SSME FMEA/CIL
REDUNDANCY SCREEN

Component Group:	**Ducts and Lines**	**Prepared:**	**D. Early**
CIL Item:	**K201-01**	**Approved:**	**T. Nguyen**
Part Number:	**RS007015**	**Approval Date:**	**7/25/00**
Component:	**LPOTP Discharge Duct**	**Change #:**	**1**
FMEA Item:	**K201**	**Directive #:**	**CCBD ME3-01-5638**
Failure Mode:	**Fails to contain oxidizer.**	**Page:**	**1 of 1**

Phase	Failure / Effect Description	Criticality Hazard Reference
PSMCD 4.1	Oxidizer leakage into aft compartment. Overpressurization of aft compartment. Loss of vehicle. Redundancy Screens: SINGLE POINT FAILURE: N/A	1 ME-C3P,D, ME-C3S, ME-C3A,C, ME-C3M

SSME EA/CIL DESIGN

Component Group:	**Ducts and Lines**	**Prepared:**	**D. Early**
CIL Item:	**K201-01**	**Approved:**	**T. Nguyen**
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Design / Document Reference

FAILURE CAUSE: A: Parent material failure or weld failure of duct.

THE DUCT ASSEMBLY (1) IS MANUFACTURED UTILIZING INCONEL 718 TUBING. INCONEL 718 FORGINGS ARE USED FOR FLANGE DETAILS AND INCONEL 718 CASTING USED FOR THE TEE SECTION. INCONEL 718 WAS SELECTED FOR ITS STRENGTH, RESISTANCE TO STRESS CORROSION, CORROSION RESISTANCE, HIGH/LOW CYCLE FATIGUE CHARACTERISTICS, AND WELDABILITY (2). MATERIALS ARE HEAT TREATED TO DEVELOP FULL MATERIAL STRENGTH AND HARDNESS (1). ALL MATERIALS USED IN THE DUCT FABRICATION ARE LOX COMPATIBLE (2). FLANGE AND DUCT 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).

(1) RS007015; (2) RSS-8582, RSS-8575

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

THE RETAINER ASSEMBLY (1) IS COMPOSED OF THE TIE, LOCK, NOSE, CAP, AND RETAINER. THE RETAINER ASSEMBLY IS MANUFACTURED UTILIZING INCONEL 718. THE INTERNAL SUPPORT (1) IS COMPOSED OF THE HUBS, LEGS, OUTLET SUPPORT, AND LINERS. THE INTERNAL SUPPORT IS MANUFACTURED UTILIZING INCONEL 718. THE INLET SUPPORT (1) IS MANUFACTURED UTILIZING ARMCO 21-6-9. THE BELLOWS ASSEMBLY (2) IS MANUFACTURED UTILIZING INCONEL 718. INCONEL 718 WAS SELECTED FOR ITS STRENGTH, RESISTANCE TO STRESS CORROSION, CORROSION RESISTANCE, HIGH/LOW CYCLE FATIGUE CHARACTERISTICS, AND WELDABILITY (3). ARMCO 21-6-9 WAS SELECTED FOR ITS STRENGTH IN THE AS WELDED CONDITION. IT IS CORROSION RESISTANT AND EXHIBITS RESISTANCE TO STRESS CORROSION CRACKING (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 BELLOWS 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 BELLOWS 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. BELLOWS ARE MANUFACTURED OF MULTIPLE PLIES EVENLY SPACED, AND ANNULAR TO IMPROVE FATIGUE LIFE, REDUCE STRESS/STRAIN CONCENTRATIONS, AND MAINTAIN CONSTANT SPRING RATE (2). BELLOWS ARE WELDED AT THE PLY ENDS PRIOR TO HYDROFORMING TO PREVENT OIL CONTAMINATION BETWEEN BELLOWS PLIES. WELDED PLIES ENDS ARE SUBSEQUENTLY MACHINED TO A UNIFORM SURFACE BEFORE FINAL WELDING TO THE SUPPORT. THIS IMPROVES THE CONNECTING WELD QUALITY, AND REDUCES PLY DISTORTION. 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) RS008601; (2) RS008893; (3) RSS-8582, RSS-8575; (4) RSS-511-13

FAILURE CAUSE: C: Parent material failure of plate.

THE COVER PLATE (1) IS MANUFACTURED FROM 321 CRES BAR. THIS MATERIAL WAS SELECTED FOR ITS STRENGTH, FABRICABILITY, GENERAL CORROSION RESISTANCE, AND STRESS CORROSION RESISTANCE (2). THE MATERIAL IS LOX COMPATIBLE (2). THE PLATE INCORPORATES RADIUS CORNERS TO REDUCE STRESS CONCENTRATION.

