpm.	Slight thrust decay. Possible F.O.D. to turbine parts from pin.	Probable P.E.R. for parts replacement or repair.	Reduce rpm as exhaust gas temperature or vibration level dictates.

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JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification				Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
			I	II	III	IV		
5 PRIMARY COMBUSTOR DIFFUSER 5.0.0								
Compressor Exit Vanes 5.1.0	Straighten airflow to primary combustor.	1. Cracks	X				Same as 4.9.0	
		2. Breakage			X		Same as 1	Positive retention of vane ends will reduce downstream damage.
Seal Support 5.2.0	Supports last compressor stage knife edge seal face.	Cracks		X			Configuration and stress levels proven in J58.	
Combustor Support 5.3.0	Axial anchorage for combustor dome section	Broken strut anchor pin breakage.			X		Designed to eliminate thermal stresses. Materials selected to reduce wear and resultant looseness and vibration.	Dual point mountings provides redundancy.

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
6 PRIMARY COMBUSTOR 6.0.0							
Outer Case 6.1.0	Pressure wall to contain engine airflow and transfers thrust loads.	1. Cracks	Negligible airflow loss.	Inspection at overhaul.	None	Parts replacement or repair.	None
		2. Rupture	Loss of function of case support and/or pressure containment. Vary from loss of air only to loss of air and fuel with possible fire.	Increased vibration. Fire warning.	Possible engine fire. Probable rotor misalignment.	Possible I.F.S and P.E.R. for parts replacement or repair.	Emergency fuel shutoff. Reduce rpm or shut down engine as vibration level dictates.
		3. Buckling	Distortion of main combustor, reduced combustor efficiency.	Increased vibration, decreased rpm, increased TSFC.	Local overheating, if minor. Slight thrust decay. Loss of rotor alignment if extensive. If massive, contact of blades and vanes and overload of No. 4 bearing.	Possible I.F.S. and probable P.E.R. for parts replacement or repair.	Reduce rpm or shut down engine as vibration level dictates.
Inner Case 6.2.0	Separation wall for engine flow, support inner ends of 1st-stage turbine vanes and No. 3 bearing.	1. Cracks	Negligible airflow loss if minor.	Inspection at overhaul.	None	Parts replacement or repair.	None
		2. Rupture	Loss of turbine vane support and loss of high rotor support.	Increased vibration, decreased rpm.	1st-stage turbine vanes and support ring shifts to contact rotor blades. Thrust decay.	Possible I.F.S. and probable P.E.R. for parts replacement or repair.	Reduce rpm or shut down engine as vibration level dictates.
		3. Buckling	Distortion of main combustor, reduced combustor efficiency. Local overheating. Possible difficult disassembly.	Increased TSFC or inspection at overhaul.	Local overheating, slight thrust decay.	Possible I.F.S. and P.E.R. for parts replacement or repair.	Reduce rpm or shut down engine as vibration level dictates.
Annular Combustor 6.3.0	Mix fuel and air and provide zone for combustion.	1. Cracks	Negligible air distribution pattern change.	Inspection at overhaul.	None	Parts replacement or repair.	None
		2. Breakout of areas, burnout of areas.	Alter air distribution pattern with change in temperature profiles. Hot spots on inner or outer cases.	Increased vibration, reduced rpm, increased TSFC.	F.O.D. to turbine, possible distorted temperature profile which will damage turbine, performance loss, thrust decay.	Possible I.F.S. and probable P.E.R. for parts replacement or repair.	Reduce rpm or shut down engine as vibration level dictates. Adjust thrust, close fuel management.
		3. Buckling	Altered air distribution pattern, reduced performance, altered temperature exit profile plus probable burnout of combustor.	Increased vibration, reduced rpm, changes in temperature indication, increased TSFC.	Same as 2 above.	Possible I.F.S. and P.E.R. for parts replacement or repair.	Reduce rpm or shut down engine as temperature or vibration dictates.

Sheet II

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
6 PRIMARY COMBUSTOR 6.0.0								
Outer Case 6.1.0	Pressure wall to contain engine airflow and transfer thrust loads.	1. Cracks		X			Forward case is one piece forging with no welds. Rear case has only butt welds.	Minimum welds and bosses prevent propagation of cracks.
		2. Rupture			X		Wall thickness sized for buckling with resultant low hoop stress.	Duct heater walls will shield the aircraft structure from the effects of this failure mode.
		3. Buckling		X	X		Air cooled to reduce metal temperatures. 30% buckling margin used.	Any misalignment of rotor resulting from this failure mode will not result in disk contact with stationary parts.
Inner Case 6.2.0	Separation wall for engine flow, support inner ends of 1st-stage turbine vanes and No. 3 bearing.	1. Cracks		X			Same as 1 for 6.1.0	Same as 1 for 6.1.0
		2. Rupture			X		Same as 2 for 6.1.0	Same as 2 for 6.1.0
		3. Buckling		X	X		Same as 3 for 6.1.0	Same as 3 for 6.1.0
Annular Combustor 6.3.0	Mix fuel and air and provide zone for combustion.	1. Cracks	X				Extensive use of butt welding plus modular construction minimizes thermal stresses.	Modular type construction limits crack propagation.
		2. Breakout of areas, burnout of areas.			X		The high velocity flow over the modules and through the ram airscoops provide basic cooling by convection with supplemental cooling supplied to those surfaces directly exposed to the hot gases.	Combustor configuration is designed to retain all remaining pieces to reduce FOD to turbine and to support remaining pieces so as to create minimum airflow distortion. T_{t} monitoring will detect this failure by indicating a distorted temperature profile.
		3. Buckling		X	X		The modular concept used in the annular combustion chamber minimizes the buckling load on the outer combustion chamber wall. Use of the modules effectively breaks the external pressure load on the wall into a number of small inward loads that are sustained by the hoop-loaded outer case. The buckling load imposed on the inner burner case is partially counteracted by the hoop-loading of the inner combustion chamber wall.	Combustor configuration will reduce airflow distortion from buckling. Igniter holes plus six other circumferentially placed holes provided for borescope inspection at phased inspection.

Sheet 1

JT9D FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
Combustor Attachments 6.3.1	Locate and support combustor.	Fretting	None in operation, possible difficult disassembly.	Inspection at overhaul.	None	Parts replacement or repair.	None
Fuel Nozzles 6.3.2	Meter and spray control for fuel.	1. Plugged, partially blocked or stuck.	No fuel is sprayed in the section affected. Reduced combustor performance and alteration of exit temperature profile.	May indicate by temperature instrumentation. Reduced thrust, increased TSFC.	Possible hot streaks which could damage turbine and/or combustor sections.	Possible U.E.R. for parts replacement or repair.	Adjust thrust. Close fuel management.
		2. Leakage at seal.	Same as 1 above.	Same as 1 above.	Same as 1 above.	Same as 1 above.	Same as 1 above.
		3. Failed housing.	Fuel flow is increased in section affected causing local hot spot.	Engine vibration.	Internal fire causing extensive damage.	I.F.S. and U.E.R. for parts replacement or repair.	Emergency fuel shutoff.
Swirler Adapters 6.3.3	Position swirler airflow relative to combustor.	1. Fretting	None in operation, possible difficult disassembly.	Inspection at overhaul	None	Parts replacement or repair.	None
		2. Cracks	Increased stress concentrations and reduction in strength.	Inspection at overhaul	None	Parts replacement or repair.	None

Sheet 8

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
Combustor Attachments 6.1.1	Locate and support combustor.	Fretting	X				Material selected has wear resistance proven in J52.	Large surface area for fretting will allow maximum time to discover effects of fretting before further damage results.
Fuel Nozzles 6.3.2	Meter and spray control for fuel.	1. Plugged, partially blocked or stuck.		X			Fuel passage size is limited to those sizes that commercial engine experience has shown to be acceptable to ensure maximum tolerance to contamination. Fuel nozzle strainers are retained in the nozzle housings during disassembly of the fuel manifold, thereby protecting the fuel nozzles from contamination during handling.	Fuel nozzles removable for inspection. T_7 monitoring will detect this failure by indicating a distorted temperature profile.
		2. Leakage at seal.	X	X	X		"E" type metal seal configuration proven on J-58.	Duct heater will shield the aircraft structure from any fire resulting from this failure mode. Cockpit monitors will detect failure and permit fuel shutoff.
		3. Failed Housing		X	X		One piece construction used, housing does not carry combustor support loads.	Same as above.
Swirler Adapters 6.3.3	Position swirler air-flow relative to combustor.	1. Fretting	X				Adequate clearance is provided between the fuel nozzles and swirlers adapters to prevent fretting.	
		2. Cracks	X				Material selected has demonstrated excellent high temperature characteristics and crack resistance.	

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
7 TURBINE 7.0.0							
1st Blade 7.1.0	Provides means to transfer gas stream energy to 1st-stage turbine disk.	1. Cracks	None	Ground inspection	None	None	None
		2. Airfoil separation	Creates unbalance of high pressure rotor with airfoil contained inside turbine. 1st vanes, 2nd vanes, etc., receive F.O.D.	Increased vibration, decreased rpm.	Decreased power on high and low pressure rotors, thrust decay.	Possible I.F.S. and P.S.R. for parts replacement or repair.	Reduce rpm or shut down engine as vibration level dictates.
2nd Blade 7.2.0	Provides means to transfer gas stream energy to 2nd-stage turbine disk.	1. Cracks	None	Ground inspection	None	None	None
		2. Tip shroud separation from airfoil.	Creates unbalance of low pressure rotor with shrouds contained inside turbine. 1st vanes, 1st blades, 2nd vanes, 3rd vanes, etc., receive F.O.D.	Increased vibration, decreased rpm.	Decreased power on low pressure rotor, thrust decay.	Possible I.F.S. and P.S.R. for parts replacement or repair.	Reduce rpm or shut down engine as vibration level dictates.

Book II

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
7 TURBINE 7.0.0								
1st Blade 7.1.0	Provides means to transfer gas stream energy to 1st-stage turbine disk.	1. Cracks		X			Extended root, tangle weights damper blade to reduce vibratory stress. Tip shrouds are not required, thus reducing centrifugal pull. Impingement and advanced convective cooling air schemes used to lower airfoil temperature stress ratios and to meet required creep and erosion life. Airfoils are coated to protect airfoil material from oxidation, erosion and corrosion. LCF life of blade greatly exceeds 10,000 cycle life because cooling scheme used directs the cooling air in the internal passage to obtain the desired temperature profile. Film cooling slots in the exterior walls are eliminated that could clog or close by foreign object damage and result in stress risers and severe temperature gradients. The airfoils have large leading edge radii and thick trailing edges. PWA 658 (IN-100) cast material selected for its excellent mechanical properties, amount of operating experience available and the accumulated fabrication techniques and process control. Proven J58 technology used throughout.	
		2. Airfoil separation.			X		Same as 1.	Cases are sized to contain blades from up to 10% blade loss. Clearance is provided between hubs and low rotor shafts to prevent contact due to unbalance from up to 10% blade loss. Provisions for borescope inspection at planned inspection.
2nd Blade 7.2.0	Provides means to transfer gas stream energy to 2nd-stage turbine disk.	1. Cracks		X			Tip shrouds reduce vibratory stresses. Conventional convective cooling scheme to maintain airfoil temperature, stress ratios, and meet creep and erosion life. LCF life of blade greatly exceeds 10,000 cycle life by use of convective cooling air scheme which eliminates film cooling slots in exterior walls. Also airfoil leading edge and trailing edge have large radius. The 2nd blade uses the same materials and coatings as the 1st blades.	
		2. Tip shroud separation from airfoil.		X			Large blend radii to transmit loads uniformly into airfoil. Cooling air exits at tip for cooling tip shrouds. Stress ratios consistent with J58 experience.	

Sheet 2

JTF22 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
		3. Airfoil separation.	Same as 1st blade, except unbalance of low pressure rotor.	Same as 1st blade, above.	Same as 1st blade above.	Same as 1st blade, above.	Same as 1st blade, above.
3rd Blade 7.3.0	Provides means to transfer gas stream energy to 3rd-stage turbine disk.	1. Cracks	None	Ground inspection.	None	None	None
		2. Tip shroud separation from airfoil.	Same as 2nd blade above.	Same as 2nd blade, above.	Same as 2nd blade above.	Same as 2nd blade, above.	Same as 2nd blade, above.
		3. Airfoil separation.	Same as 2nd blade above.	Same as 2nd blade, above.	Same as 2nd blade above.	Same as 2nd blade, above.	Same as 2nd blade, above.
2nd and 3rd Blades	Listed above.	Shroud wear.	Loss of pretwist and blade loosening.	Increased vibration.	None	Possible I.F.S. and probable F.I.R. for parts repair.	Reduce rpm or shut down engine as vibration level dictates.
1st Vanes 7.4.0	Directs combustion products into 1st blade.	1. Bowing	Performance loss.	Reduction of high pressure rotor speed.	Decreased power on high pressure rotor, thrust decay.	Decreased speed.	Request ground inspection.
		2. Cracking	None	Ground inspection.	None	None	None
		3. Airfoil burn-through.	Possible downstream damage. Performance loss.	Same as 1, plus increased vibration.	Same as 1.	Possible I.F.S. and F.I.R. for parts replacement & repair.	Reduce rpm or shut down engine as vibration level dictates.
2nd Vanes 7.5.0	Directs combustion products into 2nd blades.	1. Bowing	Performance loss.	Same as 1st vanes.	Same as 1st vanes.	Same as 1st vanes.	Same as 1st vanes.
		2. Cracking	None	Ground inspection.	None	None	None
		3. Airfoil burn-through.	Same as 1st vanes.	Same as 1st vanes.	Same as 1st vanes.	Same as 1st vanes.	Same as 1st vanes.

