SSME FMEA/CIL
REDUNDANCY SCREEN

Component Group:	**Oxidizer Turbopumps**	**Prepared:**	**C. Abesamis**
CIL Item:	**B800-01**	**Approved:**	**T. Nguyen**
Component:	**Low Pressure Oxidizer Turbopump**	**Approval Date:**	**6/7/99**
Part Number:	**RS007601**	**Change #:**	**2**
Failure Mode:	**Seal leakage-turbine inlet.**	**Directive #:**	**CCBD ME3-01-5214**
		Page:	**1 of 1**

Phase	Failure / Effect Description	Criticality Hazard Reference
S 4.1	Leakage reduces the available power to the hydraulic turbine which results in lower turbopump shaft speed and pump output pressure and flow. HPOTP discharge pressure decays due to the lower inlet pressure and head loss from cavitation across the main pump. The MCC pressure decreases and is sensed by the controller, which corrects by increasing the oxidizer system power by opening the OPOV. Correction required to maintain MCC pressure may cause a violation of the HPOTP turbine exhaust temperature redline and initiate premature engine shutdown. Mission scrub if detected by redline. Loss of vehicle due to HPOTP turbine or heat exchanger failure may result if not detected. Redundancy Screens: TURBOPUMP SYSTEM - SENSOR SYSTEM: UNLIKE REDUNDANCY A: Pass - Redundant hardware items are capable of checkout during normal ground turnaround. B: Pass - Loss of a redundant hardware items is detectable during flight. C: Pass - Loss of redundant hardware items could not result from a single credible event.	1R ME-C1S,M
M 4.1	Leakage reduces the available power to the hydraulic turbine which results in lower turbopump shaft speed and pump output pressure and flow. HPOTP discharge pressure decays due to the lower inlet pressure and head loss from cavitation across the main pump. The MCC pressure decreases and is sensed by the controller, which corrects by increasing the oxidizer system power by opening the OPOV. Correction required to maintain MCC pressure may cause a violation of the HPOTP turbine exhaust temperature redline and initiate premature engine shutdown. Mission abort if detected by redline. Loss of vehicle due to HPOTP turbine or heat exchanger failure may result if not detected. Redundancy Screens: TURBOPUMP SYSTEM - SENSOR SYSTEM: UNLIKE REDUNDANCY A: Pass - Redundant hardware items are capable of checkout during normal ground turnaround. B: Pass - Loss of a redundant hardware items is detectable during flight. C: Pass - Loss of redundant hardware items could not result from a single credible event.	1R ME-C1S,M

SSME FMEA/CIL
DESIGN

Component Group:	Oxidizer Turbopumps
CIL Item:	B600-01
Component:	Low Pressure Oxidizer Turbopump
Part Number:	RS007801
Failure Mode:	Seal leakage-turbine inlet.

Prepared:	C. Abesamis
Approved:	T. Nguyen
Approval Date:	6/7/99
Change #:	2
Directive #:	CCBD ME3-01-5214
Page:	1 of 1

Design / Document Reference

FAILURE CAUSE: **A: Front housing seal leakage.**
B: Rear housing seal leakage.

