

**SSME FMEA/CIL**  
**REDUNDANCY SCREEN**

Component Group: Ducts and Lines  
CIL Item: K101-02  
Part Number: RS007018  
Component: LPFTP Discharge Duct  
FMEA Item: K101  
Failure Mode: Fails to contain hydrogen.

Prepared: D. Early  
Approved: T. Nguyen  
Approval Date: 7/25/00  
Change #: 1  
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Phase	Failure / Effect Description	Criticality Hazard Reference
PSMCD 4.1	Fuel leakage into aft compartment. Overpressurization of aft compartment. Possible fire or detonation. Loss of vehicle.  Redundancy Screens: SINGLE POINT FAILURE: N/A	1 ME-D3P,D, ME-D3S,A,M,C

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**SSME    A/CIL**  
**DESIGN**

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**FAILURE CAUSE:    A: Parent material failure or weld failure.**

THE DUCT ASSEMBLY (1) IS MANUFACTURED UTILIZING ARMCO 21-6-9 TUBING AND INCONEL 718 FORGING FOR FLANGE DETAILS. THE FLOW STRAIGHTENER IS MANUFACTURED FROM ARMCO 21-6-9 BAR. ARMCO 21-6-9 WAS SELECTED FOR ITS STRENGTH AT CRYOGENIC TEMPERATURES, CORROSION RESISTANCE, AND RESISTANCE TO STRESS CORROSION CRACKING (2). INCONEL 718 WAS SELECTED FOR ITS STRENGTH, RESISTANCE TO STRESS CORROSION CRACKING, CORROSION RESISTANCE, HIGH/LOW CYCLE FATIGUE CHARACTERISTICS, AND WELDABILITY (2). MATERIALS ARE HEAT TREATED TO DEVELOP FULL MATERIAL STRENGTH AND HARDNESS. HYDROGEN ENVIRONMENT EFFECTS ARE NOT A PROBLEM DUE TO CRYOGENIC OPERATING TEMPERATURES (2). AN ACTIVE CORROSION INHIBITOR IS APPLIED TO THE EXTERNAL SURFACES OF THE UNINSULATED DUCT FOR ADDED CORROSION RESISTANCE (3). FLANGE SECTIONS INCORPORATE RADIUS JOINTS TO REDUCE STRESS CONCENTRATIONS. OFFSET LIMIT REQUIREMENTS ARE ESTABLISHED TO REDUCE STRESS CONCENTRATIONS AND IMPROVE WELD GEOMETRY. TUBING STOCK IS PLANISHED WHEN WELDED, OR DRAWN TO MAINTAIN SURFACE REGULARITY. WELD RINGS ARE UTILIZED TO DISSIPATE HEAT DURING WELDING AND TO IMPROVE WELD QUALITY.

(1) RS007019; (2) RSS-8582; (3) RS007018, RA1608-008, RB0125-009

**FAILURE CAUSE:    B: Flex joint assemblies structural failure of: Retainer assembly, internal support assembly (hubs, supports, legs), Inner Bellows, Welds, Liners.**

