SSME F[illegible]A/CIL
REDUNDAN[illegible] SCREEN

Component Group:	Fuel Turbopumps	Prepared:	F. Cromwell
CIL Item:	B600-03	Approved:	T. Nguyen
Part Number:	RS007601	Approval Date:	11/1/99
Component:	Low Pressure Fuel Turbopump	Change #:	2
FMEA Item:	B600	Directive #:	CCBD ME3-01-5248
Failure Mode:	Fails to transmit torque.	Page:	1 of 1

Phase	Failure / Effect Description	Criticality Hazard Reference
SMC 4.1	Turbine unloads and overspeeds with possible fragmentation of turbopump components. Loss of fuel flow to HPFTP would cause cavitation and a turbine discharge temperature redline shutdown. Potential loss of fuel containment resulting in an external fire. Loss of vehicle.	I ME-D25,A,M,C
	Redundancy Screens: SINGLE POINT FAILURE: N/A	

SSME FMEA/CIL
DESIGN

Component Group:	Fuel Turbopumps	Prepared:	F. Cromwell
CIL Item:	B600-03	Approved:	T. Nguyen
Part Number:	RS007601	Approval Date:	11/1/99
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Failure Mode:	Fails to transmit torque.	Page:	1 of 2

Design / Document Reference

FAILURE CAUSE: A: Spline failures:
Shaft-to-inducer spline
Shaft-to-wheel spline.

THE SHAFT (1) TRANSMITS THE TORQUE GENERATED BY THE TURBINE ROTORS (2) THROUGH THE TURBINE WHEEL (3) TO THE PUMP INDUCER (4). THE PARTS ARE MATED BY INVOLUTE SPLINES AT EACH END OF THE SHAFT. THE SHAFT AND THE TURBINE WHEEL ARE MANUFACTURED UTILIZING FORGED A-286 CRES (5), WHICH IS RESISTANT TO HYDROGEN ENVIRONMENT EMBRITTLEMENT, AND HAS THE REQUIRED MECHANICAL PROPERTIES. THE MATERIAL IS SOLUTION TREATED AND AGE HARDENED. THE INDUCER IS MANUFACTURED UTILIZING A SINGLE FORGING OF 6AL-2.5SN (ELI) TITANIUM ALLOY (5), WHICH AT CRYOGENIC TEMPERATURES, HAS THE REQUIRED TOUGHNESS, MECHANICAL, AND FATIGUE PROPERTIES. THIS ALLOY IS NOT SUSCEPTIBLE TO HYDROGEN ENVIRONMENT EMBRITTLEMENT AT OPERATING TEMPERATURES. THE MATERIAL IS ANNEALED TO IMPROVE MECHANICAL PROPERTIES. THE SPLINES ARE LUBRICATED AT ASSEMBLY TO PREVENT FRETTING WHILE REDUCING FRICTION FOR DISASSEMBLY. THE TURBINE NOZZLE BLOCKAGE AND TURBINE DRIVELINE ORIFICE (F-7) ARE SIZED TO PRECLUDE EXCESSIVE OPERATING SHAFT SPEED AND LOADING OF THE SPLINES. THE GREEN RUN SPECIFICATION LIMITS THE ALLOWABLE MAXIMUM SHAFT SPEED (6)

(1) RS007628; (2) RS007624, RS007625; (3) RS007626; (4) RS007604; (5) RSS-8577, (6) RL00461

FAILURE CAUSE: B: Turbine shaft nut failure.

A SHAFT NUT (1) IS INSTALLED ON EACH END OF THE SHAFT (2) TO SECURE THE TURBINE WHEEL (3) AND PUMP INDUCER (4). MOLYKOTE G LUBRICANT IS APPLIED TO THE NUT THREADS AT ASSEMBLY TO REDUCE THREAD FRICTION, PROVIDING A MORE ACCURATE CLAMPING LOAD. EACH NUT IS LOCKED (5) TO PREVENT ROTATION. ASSEMBLY PROCEDURES FOR LOCKING DEVICES ENSURE DEFECT-FREE INSTALLATION (6). THE SHAFT NUT IS MANUFACTURED UTILIZING A-286 CRES BAR, WHICH WAS SELECTED FOR ITS RESISTANCE TO HYDROGEN ENVIRONMENT EMBRITTLEMENT AND ITS MECHANICAL PROPERTIES (7). THE MATERIAL IS SOLUTION-TREATED AND AGE-HARDENED. THE LOCK IS MANUFACTURED UTILIZING 302 CRES SHEET, WHICH WAS SELECTED FOR ITS DUCTILITY, TENSILE STRENGTH, AND ITS INSENSITIVITY TO HYDROGEN ENVIRONMENT EMBRITTLEMENT (7). THE MATERIAL IS ANNEALED TO IMPROVE MECHANICAL PROPERTIES. THE NUT AND LOCKS ARE NOT SERIALIZED OR TIME HISTORY TRACKED BUT HAVE INFINITE ALLOWABLE LIFE (8).