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
		3. Airfoil separation.	Same as 1st blade, except unbalance of low pressure rotor.	Same as 1st blade, above.	Same as 1st blade above.	Same as 1st blade, above.	Same as 1st blade, above.
3rd Blade 7.3.0	Provides means to transfer gas stream energy to 3rd-stage turbine disk.	1. Cracks	None	Ground inspection.	None	None	None
		2. Tip shroud separation from airfoil.	Same as 2nd blade above.	Same as 2nd blade, above.	Same as 2nd blade above.	Same as 2nd blade, above.	Same as 2nd blade, above.
		3. Airfoil separation.	Same as 2nd blade above.	Same as 2nd blade, above.	Same as 2nd blade above.	Same as 2nd blade, above.	Same as 2nd blade, above.
2nd and 3rd Blades	Listed above.	Shroud wear.	Loss of preload and blade loosening.	Increased vibration.	None	Possible I.F.S. and probable P.N.R. for parts repair.	Reduce rpm or shut down engine as vibration level dictates.
1st Vanes 7.4.0	Directs combustion products into 1st blade.	1. Bowing	Performance loss.	Reduction of high pressure rotor speed.	Decreased power on high pressure rotor, thrust decay.	Decreased speed.	Request ground inspection.
		2. Cracking	None	Ground inspection.	None.	None	None
		3. Airfoil burn-through.	Possible downstream damage. Performance loss.	Same as 1, plus increased vibration.	Same as 1.	Possible I.F.S. and P.N.R. for parts replacement & repair.	Reduce rpm or shut down engine as vibration level dictates.
2nd Vanes 7.5.0	Directs combustion products into 2nd blades.	1. Bowing	Performance loss.	Same as 1st vanes.	Same as 1st vanes.	Same as 1st vanes.	Same as 1st vanes.
		2. Cracking	None	Ground inspection.	None	None	None
		Airfoil burn-through.	Same as 1st vanes.	Same as 1st vanes.	Same as 1st vanes.	Same as 1st vanes.	Same as 1st vanes.

Sheet 5

JT9D FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
		3. Airfoil separation			X		Same as 1.	Cases are sized to contain blades from up to 10[illegible] blade loss. Clearance is provided between high and low rotor shafts to prevent contact due to unbalance from up to 1[illegible] blade loss. Borescope boss provided for inspection.
3rd Blade 7.3.0	Provides means to transfer gas stream energy to 3rd-stage turbine disk.	1. Cracks		X			Same as 7.2.0 except less severe environment does not require cooling air to meet design requirements.	
		2. Tip shroud separation from airfoil.		X			Same as 7.2.0 except less severe environment does not require cooling air to meet design requirements.	Blades are inspectable from rear of engine at overhaul inspection.
		3. Airfoil separation			X		Same as 1.	Cases are sized to contain blades from up to 1[illegible] blade loss. Clearance is provided between high and low rotor shafts to prevent contact due to unbalance from up to 1[illegible] blade loss.
2nd and 3rd Blades	Listed above	Shroud wear					Notch angle is optimized to reduce wear. Hardfaced in the notch to further reduce wear.	Inspection for total shroud clearance can be made on the blades.
1st Vanes 7.4.0	Directs combustion products into 1st blades.	1. Bowing	X				Same as 3.	Same as 3.
		2. Cracking		X			Same as 3. In addition, cracking is inhibited by large leading and trailing edge radii.	Same as 3.
		3. Airfoil burn-through			X		TD Nickel material used has high melting point (2650°F) which provides a substantial safety margin for vane burnout in the event of overtemperature operation. High thermal conductivity of TD Nickel keeps thermal gradients to a minimum and improves thermal fatigue and reduces maximum hot spot temperatures. Impingement advanced convective cooling air schemes reduces metal temperature and increases erosion life. Vanes are coated with PWA 63 to protect the material from oxidation, erosion and corrosion.	Use of pattern [illegible] prevents migration [illegible] material which vane is retained by adjacent vanes. [illegible] or films are used in cooling system, [illegible] loss of cooling air. Traces of burning [illegible] using borescope in front end of primary [illegible].
2nd Vanes 7.5.0	Directs combustion products into 2nd blades.	1. Bowing	X				Same as 3.	Same as 3.
		2. Cracking		X			Same as 3.	Same as 1.
		3. Airfoil burn-through			X		Conventional cooling schemes and cast material PWA 503 (IN-100). Vanes are coated with PWA 64 to protect materials from oxidation, erosion and corrosion.	Same as 7.4.0 except [illegible] and [illegible] sections so that vane will [illegible] tails.

Sheet 1

JT9D FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
3rd Vanes 7.6.0	Directs combustion products into 3rd blades.	1. Bowing	Performance loss.	Reduction of low pressure rotor speed.	Decreased power on low pressure rotor, thrust decay.	Decreased speed.	Request ground inspection.
		2. Cracking	None	Ground inspection	None	None	None
		3. Airfoil burn-through	Possible downstream damage. Performance loss.	Same as 1, plus increased vibration.	Same as 1.	Possible I.F.S. and U.E.R. for parts replacement & repair.	Reduce rpm or shut down engine as vibration level dictates.
1st, 2nd, & 3rd Disks 7.7.0 7.8.0 7.9.0	Transfer blade energy to compressor drive shafts.	1. Rim lug structural failure	Severe damage to blades & vanes.	Increased vibration, decreased rpm.	Sudden loss of power on high and low pressure rotors, thrust drop.	I.F.S. and U.E.R. for parts replacement or repair. Possible F.O.D. to airframe.	Emergency shutdown of engine.
		2. Fracture	Severe damage results to the turbine. Projectiles will penetrate cases.	Increased vibration, decreased rpm.	Sudden loss of power on high and low pressure rotors, thrust drop.	I.F.S. and U.E.R. for parts replacement or repair. Possible F.O.D. to airframe.	Emergency shutdown of engine.
1st & 2nd Disk Coverplates 7.7.1 7.8.1	Direct turbine blade cooling air, provide seal lands, and mount blade dampers.	Rim lug structural failure.	Loss of blade damping and loss of cooling air to portion of blading. F.O.D. to adjacent parts, increased rotor unbalance. Projectiles may penetrate cases.	Increased vibration, decreased rpm.	Performance loss, F.O.D. to all parts downstream of turbine.	Possible I.F.S. and U.E.R. for parts replacement or repair. Possible F.O.D. to airframe.	Reduce rpm or shut down engine as vibration level dictates.
3rd Disk Tiebolts 7.9.1	Secure disk to hub and shaft. Secure seals to disks.	1. Structural failure of one bolt.	Slight F.O.D.	Inspection at overhaul	None	Parts replacement at overhaul.	None
		2. Structural failure of multiple bolts.	Misalignment of turbine disk F.O.D. to turbine section.	Increased vibration, decreased rpm.	F.O.D. to all parts.	Possible I.F.S. and U.E.R. for parts replacement or repair.	Reduce rpm or shut down engine as vibration level dictates.

Sheet 2

HPT FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
3rd Vane 7.A.0	Directs combustion products into 3rd blades.	1. Bowing	X				Same as 2nd vanes.	Same as 2nd vanes
		2. Cracking		X			Same as 2nd vanes.	Same as 2nd vanes.
		3. Airfoil burn-through			X		Same as 2nd vanes.	Same as 2nd vanes.
1st, 2nd, 3rd disks 7.7.0 7.8.0 7.9.0	Transfer blade energy to compressor drive shafts.	1. Rim lug structural failure.			X	X	First and second stage rim lugs are air cooled to reduce metal temperatures. Blade and disk vibratory stress interactions have been proven predictable by rig testing. Stress ratios used are consistent with those in use in current PWA commercial engines. PWA (Astroloy) forging material selected for excellent mechanical properties, amount of operating experience and accumulated experience in fabrication techniques and proven controls.	Cases are sized to contain blades up to a 10% blade loss. This will reduce the effect of a rim lug failure to some extent. Damage will be evident from vibration monitoring
		2. Fracture				X	A burst margin of 30% over maximum deteriorated operating speed is used. Disks are cooled by compressor discharge air to maintain low and uniform metal temperatures for long low cycle fatigue life. First and second disks do not have bolt holes in high stress areas. Third (coolest disk) has conventional bolt pattern location based on existing engine experience.	Failure can be detected by installed radioscope inspection.
1st & 2nd Disk Cover-plates 7.7.1 7.8.1	Direct turbine blade cooling air, provide seal lands, and mount blade dampers.	Fracture			X		Plates are supported by disks.	Cases and rotor are sized to withstand loads equivalent to a 10% blade loss in one stage.
3rd Disk Tiebolts 7.9.1	Secure disk to hub and shaft. Secure seals to disks.	1. Structural failure of one bolt.	X				Bolt manufacturing processes are specially controlled to provide uniform high quality and bolts are sized to withstand 10% blade loss in any one stage.	
		2. Structural failure of multiple bolts.			X		Number of bolts used is sufficient to lower load per bolt to proven stress levels.	Blade and vane engagement will occur and prevent disk rub and limit rotor misalignment.

Sheet 6

JT9D FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
Hubs 7.10.0	Transmit rotor loads to bearings.	Fracture	Severe damage results to the turbine.	Increased vibration, decreased rpm.	Sudden loss of power on high and low pressure rotors, thrust drop.	I.F.S. and P.R.R. for parts replacement or repair.	Emergency shutdown of engine.
Shafts 7.11.0	Transfer energy from turbine disks to compressors.	Separation	Moves axially aft till rotor blades create heavy rub condition on stationary vanes. (Prevents overspeeding of rotor.) Severe damage results to the turbine.	Increased vibration, decreased rpm.	Sudden loss of power on high and low pressure rotors. Compressor rotor moves axially forward with blades creating heavy rub conditions on stationary vanes, thrust drop.	I.F.S. and P.R.R. for parts replacement or repair.	Emergency shutdown of engine.
Coupling Nut 7.12.0	Secures the turbine shaft to the compressor shaft preventing any relative axial movement.	Separation	Same as Shafts above.	Increased vibration, decreased rpm.	Same as Shafts above.	I.F.S. and P.R.R. for parts replacement or repair.	Emergency shutdown of engine.
OD Seals 7.13.0	Restrict airflow from one compartment to another.	1. Excessive rub on stationary land.	Possible changes of blade cooling airflow or thrust balance bearing loads. Could cause F.O.D. to airfoils.	Increased vibration.	Not immediately noticeable and only F.O.D. will occur. Possible bearing overload may cause eventual bearing failure.	Possible I.F.S. and P.R.R. for parts replacement or repair.	Reduce rpm or shut down engine as vibration level dictates.
		2. Wear	Reduction of function.	Reduced thrust, increased TSFC.	Performance loss.	Force replacement at overhaul.	Adjust thrust, close fuel management.
Case 7.14.0	Forms gas path, transfers thrust loads, provides vane OD supports.	1. Cracks	Negligible airflow loss.	Inspection at overhaul.	None	Parts replacement or repair.	None
		2. Rupture or section blowout.	Reduction in gas stream energy due to secondary flowpath.	Thrust decrease, increased TSFC.	Drop in power output of high and low pressure rotors because of gas pressure loss.	Probable P.R.R. for parts replacement or repair.	Adjust thrust, close fuel management.
		3. Buckling	Distortion of turbine gas profile, reduced turbine efficiency. Possible F.O.D. to blades.	Increased vibration.	Local overheating, possible difficult disassembly.	Possible I.F.S. and probable P.R.R. for parts replacement or repair.	Reduce rpm or shut down engine as vibration level dictates.

Sheet 8

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
Hubs 7.10.0	Transfer rotor load to bearings.	Fracture			X		High rotor hub is an integral arm on 1st-stage disk to provide better alignment due to a reduction in the number of joints, better vibration characteristics and avoid bolts and bolt holes in high stress regions. Second stage disk hub is attached to the low pressure rotor by an integral arm near coupling. Third stage hub is an integral part of the low rotor shaft. All hubs are sized to withstand 10% blade loss in any one stage.	Blade and vane engagement will occur and prevent disk rub and limit rotor misalignment.
Shafts 7.11.0	Transfer energy from turbine disks to compressor.	Separation			X		Thrust bearing is not mounted directly on the shaft to reduce heating or scoring in the event of bearing failure. Number four roller bearing is not on the torque carrying portion of the shaft. Shaft is sized to avoid critical speed resonance problems and clearance is provided to avoid contact between high and low rotor shafts due to the unbalance from up to 10% blade loss.	In the event of axial rotor movement, due to shaft separation, blades and vanes will engage before disk damage can occur.
Coupling Nut 7.12.0	Secures the turbine shaft to the compressor shaft preventing any relative axial movement.	Separation			X		Coupling nuts are retained by tabwashers and thread engagement lengths are consistent with those used in existing commercial engines.	In the event of axial movement, blade and vane engagement will occur and brake the rotor without disk contact.
#4 Seals 7.13.0	Restrict airflow from one compartment to another.	1. Excessive rub on stationary land.		X			Serrated surface of land provides an abradable surface to dissipate heat and reduce damage.	
		2. Wear	X				Reduced by abradable feature of seal.	
Case 7.14.0	Forms gas path, transfers thrust loads, provides vane OD supports.	1. Cracks	X				One piece forging eliminates weld cracking.	
		2. Rupture or section blowout		X			Wall thickness set by either machining limitations or by blade containment requirements. Walls are air cooled to reduce metal temperature.	
		3. Buckling		X			Thirty percent buckling margin, air cooled by fan discharge air to reduce metal temperature.	

Sheet 2

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detec.	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
8 TURBINE EXHAUST 8.0.0							
Outer Case 8.1.0	Forms gas path, transfers thrust and No. 4 bearing load.	Burnthrough	Reduction in gas stream energy due to secondary flowpath.	Ground inspection.	None	None. Parts replacement or repairs.	None
Inner Case 8.2.0	Forms gas path, and transfers No. 4 bearing load.	Fracture	Loss of low pressure rotor rear bearing support.	Increased vibration, decreased rpm, thrust drop.	Sudden loss of power on high and low pressure rotors. Severe damage results to the turbine.	Possible I.F.S. or F.S.D.	Reduce rpm or shut down engine as vibration level dictates.
Exit Strut 8.3.0	Contains turbine gas path and transfers No. 4 bearing load.	Cracks	No effect on load carrying capability, redundancy provided.	Ground inspection.	None	None. Parts replacement or repair.	None
Rear Cover Fairing 8.4.0	Primary gas generator convergent-divergent nozzle.	Cracks	None, unless cracking is extensive, causing gas leakage.	Slight low to high rotor speed ratio increase and TSFC increase.	Performance loss.	None. Parts replacement or repair.	None, except for close fuel management.
T_{t7} Probes 8.5.0	Measure turbine exit temperature.	Breakage	One less probe for averaging exit temperature.	Ground inspection.	None	Ground inspection will require parts replacement or repair.	None

Sheet [illegible]

JTF17 FAILURE MODE & EFFECT ANALYSIS

Part	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
6 TURBINE EXHAUST 6.0.0								
Outer Case 6.1.0	Forms gas path, transfers thrust and No. 4 bearing load.	Burn-through		X			Cooled by fan discharge air.	
Inner Case 6.2.0	Forms gas path, and transfers No. 4 bearing load.	Fracture			X		Stress rating established with J58 experience. Cooling air provided to reduce metal temperature.	Blade and vane engagement will occur and brake the low rotor without disk rubbing or large shaft misalignment.
Exit Struts 6.3.0	Removes turbine gas swirl and transfers No. 4 bearing load.	Breaks		X			Vane material thickness is sized to 10% blade loss requirement.	Redundancy of struts is provided to carry structural loads. Visual inspection from rear of engine at [illegible]
Rear Outer Fairing 6.4.0	Primary gas generator convergent-divergent nozzle.	Buckling	X				Material thickness is sized for a 50% buckling margin. Cooling air provided to reduce metal temperatures.	
T.T Probes 6.5.0	Measure turbine exit temperature.	Breakage	X				Probes are bolted to pads on the inside of the outer exhaust case and supported at the inner case by a ball to reduce stress.	