THE RETAINER ASSEMBLY IS COMPOSED OF A TIE, RETAINER, LOCK, NOSE, AND CAP. THE TIE, RETAINER, AND LOCK (1) ARE MANUFACTURED UTILIZING INCONEL 718. THE NOSE AND CAP ARE MANUFACTURED UTILIZING ARMCO 21-6-9 SHEET. THE HUBS, LEGS, AND INNER SUPPORTS (1) ARE MANUFACTURED UTILIZING ARMCO 21-6-9 BAR AND FORGINGS. THE OUTER SUPPORTS (1) ARE MANUFACTURED UTILIZING INCONEL 718 FORGINGS. THE MACHINED OUTER SUPPORTS (INCONEL 718) ARE HEAT TREATED TO DEVELOP FULL STRENGTH AND HARDNESS (3). INNER BELLOW ASSEMBLY - TUBING (2) IS MANUFACTURED UTILIZING INCONEL 718 SHEET AND HAYNES 188 IS USED FOR THE END RINGS (2). INCONEL 718 WAS SELECTED FOR ITS STRENGTH, RESISTANCE TO STRESS CORROSION CRACKING, CORROSION RESISTANCE, WELDABILITY, AND HIGH/LOW CYCLE FATIGUE CHARACTERISTICS (3). ARMCO 21-6-9 WAS SELECTED FOR ITS STRENGTH AT CRYOGENIC TEMPERATURES, CORROSION RESISTANCE, AND RESISTANCE TO STRESS CORROSION CRACKING (3). DRY-FILM LUBRICANT IS USED TO REDUCE FRICTION, GALLING, AND PARTICLE GENERATION (1). HAYNES 188 WAS SELECTED FOR ITS LOW CYCLE FATIGUE LIFE, WELDABILITY, AND CORROSION RESISTANCE (3). DUE TO CRYOGENIC OPERATION, HYDROGEN ENVIRONMENT EFFECTS ARE NOT A PROBLEM (3). LEGS AND CONES ARE SHAPED AERODYNAMICALLY TO REDUCE FLOW FRICTION, FLOW TURBULENCE, AND LOADS ON INTERNAL PARTS (1). DURING OPERATION, PRESSURE SEPARATING LOADS CAUSE THE BELLOW TO EXPAND RELIEVING TENSION LOADS ON THE TIE AND RETAINER ASSEMBLY. CAPS ARE WELDED IN PLACE TO PREVENT INTERNAL PIECES FROM ENTERING THE FLOW, SHOULD FAILURE OF THE TIE OCCUR. DRY-FILM LUBRICANT IS USED TO REDUCE FRICTION, GALLING, AND PARTICLE GENERATION (1). MATING ROTATIONAL SURFACES HAVE TIGHT TOLERANCE CONTROLS TO INCREASE SURFACE CONTACT AREA WHICH REDUCES GALLING, STRESS RISERS, AND OFFSET LOADING. TOLERANCE CONTROLS ALSO DECREASE LUBRICANT WEAR, INCREASING LIFE. ASSEMBLY TOLERANCE DIMENSIONS ARE VERIFIED BY INSERTING A PIN DURING ASSEMBLY TO PROVIDE TOLERANCE AND PREVENT EXCESSIVE TORQUE, CAUSING BINDING. RETAINER IS LOCKED TO THE TIE BY A KEYED LOCK THAT IS WELDED TO MAINTAIN ASSEMBLY TOLERANCE. RETAINER TOLERANCE REDUCES IMPACT LOAD OF HUB ASSEMBLIES AND PROVIDES DRY FLEX RETENTION. VENT HOLES ARE INCORPORATED IN THE HUB ASSEMBLIES TO PREVENT LIQUID ACCUMULATION. INTERNAL LINERS REDUCE TURBULENCE OVER THE BELLOW ASSEMBLY AND PROVIDES LAMINAR FLOW WHICH INHIBITS FLOW INDUCED VIBRATION (1). THE INNER LINER IS POSITIONED UPSTREAM OF THE FLOW TO KEEP FROM FOLDING THE LIP INWARD. VENT HOLES ARE MANUFACTURED IN THE LINERS TO EQUALIZE PRESSURE ACROSS THE SURFACE. BELLOW ARE MANUFACTURED OF MULTIPLE PLYS EVENLY SPACED, AND ANNULAR TO IMPROVE FATIGUE LIFE, REDUCE STRESS/STRAIN CONCENTRATIONS, AND MAINTAIN CONSTANT SPRING RATE (1). BELLOW ARE WELDED AT THE PLY ENDS PRIOR TO HYDROFORMING TO PREVENT OIL CONTAMINATION BETWEEN BELLOW PLYS. WELDED PLYS ENDS ARE SUBSEQUENTLY MACHINED TO A UNIFORM SURFACE BEFORE FINAL WELDING TO THE SUPPORT. THIS IMPROVES THE CONNECTING WELD QUALITY, AND REDUCES PLY DISTORTION. BACKFILL OF THE CAVITY BETWEEN THE TWO BELLOW DURING MANUFACTURE OF THE ASSEMBLY PROVIDES A LOW PRESSURE AREA DURING CRYOGENIC OPERATION WHICH IMPROVES INSULATING CHARACTERISTICS (1). EDGES ARE MACHINED TO A RADIUS TO REDUCE WEIGHT, GALLING, AND BINDING ON ADJACENT CONTACT SURFACES. THE FLEX JOINT HAS COMPLETED BENDING MOMENT, FLEXURAL ENDURANCE, ULTIMATE PRESSURE, PROOF PRESSURE, VIBRATION, AND SECTIONING DVS TESTING (4).