(1) RS007619, (2) RS007628; (3) RS007626; (4) RS007604; (5) RS007620; (6) RL00353; (7) RSS-8577; (8) RL00532, CP320R0038

FAILURE CAUSE: C: Turbine wheel failure.

THE FIRST (1) AND SECOND (2) ROTORS BOLT ONTO THE TURBINE WHEEL (3). THE ROTORS ARE RADIALLY PILOTED ON A LIP AT THE WHEEL OUTSIDE DIAMETER. INTERNAL INVOLUTE SPLINES ON THE WHEEL INSIDE DIAMETER MATE WITH SPLINES ON THE END OF THE SHAFT (4). THE WHEEL IS LOCKED IN PLACE BY THE SHAFT NUT (5). TWO LABYRINTHS AT THE WHEEL OUTSIDE DIAMETER FORM A SEAL WITH THE STATOR (6) INSIDE DIAMETER TO LIMIT THE AMOUNT OF HYDROGEN GAS BYPASSING THE STATOR. THE WHEEL IS MANUFACTURED UTILIZING FORGED A-286 CRES, WHICH IS RESISTANT TO HYDROGEN ENVIRONMENT EMBRITTLEMENT, AND HAS THE REQUIRED MECHANICAL PROPERTIES (7). THE MATERIAL IS SOLUTION-TREATED AND AGE-HARDENED. THE TURBINE WHEEL ASSEMBLY HAS BEEN DESIGN VERIFICATION TESTED FOR VIBRATION CHARACTERISTICS (8).

(1) RS007624; (2) RS007625; (3) RS007628 (4) RS007619; (5) RS007623; (7) RSS-8577; (8) RSS-402

FAILURE CAUSE: D: Shaft failure.

THE SHAFT (1) TRANSMITS THE TORQUE GENERATED BY THE TURBINE ROTORS (2) THROUGH THE TURBINE WHEEL (4) TO THE PUMP INDUCER (3). THE TURBINE WHEEL (4) AND THE INDUCER ARE MATED TO THE ROTOR BY INVOLUTE SPLINES AND ARE SECURED BY SHAFT NUTS (5) AND LOCKS (6). THE SHAFT INCORPORATES SEALING SURFACES FOR THE TURBINE SEAL (7), LIFT-OFF SEAL (8) AND PUMP SEAL (9). THE SHAFT IS HOLLOWED TO REDUCE WEIGHT AND INCORPORATES FOUR HOLES IN THE CENTRAL CAVITY WHICH ALLOWS THE BEARING COOLANT FLOW TO RETURN TO THE INDUCER HUB NEAR THE VANE LEADING EDGES. THE SHAFT IS MANUFACTURED UTILIZING FORGED A-286 CRES, WHICH WAS SELECTED FOR ITS RESISTANCE TO HYDROGEN ENVIRONMENT EMBRITTLEMENT AND MECHANICAL PROPERTIES (10). THE MATERIAL IS SOLUTION TREATED AND AGE HARDENED. THE SEALING SURFACES ARE FLAME SPRAYED WITH TUNGSTEN CARBIDE FOR WEAR RESISTANCE

(1) RS007628 (2) RS007624, RS007625; (3) RS007604; (4) RS007626 (5) RS007619; (6) RS007620; (7) R0019801; (8) R0012152; (9) RES1099, R0019865; (10) RSS-8577

Design / Document Reference

FAILURE CAUSE: E: Inducer hub failure.

