SSME FMEA/CIL
REDUNDANCY SCREEN

Component Group: Fuel Turbopumps
CIL Item: B200-11
Component: High Pressure Fuel Turbopump
Part Number: RS007501
Failure Mode: Excessive impeller bypass leakage.

Prepared: D. Early
Approved: T. Nguyen
Approval Date: 4/21/98
Change #: 1
Directive #: CCBD ME3-01-5206

Phase	Failure / Effect Description	Criticality Hazard Reference
S 4.1	Leakage results in reduced turbopump output. Decreased flow is sensed by the controller which increases the fuel preburner oxidizer flow. Excessive turbine discharge temperature will cause a redline shutdown. Mission scrub if detected by redline. Loss of vehicle due to HPFTP turbine 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-D1S,M
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SSME FMEA/CIL
DESIGN

Component Group:	Fuel Turbopumps	Prepared:	D. Early
CIL Item:	B200-11	Approved:	T. Nguyen
Component:	High Pressure Fuel Turbopump	Approval Date:	4/21/99
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		Page:	1 of 1

Design / Document Reference

FAILURE CAUSE: A: Fracture, distortion of impeller front labyrinth.
B: Fracture, distortion of impeller rear labyrinth.

THE THREE IMPELLERS (1) (2) (3) ARE MANUFACTURED UTILIZING A TITANIUM 5A1-2.5Sn (ELI) FORGING. TITANIUM WAS SELECTED FOR ITS STRENGTH, TOUGHNESS, FATIGUE PROPERTIES, AND ITS INSENSITIVITY TO HYDROGEN ENVIRONMENT EMBRITTLEMENT AT OPERATING TEMPERATURES (4). THE MATERIAL IS ANNEALED TO IMPROVE MECHANICAL PROPERTIES. GRAIN DIRECTION IS SPECIFIED BY DRAWING REQUIREMENTS TO ACHIEVE MAXIMUM MATERIAL PROPERTIES IN THE DIRECTION OF THE HIGHEST LOADS. LABYRINTHS ON THE FRONT AND REAR SHROUDS OF THE FIRST- AND SECOND STAGE IMPELLERS AND THE FRONT SHROUD OF THE THIRD-STAGE IMPELLER MATE WITH NON-ROTATING STEPPED SEALS TO CONTROL PARASITIC LEAKAGE FLOW. THE LABYRINTHS ARE SINGLE POINT MACHINED TO AVOID THE RESIDUAL STRESSES ASSOCIATED WITH MORE ABUSIVE MACHINING METHODS SUCH AS CRUSH GRINDING. THE MATING SEALS FOR THE FRONT LABYRINTHS (5) ARE MANUFACTURED UTILIZING KEL-F TO TAKE ADVANTAGE OF ITS SOFTNESS COMPARED TO TITANIUM. KEL-F WAS SELECTED FOR ITS COLD FLOW RESISTANCE AND WEAR CHARACTERISTICS (4). THE MATING SEALS FOR THE REAR LABYRINTHS (6) ARE MANUFACTURED UTILIZING 2024 ALUMINUM ALLOY. THIS ALUMINUM ALLOY IS A RELATIVELY SOFT, LIGHTWEIGHT, CORROSION-RESISTANT MATERIAL IT IS RESISTANT TO STRESS CORROSION CRACKING AND IS NOT SUSCEPTIBLE TO HYDROGEN ENVIRONMENT EMBRITTLEMENT (4). THE MATERIAL IS SOLUTION TREATED, AGED, AND ANODIZED. THE CLEARANCE BETWEEN THE IMPELLER LABYRINTHS AND WEAR RINGS ARE CONTROLLED PER DRAWING REQUIREMENTS. THE FACTOR OF SAFETY FOR BURST FOR THE IMPELLERS HAS BEEN DEMONSTRATED BY DESIGN VERIFICATION TESTS (7). THE ROTATING ASSEMBLY HAS BEEN DESIGN VERIFICATION TESTED FOR SPRING RATE (LOAD DEFLECTION) AND NATURAL FREQUENCY (VIBRATION) DETERMINATION (8).