(1) RS008961, RS008981; (2) RS008887, RS008886; (3) RSS-8582; (4) RSS-511-13

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**FAILURE CAUSE: ALL CAUSES**

INSTALLATION IS CONTROLLED FOR ANGULARITY AND OFFSET (1). THE MINIMUM FACTORS OF SAFETY FOR THE DUCT ASSEMBLY AND FLEX JOINT MEET CEI REQUIREMENTS (2). LOW CYCLE FATIGUE LIFE FOR THE DUCT MEETS CEI REQUIREMENTS (3) EXCEPT FOR THE FLEX JOINTS WHICH ARE HIGH CYCLE FATIGUE LIFE LIMITED BY MAJOR WAIVER (4). THE FLEX JOINTS ARE ALSO LIMITED TO OPERATION IN AN ENGINE SYSTEM WITH PREDICTED HPFTP SYNCHRONOUS FREQUENCIES OF LESS THAN OR EQUAL TO 609 Hz (10). THE DUCT ASSEMBLY PARENT MATERIALS WERE CLEARED FOR FRACTURE MECHANICS/NDE FLAW GROWTH, SINCE THEY ARE NOT FRACTURE CRITICAL PARTS (5). TABLE K101 LISTS ALL THE 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. THESE WELDS HAVE BEEN ASSESSED AS ACCEPTABLE FOR FLIGHT BY RISK ASSESSMENT (6). THE DUCT ASSEMBLY HAS SUCCESSFULLY COMPLETED PRESSURE CYCLING AND ULTIMATE PRESSURE DVS TESTING (7). THE VISUAL BELLOWS INSPECTION, HE MASS LEAK, AND ACCESSIBLE BELLOWS WELDS DYE PENETRANT INSPECTION TESTS HAVE BEEN COMPLETED ON ENGINE 2010 (8) AND 2014 (9) FLEX JOINTS. NO ANOMALIES WERE FOUND. THE DUCT USED ON THESE ENGINES HAD ACCUMULATED 49 STARTS AND 12,348 SECONDS.

(1) I.L. 0126-8066; (2) RSS-8546, CP320R0003B; (3) RL00532, CP320R0003B; (4) DAR 2073; (5) NASA TASK 117; (6) RSS-8756, MCR 0964; (7) RSS-511-43; (8) CD#2-0152; (9) CD#2-87-0031; (10) DAR 2562

**SSME FM CIL  
INSPECTION AND TEST**

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Failure Causes	Significant Characteristics	Inspection(s) / Test(s)	Document Reference
A	DUCT		RS007018
	DUCT		RS007019
	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER DRAWING REQUIREMENTS.	RS007019
		THE FLANGE FORGING IS VERIFIED BY PENETRANT AND ULTRASONIC INSPECTION PER SPECIFICATION REQUIREMENTS.	RA0115-116 RA0115-012
		TUBE SURFACE IS INSPECTED PER DRAWING REQUIREMENTS.	RS007019
		AN ACTIVE CORROSION INHIBITOR COATING IS VERIFIED PER SPECIFICATION AND DRAWING REQUIREMENTS.	RS007018 RA1608-008
	HEAT TREAT	HEAT TREAT IS VERIFIED PER SPECIFICATION REQUIREMENTS.	RA0111-018 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 RA0607-094 RA0115-116 RA0115-006 RA1115-001 RA0115-127
	ASSEMBLY INTEGRITY	THE DUCT ASSEMBLY IS PROOF PRESSURE TESTED PER DRAWING REQUIREMENTS.	RS007019
		AFTER PROOF PRESSURE TEST, ALL EXTERNAL WELDS ARE PENETRANT INSPECTED AND LEAK TESTED PER DRAWING OR SPECIFICATION REQUIREMENTS.	RS007019 RA0115-116
B	RETAINER ASSEMBLY		RS008961
	RETAINER ASSEMBLY		RS008981
	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER DRAWING REQUIREMENTS.	RS008961 RS008981
	HEAT TREAT	HEAT TREAT IS VERIFIED PER SPECIFICATION REQUIREMENTS.	RA0611-020
	SURFACE FINISH	THE TIE BALL END DRY-FILM LUBRICATION IS VERIFIED PER DRAWING REQUIREMENTS.	RS008961 RS008981
	ASSEMBLY INTEGRITY	INNER RADII ARE INSPECTED PER DRAWING REQUIREMENTS.	RS008961 RS008981
		THE RETAINER ASSEMBLY IS LOAD-TESTED PER DRAWING REQUIREMENTS PRIOR TO NOSE AND CAP WELDING.	RS008961 RS008981
	INTERNAL SUPPORT ASSEMBLIES (HUB, SUPPORT, LEGS) INTERNAL SUPPORT ASSEMBLIES (HUB, SUPPORT, LEGS)		RS008961 RS008981