THE PUMP INDUCER (1) INCORPORATES FOUR FULL VANES AND FOUR LONG PARTIAL VANES WHICH ARE HYDRODYNAMICALLY SHAPED TO PROVIDE THE REQUIRED HEAD RISE TO THE HPFTP PUMP INLET AND MEET THE ICD MINIMUM NET POSITIVE SUCTION PRESSURE (NPSP) REQUIREMENTS. THE INDUCER WAS DESIGNED TO MAINTAIN A CONTROLLED OPERATING CLEARANCE WITH THE PUMP HOUSING (2) TO MAXIMIZE PUMP EFFICIENCY. THE INDUCER IS MATED TO THE SHAFT (3) BY INVOLUTE SPLINES. A RETAINING NUT (4) IS INSTALLED AND LOCKED (5) TO SECURE THE INDUCER. THE INDUCER HUB PROVIDES JOURNALS FOR THE TURBINE-END (6) AND PUMP-END BEARINGS (7). THE FOUR HOLES LOCATED IN THE INDUCER HUB NEAR THE VANE LEADING EDGES ALLOW THE BEARING COOLANT TO RETURN TO THE MAIN FLOW STREAM. THE INDUCER VANE FILLETS ARE RADIUSED TO REDUCE STRESS RISERS. THE INDUCER IS MANUFACTURED UTILIZING FORGED 5AL-2.5SN (ELI) TITANIUM ALLOY (8). THIS MATERIAL WAS SELECTED FOR ITS TOUGHNESS AND MECHANICAL AND FATIGUE PROPERTIES AT CRYOGENIC TEMPERATURES. THIS ALLOY IS NOT SUSCEPTIBLE TO HYDROGEN ENVIRONMENT EMBRITTLEMENT AT OPERATING TEMPERATURES. THE MATERIAL IS ANNEALED TO IMPROVE ITS PROPERTIES. THE INDUCER HAS BEEN DESIGN VERIFICATION TESTED FOR VIBRATION CHARACTERISTICS (9). FOUR INDUCERS, WHICH EACH HAVE ACCUMULATED OVER 15,000 TOTAL SECONDS, HAVE BEEN TYPE 4C DYE PENETRANT INSPECTED WITH NO CRACKS DETECTED.

(1) RS007604; (2) RS007632, R0019864; (3) RS007628; (4) RS007619; (5) RS007620; (6) RS007606; (7) RS007605; (8) RSS-8577; (9) RSS-402

FAILURE CAUSE: ALL CAUSES

LPFTP 9001 WAS OVERSPUN TO 37,000 RPM DURING A COCO 1B TEST. A REVIEW OF THE ACCELEROMETER DATA FROM THIS TEST WAS UTILIZED TO SATISFY THE DESIGN VERIFICATION REQUIREMENT FOR IDENTIFICATION OF CRITICAL SPEEDS (1). NO STRUCTURAL FAILURES OF THE ROTATING COMPONENTS RESULTED FROM THIS OVERSPEED. THE HIGH AND LOW CYCLE FATIGUE LIFE OF THE SHAFT, INDUCER, WHEEL, SHAFT NUT, AND LOCK 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 ARE NOT FRACTURE CRITICAL PARTS. EXCEPT FOR THE LPFTP INDUCER WHICH WAS CLEARED BY CRITICAL INITIAL FLAW SIZE DETECTABILITY (4). REUSE OF PARTS DURING OVERHAUL IS CONTROLLED BY THE REQUIREMENTS OF THE OVERHAUL SPECIFICATION (5).

(1) RSS-402; (2) RL00532, CP320R0003B; (3) RSS-8545, CP320R0003B; (4) NASA TASK 117; (5) RL00531

SSME FMEA/CIL
INSPECTION AND TEST

Component Group:	Fuel Turbopumps	Prepared:	F. Cromwell
CIL Item:	B600-03	Approved:	T. Nguyen
Part Number:	RS007601	Approval Date:	11/1/99
Component:	Low Pressure Fuel Turbopump	Change #:	2
FMEA Item:	B600	Directive #:	CCBD ME3-01-5248
Failure Mode:	Fails to transmit torque.	Page:	1 of 3

Failure Causes	Significant Characteristics	Inspection(s) / Test(s)	Document Reference
A, C, D, E	INDUCER WHEEL SHAFT		RS007604 RS007626 RS007628
	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER DRAWING AND SPECIFICATION REQUIREMENTS.	RS007626 RS007628 RL00170-157
		THE INDUCER AND WHEEL FORGINGS ARE ULTRASONIC AND PENETRANT INSPECTED PER SPECIFICATION REQUIREMENTS	RA0115-012 RA0115-116
		THE SHAFT, INDUCER, AND WHEEL ARE PENETRANT INSPECTED PER SPECIFICATION REQUIREMENTS	RA0115-115
	HEAT TREAT	HEAT TREAT IS VERIFIED PER DRAWING REQUIREMENTS.	RS007604 RS007628
	SURFACE FINISH	SPLINES MOLYKOTE LUBRICATION IS VERIFIED PER SPECIFICATION REQUIREMENTS.	RL00353
		SHAFT FLAME SPRAY IS VERIFIED PER DRAWING REQUIREMENTS.	RS007628