THE FORWARD HOUSING SEAL (1) IS A TEFLON COATED, WIDE TIP PRESSURE ASSISTED SEAL, SPECIFICALLY INTENDED TO BE COMPATIBLE WITH ALUMINUM SURFACES. THE SEAL IS SECURED IN A RELIEF CAVITY IN THE HOUSING (2) AND PREVENTS LEAKAGE OF TURBINE WORKING FLUID BETWEEN THE HOUSING AND BEARING SUPPORT (3). ABSENCE OF AN INTEGRATED SPACER RING ALLOWS COMPLETE BOTTOMING OF THE ROTOR/STATOR ASSEMBLY IN THE HOUSING. THE SEAL DESIGN IS INSENSITIVE TO ORIENTATION DURING ASSEMBLY. THE FORWARD SEAL IS MADE FROM INCONEL 718, WHICH WAS SELECTED FOR ITS REQUIRED STRENGTH, AND RESISTANCE TO CORROSION AND STRESS CORROSION CRACKING (11). THE AFT HOUSING SEAL (4) IS LOCATED BETWEEN THE HOUSING AND NOZZLE CYLINDER (5), AND IS RETAINED BY AN INCONEL 718 BACKING RING (6). THE AFT SEAL HAS A "C" CONFIGURATION CROSS-SECTION WHICH EXPANDS UPON PRESSURIZATION. A POSITIONING PIN IN THE NOZZLE SEAL GROOVE PREVENTS REVERSE SEAL INSTALLATION. THE AFT SEAL IS MANUFACTURED UTILIZING INCONEL X-750, WHICH WAS SELECTED FOR ITS STRENGTH AND FLEXIBILITY, AND RESISTANCE TO CORROSION AND STRESS CORROSION CRACKING (7). THE AFT SEAL IS SOLUTION HEAT TREATED, AGE-HARDENED, AND SILVER PLATED FOR LUBRICITY, FRICTIONAL WEAR RESISTANCE, AND ANTI-GALLING CHARACTERISTICS (1) (4). THE HOUSING SEALING SURFACE FOR THE REAR SEAL IS HARD ANODIZED FOR IMPROVED WEAR RESISTANCE AND INCORPORATES A VENTED DOWNSTREAM CAVITY DESIGN (2) TO MINIMIZE PRESSURE LOADING OF THE NOZZLE/STATOR ASSEMBLY (6). CLEANLINESS REQUIREMENTS DURING HANDLING AND ASSEMBLY PRECLUDES CONTAMINATION INTRODUCTION TO THE SEALING SURFACE (9). THE SEALS HAVE BEEN ASSESSED TO HAVE INFINITE LIFE (10) AND ARE NOT TRACKED BY SERIALIZATION. LPOTP NOZZLES ARE LIFE LIMITED PER DEVIATION (12).

(1) R035534; (2) RS007802; (3) R033573; (4) RES1275; (5) RS007810; (6) RS007820; (7) RSS-8579-5; (8) RS007808; (9) RL10001; (10) RL00532, CP320R0003B; (11) RSS-8579-9; (12) DAR 2956

FAILURE CAUSE: **C: Excessive oxidizer labyrinth seal leakage.**

THE LABYRINTH SEAL CLEARANCE IS CONTROLLED BY DRAWING, TO ENSURE MINIMUM LEAKAGE FROM THE HYDRAULIC TURBINE. THE LABYRINTH IS MACHINED INTO THE ROTOR (1) AND IS A CONSTANT-DIAMETER SEAL WITH 19 UNIFORM ROWS OF FORWARD SWEPT TEETH. THE ROTOR IS MANUFACTURED UTILIZING K-MONEL FORGINGS, WHICH WAS SELECTED FOR ITS CORROSION RESISTANCE CHARACTERISTICS, DUCTILITY, AND TOUGHNESS PROPERTIES AT CRYOGENIC TEMPERATURES (2). THE REDUNDANT ROW DESIGN AFFORDS SOME DEGRADATION TO THE LABYRINTH WHILE STILL RETAINING THE MAJORITY OF ITS SEALING FUNCTION. THE STATIONARY MATING SEAL RING (3) IS MANUFACTURED UTILIZING SILVER AND IS PILOTED ON BOTH THE NOZZLE (4) AND DEFLECTOR (5) STRUCTURE FOR RETENTION. REVERSE RING INSTALLATION IS NOT POSSIBLE DUE TO THE PILOT DESIGN. SILVER WAS SELECTED FOR ITS RESISTANCE TO IGNITION, FRICTIONAL WEAR RESISTANCE, THERMAL CONDUCTIVITY, AND ANTI-GALLING CHARACTERISTICS (2). THE ROTOR AND SEAL RING ARE SOLUTION HEAT TREATED AND AGE-HARDENED (1) (3). VENT HOLES DESIGNED INTO THE SEAL RING STRUCTURE (3) PREVENT PRESSURE BUILDUP AND DISTORTION OF THE SEAL RING ONTO THE LABYRINTH SEAL. CLEANLINESS REQUIREMENTS AT THE HANDLING, ASSEMBLY (6) AND VEHICLE OPERATIONAL LEVEL (7) PRECLUDES CONTAMINATION INDUCED RUBBING OF THE SEAL ELEMENTS. ROTOR ASSEMBLIES MANUFACTURED BY CONTURA WHICH MAY CONTAIN WORSE CASE (ZERO RADIUS) DISCREPANCIES ARE LIFE LIMITED PER MAJOR WAIVER (8).