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B	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER DRAWING REQUIREMENTS.	RS008961 RS008981
	ASSEMBLY INTEGRITY	INNER RADII ARE INSPECTED PER DRAWING REQUIREMENTS.	RS008961 RS008981
	BELLOWS, INNER BELLOWS, INNER		RS008886 RS008887
	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER DRAWING REQUIREMENTS.	RS008886 RS008887
		THE BELLOWS GRAIN DIRECTION IS VERIFIED PER DRAWING REQUIREMENTS.	RS008886 RS008887
		THE BELLOWS SEAM WELD DIRECTION AND LOCATION IS VERIFIED PER DRAWING REQUIREMENTS.	RS008886 RS008887
	HEAT TREAT	HEAT TREAT IS VERIFIED PER SPECIFICATION REQUIREMENTS.	RA1611-002
	CLEANLINESS OF COMPONENTS	THE BELLOWS PLIES ARE VERIFIED CLEAN PER SPECIFICATION REQUIREMENTS PRIOR TO ASSEMBLY AND CONVOLUTING.	RA1610-044
	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 RA0607-094/RA1607-079 RA0115-116 RA0115-006 RA1115-001 RA0115-127
		WELDS ARE PENETRANT INSPECTED AFTER PLANISHING PER SPECIFICATION REQUIREMENTS.	RA0115-116
	ASSEMBLY INTEGRITY	THE BELLOWS ECCENTRICITY, CONVOLUTE HEIGHTS, CROWN AND ROOTS RADIUS, PLY THICKNESS, AND SURFACE IRREGULARITY ARE VERIFIED PER DRAWING AND SPECIFICATION REQUIREMENTS.	RS008886 RS008887 RL00078
	LINER LINER		RS008961 RS008981
	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER DRAWING REQUIREMENTS.	RS008961 RS008981
	SURFACE FINISH	THE LINER DRY-FILM LUBRICATION IS VERIFIED PER DRAWING REQUIREMENTS.	RS008961 RS008981
	ASSEMBLY INTEGRITY	INNER RADII ARE INSPECTED PER DRAWING REQUIREMENTS.	RS008961 RS008981
	FLEX JOINT FLEX JOINT		RS008961 RS008981

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Failure Causes	Significant Characteristics	Inspection(s) / Test(s)	Document Reference
B	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 RA0607-094 RA0115-116 RA0115-006 RA1115-001 RA0115-127
	ASSEMBLY INTEGRITY	FLEX JOINTS ARE GIMBAL TESTED PER DRAWING REQUIREMENTS.  FLEX JOINTS ARE ACCEPTANCE TESTED PER SPECIFICATION REQUIREMENTS.	RS008981 RS008961  RL00215 RL00214
ALL CAUSES	LPFTP DISCHARGE DUCT		RS007018
	CLEANLINESS OF COMPONENTS	ASSEMBLIES ARE VERIFIED CLEAN PER SPECIFICATION REQUIREMENTS.	RA1610-002 RA1610-009
	ASSEMBLY INTEGRITY	THE DUCT OVALITY IS INSPECTED PER SPECIFICATION REQUIREMENTS.	RL00815
	HOT-FIRE ACCEPTANCE TESTING (GREEN RUN)	DUCTS ARE ENGINE HOT-FIRE ACCEPTANCE TESTED PER SPECIFICATION REQUIREMENTS.	RL00461 RL00050-04 RL00056-06 RL00056-07
	FLIGHT FLOW TESTING	A HELIUM BAG INSPECTION IS PERFORMED PRIOR TO EACH LAUNCH PER SPECIFICATION REQUIREMENTS.  THE EXTERNAL SURFACE IS VISUALLY INSPECTED PRIOR TO EACH LAUNCH.  A HELIUM SIGNATURE LEAK TEST IS PERFORMED PRIOR TO EACH LAUNCH. (LAST TEST)	OMRSD V41BU0.030 OMRSD V41BU0.380  OMRSD V41BU0.070  OMRSD S00000.950