(1) R0019226; (2) RS007555; (3) RS007556. (4) RSS-8580-10; (5) R0012199, R0012205; (6) RS007529; (7) RSS-404-36; (8) RSS-404-37

FAILURE CAUSE: C: Kel-F wear ring damage.

SAME AS FAILURE CAUSE A PLUS:

THE KEL-F SEALS (1) (2) CONTROL THE AMOUNT OF PARASITIC LEAKAGE ALONG THE IMPELLERS FRONT SHROUDS. KEL-F WAS SELECTED FOR ITS SOFTNESS COMPARED TO TITANIUM, RESISTANCE TO COLD FLOW, AND WEAR CHARACTERISTICS. THE MATERIAL IS ANNEALED TO STRESS RELIEVE THE SEAL AFTER MACHINING. THE KEL-F SEALS ARE INSTALLED IN SUPPORTS (3) (4) AND POSITIONED INTO THE INLET (5) OR DIFFUSERS (6) (7). A NUT (8) (9), SECURES THE SUPPORT TO THE INLET OR DIFFUSERS. THE ASSEMBLY IS LOCKED INTO EITHER THE INLET OR THE DIFFUSER BY A PIN (10) BETWEEN IT AND THE MATING STRUCTURE. A LOCK TAB (11) LOCKS THE NUT TO THE SUPPORT. RADIAL POSITIONING OF THE KEL-F SEAL WITHIN THE SUPPORT IS PROVIDED BY TWO OUTSIDE DIAMETER PILOTS AT ASSEMBLY AND TWO INSIDE DIAMETER PILOTS IN OPERATION. AXIAL POSITIONING IS CONTROLLED BY A FLAT SURFACE AGAINST THE SUPPORT AND A TAPERED SURFACE AGAINST THE NUT. A SHIM (12) BETWEEN THE NUT AND SUPPORT IS SIZED TO PROVIDE FREEDOM FOR RELATIVE SLIDING BETWEEN THE TAPERED SURFACES OF THE SEAL AND NUT. THIS ASSURES AXIAL PRELOAD ON THE SEAL WHILE ACCOMMODATING THE LARGE DIFFERENTIAL IN THERMAL CONTRACTION RATES FOR THE TWO MATERIALS. THE DIAMETERS OF THE RADIAL PILOTS IN CONJUNCTION WITH VENT HOLES IN THE SUPPORT BETWEEN THE PILOTS ARE CONFIGURED TO OPTIMIZE THE PRESSURE BALANCE ON THE SEAL. SEVERAL INSTANCES OF INTERNAL AND EXTERNAL KEL-F MELT HAVE BEEN OBSERVED DUE TO LOSS OF STACK PRELOAD DURING OPERATION. THIS CONDITION HAS NO EFFECT ON TURBOPUMP PERFORMANCE AND REPLACEMENT OF THE SEALS FOR DAMAGE IS A MAINTENANCE ITEM AT OVERHAUL.

(1) R0012205; (2) R0012199; (3) R0012201; (4) R0012206 (5) RS007535 (6) RS007527; (7) RS007532; (8) R0012197; (9) R0012203; (10) RD122-3003; (11) R0012198 R0012204; (12) R0012207

FAILURE CAUSE: ALL CAUSES

THE HIGH AND LOW CYCLE FATIGUE LIFE FOR THE SECOND STAGE IMPELLER AND KEL-F WEAR RINGS MEETS CEI REQUIREMENTS (1). THE FIRST STAGE IMPELLER IS LIFE LIMITED BY MAJOR WAIVER (6). THE MINIMUM FACTORS OF SAFETY FOR THESE PARTS MEET CEI REQUIREMENTS (2). THE KEL-F SEALS PARENT MATERIAL WAS CLEARED FOR FRACTURE MECHANICS/NDE FLAW GROWTH SINCE THEY ARE NOT FRACTURE CRITICAL PARTS, EXCEPT FOR FIRST, SECOND, AND THIRD-STAGE IMPELLERS WHICH WERE CLEARED BY CRITICAL INITIAL FLAW SIZE DETECTABILITY (3). THE CONTROLLER SOFTWARE IS CONFIGURED TO DETECT AND RESPOND PROPERLY TO THE FAILURES IDENTIFIED AND COMMAND A SAFE ENGINE STATE (4). REUSE OF PARTS DURING OVERHAUL IS CONTROLLED BY THE REQUIREMENTS OF THE OVERHAUL SPECIFICATION (5).