(1) RS007806; (2) RSS-8579-9; (3) RS007816; (4) RS007810; (5) R033574; (6) RL10001; (7) ICD 13M15000; (8) DAR 2160

FAILURE CAUSE: **ALL CAUSES**

INCONEL X-750, INCONEL 718, K-MONEL, AND SILVER SATISFY LOX COMPATIBILITY REQUIREMENTS (1). THE HIGH CYCLE AND LOW CYCLE FATIGUE LIFE FOR THE FORWARD AND AFT SEAL, ROTOR, AND SEAL RING MEET CEI REQUIREMENTS (2). THE MINIMUM FACTORS OF SAFETY FOR THESE PARTS MEET CEI REQUIREMENTS (3). THE HARDWARE PARENT MATERIALS WERE CLEARED FOR FRACTURE MECHANICS/NDE FLAW GROWTH SINCE THEY CONTAIN NO FRACTURE CRITICAL PARTS EXCEPT FOR THE LPOTP HOUSING WHICH WAS CLEARED BY RISK ASSESSMENT (4). THE FMEA/CIL WELDS ARE CLEARED FOR FRACTURE MECHANICS/NDE FLAW GROWTH BY THE WELD ASSESSMENT (5). TABLE B600 LISTS ALL FMEA/CIL WELDS AND IDENTIFIES THOSE WELDS IN WHICH THE CRITICAL INITIAL FLAW SIZE IS NOT DETECTABLE AND THOSE WELDS IN WHICH THE ROOT SIDE IS NOT ACCESSIBLE FOR INSPECTION. THOSE WELDS IN WHICH THE CRITICAL INITIAL FLAW SIZE IS NOT DETECTABLE ARE ACCEPTABLE FOR FLIGHT BY RISK ASSESSMENT (5). THE CONTROLLER SOFTWARE IS CONFIGURED TO DETECT AND RESPOND TO THE FAILURES IDENTIFIED AND COMMAND A SAFE ENGINE STATE (6). REUSE OF PARTS DURING OVERHAUL ARE CONTROLLED BY THE REQUIREMENTS OF THE OVERHAUL SPECIFICATION (7).

(1) RSS-8579-9; (2) RL00532, CP320R0003B; (3) RSS-8546-16, CP320R0003B; (4) NASA TASK 117; (5) RSS-8756; (6) CP406R0006, 3.2.3.5.2; (7) RL01210

SSME FMEA/CIL
INSPECTION AND TEST

Component Group:	**Oxidizer Turbopumps**	**Prepared:**	**C. Abesamis**
CIL Item:	**B500-01**	**Approved:**	**T. Nguyen**
Component:	**Low Pressure Oxidizer Turbopump**	**Approval Date:**	**6/7/99**
Part Number:	**RS007801**	**Change #:**	**2**
Failure Mode:	**Seal leakage-turbine inlet.**	**Directive #:**	**CCBD ME3-01-5214**
		Page:	**1 of 2**

Failure Causes	Significant Characteristics	Inspection(s) / Test(s)	Document Reference
A, B	SEAL SEAL HOUSING		R035534 RES1275 RS007802
	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER DRAWING AND SPECIFICATION REQUIREMENTS.	RES1275 RB0170-153 RB0170-099 RB0170-051
		SEALS ARE PENETRANT INSPECTED PRIOR TO PLATING PER SPECIFICATION REQUIREMENTS.	RA0115-116
	HEAT TREAT	HEAT TREAT IS VERIFIED PER SPECIFICATION AND DRAWING REQUIREMENTS.	RA0611-020 RES1275 R035534
	SURFACE FINISH	HOUSING ANODIZING IS VERIFIED PER DRAWING AND SPECIFICATION REQUIREMENTS.	RS007802 RA1609-003
		SILVER PLATING IS VERIFIED PER SPECIFICATION AND DRAWING REQUIREMENTS.	RA1608-001 RES1275
		TEFLON COATING IS VERIFIED PER SPECIFICATION REQUIREMENTS.	RA1608-001
	ASSEMBLY INTEGRITY	SEALING SURFACES ARE INSPECTED PER DRAWING REQUIREMENTS.	RES1275 R035534 RS007802 RF0004-027
		NOZZLE AND HOUSING PILOTING DIAMETERS ARE INSPECTED PER DRAWING REQUIREMENTS.	RS007810 RS007802
C	ROTOR		RS007805