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
9 [illegible] DIFFUSER 9.0.0							
Outer Case 9.1.0	Provides load path for engine mounting, forms airflow path for duct diffuser, and provides access ports to inner casing panels.	Cracking	Possible combustor hot spots. Burnthrough of combustor or cooling liners.	Increased vibration, decreased rpm.	Increased engine deflection and nonuniform loads imposed on engine mounts causing possible mount distortion and internal rubbing of blades and vanes. Reduced augmentation.	Possible I.F.S. and U.E.R. for inspection and parts replacement.	Reduce rpm or shut down engine as vibration level dictates.
Inner Case 9.2.0	Forms inner airflow path for duct diffuser	Cracking	Distortion of inner liner. Reduction of cooling flow to inner liner. Possible combustor hot spots. Diffuser efficiency reduced.	Decreased rpm, increased TSFC.	Small loss of efficiency, reduced augmentation.	Possible U.E.R. for parts replacement or repair.	Reduce thrust requirement.
Struts 9.3.0	Supports inner case.	Cracking	Possible combustor damage. Diffuser efficiency reduced slightly.	Decreased rpm.	Reduced augmentation.	Possible U.E.R. for parts replacement or repair.	Reduce thrust requirement.
Inner Access Panel 9.4.0	Forms inner airflow path for duct diffuser and provides access to inner cavity.	Separation	F.O.D. to duct burner, hot spots probable, loss of efficiency.	Increased vibration, decreased rpm, increased TSFC.	F.O.D. to aft parts, reduced augmentation.	Possible I.F.S. and U.E.R. for inspection and parts replacement.	Reduce thrust requirement. Reduce rpm or shut down engine as vibration level dictates.

Sect V

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
5 DUCT DIFFUSER 9.0.0								
Outer Case 9.1.0	Provides load path for engine mounting, forms airflow path for duct diffuser, and provides access ports to inner access panels.	Buckling		X			Case wall material thickness is sized to provide more than 30% buckling margin.	
Inner Case 9.2.0	Forms inner airflow path for duct diffuser.	Buckling		X			Case wall material thickness is sized to provide more than 30% buckling margin.	
Struts 9.3.0	Supports inner case.	Buckling		X			Strut wall thickness is manufacturing limited, resulting in at least 30% buckling margin.	
Inner Access Panel 9.4.0	Forms inner airflow path for duct diffuser and provides access to inner cavity.	Separation			X		Diffuser wall has very slight diffusion angle and can tolerate some panel separation.	Multiple fasteners used will prevent complete separation of panel.

Sheet 3

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
10 DUCT BURNER 10.0.0							
Inlet Support Case 10.1.0	Provides load path for engine mounting. Forms airflow path for fan duct and provides support for duct heater.	Buckling	Misalignment of duct heater combustor. Possible loss of heater efficiency.	Increased vibration, decreased rpm, increase of TSFC.	Increased engine deflection and increased loads beyond on front mount causing possible thrust distortion and internal rubbing of blades and vanes. Reduced augmentation.	Possible A.P., I.F.S., and U.E.R. for parts replacement or repair.	Reduce rpm or shut down engine as vibration level dictates.
Combustor 10.2.0	Provides means of mixing fan duct gases with fuel and burning efficiently.	Burnthrough	Reduced duct heater efficiency.	Increased TSFC, reduced thrust.	Reduced augmentation. F.O.D. to aft parts.	Possible A.P. and U.E.R. for parts replacement or repair.	Reduce thrust requirement.
Combustor Support Pin 10.2.1	Locates and supports duct combustor axially.	1. Wear	No effect - Remaining pins carry load.	Inspection at overhaul.	None	None. Ground inspection will require pin replacement	None
		2. Shear	Same as 1.	Same as 1.	Same as 1.	Same as 1.	Same as 1.
Fuel Nozzles 10.2.2	Provides spray pattern for duct combustor.	Clogged or inoperative.	No fuel is sprayed in the section affected. Reduced duct heater efficiency.	Inspection at overhaul, increased TSFC, reduced thrust.	None	Possible A.P. Ground inspection will require parts replacement or repair.	Adjust thrust. Close fuel management.
Manifold 10.2.3	Provides means of supplying fuel to injector nozzles and provides support for injector.	Rupture	Allows fuel to escape in duct and not be supplied to injectors. Reduced Zone II duct heater efficiency and possible burnthrough damage to duct liners and vanes.	Temperature probe reading abnormal. Increase of TSFC.	Reduced augmentation.	A.P. and U.E.R. for parts replacement or repair.	Cut off Zone II fuel supply by reducing thrust level required.
Liners 10.3.0	Provides isolation of structural cases from heat.	Burnthrough	Downstream liner overheating due to loss of cooling air, possible burnout. Duct heater efficiency reduced.	Decreased thrust, increased TSFC.	Reduced augmentation.	Possible A.P. and U.E.R. for parts replacement or repair.	Adjust thrust. Close fuel management.
Turbulator 10.4.0	Directs heater bypass air and Zone II fuel into heater stream to improve combustion.	Breakage	F.O.D. to duct heater, hot spots probable. Duct heater efficiency reduced.	Increased vibration, decreased thrust, increased TSFC.	Reduced augmentation.	Possible A.P. Ground inspection will require parts replacement or repair.	Adjust thrust. Close fuel management.

Sect B

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
10 DUCT HEATER 10.0.0								
Outer Support Case 10.1.0	Provides load path for engine mounting, forms station mount for the fans and provides support for duct heater.	Buckling		X			Case thickness is sized to provide a 20% buckling margin. Fan discharge air is provided to reduce metal temperatures.	
Combustor 10.2.0	Provides means of mixing fan duct gases with fuel and burning efficiently.	Burnthrough		X			Fan discharge air is used for cooling to reduce metal temperatures. Modular construction is utilized. Modules are supported from the inner and outer duct cases which minimizes the structural and thermal problems.	
Combustor Support Pin 10.2.1	Locates and supports duct combustor dome axially.	1. Wear	X				Hardcoated pins and replaceable hardened bushings are used to improve wear characteristics.	
		2. Shear	X				Shear load on combustor is distributed among eight low stressed pins.	
Fuel Nozzles 10.3.2	Provides spray pattern for duct combustor.	Clogged or inoperative.		X			Fuel passage size is limited to those sizes that commercial engine experience has shown to be acceptable to ensure minimum susceptibility to contamination and sticking of the variable area nozzle valve. Fuel nozzle strainers are retained in the nozzle housings during disassembly of the fuel manifold, thereby protecting the fuel nozzles from contamination during handling.	Fuel nozzles are readily removed for inspection or replacement with engine cowl open.
Manifold 10.3.3	Provides means of supplying fuel to injector nozzles and provides support for injectors.	Rupture			X		Tube wall thickness is sized to withstand proof test at twice operating pressures and forged ring sections are used to eliminate welding of the fuel injector heads and improve fabrication techniques.	Cold fan air over walls of duct heater will not support combustion of large fuel leakage thus precluding case burnthrough as a result of this failure mode.
Liners 10.3.4	Provides isolation of structural cases from heat.	Burnthrough		X			Fan discharge air provided for cooling to reduce liner metal temperatures. Modular construction is utilized for outer liner. Modules supported from duct outer case to minimize structural & thermal problems. Inner liner is designed with 20% buckling margin.	Very minimal loss in performance. No structural function. Liners are inspectable from rear of engine at transit inspection.
Turbulator 10.4.0	Directs heater bypass air and Zone II fuel into heater stream to improve combustion.	Breakage	X				Material selected has good high temperature life. Stresses are extremely low.	

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
11 VARIABLE NOZZLE 11.0.0							
Nozzle Flap 11.1.0	Used to vary nozzle area.	Burnout	Nose-duct heater control will correct area.	Ground inspection	Hot streak aft may burnout additional parts.	P.S.R. for parts replacement.	None
Flap Seal 11.2.1	Provides air seal between nozzle flaps.	Burnout	Same as 11.1.0 above.	Same as 11.1.0 above.	Same as 11.1.0 above.	Same as 11.1.0 above.	Same as 11.1.0 above.
Flap Roller and Track 11.1.2	Provides means for translating flap and rotating flap about flap hinge.	Roller binding	Skidding roller will cause excessive wear on track.	Ground inspection.	None	P.S.R. for parts replacement.	None
Nozzle Sync. Ring 11.2.0	Synchronizes actuators and flaps.	Rupture	Reduced duct heater efficiency. Possible flap burnout due to loss of cooling film over flaps.	Thrust decay, increased TSFC.	Reduced thrust from duct heater.	Possible A.P. and P.S.R. for parts replacement.	Adjust thrust. Close fuel management.
Sync. Ring Roller and Track 11.2.1	Provides means for translating and guiding.	Roller binding	Skidding roller will cause excessive wear on track.	Reduced duct heater response rate.	Reduced duct heater response rate.	P.S.R. for parts replacement.	None. Ground inspection.
Sync. Ring Air Seal 11.2.3	Used to seal static pressure between fan duct and sync. ring.	Excessive wear of seal segment.	Reduced cooling film over nozzle flaps. Possible flap burnout.	Thrust decay.	Reduced thrust from duct heater.	P.S.R. for parts replacement.	None. Ground inspection.
Nozzle Actuator 11.3.0	Used to actuate nozzle flaps.	1. Rod end failure	None - Sync. ring maintains operation with 3 actuators operating.	Ground inspection	None	Parts replacement at overhaul.	None
		2. Rod binding in seals	Possible reduced nozzle response rate.	Reduced duct heater response rate.	Reduced duct heater response rate.	Inspect and repair.	None. Ground inspection.
		3. Loss of hydraulic pressure.	Nozzle flaps will go to the open position.	Fan rpm rise, thrust decay.	Increase in fan rpm and possible overspeed condition. At cruise altitude, duct heater blowout is possible, but improbable.	A.P. and ground inspection and repair of hydraulic system.	Operate with full augmentation or shut down duct heater.

Sheet 6

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
11 VARIABLE NOZZLE 11.0.0								
Nozzle Flap 11.1.0	Used to vary nozzle area.	Burnout	X				Configuration closely follows that proven in afterburners operating at higher temperature. Fan discharge air (1250° less than typical afterburner cooling air temperature) is provided for cooling to reduce metal temperatures.	Highest temperatures do not occur at full augmented conditions, but at a lower level of augmentation where the nozzle is less than full open and the exhaust stream impingement angles are greater.
Flap Seal 11.1.1	Provides air seal between nozzle flaps.	Burnout	X				Same as 11.1.0	
Flap Roller and Track 11.1.2	Provides means for translating flap and rotating flap about flap hinge.	Roller Binding	X				Configuration is the same as that proven in the J58 afterburner and is operating in a cooler environment.	
Nozzle Sync. Ring 11.2.0	Synchronizes actuators and flaps.	Rupture		X			Structure is patterned after that proven in the J58. Stress margins are consistent with those proven in the J58 afterburner.	
Sync. Ring Roller and Track 11.2.1	Provides means for translating and guiding.	Roller Binding		X			Configuration used is the same as that proven in the J58 with consistent stress margins.	
Sync. Ring Air Seal 11.2.2	Used to seal nozzle pressure between fan duct and sync. ring.	Excessive wear of seal segments.		X			Configuration used is the same as that proven in the J58 with consistent stress margins.	
Nozzle Actuator 11.3.0	Used to actuate nozzle flaps.	1. Rod end failure.		X			Configuration and materials proven on J58.	
		2. Rod binding in seals.		X			Heated rod design proven on J58. Mounting used eliminates side loads.	
		3. Loss of hydraulic pressure. (Line breakage)			X		External ferrule lines are used to supply actuator. Tubing design is based on proven J58 technology.	A positive aerodynamic opening force on the [illegible] nozzle ensures the opening in the event of loss of hydraulic power. This provides the largest available engine thrust over most of the operating envelope.

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
Support Cone 11.4.0	Provides support and guide for nozzle flaps and sync. ring.	Deflection	None - Duct heater control will reset nozzle area.	Ground inspection.	None	U.E.R. for parts replacement.	None
Nozzle Feedback Control Rod 11.5.0	Nozzle position feedback to nozzle control valve.	Linkage Failure	Nozzle shifts to the open position	Fan rpm rise, thrust decay.	Increase in fan rpm to possible overspeed. At extreme altitude duct heater blowout is possible, but improbable.	A.T. and parts replacement. possible U.E.R.	Operate with full augmentation or shutdown duct heater.

[illegible]

SAFETY FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification				Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
			I	II	III	IV		
Support Cone 11.4.0	Provides support and guide for nozzle flaps and sync. ring.	Deflection	X				A one-piece shell weldment is used with stress ratios consistent with J58 experience.	
Nozzle Feed-back Control Rod 11.3.0	Nozzle position feed-back to nozzle control valve.	Linkage Failure		X			Configuration proven on J58.	

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
12 REAR MOUNT 12.0.0							
Ring 12.1.0	Provides rear support for engine	Deflection	Excessive engine deflection and excessive loads imposed on front mount.	Vibration increase. Ground inspection.	Engine distortion.	Possible I.F.S. and U.E.R. for inspection and parts replacement.	Reduce rpm or shut down engine as vibration level dictates.
Case 12.2.0	Provide airflow path for duct heater and load path for engine mounting.	Buckling	Excessive engine deflection and excessive loads imposed on front mount.	Vibration increase. Ground inspection.	Engine distortion.	Possible I.F.S. and U.E.R. for inspection and parts replacement.	Reduce rpm or shut down engine as vibration level dictates.