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**

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Base Line Rationale	Variance	Change Rationale	Variant Dash Number
1. K101-02 APPLICATION OF CORROSION INHIBITOR.	ACTIVE CORROSION INHIBITOR IS NOT APPLIED.	USE AS IS RATIONALE: (1) DUCTS ARE LOW-SHELF TIME CONFIGURATION REDUCING THE POSSIBILITIES OF CORROSION. (2) DUCTS ARE LIFE LIMITED BY MAJOR WAIVER, DAR 2074.	RS007018-471

**SSME I A/CIL  
WELD JOINTS**

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Component	Basic Part Number	Weld Number	Weld Type	Class	Root Side Not Access	Critical Initial Flaw Size Not Detectable		Comments
						HCF	LCF	
DUCT	RS007019	1	GTAW	I				
DUCT	RS007019	3	GTAW	I	X	X	X	
DUCT	RS007019	4	GTAW	I	X	X		
DUCT	RS007019	5	GTAW	I	X	X		
DUCT	RS007019	6	GTAW	I	X			
DUCT	RS007019	7	GTAW	I	X	X		
DUCT	RS007019	8	GTAW	I	X	X		
DUCT	RS007019	9	GTAW	I	X			
DUCT	RS007019	10	GTAW	I	X	X		
DUCT	RS007019	11-15	GTAW	I	X	X	X	
DUCT	RS007019	18	GTAW	I	X	X		
DUCT	RS007019	19	GTAW	I	X			
DUCT	RS007019	20	GTAW	I	X	X	X	
DUCT	RS007019	21	GTAW	I	X	X		
DUCT	RS007019	22	GTAW	I	X	X		
DUCT	RS007019	23	GTAW	I	X	X		
DUCT	RS007019	24	GTAW	I	X	X	X	
BELLOWS	RS008886	1,2	GTAW	I				
BELLOWS	RS008886	3,4	EBW	I				
BELLOWS	RS008886	5,6	GTAW	I				
BELLOWS	RS008887	1,2	GTAW	I				
BELLOWS	RS008887	3,4	EBW	I				
BELLOWS	RS008887	5,6	GTAW	I				
FLEX JOINT	RS008961	25-30	GTAW	I		X		
FLEX JOINT	RS008961	32	GTAW	I	X			
FLEX JOINT	RS008961	33	GTAW	I	X			
FLEX JOINT	RS008961	34	GTAW	I	X			
FLEX JOINT	RS008961	35	GTAW	I	X			
FLEX JOINT	RS008961	36,37	GTAW	II				
FLEX JOINT	RS008961	38	GTAW	I				
FLEX JOINT	RS008961	39	GTAW	I	X			



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						HCF	LCF	
FLEX JOINT	RS008961	40	GTAW	I,II	X			
FLEX JOINT	RS008961	41	GTAW	I	X			
FLEX JOINT	RS008961	43	GTAW	I				
FLEX JOINT	RS008961	44	GTAW	I				
FLEX JOINT	RS008961	51-56	GTAW	I		X		
FLEX JOINT	RS008961	59	GTAW	I				
FLEX JOINT	RS008961	72	GTAW	I	X			
BELLOWS	RS008971	1,2	GTAW	I				
BELLOWS	RS008971	3,4	EBW	I				
BELLOWS	RS008971	5,6	GTAW	I				
BELLOWS	RS008971	9,10	EBW	I				
FLEX JOINT	RS008981	25-30	GTAW	I		X		
FLEX JOINT	RS008981	32,33,41	GTAW	I	X			
FLEX JOINT	RS008981	34	GTAW	I				
FLEX JOINT	RS008981	35,38	GTAW	I	X			
FLEX JOINT	RS008981	39	GTAW	I				
FLEX JOINT	RS008981	40	GTAW	I,II	X			
FLEX JOINT	RS008981	43	GTAW	I				
FLEX JOINT	RS008981	44	GTAW	I		X		
FLEX JOINT	RS008981	45,46	GTAW	II	X	X		
FLEX JOINT	RS008981	47,48	GTAW	II	X			
FLEX JOINT	RS008981	49,50	GTAW	II				
FLEX JOINT	RS008981	51-56	GTAW	I		X		
FLEX JOINT	RS008981	59	GTAW	I				
FLEX JOINT	RS008981	60	GTAW	II				
BELLOWS	RS008991	1,2	GTAW	I				
BELLOWS	RS008991	3,4	EBW	I				
BELLOWS	RS008991	5,6	GTAW	I				
BELLOWS	RS008991	9,10	GTAW	I				