Compone: :up: Oxidizer Turbopumps
CIL Item: B800-01
Component: Low Pressure Oxidizer Turbopump
Part Number: RS007801
Failure Mode: Seal leakage-turbine inlet.

Prepared: C. Abesat
Approved: T. Nguyen
Approval Date: 8/7/99
Change #: 2
Directive #: CCBD ME3-01-5214

Failure Causes	Significant Characteristics	Inspection(s) / Test(s)	Document Reference
C	MATERIAL INTEGRITY	ROTOR IS PENETRANT INSPECTED PER SPECIFICATION REQUIREMENTS.	RA0115-116
		ROTOR IS ULTRASONIC INSPECTED AFTER WELDING PER SPECIFICATION REQUIREMENTS.	RA0115-012
	HEAT TREAT	HEAT TREAT IS VERIFIED PER SPECIFICATION REQUIREMENTS.	RA0611-020
	WELD INTEGRITY	ALL WELDS ARE INSPECTED TO DRAWING AND SPECIFICATION REQUIREMENTS PER WELD CLASS. INSPECTIONS INCLUDE: VISUAL, DIMENSIONAL, PENETRANT, RADIOGRAPHIC, ULTRASONIC, AND FILLER MATERIAL, AS APPLICABLE.	RL10011 RA1607-071 RA0115-116 RA0115-006 RA1115-001 RA0115-127
	SEALING RING		RS007816
	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER DRAWING REQUIREMENTS.	
		SEALING RING IS PENETRANT INSPECTED PER SPECIFICATION REQUIREMENTS.	RA0115-116
	ASSEMBLY INTEGRITY	SEALING RING SEAL DIAMETER AND ROTOR LABYRINTH SEAL DIAMETER ARE INSPECTED PER DRAWING REQUIREMENTS.	RS007816
ALL CAUSES	LPOTP		RS007801
	ASSEMBLY INTEGRITY	THE PUMP SUBASSEMBLIES ARE INSPECTED DURING OVERHAUL PER SPECIFICATION REQUIREMENTS. INSPECTIONS INCLUDE: VISUAL, DIMENSIONAL, PENETRANT, AND REPLACEMENT OF USAGE ITEMS AS APPLICABLE, PER OVERHAUL SPECIFICATION.	RA0115-116 RL01219
		OPERATION/PERFORMANCE IS VERIFIED BY ENGINE HOT FIRE TESTING AND 2ND E & M TESTS ON INSPECTIONS.	RL00050-04 RL00056-06 RL00056-07 RL00461
		TORQUE CHECKS ARE PERFORMED PRIOR TO EACH FLIGHT.	OMRSD V41BS0.030
		DATA FROM PREVIOUS FLIGHT OR HOT FIRE IS REVIEWED FOR PROPER TURBOPUMP OPERATION/PERFORMANCE. (LAST TEST)	MSFC PLN 1228

Failure History: Comprehensive failure history data is maintained in the Problem Reporting database (PRAMS/PRACA)
Reference: NASA letter SA21/88/308 and Rocketdyne letter 88RC09751.

Operational Use: Not Applicable.