(1) RL00532, CP320R0003B; (2) RSS-8546-16, CP320R0003B; (3) NASA TASK 117; (4) CP406R0002 PT 1 3.2.3.5.3; (5) RL00528; (6) DAR 1695

SSME FMEA/CIL
INSPECTION AND TEST

Component Group: Fuel Turbopumps
CIL Item: B200-11
Component: High Pressure Fuel Turbopump
Part Number: RS007501
Failure Mode: Excessive impeller bypass leakage.

Prepared: D. Early
Approved: T. Nguyen
Approval Date: 4/21/99
Change #: 1
Directive #: CCBD ME3-01-5206

Failure Causes	Significant Characteristics	Inspection(s) / Test(s)	Document Reference
A, B	FIRST-STAGE IMPELLER SECOND-STAGE IMPELLER THIRD-STAGE IMPELLER		R0019226 RS007555 RS007556
	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER SPECIFICATION REQUIREMENTS.	RB0170-152
		THE FORGING IS PENETRANT AND ULTRASONIC INSPECTED PER SPECIFICATION REQUIREMENTS.	RA0115-116 RA0115-012
		THE FORGINGS GRAIN DIRECTION IS VERIFIED PER DRAWING REQUIREMENTS.	RS007556
		THE IMPELLER SPIN TEST VERIFIES MAXIMUM GROWTH PER DRAWING AND SPECIFICATION REQUIREMENTS.	R0019226 RS007555 RS007556 RL00075
		THE IMPELLER IS PENETRANT INSPECTED AFTER SPIN TEST PER SPECIFICATION REQUIREMENTS.	RA0115-116
	ASSEMBLY INTEGRITY	LABYRINTHS DIAMETERS AND SURFACE FINISH ARE VERIFIED PER DRAWING REQUIREMENTS.	R0019226 RS007555 RS007556
	OVERHAUL	IMPELLERS ARE INSPECTED AT OVERHAUL PER SPECIFICATION REQUIREMENTS.	RF0004-302
C	SEAL SEAL		R0012199 R0012205
	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER SPECIFICATION REQUIREMENTS.	RB0130-009
	HEAT TREAT	THE ANNEALED CONDITION IS VERIFIED PER DRAWING REQUIREMENTS AFTER THE MACHINING OPERATION	R0012199 R0012205
	ASSEMBLY INTEGRITY	IMPELLER LABYRINTH DIAMETERS ARE INSPECTED PER DRAWING REQUIREMENTS.	R0019226 RS007555 RS007556

Component Group: Fuel Turbopumps
CIL Item: B200-11
Component: High Pressure Fuel Turbopump
Part Number: RS007501
Failure Mode: Excessive impeller bypass leakage.

Prepared: D. Early
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Approval Date: 4/21/99
Change #: 1
Directive #: CCBD ME3-01-5206