Chart II

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
13 REAR MOUNT 13.0.0	Provide airframe attachment points for the engine.							
Ring 13.1.0	Provide rear support for the engine.	1. Yielding	X				Combined stresses from engine, maneuver, and gust loads were limited to 0.2% of the yield strength or 67% of the ultimate strength, whichever is lower. In cold state, the maximum stress will be equal to or less than 50% of the 0.2% yield strength. This criteria, based on our commercial engine experience, assures no permanent set at limit load conditions and no failures at ultimate load conditions. Ground handling attachment points are provided to prevent overloading during maintenance.	
		2. Cracks	X				The engine mount ring cross section is trapezoidal in shape. This configuration allows for thermal expansion while providing maximum structural strength. The trapezoidal design was chosen because the conventional "V" cross section ring structure used on the JT3D and JT4 was unsatisfactory in the J58 application, while the selected shape performed satisfactorily. These failures were attributed to the larger cyclic temperature gradient imposed on the straight sides of the ring during each engine environmental operating cycle. This larger gradient is due to the higher Mach number operation of the J58 as compared to previous engines.	
Case 13.2.0	Provide airflow path for duct heater and load path for engine mounting loads.	Buckling	X	X	X		Wall thickness is sized for a 1.3 stress margin for pressure and moment buckling and a 1.3 stress margin for creep buckling.	Cool fan discharge air flowing along inside of case will prevent burnthrough of buckled areas.

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
13 LUBRICATION & BREATHER SYSTEMS 13.0.0							
Oil Pumps:							
Supply Pump 13.1.0	Supply pressure oil for lubrication and cooling.	1. Housing or journal wear or galling.	Reduced performance.	Reduced oil pressure at idle.	Contaminate oil system.	Possible I.F.S. and parts replacement.	Shutdown if oil pressure is below minimum.
Scavenge Pumps 13.2.0	Scavenge oil from compartments and gearboxes.	2. Seizure a. Main Pump	Loss of function. Loss of engine lubrication.	Loss of oil pressure.	Loss of bearings unless shut down immediately.	I.F.S. and P.R.R. for inspection and parts replacement.	Emergency shutdown.
		b. Scavenge Pump	Loss of function. Loss of engine lubrication.	Increased oil temperature and consumption.	Flooding of compartments & breathing of oil through breather system. Probable loss of oil through seals. Overtemperature and overload of bearings and gears possible due to operating submerged.	I.F.S. and possible P.R.R. for inspection and parts replacement.	Shutdown.
Internal Lines 13.3.0	Transfer oil to and from compartments.	1. Leakage	Loss of engine lubrication.	Increased oil consumption. Reduction of oil pressure.	If into high temperature area may result in fire.	Possible I.F.S. and P.R.R. for inspection.	Shutdown if oil level in tank is low or oil pressure is below limits.
		2. Fracture	Loss of function. Uncontrolled flow of oil.	Reduction of oil pressure. Increased oil consumption.	Reduction of oil pressure, compartment starvation. Uncontrolled oil flow possibly into high temperature areas with resultant fire.	I.F.S. and P.R.R. for parts replacement.	Shutdown.

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JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification				Design Philosophy to Preclude Failure	Safety Philosophy to Reduce Hazard
			I	II	III	IV		
13 LUBRICATION AND BREATHER SYSTEM 13.0.0								
Oil Pumps								
Supply Pump 13.1.0	Supply pressure oil for lubrication and cooling.	1. Bearing or journal wear or galling.		X			Replaceable journal bearing inserts are used.	
Scavenge Pumps 13.2.0		2. Seizure a. Main Pump			X		Clearances sized from experience on existing P&WA engines. Aluminum housings used to permit foreign object ingestion. Chip detectors provided to indicate pump failures.	Oil level and pressure monitoring would allow engine shutdown prior to complete loss of oil to main bearings.
		b. Scavenge Pump			X		Clearances sized from experience on existing P&WA engines. Aluminum housings used to permit foreign object ingestion. Chip detectors provided to indicate pump failures.	Oil level and pressure monitoring would allow engine shutdown prior to complete loss of oil to main bearings. The No. 1, 2, and 3 bearing compartment scavenge pumps are located outside the engine and are readily available for inspection and replacement.
External Lines 13.3.0	Transfer oil to and from compartments.	1. Leakage	X	X			Two types of connectors are used in the JTF17 engine. These are integral ferrule AN type threaded joints using a standard one-tube coupling arrangement, and bolted flange joints using metallic face seals. These joints have been developed to a very high level of reliability and low incidence of leakage on the J58 engine.	
		2. Fracture			X		The designs of the lines, fittings and associated hardware used in the JTF17 engine fuel, oil, hydraulic and air systems are based directly on J58 experience. The lines are designed with support brackets located to keep tube resonant frequencies well above any engine frequencies.	This failure mode will not result in cabin air contamination. Reduction of oil to bearings is compensated for by inner race flow and improved materials used. Main shaft hydrostatic seals do not require oil cooling during engine operation.

Rev 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
Strainers & Filters 15.6.0	Remove foreign particles from oil.	1. Rupture	Supply unfiltered oil.	Same as 2b.	Unfiltered oil may result in jet plugging and excessive bearing and seal wear. Filter fragments may plug jet screens.	Possible I.F.S. and P.E.R. for inspection and parts replacement.	Same as 2b.
		2. Plugging a. Main Filter	Divert oil flow to bypass filter.	Cockpit warning indicator goes on and red warning button on filter pops up.	None	None	Inspection and cleaning of filter required.
		b. Bypass Filter	Supply unfiltered oil.	High ΔP across filter system.	Unfiltered oil may result in jet plugging and excessive bearing and seal wear.	Possible P.E.R. for inspection and parts replacement.	Same as above.
		c. Jet Screens	Loss of lubrication if complete plugging occurs.	Possible increase in vibration and/or breather pressure. Increased oil temperature.	Overtemperature and wear of bearings and seals. If prolonged and excessive, may result in failure.	Possible I.F.S. and P.E.R. for inspection and parts replacement.	Reduce thrust or shut down if vibration becomes excessive.
Seals (Static) 15.5.0	Prevent oil leakage.	Leakage	Loss of engine lubricant.	High oil consumption.	If into high temperature area may result in fire.	Possible P.E.R. for inspection and parts replacement.	Inspection required.
Oil Pressure Regulating Valve 15.8.0	Maintain constant oil pressure in the oil supply system.	1. Instability	Fluctuating oil pressure (Greater than ± 5 psi)	Low oil pressure.	Low oil pressure periods: 1. Insufficient oil flow. 2. Increased oil temperature.	I.F.S.	Shutdown.
				High oil pressure.	High oil pressure periods: 1. Pump journal wear. 2. Increased oil flow to bearing compartment.	I.F.S.	Shutdown.
		2. Damper Orifice Screen Failure	None unless screen debris enters valve causing sticking or instability - see item 1.	Same as item 3.	Same as item 1.	Same as item 1.	Shutdown.
		3. Sticking a. Closed Position	Loss of function.	High oil pressure.	High oil pressure: 1. Pump journal failure. 2. Pump housing failure. 3. Tubing leaks and failure. 4. Increased oil flow to bearing compartment.	I.F.S.	Shutdown.
		b. Open Position	Loss of function.	Abnormal oil pressure.	1. Loss of oil pressure. 2. Insufficient oil flow. 3. Increased oil temperature.	I.F.S.	Shutdown.

Sheet 6

JTF22 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Safety Philosophy To Reduce Hazard
Strainers and Filters 13.4.5	Remove foreign particles from oil.	1. Rupture		X			Stress levels are extremely low.	
		2. Plugging a. Main Filter		X			Wire cloth configuration used should be superior to existing filters. Redundancy provided by bypass filter.	Filter replaceable at planned inspection (engine installed, cowl open).
		b. Bypass Filter		X			Porous metal configuration with bypass valve provided.	Provision incorporated for in flight monitoring of filter pressure drop. Pop out button incorporated to show ground crew of plugged filter. Provision for installing only detector plugs incorporated.
		c. Jet Screens	X	X	X		Screens are in series with filters, externally removable for inspection.	Each jet screen serves a separate group of oil jets. Plugging of one screen will reduce oil flow to one group of jets only.
Seals (Static) 13.5.5	Prevent oil leakage.	Leakage		X			Configuration proven on J58.	
Oil Pressure Regulating Valve 13.4.6	Maintain constant oil pressure in the oil supply system.	1. Instability		X			Configuration patterned after proven J58 valve.	
		2. Damper Orifice Screen Failure		X			Stress levels are extremely low and screen is protected from external plugging.	
		3. Sticking a. Closed Position		X			Materials, coatings and clearances proven in J58.	
		b. Open Position			X		Materials, coatings and clearances proven in J58.	Engine parts will not fail with a positive oil pressure. Deterioration of oil from increased temperature should not occur on an SST mission of 2.3 hours. Cockpit monitors will detect this failure and prevent additional damage.

Sheet 1

JTF22 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
Oil Tank 13.7.0	Provide container for engine oil supply.	1. Cracks	Loss of engine lubricant.	Excessive oil consumption.	Oil starving of engine.	Possible I.F.S.D.	Inspection required.
		2. Rupture	Loss of function.	Low oil pressure. Excessive oil consumption.	Loss of lube system. Possible bearing seizure and seizing of engine rotor.	I.F.S.D. and F.E.R. for overhaul.	Shutdown.
Oil Tank Mounting 13.7.1	Position and support oil tank.	Breakage	Loss of oil tank support.	Oil loss due to leaking connections or possible tank rupture.	Same as oil tank depending on severity.	I.F.S.	Shutdown.
Deoiler 13.8.0	To retain engine oil by separating entrained oil from breather system air before overboard discharge of air.	1. Cracks	None	Inspection at overhaul.	None	None	None
		2. Centrifugal Breakup (Extremely Remote Probability)	Loss of function; High gearbox vibration; Contamination of gearbox and oil system. Damage to G/B bearings, seals, gears from contaminants.	Increased gearbox vibration and high oil consumption.	Oil loss through breather system. Possible damage to other components in oil system from contaminants.	I.F.S.D. and F.E.R.	Shutdown.

Sheet [illegible]

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification				Design Philosophy to Preclude Failure	Design Philosophy to Reduce Hazard
			I	II	III	IV		
Oil Tank 13.7.0	Provide container for engine oil supply.	1. Cracks	X	X	X		All corners and contours of the tank have large radii to reduce stress concentrations and to avoid local thinning during fabrication.	Cockpit monitors will detect low oil pressure prior to excessive bearing damage. Engine configuration eliminates possibility of oil leaking onto hot turbine or primary combustor cases. Duct heater case is cooled and reduces fire hazard.
		2. Rupture			X		The formed sheet metal skin is reinforced by internal tubular supports to resist buckling and rupture. Tanks are tested at pressures in excess of those experienced at maximum operating conditions to determine structural integrity.	Cockpit monitors will detect low oil pressure prior to extensive bearing damage. Engine configuration eliminates possibility of oil leaking onto hot turbine or primary combustor cases. Duct heater case is cooled and reduces fire hazard.
Oil Tank Mounting 13.7.1	Position and support oil tank.	Breakage		X			The tank is supported by two brackets and two metal straps. The straps, which are attached to the brackets, are pulled tightly over wear strips around the outside of the tank. These strips serve as wear pads in the locations of the brackets and provide protection from chafing by the metal straps.	Tank will be temporarily supported by plumbing for duration of mission.
Deoiler 13.8.0	To retain engine oil by separating entrained oil from breather system air before overboard discharge of air.	1. Cracks	X				One piece cast construction with extremely low stresses.	
		2. Centrifugal Breakup [illegible]		X			One piece cast construction with extremely low stresses.	

Sheet 6

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
Breather Pressurizing Valve 13.8.5	To maintain pressure in breather system, prevent oil pump cavitation and high ΔP across bearing compartment seals.	1. Bellows Rupture	Slightly higher than normal breather pressure to open parallel safety valve.	Slight increase in breather pressure.	None	None	Inspection required.
		2. Bellows Spring Break	Valve will remain open at all times.	Reduced oil and breather pressure.	None at low altitude (below 35,000 ft). Low breather pressure at higher altitude could cause oil pressure and scavenge pump cavitation and oil starvation or flooding of bearing compartments.	None at low altitude. Reduced oil and breather pressure at high altitude.	Reduce altitude or shutdown.
		3. Safety Valve Breaks or Spring Retainer Pin Shears	Safety valve will open and bypass flow around bellows valve.	Same as 2 above.	Same as 2 above.	Same as 2 above.	Same as 2 above.
		4. Frozen Valve a. Closed	Same as 1 above.	Same as 1 above.	Same as 1 above.	Same as 1 above.	Same as 1 above.
		b. Open	Same as 2 above.	Same as 2 above.	Same as 2 above.	Same as 2 above.	Same as 2 above.
Main Oil Cooler 13.10.0 or Duct Oil Cooler 13.11.0	Remove heat from engine oil.	Core Blockage	Decreased heat transfer from oil due to pressure bypass valve opening.	High ΔP across cooler.	Possible oil temperature increase if main cooler core plugs.	Possible return of increased temperature fuel to airframe if duct cooler core plugs.	Inspect and repair.
Main Cooler Pressure Bypass Valve 13.10.1 or Duct Cooler Pressure Bypass Valve 13.11.1	Bypass oil in the event of cooler core blockage.	1.a Valve sticks closed.	Oil pump working against higher head.	High ΔP across cooler.	Possible oil pump deterioration.	None	Inspect and repair.
		1.b Valve sticks open.	Partial loss of duct or main cooler capability.	Continuous monitoring of ΔP across cooler.	Possible oil temperature increase if main cooler valve sticks open.	Possible return of increased temperature fuel to airframe if duct cooler valve sticks open.	Inspect and repair.