SSME FA/CIL WELD JOINTS

Component Group: Oxidizer Turbopumps
CIL Item: B8D0
Component: Low Pressure Oxidizer Turbopump
Part Number: RS007801

Prepared: C. Abesamis
Approved: T. Nguyen
Approval Date: 6/7/99
Change #: 2
Directive #: CCBD ME3-01-5214
Page: 1 of 1

Component	Basic Part Number	Weld Number	Weld Type	Class	Root Side Not Access	Critical Initial Flaw Size Not Detectable HCF	Critical Initial Flaw Size Not Detectable LCF	Comments
ROTOR	RS007805	1PLC(OPT)	GTAW	I				
ROTOR	RS007805	1PLC(OPT)	EBW	I				
NOZZLE	RS007810	1PLC	EBW	I				

SSME FMEA/CIL
FIELD CONFIGURATION VARIANCES FROM CIL RATIONALE

Component Group: Oxidizer Turbopumps
Item Name: Low Pressure Oxidizer Turbopump
Item Number: B800
Part Number: RS007801

Prepared: C. Abesamis
Approved: T. Nguyen
Approval Date: 6/7/99
Change #: 1
Directive #: CCBD ME3-01-5214

Base Line Rationale	Variance	Change Rationale	Variant Dash Number
1. B800-05, B800-08 BEARINGS ARE PROCESSED AND INSPECTED PER SPECIFICATION REQUIREMENTS (RL00918). (ECP 909)	BEARINGS ARE PROCESSED AND INSPECTED PER SPECIFICATION REQUIREMENTS (RL00558).	LONG TERM FATIGUE LIFE OF BEARINGS IS EXTENDED BY REDUCING THE ALLOWABLE SIZE AND QUANTITY OF ALLOWABLE DEFECTS. USE AS IS RATIONALE: 1. THE HIGH CYCLE AND LOW CYCLE FATIGUE LIFE OF BEARINGS PROCESSED PER RL00558 MEET CEI REQUIREMENTS. 2. THE MINIMUM FACTORS OF SAFETY FOR BEARINGS PROCESSED PER RL00558 MEET CEI REQUIREMENTS (RSS-8546-16).	-011, -121, -051, -071, -081, -091, -101, -111, -141, -151, -161, -181
2. B800-01 - CAUSE C / B800-09 CAUSE E THE SUPPORT IS PILOTED BY THE DEFLECTOR, WHICH IN TURN IS PILOTED BY THE NOZZLE.	THE SEAL IS PILOTED BY THE SUPPORT THE SUPPORT IS PILOTED BY THE NOZZLE.	THE PHASE II SILVER SEAL IS DESIGNED TO BE PILOTED BY THE ONE PIECE BEARING SUPPORT. THE PHASE II DESIGN ADEQUATELY CONTROLS THE STACK-UP OF THE STATIONARY HARDWARE TO PREVENT MOTION BETWEEN MATING PARTS.	RS007810-021 RS007801-191, -201
3. B800-04 CAUSE A THE INDUCER IS REDESIGNED FOR USE WITH THE LARGE THROAT MCC. THE NEW DESIGN DEMONSTRATED INCREASED PUMP CAPABILITIES AT HIGHER FLOW/SPEED WITH ACCEPTABLE INCREASE IN HEAD OUTPUT.	THE INDUCER IS DESIGNED FOR PHASE II/ BLOCK I OPERATING CONDITIONS	THE PHASE II INDUCER WAS DESIGNED FOR OPERATION WITH THE STANDARD THROAT ENGINE.	RS007812-005 RS007801-201 -191
4. B800-06 - CAUSE D, H THE BEARING OUTER RACE IS SECURED BY A TWO PIECE BEARING SUPPORT. THE SUPPORT FEATURES A STIFF INTEGRAL THRUST SHOULDER DESIGNED TO REACT TO BEARING THRUST LOADS.	THE OUTER RACE NUT SECURES THE PUMP END BEARING OUTER RACE TO THE SUPPORT. PRELOAD SUPPLIED BY THE OUTER RACE NUT REDUCES POTENTIAL FOR FRETTING OR GALLING	THE PHASE II DESIGN USING A NUT TO RETAIN THE OUTER RACE PROVIDES ADEQUATE CLAMPING AND ALIGNMENT	RS007814-015 RS007825-007 RS007826-003 RS007801-201 191
5. B800-05 - CAUSE B / B800-08 - CAUSE I BALLS ARE MADE FROM SILICON NITRIDE, WHICH WILL ELIMINATE WEAR.	THE BALLS AND RACES OF THE BEARINGS ARE MANUFACTURED UTILIZING 440C CRES	THE 440C BALLS IN THE PHASE II DESIGN ARE CONTROLLED FOR WEAR AND SPALLING BY OMRSD AND DAR Z880	RS007831-091, -181 RS007801-201 -191