Failure Causes	Significant Characteristics	Inspection(s) / Test(s)	Document Reference
C	ASSEMBLY INTEGRITY	SEAL LAND DIAMETERS ARE INSPECTED PER DRAWING REQUIREMENTS.	R0012199 R0012205
		SEAL IS VERIFIED AS BOTTOMED PER SPECIFICATION REQUIREMENTS.	RI 00351
		NUT TORQUE IS VERIFIED PER DRAWING REQUIREMENTS	RS007501
		LOCK IS DEFORMED PER DRAWING REQUIREMENTS.	
		THE ROTATING ASSEMBLY BALANCE IS VERIFIED PER SPECIFICATION REQUIREMENTS.	RL00352
		KEL F WEAR RINGS ARE VISUALLY INSPECTED PER SPECIFICATION REQUIRMENTS.	RL00050-04
ALL CAUSES	HPFTP		RS007501
	CLEANLINESS OF COMPONENTS	COMPONENTS ARE VERIFIED CLEANED PER SPECIFICATION REQUIREMENTS.	RL10001
	ASSEMBLY INTEGRITY	TURBOPUMP OPERATION IS VERIFIED THROUGH ENGINE HOT-FIRE ACCEPTANCE TESTING.	RL00451
		THE PUMP SUBASSEMBLIES ARE INSPECTED DURING OVERHAUL PER SPECIFICATION REQUIREMENTS. INSPECTIONS INCLUDE. VISUAL, DIMENSIONAL, PENETRANT, AND REPLACEMENT OF USAGE ITEMS AS APPLICABLE. PER OVERHAUL CLASSIFICATION	RL00528 RAD115-116
		SHAFT TRAVEL IS PERFORMED PRIOR TO EACH FLIGHT.	OMRSD V41BS0.020
		TORQUE CHECKS ARE PERFORMED PRIOR TO EACH FLIGHT.	
		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 88RC09761.
Operational Use: Not Applicable.

SSME FMEA/CIL
FIELD CONFIGURATION VARIANCES FROM CIL RATIONALE

Component Group: Fuel Turbopumps
Item Name: High Pressure Fuel Turbopump
Item Number: B200
Part Number: RS007501

Prepared: D. Early
Approved: T. Nguyen
Approval Date: 4/21/99
Change #: 2
Directive #: CCBD ME3-01-5208

Base Line Rationale	Variance	Change Rationale	Variant Dash Number
1. B200-15 RS007502; CAUSE A. B200-24; RS007605; CAUSE A THE INNER AND OUTER BEARING RACES ARE EDDY CURRENT INSPECTED PER RL00743.	BEARING RACES RECEIVED FROM SUPPLIER SPLIT BALL BEARING INCORPORATED RECEIVED NO GENERAL EDDY CURRENT INSPECTION	GENERAL EDDY CURRENT INSPECTION OF RACES REPLACES TYPE IVC IN PENETRANT INSPECTION IN DETECTING SURFACE FLAWS USE AS IS RATIONALE: 1. RACES SUPPLIED BY SPLIT BALL BEARING INCORPORATED RECEIVED 10X VISUAL AND TYPE IVC PENETRANT INSPECTION INSTEAD OF GENERAL EDDY CURRENT INSPECTION. FLAW DETECTABILITY RELIABILITY LEVELS BETWEEN PENETRANT AND GENERAL EDDY CURRENT INSPECTIONS ARE 0.060 AND 0.057 RESPECTIVELY.	SEE DAR 2745 FOR VARIANT PART SERIAL NUMBERS.
2. B200-13 RS007527, RS007532, CAUSE A & B. B200-26: RS007532; CAUSE B. DIFFUSER HIDDEN SURFACES ARE PENETRANT INSPECTED PER RL00343.	SOME DIFFUSERS MAY NOT RECEIVE THE POST PROOF TEST HIDDEN SURFACE IIa PENETRANT INSPECTION	USE AS IS RATIONALE 1 IMPLEMENTATION OF HIDDEN SURFACE INSPECTION REQUIREMENT IS NOT A RESULT OF AN OBSERVED HARDWARE ANAOMALY BUT AS A RESULT OF ROCKETDYNE'S STAND DOWN.	SEE DAR 2751 FOR VARIANT PART SERIAL NUMBERS
3 B200-14 CAUSE A, RS007568 B200-21 CAUSE B, RS007568 B200-26 CAUSE A, RS007568 WELD JOINTS RS007568 TABLE B200 HPFTP FMEA/CIL WELD JOINTS RS007568 HOUSING CURRENT CONFIGURATION IS THE ONE(1) PIECE "-113" CAP, USING FOUR (4) WELDS AND FOUR (4) WELD NUMBERS	SOME HOUSINGS (POSSIBLY TWO) MAY HAVE BEEN FABRICATED WITH THE TWO (2) PIECE "-113" CAPS (THIS HAS AN EXTRA WELD: #13 AND THREE EXTRA WELD NUMBERS 13, 68 & 69)	TO REDUCE CONFUSION ON THE DRAWING AND ON THE MANUFACTURING FLOOR	SEE MCR 2524. SAME -113 DASH NUMBER.
4 B200-02; CAUSE A, RS007524 CAUSE B, RS007524; CAUSE C, RS007524	SOME TURBINE BEARING SUPPORTS (RS007524) ARE FABRICATED USING A WELDMENT OF HAYFS 188 SHEET METAL INSTEAD OF THE EDM FORGING.	HIGH CYCLE FATIGUE INDUCED INLET SHEET METAL CRACKS DO OCCUR FROM THE OPERATIONAL ENVIRONMENT EXPERIENCED DURING ENGINE OPERATION. THE CRACKING IS CONTROLLED PER THE REQUIREMENTS OF THE SHEET METAL INSPECTION SPECIFICATION (RL00655) WHICH LIMITS THE CRACKING LENGTH, SPACING, AND SHAPE, TO PRECLUDE SHEET METAL PIECES FROM DISLODGING. THE CRITERIA IS BASED ON CRACK GROWTH RATES AND ENGINE TEST EXPERIENCE. ANY CRACKS, WHICH EXCEED THE SPECIFICATION LIMITS, ARE WELD REPAIRED (RF0001-007). THE TURBINE BEARING SUPPORT WITH WELDED SHEET METAL IS LIFE LIMITED BY MAJOR WAIVER DAR 2709.	RS007524-201 AND SUBS.