Sheet 8

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
Breather Pressurizing Valve 13.9.0	To maintain pressure in breather system, prevent oil pump cavitation and high ΔP across bearing compartment seals.	1. Bellows Rupture	X				Bellows fabrication techniques and material have been proven in the J58 and JT9 engines. A bellows failure will cause the primary valve to close preventing low breather pressure and cause the secondary relief valve to open preventing high breather pressures.	
		2. Bellows Spring Break	X				The use of high strength, high temperature material and low stress levels coupled with proven design practices precludes the probability of spring breakage.	
		3. Safety Valve Breaks or Spring Retainer Pin Shears			X		Valve utilizes high strength, high temperature material with low stress levels.	Cockpit monitors will detect low oil pressure or quantity before extensive bearing damage occurs.
		4. Frozen Valve a. Closed	X				The simple poppet valve design has been substantiated by successful JT9 experience.	
		b. Open			X		The simple poppet valve design has been substantiated by successful JT9 experience.	Cockpit monitors will detect low oil pressure or quantity before extensive bearing damage occurs.
Main Oil Cooler 13.10.0 or Duct Oil Cooler 13.11.0	Remove heat from engine oil.	Core Blockage		X			Valve configuration and materials used are based on existing commercial engine and J58 designs.	Pressure bypass valves bypass plugged cooler.
Pressure Bypass Valve 13.10.1 or 13.11.1	Bypass oil in the event of cooler core blockage.	1.a Valve sticks closed.		X			Valve configuration and materials used are based on existing commercial engine and J58 designs.	Cockpit monitors will detect this failure mode by measurement of high ΔP across cooler.
		1.b Valve sticks open.		X			Valve configuration and materials used are based on existing commercial engine and J58 designs.	Cockpit monitors will detect this failure mode.

Part I

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
14 REVERSER-SUPPRESSOR 14.0.0							
Mount Ring 14.1.0	Part of the heater nozzle support case and provides support points for holding R/S to engine.	Deflection.	Tertiary door binding or jamming due to deformation of R/S.	Reduced performance. Ground inspection. Also see Section 14.3.6.	Reduced performance. See Section 14.3.0.	Ground inspection may require parts replacement.	Adjust thrust, close fuel management. Request inspection. Also see Section 14.3.0
Main Structure 14.2.0	Listed below.						
Structural Members 14.2.1	Structural framework for transmitting loads and holding shape of R/S.	Loose or sheared rivet, failed weld or fractured parent metal.	Overstress of adjacent parts and progressive failures until operation of clamshell or tertiary air doors is impaired by bag or deformation.	Impaired operation, ground inspection.	None until operation of moving parts is impaired.	Removal of reverser-suppressor for repair.	If R/S operation is impaired, reduce thrust and do not use reverser.
Inner Skin 14.2.2	Form smooth air flow path and shield structure from hot gases.	Tear loose or crack.	Disrupt air stream causing reduced performance, weaken structure, expose structure to high temperature gases.	Reduced cruise thrust, ground inspection.	None if cracked, reduced performance if loose or burned through.	Removal of reverser-suppressor for repair.	Adjust thrust. Close fuel management. Request inspection.
Outer Skin 14.2.3	Form smooth air flow path and structural rigidity.	Tear loose or crack.	Disrupt air stream causing reduced performance and weaken structure.	Reduced cruise thrust.	None if cracked, reduced performance if loose.	Possible removal of reverser-suppressor for repair.	Adjust thrust. Close fuel management. Request inspection.
Mount Lugs 14.2.4	Provides attach points for holding R/S struts to engine.	Bolt fracture or failure of lug.	None, more than 2 adjacent lugs must fail to propagate effect.	Ground inspection for excessive gap at mount face.	None	Parts replacement at overhaul or remove reverser-suppressor for repair.	None
Tertiary Air Door 14.3.0	1. Prevent loss of exhaust gases during supersonic operation.	Jammed open.	Gas leakage. Clamshells will be locked out of supersonic position.	Reduced thrust at supersonic condition, ground inspection.	Reduced supersonic performance.	Inspect and repair.	Adjust thrust. Close fuel management. Request inspection.
	2. Admit tertiary air during subsonic operation.	Jammed closed.	Reduced subsonic performance and overstress of parts from excessive OD to ID ΔP.	Thrust reduction, ground inspection.	Reduced subsonic performance.	Inspect and repair.	Adjust thrust. Request inspection.
	3. Permit exit of exhaust gases during reverse.	Jammed closed.	Clamshells will be locked out of reverse position.	Loss of reverse capability, ground inspection.	Loss of reverse thrust.	Inspect and repair.	Adjust for lack of reverse thrust. Request inspection.

Chart B

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
14 REVERSER-SUPPRESSOR 14.0.0								
Mount Ring 14.1.0	Part of duct heater nozzle support case and provides support points for bolting R/S to engine.	Deflection.		X			Configuration used is designed to limit deflection by taking radial loads in webs and axial loads in struts from case.	Multiple truss arrangement re-distributes loads in event of excessive deflection or local failure.
Main Structure 14.2.0	Listed below.							
Structural Members 14.2.1	Structural framework for transmitting loads and holding shape of R/S.	Loose or sheared rivets, failed weld or fractured parent metal.		X			Sufficient rivets used to divide loads so as to give rivet stress levels consistent with existing design practices. Minimum welding used is done on a subassembly basis to maintain high quality. Stress levels in parent metal are consistent with current design practices.	Redundancy in number of rivets used.
Inner Skin 14.2.2	Form smooth air flow path and shield structure from hot gases.	Tear loose or crack.		X			Cooling air provided to reduce metal temperatures. Material selected for high temperature properties and oxidation resistance. Redundancy in rivets holding skin to rings.	Load is transferred to main structure. Area accessible for visual inspection at transit inspection.
Outer Skin 14.2.3	Form smooth air flow path and structural rigidity.	Tear loose or crack.		X			Cooling air provided reduces heating of outer skin. Faired in direction of air flow to limit shearing. Stress margins are consistent with current design practice for titanium aircraft structures.	Structure is reinforced in high stress areas to accommodate loss of stressed skin in critical locations.
Mount Lugs 14.2.4	Provides attach points for bolting R/S struts to engine.	Bolt fracture or failure of lug.	X				Number of lugs used is sufficient to limit lug stresses to within material capabilities. Bolt length selected to permit thermal compensation and prevent loosening.	Loads can redistribute such that half the lugs with no more than two adjacent failed can carry normal loads.
Tertiary Air Door 14.3.0	1. Prevent loss of exhaust gases during supersonic operation.	Jammed open.	X				Simple pin hinge configuration used is isolated from case deflections to prevent binding.	Loss of performance only.
	2. Admit tertiary air during subsonic operation.	Jammed closed.		X			Simple pin hinge configuration used is isolated from case deflections to prevent binding.	Skin may buckle but structure will not fail under resultant ΔP.
	3. Permit exit of exhaust gases during reverse.	Jammed closed.			X		Simple pin hinge configuration used is isolated from case deflections to prevent binding.	Interlock will not permit reverse operation.

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
Door-Panels (Honeycomb) 14.3.1	Structural support and flow path contour.	Separation of skin from core or fracture of attach points.	None, unless extreme in which case air flow could be disrupted with minor loss in performance.	Ground inspection.	None	Inspect and repair door panel.	None
Door-Seals 14.3.2	Prevent exhaust gas leakage during supersonic operation.	Leakage	Gas leakage.	Reduced supersonic thrust, ground inspection.	Slight loss in performance.	Inspect and repair.	Adjust thrust. Close fuel management. Request inspection.
Door-Hinges 14.3.3	Support and permit movement of doors.	Loose pin, broken pin, broken hinge support.	Door may cock, bind or jam impeding operation of all tertiary air doors and/or disturbing air flow.	Reduced thrust.	Slight loss in performance.	Inspect and repair.	Adjust thrust. Close fuel management. Request inspection.
Door-Linkage 14.3.4	1. Actuate clamshell in forward flight.	Broken link, rod, arm or binding.	None if failed parts do not jam. System provides redundancy.	Ground inspection.	None	Premature replacement of part required.	None
	2. Actuate tertiary air doors in reverse.	Broken link, rod, arm or binding.	None if failed parts do not jam. System provides redundancy.	Ground inspection	None	Premature replacement of part required.	None
	3. Synchronize movement of T/A doors.	Broken link, rod, arm or binding.	None if failed parts do not jam. System provides redundancy.	Ground inspection.	None	Premature replacement of part required.	None
Clamshell 14.4.0	1. Provides convergent throat during subsonic operation.	Fails to go into position.	Reduces subsonic performance, may hold tertiary air doors partially closed.	Reduced subsonic thrust.	Reduced subsonic performance.	Inspect and repair.	Adjust thrust. Request inspection.
	2. Provides divergent throat during supersonic operation.	Fails to go into position.	Reduced supersonic performance, may hold tertiary air doors partly open.	Reduced supersonic thrust.	Reduced supersonic performance.	Inspect and repair.	Adjust thrust, close fuel management. Request inspection.
	3. Serve as exhaust gas blockage doors during reverse.	Fails to go into position.	Prevent application of reverse thrust and will not lock tertiary air doors open.	Loss of reverse capability.	No reverse thrust available.	Inspect and repair.	Adjust descent and landing procedure based on reverser not operating.
Structure 14.4.1	Structural support to carry gas loads, actuation forces and clamshell synchronizing loads.	Deflection, sheared rivets, cracked ribs.	May damage moving parts, distort air flow path, or damage downstream parts if a piece tears out.	Reduced thrust if severe, ground inspection.	None, unless damage is severe enough to reduce performance.	Premature replacement of clamshell required.	Adjust thrust, close fuel management. Request inspection.

Sheet 8

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
Door-Panels (Honeycomb) 14.3.1	Structural support and flow path contour.	Separation of skin from core or fracture at attach points.	X				Resistance welded honeycomb is used, rather than conventional brazed panels, because of superior fatigue properties and adaptability to thermals.	Loss of performance only.
Door-Seals 14.3.2	Prevent exhaust gas leakage during supersonic operation.	Leakage	X				The door seals are designed so that operating pressure tends to force the seal harder against the mating surface.	Slight loss in performance only.
Door-Hinges 14.3.3	Support and permit movement of doors.	Loose pin, broken pin, broken hinge support.	X				All door hardware, such as hinges and brackets, is made of forged titanium and is mechanically attached to the doors. The spherical joint at each pivot provides a hinge that is self-aligning and not subject to binding due to structural deflections or normal manufacturing tolerances.	Loss of performance only.
Door-Linkage 14.3.4	1. Actuate clamshell to forward flight.	Broken link, rod, arm or binding.	X				Adequate stress and buckling margins used.	Redundancy provided by multiple linkage.
	2. Actuate tertiary air doors in reverse.	Broken link, rod, arm or binding.	X				Adequate stress and buckling margins used.	Redundancy provided by multiple linkage.
	3. Synchronize movement of T/A doors.	Broken link, rod, arm or binding.	X				Adequate stress and buckling margins used.	Redundancy provided by multiple linkage.
Clamshell 14.4.0	1. Provides convergent throat during subsonic operation.	Fails to go into position.		X			Clamshells are interconnected and positioned by aerodynamic forces.	Interlock will prevent application of forward power if clamshells stuck in reverse. Performance loss only if stuck in supersonic position.
	2. Provides divergent throat during supersonic operation.	Fails to go into position.		X			Clamshells are interconnected and positioned by aerodynamic forces.	Interlock will prevent application of forward power if clamshells stuck in reverse. Performance loss only if stuck in subsonic position.
	3. Serve as exhaust gas blockage doors during reverse.	Fails to go into position.			X		Two redundant hydraulic actuators are provided to position the clamshells in reverse.	Interlock will prevent application of reverse power.
Structure 14.4.1	Structural support to carry gas loads, actuation forces and clamshell synchronizing loads.	Deflection, sheared rivets, cracked ribs.		X			Configuration used minimizes stress concentration, stress margins consistent with current aircraft structure practice.	Loads will redistribute through intact skin and rivets to other ribs.

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
Skin 14.4.2	Airflow contour and structural support.	Tearing loose from ribs, buckling, or cracking.	May cause secondary damage by overstressing adjacent parts, excessive deformation or disturbed air flow.	Ground inspection or performance reduction if severe.	None unless damage is severe enough to affect performance.	Inspect and repair. May require clamshell removal.	Adjust thrust, clean fuel management. Request inspection.
Pivot Supports & Bearings 14.4.3	Support clamshell and permit rotation to three positions.	Structural failure or binding.	Possible shift in position or loss of clamshell rotation capability.	Impaired reverser operation, ground inspection or reduced thrust.	Possible reduced performance in any or all modes.	Premature part replacement.	Adjust thrust as required.
Actuation Linkage 14.4.4	Position clamshell and synchronize movement with tertiary air doors.	1. Broken Links, arms or pins.	None, system provides redundancy.	Ground inspection.	None	Premature replacement of part required.	None
		2. Jammed	Same as 14.4.3.	Same as 14.4.3.	Same as 14.4.3.	Same as 14.4.3.	Same as 14.4.3.
Actuators 14.4.5	Move clamshells to reverse position.	1. Loss of hydraulic pressure (Line Breakage)					
		a. Reverse Selected	Clamshell and tertiary air doors will remain in subsonic position. Interlock will prevent application of reverse power setting.	Loss of reverse capability.	Loss of reverse thrust only.	Inspect and repair.	Adjust descent and landing plan. Request inspection.
		b. Failure While in Reverse Operation	Clamshell and tertiary air doors will return to subsonic position and return engine to idle.	Same as 1.a.	Same as 1.a.	Same as 1.a.	Same as 1.a.
		2. Seizure	Clamshells will be locked and possibly tertiary doors also.	Limited operation of reverser.	Related position may prevent forward or reverse thrust through control interlock system.	Same as 1.a.	Same as 1.a.