Base Line Rationale	Variance	Change Rationale	Variant Dash Number
6. B800-01 - CAUSE A&B, B800-02, CAUSE A-D, B800-08 CAUSE D LPOTP NOZZLES ARE LIFE LIMITED PER DEVIATION DAR 2956	LPOTP NOZZLES ARE LIFE LIMITED PER DEVIATION DAR 2742	PHASE II LPOTP NOZZLES ARE LIFE LIMITED PER DEVIATION DAR 2742	RS007810-021
7. B800-08 - CAUSE M THE SHIM AND SPRING ARE MANUFACTURED UTILIZING INCOLOY 903, WHICH WAS SELECTED FOR CRYOGENIC MECHANICAL PROPERTIES.	B800-08 - CAUSE K THE SHIMS WERE MANUFACTURED UTILIZING NICKEL 200.	THE PHASE II DESIGN SHIM MATERIAL, NICKEL 200, PROVIDES ADEQUATE PROPERTIES FOR ITS FUNCTION.	RS007817 RS007801-201 -191
THE PUMP END BEARING OUTER RACE IS PILOTED BY THE SUPPORT AND IS RETAINED, TIGHT AGAINST THE SUPPORT SHOULDER ALONG WITH SHIMS AND SPRING, AND IS SECURED IN PLACE BY THE DEFLECTOR.	B800-09 - CAUSE D THE PUMP END BEARING OUTER RACE IS PILOTED BY THE SUPPORT AND IS RETAINED, ALONG WITH A SHIM, BY THE OUTER RACE NUT.	THE PHASE II DESIGN USING A NUT TO RETAIN THE OUTER RACE PROVIDES ADEQUATE CLAMPING AND ALIGNMENT.	
8. B800-01 THROUGH B800-09 THE PUMP SUBASSEMBLIES ARE INSPECTED DURING OVERHAUL PER SPECIFICATION REQUIREMENTS RL01219	THE PUMP SUBASSEMBLIES ARE INSPECTED DURING OVERHAUL PER SPECIFICATION REQUIREMENTS RL00473	THE RL00473 WAS SPECIFICALLY WRITTEN FOR THE PHASE II DESIGN	RS007801-191,-201
9. B800-02 THROUGH B800-04 AND B800-06 THROUGH B800-09 ASSEMBLY INTEGRITY IS VERIFIED PER DRAWING AND SPECIFICATION REQUIREMENTS RL01323	ASSEMBLY INTEGRITY IS VERIFIED PER DRAWING AND SPECIFICATION REQUIREMENTS RL00006.	THE RL00006 WAS SPECIFICALLY WRITTEN FOR THE PHASE II DESIGN	RS007801-191,-201
10. B800-04 FAILURE CAUSE A AND B NET POSITIVE SUCTION PRESSURE REQUIREMENTS WERE SATISFIED OVER THE ENTIRE OPERATING RANGE BY DESIGN VERIFICATION TESTING VRS 0553	NET POSITIVE SUCTION PRESSURE REQUIREMENTS WERE SATISFIED OVER THE ENTIRE OPERATING RANGE BY DESIGN VERIFICATION TESTING DVS-SSME-401B	THE DVS SSME 401B WAS SPECIFICALLY WRITTEN FOR THE PHASE II DESIGN	RS007801-191,-201

Base Line Rationale	Variance	Change Rationale	Variant Dash Number
11. B800-01 - CAUSE C VENT HOLES DESIGNED INTO THE SEAL RING STRUCTURE PREVENT PRESSURE BUILDUP AND DISTORTION OF THE SEAL RING ONTO THE LABYRINTH SEAL.	VENT HOLES DESIGNED INTO THE SUPPORT STRUCTURE PREVENT PRESSURE BUILDUP AND DISTORTION OF THE SEAL RING ONTO THE LABYRINTH SEAL.	PHASE II DESIGN ADEQUATELY PREVENTS PRESSURE BUILD UP	RS007816-009 RS007801-201 -191