Component Group: Fuel Turbopumps
Item Name: High Pressure Fuel Turbopump
Item Number: B200
Part Number: RS007501

Prepared: D. Early
Approved: T. Nguyen
Approval Date: 4/21/99
Change #: 2
Directive #: CCBD ME3-01-5206

Base Line Rationale	Variance	Change Rationale	Variant Dash Number
5 B200-16 CAUSE A, B200-17 CAUSE A, B200-18 CAUSE A, B200-19 CAUSE A, B200-22; CAUSE A,B,C,E	SOME LIFT-OFF SEAL HOUSING DRAIN LINES ARE FABRICATED USING INTERSECTING LINE DRILLED HOLES THE HOLE THAT INTERSECTS THE OUTSIDE DIAMETER OF THE HOUSING FLANGE HAS A PLUG INSTALLED. THE PLUG IS THEN WELDED AT THE HOUSING OUTSIDE DIAMETER TO FORM A TIGHT GAS SEAL	LOW CYCLE FATIGUE CRACKING HAS BEEN OBSERVED IN THE PLUG WELD. CRACK INITIATION AND PROPAGATION OCCURS AT SHUTDOWN/COOLDOWN ALL UNITS RECEIVE A STANDARD POST FLIGHT INSPECTIONS BY LEAK CHECK. LEAK CHECK POST FLIGHT WILL DETECT A CRACK PRIOR TO REFLIGHT. POST LEAKAGE AT THE DRAIN LINE IS LIMITED TO 10 SCIM. ALL FLIGHT UNITS WILL CONTINUE TO RECEIVE A LEAK CHECK POST FLIGHT FOR THE DRAIN LINE PLUG WELD UNITL THE ENTIRE FLEET IS RETROFIT WITH THE EDM DRAIN LINE CONFIGURATION	R0019230-071 AND SUBS.