Sheet 8

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification				Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
			I	II	III	IV		
Skin 14.6.2	Airflow contour and structural support.	Tearing loose from ribs, buckling, or cracking.		X			Material selected for high temperature properties. Sufficient number of rivets used to reduce skin load at each fastener to acceptable levels.	Sufficient rigidity exists with only inner or outer skin intact.
Pivot Supports and Bearings 14.6.3	Support clamshell and permit rotation to either position.	Structural failure or binding.		X			Bearings proven in JT8D operation, bearing supports are one piece forgings, stress levels consistent with existing engines.	Compact design requires secondary failure to be in compression mode.
Actuation Linkage 14.6.4	Position clamshell and synchronize movement with tertiary air doors.	1. Broken links, arms or pins.	X				Tension design pull rod, sized to limit stress margins to acceptable levels. Configuration uses proven J58 afterburner designs.	Redundant linkage system.
		2. Jammed		X	X		Configuration uses proven J58 afterburner designs.	Interlock system will prevent application of power in wrong mode so performance only is affected.
Actuators 14.6.5	Move clamshells to reverse position.	1. Loss of hydraulic pressure. (Line Breakage)			X		Integral ferrule plumbing proven on J58 is used.	Interlock will prevent application of reverse power setting.
		a. Reverse Selected			X		Integral ferrule plumbing proven on J58 is used.	Clamshell moves to forward flight position and throttle moves to idle.
		b. Failure While in Reverse Operation			X		Integral ferrule plumbing proven on J58 is used.	Clamshell moves to forward flight position and throttle moves to idle.
		2. Seizure			X		Two hydraulic actuators, based on the proven J58 design are used to rotate the clamshells to the reverse position. During all other flight modes the actuators are not pressurized and are supplied with only low-pressure fuel cooling flow. One actuator is located within each of the two clamshell tertiary door interlock modules. This location protects the actuators from high temperatures and foreign matter that would tend to shorten the life of the piston rod seals. The actuators are exposed to engine secondary air with a maximum temperature of 700°F.	Interlock system prevents application of power in mode not selected.

Sheet [illegible]

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
Fuel Control, Interlock System 14.4.6	Prevent non-intended operation of reverser.	1. Broken link, arm, pin or cable.	Loss of synchronized operation and fail safe thrust advance feature.	Loss of interlock function, ground inspection.	Loss of interlock function.	Possible I.F.S., inspect and repair.	Adjust thrust or shut down engine as indicated by reverser position. Request inspection.
		2. Jammed.	Clamshell actuation forces will shear pin in interlock system.	Loss of interlock function, ground inspection.	Loss of interlock function.	Possible I.F.S., inspect and repair.	Same as 1 above.
Seals 14.4.7	Prevent secondary air leakage past OD of clamshell during supersonic operation.	Breakage or bending.	Gas leakage.	Slight loss in cruise thrust, ground inspection.	Slight loss in cruise performance.	Inspect and repair.	Adjust thrust. Close fuel management.
Exit Flap 14.5.2	1. Provide convergent exit-nozzle during subsonic operation.	Will not move into closed position.	Will cause overexpansion of exhaust gases.	Reduced subsonic thrust.	Reduced subsonic performance.	Inspect and repair.	Adjust thrust. Request inspection.
	2. Provide divergent exit-nozzle during cruise.	Will not move into open position.	Will restrict full and efficient expansion of exhaust gases.	Reduced cruise thrust.	Reduced cruise performance.	Inspect and repair.	Adjust thrust. Close fuel management. Request inspection.
	3. Provide variable expansion nozzle between the above two positions.	Will not move to pressure balanced position.	Will not provide proper expansion ratio for exhaust gases.	Reduced transonic and supersonic thrust.	Reduced transonic and supersonic performance.	Inspect and repair.	Adjust thrust. Close fuel management. Request inspection.
Structure 14.5.1	Supporting framework for attaching skin sheets, hinges and position stops.	Sheared or loose rivet, fractured weld or braze.	None until damage progresses to point of improper shape or position.	Ground inspection.	None unless damage becomes severe enough to affect performance.	Inspect and repair.	Adjust thrust. Close fuel management. Request inspection.
Inner Skin 14.5.3	Provide smooth inner flow surface and shield structure from exhaust gas temperatures.	Become loose, crack, tear off or burnout.	None unless skin peels back, causes structure to buckle or rips off completely.	Reduced thrust, ground inspection.	None unless damage becomes severe enough to affect performance.	Inspect and repair.	Adjust thrust. Close fuel management. Request inspection.

Sheet 8

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Effect
Fuel Control, Interlock System 16.6.6	Prevent non-intended operation of reverser.	1. Broken link, arm, pin or cable.		X			Configuration and stress margins proven in J58.	Cockpit monitoring will detect this problem and alert pilot to corrective action.
		2. Jammed		X			The interlock assembly is shielded from dirt and foreign matter, and easy to service or replace.	Will prevent selecting mode other than the one in use if this mode is unusable, engine may be shut down with power lever.
Seals 16.6.7	Prevent secondary air leakage past OD of clamshell during supersonic operation.	Breakage or bending.		X			Configuration used is a simple cantilever leaf spring with minimum stress concentrations. Seal maximum deflection is limited by adjustment of clamshell.	Slight performance loss only.
Exit Flap 16.3.0	1. Provide convergent exit-nozzle during subsonic operation	Will not move into closed position.		X			The sixteen exit flaps are free floating and aerodynamically actuated. Interconnection links between flaps ensure that each flap receives actuation forces from adjacent flaps plus the gas loading.	Loss in subsonic performance only. Flaps easily checked for freedom of movement from rear of engine at transit inspection.
	2. Provide divergent exit-nozzle during cruise.	Will not move into open position.		X			The sixteen exit flaps are free floating and aerodynamically actuated. Interconnection links between flaps ensure that each flap receives actuation forces from adjacent flaps plus the gas loading.	Loss of supersonic performance only.
	3. Provide variable expansion ratio between the above two positions.	Will not move to pressure balance position.		X			The sixteen exit flaps are free floating and aerodynamically actuated. Interconnection links between flaps ensure that each flap receives actuation forces from adjacent flaps plus the gas loading.	Loss of performance only.
Structure 16.3.1	Supporting framework for attaching skin sheets, hinges and position stops.	Sheared or loose rivet, fractured weld or braze.		X			Current aircraft structural practice was used to limit stresses to within material capabilities. Welds are stress relieved and insulation between inner skin and ribs reduces rib temperature.	Loads will redistribute through skin to intact members.
Inner Skin 16.3.2	Provide smooth inner flow surface and shield structure from exhaust gas temperature.	Buckle, loose, crack, tear off or burnout.		X			Structural loads not carried by inner skin, corrugated to resist panel type vibration, coated to resist oxidation, secured by multiple rivets. Wear is reduced by coatings at wear points.	Loads will redistribute through skin to intact members. Area accessible for visual inspection at transit inspection.

Sheet [illegible]

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
Outer Skin 14.5.2	Provide smooth outer flap surface and add to structural rigidity.	Burnt, loose, crack or peel.	Reduce overall strength of flap or disturb air flow.	Reduced thrust, ground inspection.	Reduced performance.	Inspect and repair.	Same as 14.5.1 above.
Hinge 14.5.4	Support exit flap and permit movement to limits of stops.	Broken or frozen.	May hamper movement of exit flaps and cause slight loss in performance.	Reduced thrust, ground inspection.	Possible reduced performance.	Inspect and repair.	Same as 14.5.1 above.
Position Limit Stops 14.5.5	Limit travel and help synchronize movement.	Broken or jammed.	Flaps may go beyond or not reach correct operating position, could cause overstress of adjacent parts.	Reduced thrust, ground inspection.	Reduced performance.	Inspect and repair.	Same as 14.5.1 above.
Seals 14.5.6	Bridge gap between flaps and synchronize flap movement. Prevent leakage.	Tear loose or bind.	Excessive gas leakage or binding of flap movement.	Reduced thrust, ground inspection.	Reduced performance, particularly at cruise.	Inspect and repair.	Adjust thrust. Close fuel management. Request inspection.

Sheet 8

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
Outer Skin 14.3.3	Provide smooth outer flow surface and add to structural rigidity.	Become loose, crack or peel.		X			Stress concentration points are reduced by seam welding which provides continuous attachment to ribs. Peeling is avoided by a fairing strip at the leading edge to provide a smooth contour. Flaps do not feel exit shock effects.	Loads will redistribute through skin to intact members. Area accessible for visual inspection at transit inspection
Hinge 14.3.4	Support exit flap and permit movement to limits of stops.	Broken or frozen.		X			Simple pin joint with double clevis to avoid bending loads.	Sync. system and seals will keep flap in proper position.
Position Limit Stops 14.3.5	Limit travel and help synchronize movement.	Broken or jammed.		X			Oversized stops used to absorb possible impact loads during transitions. TF 30 experience used in design.	Redundant system to each flap.
Seals 14.3.6	Bridge gap between flaps and synchronize flap movement. Prevent leakage.	Tear loose or bind.		X			Multiple fasteners used to secure skin to channel. Binding limited by use of hard surface coatings on contact areas.	Loss of performance only.

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
15 NO. 1 and NO. 2 BEAR- 16 ING COMPART- MENT 15.0.0 16.0.0	To provide support and thrust restraint for main engine rotors. (Forward end)						
Bearing 15.1.0 16.1.0	Support and position forward end of rotor, resist axial rotor thrust.	1. Cage wear	None	Inspection at overhaul.	Possible contamination of oil system.	None	None
		2. Race or ball wear	Loss of function over a long period of time.	Increasing vibration.	Increased vibration to point of ultimate failure. Extensive damage from rub.	Possible I.F.S. and U.E.R. for overhaul.	Reduce rpm or shut down engine as vibration level dictates.
		3. Cage separation	Loss of function.	Vibration increase, rpm decrease.	Loss of bearing. Effect same as Bearing Support.	Possible I.F.S. and U.E.R. for inspection and parts replacement.	Reduce rpm or emergency shut down as vibration dictates.
		4. Seizure	Loss of function, possible rotor seizure.	rpm decrease, vibration increase.	Same as Bearing Support, plus possible shaft seizure or low turbine blades rubbing into cases.	I.F.S. and U.E.R. for overhaul.	Emergency shutdown.
Bearing Support 15.1.1 16.1.1	Position and retain thrust bearing.	Circumferential crack and separation	Loss of function.	Vibration increase, rpm decrease.	Axial and radial shift of rotor(s). Excessive rubbing of blades and stators, bearing failure.	Possible I.F.S. and U.E.R. for inspection and parts replacement.	Reduce rpm or shut down engine as vibration level dictates.
Bearing Flange 15.1.2 16.1.2	Position and retain bearing outer race.	Fracture	Loss of function.	Vibration increase, rpm decrease.	Axial and radial shift of rotor(s). Excessive rubbing of blades and stators, bearing failure.	Possible I.F.S. and U.E.R. for inspection and parts replacement.	Reduce rpm or shut down engine as vibration level dictates.

Sheet 8

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
15 and 16 NO. 1 and NO. 2 BEARING COMPARTMENT 15.0.0 16.0.0	To provide support and thrust restraint for main engine rotors. (Forward end)							
Bearing 15.1.0 16.1.0	Support and position forward end of rotor, resist axial rotor thrust.	1. Cage wear	X				All bearing cages for the JTF17 are of the fully machined type and are inner land riding. This design has proven superior in oil starvation tests in both engine and bearing rig tests. Centrifugal dirt entrapment also tends to cause higher wear in outer land riding designs. Cages are balanced separately prior to assembly into the bearing because this technique has been shown to provide long wear life in other engines.	
		2. Race or ball wear	X				In addition to the minimum life requirement and loading to prevent skidding the bearings are designed to be capable of taking an applied load equivalent to 10% blade loss of any stage. They will also take the ultimate maneuver loads imposed on the engine.	Provisions have been made to incorporate magnetic chip detectors in bearing compartment sumps.
		3. Cage separation			X		Same as 2.	Rotors are designed to withstand a bearing failure producing loads up to those from a 10% blade loss in any one stage.
		4. Seizure			X		Under race oil cooling is used to cool all engine bearings.	Thrust carrying bearings (1 and 2) are mounted such that seizure cannot cause shaft separation. Number 4 bearing is located on a non-torque carrying shaft. Number 3 bearing seizure and heat generation sufficient to separate the high rotor shaft will permit the blade and vane engagement features to prevent disk overspeed. The magnitude of heat generation in bearings 3 and 4 is greatly reduced by the fact that no axial thrust load is carried.
Bearing Support 15.1.1 16.1.1	Position and retain thrust bearing.	Circumferential crack and separation			X		One piece forged construction, fully machined.	Same as 15.1.0-2
Bearing Flange 15.1.2 16.1.2	Position and retain bearing outer race.	Fracture			X		Large blend radius used to feed load from bearing to flange.	Same as 15.1.0-2

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
Hydro-Static Seals 15.2.0 16.2.0	Retain oil in compartment, reduce air leakage into lube system at junction of static and rotating parts.	1. Wear	None	Inspection at overhaul.	None	None	None
		2. Complete wear out	Loss of function.	Increased oil temperature and rate of consumption.	Increased oil consumption, increased breather pressure and flow, increased oil temperature.	Possible I.F.S.D. and F.R.R. for inspection and parts replacement.	Reduce rpm or shut down engine as oil temperature and consumption dictate.
Lab Seals 15.3.0 16.3.0	Provide low pressure and temperature air around hydrostatic seals by metering high temperature-pressure outside air, and insure that any oil leakage past compartment seals is vented overboard.	1. Rub	None	Inspection at overhaul.	None	None	None
		2. Excessive clearance.	Loss of pressure differential across seals.	Inspection at overhaul.	None unless hydrostatic seals have failure.	Parts replacement or repair required at overhaul.	None
Plumbing 15.4.0 16.4.0	Provide oil to bearings, pressurize and vent hydrostatic seals.	1. Breakage a. Air Lines	Loss or reduction of function. Wear on Hydrostatic seals.	Inspection at overhaul.	None (unless compartment hydrostatic seals also failed.)	Parts replacement at overhaul.	None
		b. Oil Line	Loss of function.	Reduction in oil pressure, loss of oil.	Loss of lube system and pressure. Compartment flooding. If internal, nacelle and/or engine wetting.	I.F.S.D. and possible F.R.R. for parts replacement.	Emergency shutdown.
		2. Plugging or blockage of jets.	Loss of function. Degree dependent on extent.	Increased oil temperature and consumption. Possible increase in vibration and/or breather pressure.	Increased temperature of bearing and seals (excessive wear and/or complete failure).	Possible I.F.S.D. and F.R.R. for bearing replacement.	Reduce rpm or shut down engine as oil temperature and consumption dictate.