Component Group:	Fuel Turbopumps	Prepared:	F. Cromwell
CIL Item:	B600-03	Approved:	T. Nguyen
Part Numb.	RS007501	Approval Date:	11/1/99
Component:	Low Pressure Fuel Turbopump	Change #:	2
FMEA Item:	B600	Directive #:	CCBD ME3 01-5248
Failure Mode:	Fails to transmit torque.	Page:	2 of 3

Failure Causes	Significant Characteristics	Inspection(s) / Test(s)	Document Reference
A, C, D, E	SURFACE FINISH	SHAFT FLAME SPRAY IS VERIFIED PER DRAWING REQUIREMENTS.	RS007628
	ASSEMBLY INTEGRITY	SPLINES ARE INSPECTED PER SPECIFICATION AND DRAWING REQUIREMENTS.	RA0115-143 RS007604 RS007625 RS007629
		THE ROTATING ASSEMBLY TORQUE IS VERIFIED AT ASSEMBLY PER SPECIFICATION REQUIREMENTS.	RL00353
		SUBASSEMBLY BOTTOMING IS VERIFIED PER SPECIFICATION REQUIREMENTS	RL00353
		ROTATING COMPONENTS BALANCE IS VERIFIED PER SPECIFICATION REQUIREMENTS.	RL00546
		THE INDUCER HUB STRETCHING IS VERIFIED PER DRAWING AND SPECIFICATION REQUIREMENTS.	RS007601 RL00353
B	NUT LOCK SHAFT		RS007619 RS007620 RS007628
	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER DRAWING REQUIREMENTS	
	HEAT TREAT	SHAFT HEAT TREAT IS VERIFIED PER SPECIFICATION REQUIREMENTS.	RS007628

Component Group:	Fuel Turbopumps	Prepared:	[illegible]
CIL Item:	B600-03	Approved:	T. Nguyen
Part Number:	RS007601	Approval Date:	11/1/99
Component	Low Pressure Fuel Turbopump	Change #:	2
FMEA Item:	B600	Directive #:	CCBD ME3-01-5248
Failure Mode:	Fails to transmit torque.	Page:	3 of 3

Failure Causes	Significant Characteristics	Inspection(s) / Test(s)	Document Reference
B	HEAT TREAT	NUT IS INSPECTED FOR HARDNESS PER DRAWING REQUIREMENTS.	RS007619
	ASSEMBLY INTEGRITY	NUT TORQUE IS VERIFIED PER DRAWING REQUIREMENTS	RS007601
		LOCK DEFORMATION IS VERIFIED PER DRAWING REQUIREMENTS.	
ALL CAUSES	LPFTP		RS007501
	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 CLASSIFICATION.	RL00531 RA0115-110
		OPERATION/PERFORMANCE IS VERIFIED BY ENGINE HOT-FIRE TESTING AND 2ND E & M TESTS ON INSPECTIONS	RL00050-04 RL00050-05 RL00050-07 RL00481
		TORQUE CHECKS ARE PERFORMED PRIOR TO EACH FLIGHT.	OM/RSD V41BS0.010
		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 SA21/68/308 and Rocketdyne letter 89RC09761.

Operational Use: Not Applicable

Component Group: Fuel Turbopumps
CIL Item: B600
Part Number: RS007601
Component: Low Pressure Fuel Turbopump
FMEA Item: B600

Prepared: P. Cromwell
Approved: T. Nguyen
Approval Date: 11/1/99
Change #: 2
Directive #: CCBD ME3-01-5248
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
MANIFOLD	RS007603	1	EBW	Ia	X			
MANIFOLD	RS007603	2	GTAW	I				
MANIFOLD	RS007603	5,8,10	GTAW	II	X	X		
MANIFOLD	RS007603	9,10	GTAW	II	X			
MANIFOLD	RS007603	13	GTAW	I				
MANIFOLD	RS007603	17	EBW	II	X	X	X	
MANIFOLD	RS007603	18	GTAW	I	X	X	X	

SSME FMEA/CIL

FIELD CONFIGURATION VARIANCES FROM CIL RATIONALE

Component Group: Fuel Turbopumps
Item Name: Low Pressure Fuel Turbopump
Item Number: B600
Part Number: RS007601

Prepared: F. Cromwell
Approved: T. Nguyen
Approval Date: 11/1/99
Change #: 3
Directive #: CCBD ME3-01-5248