SSME FMEA/CIL
WELD JOINTS

Component Group: Fuel Turbopumps
CIL Item: B200
Component: High Pressure Fuel Turbopump
Part Number: RS007501

Prepared: D. Early
Approved: T. Nguyen
Approval Date: 4/21/99
Change #: 2
Directive #: CCBD ME3-01-5206

Component	Basic Part Number	Weld Number	Weld Type	Class	Root Side Not Access	Critical Initial Flaw Size Not Detectable HCF	LCF	Comments
SHIELD	R0012171	1-24, 28-62	GTAW	II	X			
SHIELD	R0012171	26	GTAW	II				
LIFT-OFF SEAL	R0019230	1, 2	GTAW	II	X			
SHIELD	R0019788	26, 28	GTAW	II				
SHIELD	R0019788	27 50	GTAW	II	X			
SHIELD	R0019788	51, 52	GTAW	I				
SHIELD	R0019788	53, 55	GTAW	II				
BELLOWS	RS007505	1-4	GTAW	I		X		
BELLOWS	RS007505	5, 6	EBW	I		X		
INLET	RS007512	4	GTAW	I		X		
INLET	RS007512	5-6	GTAW	I				
INLET	RS007512	7-10, 12, 13	GTAW	I				
INLET	RS007512	11	EBW	II				
INLET	RS007512	14 15	GTAW	I				
INLET	RS007512	16	GTAW	I		X		
BEARING SUPPORT	RS007524	14	EBW	I				
BEARING SUPPORT	RS007524	18	EBW	I	X			
BEARING SUPPORT	RS007524	29, 30	GTAW	I	X	X		
BEARING SUPPORT	RS007524	1*8	GTAW	I	X			
BEARING SUPPORT	RS007524	119, 121	EBW	I				
BEARING SUPPORT	RS007524	120	GTAW	II	X			
BEARING SUPPORT	RS007524	229-241	GTAW	II	X			
HOUSING	RS007568	75 223, 228 230 298	GTAW	I	X	X	X	
HOUSING	RS007568	74	GTAW	I				
HOUSING	RS007568	48	EBW	I	X	X	X	
HOUSING	RS007568	49	GTAW	I	X			
HOUSING	RS007568	51	GTAW	II	X	X		
HOUSING	RS007568	52	GTAW	II	X			
HOUSING	RS007568	53	EBW	I				

Component	Basic Part Number	Weld Number	Weld Type	Class	Root Side Not Access	Critical Initial Flaw Size Not Detectable HCF	LCF	Comments
HOUSING	RS007568	55	EBW	II	X			
HOUSING	RS007568	56	GTAW	II	X			
HOUSING	RS007568	57, 324 325	GTAW	II				
HOUSING	RS007568	58	GTAW	II	X	X	X	
HOUSING	RS007568	59	EBW	I				
HOUSING	RS007568	74, 229, 297	GTAW	I	X	X	X	
HOUSING	RS007568	76, 77	GTAW	I		X		
HOUSING	RS007568	78-89	GTAW	II	X			
HOUSING	RS007568	90-101	GTAW	II	X			
HOUSING	RS007568	102	GTAW	I	X			
HOUSING	RS007568	139	GTAW	II	X			
HOUSING	RS007568	140	GTAW	II	X			
HOUSING	RS007568	153, 154	GTAW	II	X			
HOUSING	RS007568	174-185	GTAW	II	X			
HOUSING	RS007568	191 192, 195, 196 245, 455 456	GTAW	II	X	X		
HOUSING	RS007568	193, 194, 197-202 204-207	GTAW	II		X		
HOUSING	RS007568	203, 217, 218, 234, 236	GTAW	II	X	X		
HOUSING	RS007568	212, 213	GTAW	II				
HOUSING	RS007568	214 215	GTAW	II	X			
HOUSING	RS007568	222, 239	GTAW	I		X		
HOUSING	RS007568	224, 225	GTAW	I		X	X	
HOUSING	RS007568	226, 227	GTAW	I		X		
HOUSING	RS007568	231, 232	GTAW	II	X	X		
HOUSING	RS007568	233	GTAW	II	X			
HOUSING	RS007568	237 238	GTAW	II				
HOUSING	RS007568	246-248	GTAW	II				
HOUSING	RS007568	326-349	GTAW	II	X			
HOUSING	RS007568	374-397	GTAW	II	X			
HOUSING	RS007568	399	GTAW	I	X	X	X	