Sheet 8

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
Hydrostatic Seals 15.2.0 16.2.0	Retain oil in compartment, reduce air leakage into lube system at junction of static and rotating parts.	1. Wear	X				Seal faces are not in contact except at start-up.	
		2. Complete wear out			X		The hydrostatic primary seal which has the capability to act as a conventional carbon rubbing face seal in the event of loss of supply air pressure through the use of preload springs that force the seal ring against the seal plate similar to current carbon rubbing seals. The seal plate which is cooled with a positive flow of oil through closely spaced holes within the plate to retard wear in the event of seal ring and seal plate contact.	Oil loss will be reduced by lab seals. Oil leakage will be vented overboard without cabin bleed air contamination. Seal carrier will not contact seal plate and generate heat.
Lab Seals 15.3.0 16.3.0	Provide low pressure and temperature air around hydrostatic seals by metering high temperature-pressure outside air, and ensure that any oil leakage past compartment seals is vented overboard.	1. Rub	X				No rubbing or contacting surfaces are used in this design. Clearance used accounts for thermal growth.	
		2. Excessive clearance		X			Multiple sealing surfaces are used to provide redundancy. Stepped seal design increases cooling efficiency per surface.	
Plumbing 15.4.0 16.4.0	Provide oil to bearings, pressurize and vent hydrostatic seals.	1. Breakage a. Air Lines		X			See lubrication system, section 13, item 13.3.0.1.	See lubrication system, section 13, item 13.3.0.1.
		b. Oil Line			X		Same as 1.a.	
		2. Plugging or blockage of jets			X		Strainers, filters and chip detectors provided.	See section 13, item 13.4.0.1.

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
17 NO. 3 BEARING COMPARTMENT 17.0.0	To support turbine end of high rotor.	Same as Section 15-16	Same as Section 15-16.	Same as Section 15-16.	Same as Section 15-16 with high turbine blades rubbing into stators.	Same as Section 15-16.	Same as Section 15-16.
18 NO. 4 BEARING COMPARTMENT 18.0.0	To support turbine end of low rotor.	Same as Section 15-16	Same as Section 15-16.	Same as Section 15-16.	Same as Section 15-16 with low turbine blades rubbing into stators.	Same as Section 15-16.	Same as Section 15-16.
Oil Pump 18.5.0	Scavenge #4 compartment lube.	Failure to operate.	See Lubrication and Breather System - Section 12.				

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JTF17 FAILURE MODE & EFFECT ANALYSIS

	Item	Function	Failure Mode	Hazard Classification				Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
				I	II	III	IV		
17	NO. 3 BEARING COMPART-MENT 17.0.0	To support turbine end of high rotor.	Same as Section 15-16						
18	NO. 4 BEARING COMPART-MENT 18.0.0	To support turbine end of low rotor.	Same as Section 15-16						
	Oil Pump 18.5.0	Scavenge #4 compart-ment tube.	Failure to operate.			X		Design of pump and drive proven in J58. Also see section 13, item 13.7.0.	See section 13, item 13.3.0.

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JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
19 TOWERSHAFT BEARING AND SHAFTING 19.0.0	Transfer external power to main rotor for starting and transfer rotor power to external gear boxes.						
Bearings 19.1.0	To position and support gearing and shafts.	1. Roller, ball, cage, race wear.	None to loss of function, degree dependent on severity.	Increased vibration.	Increased gear wear to displacement of gearing with possible resultant failure of gear.	Possible I.F.S. and probable P.E.R. for inspection and parts replacement.	Shutdown or reduce power as vibration dictates.
		2. Bearing disintegration.	Loss of function.	Loss of accessory or starting power.	Displacement of gearing. Damage to gearing and static structure.	I.F.S. and P.E.R. for inspection and parts replacement.	Shutdown.
Shafting 19.2.0	Transfer torque from internal gearing to external component gearbox.	1. Spline or shaft shear.	Loss of function.	Loss of power to accessory drive system.	Loss of starting or accessory drive capability. Possible damage to shaft housing.	I.F.S. and possible P.E.R. for parts replacement.	Shutdown.
		2. Spline wear.	None (unless prolonged use.)	Inspection at overhaul.	None. Parts replacement required at overhaul.	None	None

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JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
19 TOWERSHAFT DRIVES AND GEARING 19.0.0	Transfer external power to main rotor for starting and transfer rotor power to external gear boxes.							
Bearings 19.1.0	To position and support gearing and shafts.	1. Roller, ball, cage, race wear.	X	X			All shafts and gears are straddle-mounted on anti-friction bearings that are designed to support the required radial and axial loads for a minimum B-10 life expectancy of 10,000 hours as defined by the AFBMA (Anti-Friction Bearing Manufacturers Association). Bearings are heat-treated at 1000°F to stabilize them for minimum distortion at operating temperatures. All bearing cages are steel and are silver plated. These bearing materials are used in all JT8 accessory drives and have demonstrated reliability and long life in development and service. In JT8 use, accessory bearings operate at temperatures of 400 to 450°F. In the JTF17 the operational temperature will be approximately 230°F (170 to 220°F cooler).	
		2. Bearing disintegration.			X			Any failure mode causing a loss of power to one of the gearboxes will result in the engine shutting itself down or in the case of the oil pump drive gearbox, cockpit monitors will detect the failure and permit shutdown before extensive bearing damage occurs.
Shafting 19.2.0	Transfer torque from internal gearing to external component gearbox.	1. Spline wear	X				All splines are provided with positive lubrication. Full depth splines are used to give maximum working depth for a given face width.	
		2. Spline or shaft shear			X		The power train is capable of delivering the rated power to all associated accessory pads continuously from ground idle to maximum speed, and can withstand a torque equivalent to five times the continuous rated power of any one accessory in addition to the continuous rated power of all other associated accessories at ground idle speed without failure or permanent deformation.	

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JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
Gears 19.3.0	Transfer torque between main rotor and towershaft.	1. Wear	None (unless prolonged use).	Possible vibration increase.	None. Parts replacement required at overhaul.	None	Inspection required.
		2. Gear web or rim fracture.	Loss of function.	Loss of accessory or starting drive ability. May run for period with excessive vibration.	Damage to mating gears, housing and bearings.	I.F.S. and U.E.R. for parts replacement.	Shutdown.
		3. Tooth fracture.	Loss of function.	Loss of accessory or starting drive ability. May run for period with excessive vibration.	Damage to mating gears. Damage to static housings and bearings.	I.F.S. and U.E.R. for parts replacement.	Shutdown.
Seals 19.3.0	Prevent loss of oil, low breather pressure at altitude, and prevent air leakage into lube system at high nacelle pressures.	1. Cracking, tearing, wear.	Partial loss of function.	Oil leakage into nacelle or overboard. May show as increased oil consumption.	Increased oil consumption, external leakage.	U.E.R. for inspection and parts replacement.	Inspection required.
		2. Complete wear out.	Loss of function. Degree dependent upon severity and extent of damage.	Increased rate of oil consumption, or possible loss of oil pressure or flooding of compartments as a result of main oil pump or scavenge pump cavitation.	In addition to paragraph 1, above, cavitation of oil pumps at low breather pressure, and increased breather pressure and flow at high nacelle pressure.	Possible I.F.S. and U.E.R. for inspection and parts replacement.	Reduce rpm or shut down engine as oil consumption dictates

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JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
Gears 19.3.0	Transfer torque between main rotor and powershaft.	1. Wear	X				The balanced tooth concept is used for all gear design. With this concept, the endurance bending strength of the pinion and gear in a mesh is equalized to give maximum possible life. Gear misalignment is limited to 0°07' to minimize wear.	
		2. Gear web or rim fracture.			X		Shot peened to increase fatigue life. Stress levels proven in J58.	
		3. Tooth fracture.			X		Shot peened to increase fatigue life. Stress levels proven in J58.	
Seals 19.4.0	Prevent loss of oil, low breather pressure at altitude, and prevent air leakage into lube system at high fan discharge pressures.	1. Cracking, tearing, wear.		X			"O" ring configuration used. Materials being evaluated for increased life.	
		2. Complete wear out.		X			Redundancy provided by two seals in series.	Deoiler and breather pressurizing valve designed to operate temporarily under these conditions.

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JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
20 ENGINE ACCESSORY DRIVE GEARBOX 20.0.0	Support and drive accessory components; fuel pump, hydraulic pump, tachometer, deoiler, control.						
Bearings 20.1.0	To position and support gearing.	1. Roller, ball, cage, race wear.	None to loss of function, degree dependent upon severity.	Increasing vibration.	Increased gear wear to displacement of gearing with possible resultant failure of gear if prolonged or excessive.	Possible T.R.R. for inspection and parts replacement.	Normal shut down or reduction in power as vibration dictates.
		2. Bearing disintegration.	Loss of function	Loss of thrust. Rpm drop.	Displacement of gearing. Damage to gearing and static structure.	T.R.R. and F.R.R. for inspection and parts replacement.	Shutdown.
Shafting 20.1.0	Transfer torque from gears to gears or accessory.	1. Spline or shaft shear.	Loss of function.	Loss of thrust. Rpm drop.	Loss of accessory drive capability. Possible damage to shaft housing.	T.R.R. and F.R.R. for inspection and parts replacement.	Shutdown.
		2. Spline wear.	None (unless prolonged use).	Possible vibration increase.	None	Parts replacement required at overhaul.	None
Gears 20.3.0	Transfer torque between shafts.	1. Wear	None (unless prolonged use).	Possible vibration increase.	None	Parts replacement required at overhaul.	None
		2. Tooth fracture.	Loss of function.	Loss of thrust. May run for period with excessive vibration.	Damage to mating gears. Damage to static housings and bearings.	T.R.R. and F.R.R. for inspection and parts replacement.	Shutdown.
		3. Gear web or rim fracture.	Loss of function.	Same as 2 above.	Same as 2 above.	Same as 2 above.	Shutdown.

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JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification				Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
			I	II	III	IV		
20 ENGINE ACCESSORY DRIVE GEARBOX 20.0.0	Support and drive accessory components; fuel pump, hydraulic pump, tachometer, deoiler, control.							
Bearings 20.1.0	To position and support gearing.	1. Roller, ball, cage, race wear.	X	X			All shafts and gears are straddle-mounted on anti-friction bearings that are designed to support the required radial and axial loads for a minimum B-10 life expectancy of 10,000 hours as defined by the AFBMA (Anti-Friction Bearing Manufacturers Association). Bearings are heat-treated at 1000°F to stabilize them for minimum distortion at operating temperatures. All bearing cages are steel and are silver plated. These bearing materials are used in all J58 accessory drives and have demonstrated reliability and long life in development and service. In J58 use, accessory bearings operate at temperatures of 550 to 650°F. In the JTF17 the operational temperature will be approximately 450°F (170 to 230°F cooler).	
		2. Bearing disintegration.			X		Cooling oil provided to maintain design temperature.	Any failure of gearbox internal components will be contained within the gearbox. Cockpit monitors will detect the failure and permit engine shutdown without extensive damage or the engine will shut itself down.
Shafting 20.2.0	Transfer torque from gears to gears or accessory.	1. Spline or shaft shear.			X		Individual accessory drives are capable of delivering the rated power continuously from ground idle to maximum speed, and can withstand a static torque equivalent to five times the rated power at ground idle speed without failure or permanent deformation.	
		2. Spline wear	X				All splines are provided with positive lubrication to reduce wear.	
Gears 20.3.0	Transfer torque between shafts.	1. Wear	X				The balanced tooth concept is used for all gear design. With this concept, the endurance bending strength of the pinion and gear in a mesh is equalized to give maximum possible life.	Provisions are provided for magnetic chip detectors in each gear box.
		2. Tooth fracture, gear web or rim fracture.			X		Gear and shaft stress values are comparable to those used in the J58 engine and have been verified by over 32,000 hours of development testing. All gear teeth and gear webs are shot peened to increase fatigue life.	

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
Seals (Component Drive Pad) 20.4.0	Prevent loss of oil, fuel-oil contamination, low breather pressure at altitude, and reduce air leakage into lube system at high nacelle pressures.	1. Cracking, scoring, wear.	Partial loss of function.	Oil leakage into nacelle or overboard. May show as increased consumption.	Increased oil consumption, external leakage.	Ground inspection may require R.R.R. for inspection and parts replacement.	None
		2. Complete wear out.	Loss of function. Degree dependent upon severity and extent of damage.	Increased rate of oil consumption, or possible loss of oil pressure.	In addition to paragraph 1, above, cavitation of oil pumps if low breather pressure, flooding of compartments as a result of main oil pump or scavenge pump cavitation, possible oil contamination from fuel if accessory fuel component seal failure had occurred, and increased breather pressure and flow if high nacelle pressure.	Possible I.F.S. and R.R.R. for inspection and parts replacement.	Reduce rpm or shut down engine as oil consumption dictates.
Scavenge Pump 20.5.0	Scavenge gearbox lube.	Failure to operate.	See Lubrication and Breather System, Section 13.	See Lubrication and Breather System, Section 13.	See Lubrication and Breather System, Section 13.	See Lubrication and Breather System, Section 13.	See Lubrication and Breather System, Section 13.
Housing (applies to each of the three gearboxes) 20.6.0 21.5.0 22.5.0	Enclose, position and support bearings and seals. Provide mount attachment points and component mountings as applicable.	Structural	Same as bearing and seal failure of affected gearbox.	Same as bearing and seal failure of affected gearbox.	Same as bearing and seal failure of affected gearbox.	Same as bearing and seal failure of affected gearbox.	Same as bearing and seal failure of affected gearbox.
Mount (applies to each of the three gearboxes) 20.6.1 21.5.1 22.5.1	Position and support gearbox.	Structural	Same as bearing and seal failure of affected gearbox.	Same as bearing and seal failure of affected gearbox.	Same as bearing and seal failure of affected gearbox.	Same as bearing and seal failure of affected gearbox.	Same as bearing and seal failure of affected gearbox.