Base Line Rationale	Variance	Change Rationale	Variant Dash Number
1. B600-05: RS007605, RS007606; CAUSE A. THE INNER AND OUTER BEARING RINGS ARE EDDY CURRENT INSPECTED PER RA1615-034.	BEARING RINGS RECEIVED FROM SUPPLIER SPLIT BALL BEARING INCORPORATED RECEIVED NO GENERAL EDDY CURRENT INSPECTION.	GENERAL EDDY CURRENT INSPECTION OF RINGS REPLACES TYPE IVC IN PENETRANT INSPECTION IN DETECTING SURFACE FLAWS. USE AS IS RATIONALE: 1 RINGS ARE 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 B600-10. THE HOUSING INSULATION IS PROTECTED BY A KEVLAR COMPOSITE SURFACE WITH L-T-90 FIRE RETARDANT ALUMINUM TAPE APPLIED TO THE KEVLAR SURFACE	CERTAIN FLIGHT HOUSINGS HAVE NICKEL PLATED INSULATION WITH COPPER PLATED TIE-IN AREAS.	THE BLOCK I AND PHASE II HAVE NICKEL PLATING TO PROTECT THE INSULATION FROM MECHANICAL DAMAGE AND PROVIDE A MOISTURE BARRIER. THE HOUSING IS COPPER PLATED AT THE INSULATION CLOSE-OUT AREAS TO IMPROVE THE NICKEL BOND. THE MINIMUM FACTORS OF SAFETY FOR THE INSULATED HOUSING MEET C.E.I. REQUIREMENTS. DAR 2068 ADDRESSES THE TIME CONSTRAINTS FOR NICKEL PLATED INSULATION WITH COPPER PLATED TIE-IN CONFIGURATIONS.	RS007632 121, -131, -231, -21*
3. B600-05 THE BALLS ARE POSITIONED BY AN FEP COATED ARMALON CAGE. FEP COATING ON CAGES USED TO REDUCE POCKET AND BALL WEAR THUS INCREASING BEARING LIFE.	BLOCK I AND PHASE II PUMPS DO NOT HAVE FEP COATED CAGES.	BLOCK I AND PHASE II CAGES HAVE TEFLON CONTAINED IN THE FIBERGLASS CAGE THAT PROVIDES BEARING LUBRICATION.	RS007605-027 RS007606-007, -025
4. B600-01. BLOCK II NOZZLE ASSEMBLY ALLOWS A MINIMUM OF 12 OF THE 43 NOZZLE PASSAGES TO BE BLOCKED.	BLOCK I PHASE II NOZZLE ASSEMBLY ALLOWS A MINIMUM OF 16 OF THE 43 NOZZLE PASSAGES TO BE BLOCKED	THE BLOCK I PHASE II NOZZLE ASSEMBLY DOES NOT VIOLATE THE REQUIREMENTS OF THE BLOCK II NOZZLE ASSEMBLY. BLOCK I PHASE II NOZZLE MEETS CEI NOZZLE VANE REQUIREMENTS.	R0019780-091
5 B600-02. CAUSE B,C THE SECOND STAGE ROTOR BRAZE JOINT INTEGRITY IS ULTRASONIC INSPECTED PER DRAWING REQUIREMENTS.	CERTAIN SECOND STAGE ROTORS RECEIVED NO ULTRASONIC INSPECTION OF THE BRAZE JOINT.	THE BRAZE JOINTS OF ALL SECOND STAGE ROTORS HAVE RECEIVED A VISUAL AND PENETRANT INSPECTION. ALL PARTS SUSPECTED TO HAVE BRAZE JOINT ANOMALIES HAVE BEEN ADDRESSED.	RS007625-031
6. B600-02. CAUSE D NOZZLE COPPER PLATING ADHESION IS VERIFIED PER DRAWING REQUIREMENTS.	CERTAIN NOZZLES DID NOT RECEIVE A BAKE TEST.	ADHESION BAKE TEST IS NOT REQUIRED FOR NOZZLES WHICH HAVE BEEN PREVIOUSLY HOT FIRE TESTED. THE HOT FIRE ENVIRONMENT ADEQUATELY VERIFIES THE COPPER PLATING ADHESION INTEGRITY.	RS007622-025 R0019783-023
7. B600-02. CAUSE E. THE STATOR COPPER PLATING ADHESION IS VERIFIED PER DRAWING REQUIREMENTS	CERTAIN STATORS DID NOT RECEIVE A BAKE TEST.	ADHESION BAKE TEST IS NOT REQUIRED FOR STATORS WHICH HAVE BEEN PREVIOUSLY HOT FIRE TESTED. THE HOT FIRE ENVIRONMENT ADEQUATELY VERIFIES THE COPPER PLATING ADHESION INTEGRITY	RS007623-031