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JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
Seals (Component Drive) 20.4.0	Prevent loss of oil, fuel-oil contamination, low breather pressure at altitude, and reduce air leakage into lube system at high nozzle pressures.	1. Cracking, tearing, wear.		X			All accessory pads are sealed with replaceable cartridge type seals similar to the J58. The seal carbon ring material was chosen for its low frictional coefficient and its oxidation resistance at elevated temperatures.	
		2. Complete wear out.			X		Gearbox lubrication is supplied directly from the main engine oil system. Oil is introduced through jets located at strategic points in the gearbox and is distributed through the various shafts to the gears, bearings, and seal faces for lubrication and cooling.	Overboard vents provided to remove leakage. Breather pressurizing valve and cooling are designed to operate temporarily under these conditions.
Scavenge Pump 30.5.0	Scavenge gearbox lube.	Failure to operate.			X		Pump is gear driven from gearbox, inlet is screen protected. Also see section 13, item 13.2.0.	Cockpit monitors will detect oil loss and permit engine shutdown without further damage.
Mounting (applies to each of the three gearboxes) 20.6.0 21.3.0 22.5.0	Enclose, position and support bearings and seals. Provide mount attachment points and component mountings as applicable.	Structural			X		All production gearbox housings except the engine accessory drive gearbox, are cast titanium. This material provides the best strength-to-weight ratio at the temperatures encountered, and utilizes the stiff supporting characteristics of the thick walled cast construction. During Phase II-C an investigation was initiated to improve casting techniques used for titanium gearboxes. Until casting is thoroughly proven, early prototype engines will be fitted with fabricated titanium housings. Fabricated titanium gearbox housings have been used successfully throughout the J58 development and production program. All gearboxes are deflection limited and stress levels are consistent with existing commercial engines. The engine accessory drive gearbox is cast steel to be compatible with the thermal properties of the fuel control, primary combustion fuel pump and the hydraulic pump.	Housings are sized to contain internal failures. Oil loss through failed sections will only contact relatively cool duct outer cases reducing fire hazard.
Mount (applies to each of the three gearboxes) 20.6.1 21.3.1 22.5.1	Position and support gearbox.	Structural		X			Forged link configuration with extremely low stress levels, ball joint connectors provided where required for thermal expansions.	

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JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
21 OIL PUMP DRIVE GEARBOX 21.0.0	Support & Drive Main Oil & Scavenge Pumps (For analysis of oil pumps, see Lubrication and Breather System, Section 13.)						
Bearings 21.1.0	To position and support gearing.	1. Roller, Ball, Cage, Race Wear.	Loss of function, degree dependent upon severity.	Vibration increasing with severity.	Displacement of gearing. Possible failure of gear.	Possible I.F.S. and P.E.R. for parts replacement.	Shut down or reduce rpm as vibration dictates.
		2. Bearing disintegration.	Loss of function.	Loss of oil pressure. Increased vibration.	Displacement of gearing, damage to gearing and static structure. Possible loss of engine lubricant supply. Engine bearing seizure unless shut down.	I.F.S. and P.E.R. for parts replacement.	Emergency shutdown.
Shafting 21.2.0	Transfer torque to gears or pumps.	1. Spline wear, galling, cracks.	None (unless prolonged use)	Vibration increase.	None	Parts replacement required at overhaul.	None
		2. Shaft or Spline Shear.	Loss of function.	Loss of oil pressure. Increase in oil temperature & consumption or reduced engine rpm.	Loss of drive capability to oil pump or scavenge pump or both. Loss of engine lubricant supply. Engine bearing seizure unless shut down.	I.F.S. and P.E.R. for parts replacement.	Emergency shutdown.
Gears 21.3.0	Transfer torque between shafts.	1. Wear	None (unless prolonged use)	Possible vibration increase.	None	Parts replacement required at overhaul.	None
		2. Tooth fracture, rim or web failure.	Loss of function.	Loss of oil pressure. Reduced engine rpm or increase in oil temperature.	Damage to mating gears and static structure. Loss of drive capability to oil pump or scavenge pump or both. Possible loss of engine lubricant supply. Engine bearing seizure unless shutdown.	I.F.S. and P.E.R. for parts replacement.	Emergency shutdown.

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JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
21 OIL PUMP DRIVE GEARBOX 21.0.0	Support and Drive Main and Scavenge Pumps (For analysis of oil pumps, see Lubrication and Breather System, Section 13.)							
Bearings 21.1.0	To position and support gearing.	1. Roller, Ball, Cage, Race Wear	X	X			All shafts and gears are straddle-mounted on anti-friction bearings that are designed to support the required radial and axial loads for a minimum B-10 life expectancy of 10,000 hours as defined by the AFBMA (Anti-Friction Bearing Manufacturers Association). Bearings are heat-treated at 1000°F to stabilize them for minimum distortion at operating temperatures. All bearing cages are steel and are silver plated. These bearing materials are used in all J58 accessory drives and have demonstrated reliability and long life in development and service. In J58 use, accessory bearings operate at temperatures of 600 to 650°F. In the JTF17 the operational temperature will be approximately 430°F (170 to 220°F cooler).	Provisions are provided for chip detectors in oil pump gearbox.
		2. Bearing disintegration.			X		Cooling oil provided to maintain design temperature.	Any failure of gearbox internal components will be contained within the gearbox. Cockpit monitors will detect the failure and permit engine shutdown without extensive damage.
Shafting 21.2.0	Transfer torque to gears or pumps.	1. Spline wear	X				All accessory drive splines are provided with positive lubrication to reduce wear and binding.	
		2. Shaft or spline shear			X		Individual accessory drives are capable of delivering the rated power continuously from ground idle to maximum speed, and can withstand a static torque equivalent to five times the rated power at ground idle speed without failure or permanent deformation.	
Gears 21.3.0	Transfer torque between shafts.	1. Wear	X				The balanced tooth concept is used for all gear design. With this concept, the endurance beam strength of the pinion and gear in a mesh is equalized to give maximum possible life.	
		2. Tooth fracture, rim or web failure.			X		Gear and shaft stress values are comparable to those used in the J58 engine and have been verified by over 32,000 hours of development testing. All gear teeth and gear webs are shot peened to increase fatigue life.	

Sheet 5

JTF17 FAILURE MODE & EFFECT ANALYSIS

Part	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Mission	Crew Action Required
Seals 21.4.0	Prevent loss of oil, prevent oil contamination. Maintain proper breather pressure.	1. Wear	None	Oil leakage into nacelle. Increased oil consumption.	Increased oil consumption.	Possible I.F.S. Ground inspection may require P.E.R. for oil leakage overboard.	[illegible] as oil level dictates.
		2. Complete wearout.	Loss of function.	Increased oil consumption. Possible loss of oil pressure.	In addition to paragraph 1, above, cavitation of oil pumps if low breather pressure condition occurs. Increased breather pressure if nacelle pressure is high.	I.F.S. and possible P.E.R. for parts replacement.	Shutdown if oil consumption and oil pressure dictate.

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JT9D FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy to Preclude Failure	Design Philosophy to Reduce Hazard
Seals 21.4.0	Prevent loss of oil, prevent oil contamination. Maintain proper breather pressure.	1. Wear		X			All accessory pads are sealed with replaceable cartridge type seals similar to the J58. The seal carbon ring material was chosen for its low frictional coefficient and its oxidation resistance at elevated temperatures.	
		2. Complete wearout.			X		Gearbox lubrication is supplied directly from the main engine oil system. Oil is introduced through jets located at strategic points in the gearbox and is distributed through the various shafts to the gears, bearings, and seal faces for lubrication and cooling.	Breather pressurizing valve and deoiler are designed to operate temporarily under these conditions.

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JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
22 AIRCRAFT ACCESSORY DRIVE GEARBOX 22.0.0	Transfer external power to main rotor for starting. Transfer rotor power to external power take-off to drive aircraft accessories.						
Bearings 22.1.0	To position & support gearing.	1. Roller, Ball, Cage, Race Wear.	None to loss of function. Degree dependent upon severity.	Increased vibration.	Increased gear wear or displacement of gearing with possible resultant failure of gear if prolonged or extreme.	Possible I.F.S. and U.E.R. for parts replacement.	Reduction in power requirement or de-coupling of aircraft subsystem or engine shutdown as vibration dictates.
		2. Bearing disintegration.	Loss of function.	Loss of gearbox power.	Displacement of gearing damage to gearing and static structure.	I.F.S. and U.E.R. for parts replacement.	Shutdown.
Shafting 22.2.0	Transfer torque from internal gearing to power take-off.	1. Spline wear.	None (unless prolonged use)	Possible vibration increase.	None	Parts replacement required at overhaul.	None
		2. Shear section failure.	Loss of function.	Loss of gearbox power.	None	Possible U.E.R. for parts replacement.	Decouple aircraft subsystem.
		3. Shaft or spline shear.	Loss of function.	Loss of gearbox power. Engine may run for period with increased vibration.	Damage to static structure. Possible damage to gearing and bearings.	Possible I.F.S. and U.E.R. for parts replacement.	Decouple aircraft subsystem or shut down as vibration dictates.
Gears 22.3.0	Transfer torque between shafts.	1. Wear	None (unless prolonged use).	Possible vibration increase.	None	Inspection at overhaul.	None

Sheet [illegible]

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification				Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
			I	II	III	IV		
22 AIRCRAFT ACCESSORY DRIVE GEARBOX 22.0.0	Transfer external power to main rotor for starting. Transfer rotor power to external power take-off to drive aircraft accessories.							
Bearings 22.1.0	To position and support gearing.	1. Roller, Ball, Cage, Race Wear.	X	X			All shafts and gears are straddle-mounted on anti-friction bearings that are designed to support the required radial and axial loads for a minimum B-10 life expectancy of 10,000 hours as defined by the AFBMA (Anti-Friction Bearing Manufacturers Association). Bearings are heat-treated at 1000°F to stabilize them for minimum distortion at operating temperatures. All bearing cages are steel and are silver plated. These bearing materials are used in J58 accessory drives and have demonstrated reliability and long life in development and service. In J58 use, accessory bearings operate at temperatures of 600 to 650°F. In the JTF17 the operational temperature will be approximately 430°F (170 to 220°F cooler).	
		2. Bearing disintegration.			X		Cooling oil provided to maintain design temperatures.	In the event of internal gearbox failures, input shafting is designed to shear and prevent damage propagation. Gearbox will contain all internal component failures. Cockpit monitors will detect loss of aircraft accessory drive power.
Shafting 22.2.0	Transfer torque from internal gearing to power take-off.	1. Spline wear.	X				All accessory drive splines are provided with positive lubrication to reduce wear and binding.	
		2. Shear section failure.			X		Shear section design is based on proven practices.	
		3. Shaft or spline shear.			X		Individual accessory drives are capable of delivering the rated power continuously from ground idle to maximum speed, and can withstand a static torque equivalent to five times the rated power at ground idle speed without failure or permanent deformation.	
Gears 22.3.0	Transfer torque between shafts.	1. Wear	X				The balanced tooth concept is used for all gear design. With this concept, the endurance beam strength of the pinion and gear in a mesh is equalized to give maximum possible life.	

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Name	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
		2. Tooth fracture, gear rim or web failure.	Loss of function.	Loss of gearbox power. Engine may run for period with increased vibration.	Damage to mating gear. Damage to static structure.	Possible I.F.S. and P.E.R. for parts replacement.	Decouple aircraft subsystem or shutdown as vibration dictates.
Seals 22.4.0	Prevent loss of oil. Prevent oil contamination. Maintain proper breather pressure.	1. Wear	None	Oil leakage into nacelle. Increased oil consumption.	Increased oil consumption.	Possible I.F.S. Ground inspection may require P.E.R. for oil leakage overboard.	Possible shutdown as oil level dictates.
		2. Complete wear out.	Loss of function.	Increased oil consumption. Possible loss of oil pressure.	In addition to paragraph 1, above, cavitation of oil pumps if low breather pressure. Increased breather pressure if nacelle pressure is high.	Possible I.F.S. and P.E.R. for parts replacement.	Shutdown if oil consumption and oil pressure dictate.

Sheet 8

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification				Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
			I	II	III	IV		
		2. Tooth fracture, gear rim or web failure.			X		Gear and shaft stress values are comparable to those used in the J58 engine and have been verified by over 32,000 hours of development testing. All gear teeth and gear webs are shot peened to increase fatigue life.	
Seals 22.4.0	Prevent loss of oil. Prevent oil contamination. Maintain proper breather pressure.	1. Wear		X			All accessory pads are sealed with replaceable cartridge type seals similar to the J58. The seal carbon ring material was chosen for its low frictional coefficient and its oxidation resistance at elevated temperatures.	
		2. Complete wear out.			X		Gearbox lubrication is supplied directly from the main engine oil system. Oil is introduced through jets located at strategic points in the gearbox and is distributed through the various shafts to the gears, bearings, and seal faces for lubrication and cooling.	Overboard vents provided to remove leakage. Breather pressurizing valve and deoiler designed to operate temporarily under these conditions.

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required
23 STARTING BLEED SYSTEM 23.0.0	Start valves bleed 5th-stage compressor air at starting and remain closed during flight.						
Valves 23.1.0	Controls flow of starting bleed air.	1. S/B Valve sticks open.	SLTO - Leakage Cruise - Leakage Landing - Leakage	SLTO - None Cruise - None Landing - None Inspection at overhaul	SLTO - Decrease in thrust Cruise - Decrease in thrust Landing - Decrease in thrust	P.R.R. for inspection and parts replacement.	SLTO - None Cruise - None Landing - None
		2. S/B Valve sticks closed.	SLTO - Remaining valves operate slightly faster. Cruise - Same as SLTO Landing - Same as SLTO.	SLTO - None Cruise - None Landing - None Inspection at overhaul	SLTO - None Cruise - None Landing - None	None, replace at overhaul.	SLTO - None Cruise - None Landing - None
		3. Piston ring fails	SLTO - None Cruise - None Landing - None	SLTO - None Cruise - None Landing - None Inspection at overhaul	SLTO - None Cruise - None Landing - None	None, replace at overhaul.	SLTO - None Cruise None Landing - None
		4. Valve stem failure.	SLTO - None Cruise - None Landing - None	SLTO - None Cruise - None Landing - None Inspection at overhaul.	SLTO - Decrease in thrust Cruise - Same as SLTO Landing - Same as SLTO	None, replace at overhaul.	SLTO - None Cruise None Landing - None

Sheet 8

JTF17 FAILURE MODE & EFFECT ANALYSIS

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard
23 STARTING BLEED SYSTEM 23.0.0	Eight valves bleed 5th-stage compressor air at starting and remain closed during flight.							
Valve 23.1.0	Controls flow of starting bleed air.	1. S/B Valve sticks open.	X				Configuration used is similar to valves on PWA commercial JT8D and military J52 engines. Valve is closed by fan discharge pressure during operation above idle and clearances are sized to minimize sticking. Rubbing surfaces are hardcoated or lubricated with anti galling compound.	Valves designed to be removable through the access covers located on the fan duct diffuser case.
		2. S/B Valve sticks closed.	X				Valve is spring loaded open when engine is not operating. Clearances are sized to minimize sticking. Surface treatment same as above.	
		3. Piston ring fails.	X				Rubbing surfaces are lubricated with anti galling compound and ring is sized to maintain loads within material capabilities.	
		4. Valve stem failure.	X				Stem sized to maintain loads within material capabilities.	