(1) RS007167; (2) RSS-8582

Component Group:	**Ducts and Lines**	**Prepared:**	**D. Early**
CIL Item:	**K201-01**	**Approved:**	**T. Nguyen**
Part Number:	**RS007015**	**Approval Date:**	**7/25/00**
Component:	**LPOTP Discharge Duct**	**Change #:**	**1**
FMEA Item:	**K201**	**Directive #:**	**CCBD ME3-01-5638**
Failure Mode:	**Fails to contain oxidizer.**	**Page:**	**2 of 2**

Design / Document Reference

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). HIGH AND LOW CYCLE FATIGUE MEET CEI REQUIREMENTS, WITH THE EXCEPTION OF THE FLEX JOINT IS LIFE LIMITED BY WAIVER (3). THE DUCT ASSEMBLY PARENT MATERIAL WAS CLEARED FOR FRACTURE MECHANICS/NDE FLAW GROWTH, SINCE THEY ARE NOT FRACTURE CRITICAL PARTS (4). TABLE K201 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 (5). THE DUCT ASSEMBLY HAS SUCCESSFULLY COMPLETED PRESSURE CYCLING AND ULTIMATE PRESSURE DVS TESTING (6). THE VISUAL BELLOWS INSPECTION, HE MASS LEAK, AND ACCESSIBLE BELLOWS WELDS DYE PENETRANT INSPECTION TESTS HAVE BEEN COMPLETED ON ENGINE 2010 (7) AND 2014 (8) FLEX JOINTS. NO ANOMALIES WERE FOUND. THE 2010 DUCT HAD ACCUMULATED 58 STARTS AND 18,150 SECONDS. THE 2014 DUCT HAD ACCUMULATED 60 STARTS AND 17,099 SECONDS.

(1) I.L. 0126-8066; (2) RSS-8546, CP320R0003B; (3) RL00532, CP320R0003B, DAR 1436; (4) NASA TASK 117; (5) RSS-8756; (6) RSS-511-43; (7) CD#2-0152; (8) CD#2-87-0031

SSME FM CIL
INSPECTION AND TEST

Component Group:	**Ducts and Lines**	**Prepared:**	**D. Early**
CIL Item:	**K201-01**	**Approved:**	**T. Nguyen**
Part Number:	**RS007015**	**Approval Date:**	**7/25/00**
Component:	**LPOTP Discharge Duct**	**Change #:**	**1**
FMEA Item:	**K201**	**Directive #:**	**CCBD ME3-01-5638**
Failure Mode:	**Fails to contain oxidizer.**	**Page:**	**1 of 3**

Failure Causes	Significant Characteristics	Inspection(s) / Test(s)	Document Reference
A	DUCT ASSEMBLY		RS007015
	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER DRAWING REQUIREMENTS.	RS007015
		DETAIL PARTS ARE PENETRANT INSPECTED PER SPECIFICATION REQUIREMENTS.	RA0115-116
	HEAT TREAT	HEAT TREAT IS VERIFIED PER SPECIFICATION REQUIREMENTS.	RA0611-020
		THE FLANGE FORGING TENSILE TEST IS VERIFIED PER SPECIFICATION REQUIREMENTS AFTER HEAT TREAT.	RA0115-012
	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	LEAK TEST IS VERIFIED PER DRAWING REQUIREMENTS.	RS007015
		THE DUCT ASSEMBLY IS PROOF PRESSURE TESTED PER DRAWING REQUIREMENTS.	RS007015
B	RETAINER ASSEMBLY		RS008601
	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER DRAWING REQUIREMENTS.	RS008601
	HEAT TREAT	HEAT TREAT IS VERIFIED PER SPECIFICATION AND DRAWING REQUIREMENTS.	RA0611-020 RS008601
	SURFACE FINISH	THE TIE AND RETAINER DRY-FILM LUBRICATION IS VERIFIED PER DRAWING REQUIREMENTS.	RS008601
	ASSEMBLY INTEGRITY	INNER RADII ARE INSPECTED PER DRAWING REQUIREMENTS.	RS008601
		THE RETAINER LOAD-TEST PRIOR TO CAP AND NOSE CLOSE-UP WELD IS VERIFIED PER DRAWING REQUIREMENTS.	RS008601
	SUPPORT ASSEMBLY		RS008601
	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER DRAWING REQUIREMENTS.	RS008601
	HEAT TREAT	HEAT TREAT IS VERIFIED PER SPECIFICATION AND DRAWING REQUIREMENTS.	RA0611-020 RS008601
	SURFACE FINISH	THE HUB DRY-FILM LUBRICATION IS VERIFIED PER DRAWING REQUIREMENTS.	RS008601
	ASSEMBLY INTEGRITY	INNER RADII ARE INSPECTED PER DRAWING REQUIREMENTS.	RS008601
		THE BALL AND SOCKET JOINT LAPPING, ALIGNMENT AND SURROUNDING RADII ARE VERIFIED PER DRAWING REQUIREMENTS.	RS008601
	BELLOW		RS008893
	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER DRAWING REQUIREMENTS.	RS008893

Failure Causes	Significant Characteristics	Inspection(s) / Test(s)	Document Reference
B	MATERIAL INTEGRITY	THE BELLOWS GRAIN DIRECTION IS VERIFIED PER DRAWING REQUIREMENTS.	RS008893
	HEAT TREAT	HEAT TREAT IS VERIFIED PER SPECIFICATION REQUIREMENTS.	RA0611-020 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
		THE BELLOWS SEAM WELD DIRECTION AND LOCATION IS VERIFIED PER DRAWING REQUIREMENTS.	RS008893
	ASSEMBLY INTEGRITY	THE BELLOWS ECCENTRICITY, CONVOLUTE HEIGHTS CROWN AND ROOTS RADIUS, PLY THICKNESS, AND SURFACE IRREGULARITY ARE VERIFIED PER DRAWING AND SPECIFICATION REQUIREMENTS.	RS008893 RL00078
	WELDS		RS008893
	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
	LINERS		RS008601
	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER DRAWING REQUIREMENTS.	RS008601
	HEAT TREAT	HEAT TREAT IS VERIFIED PER SPECIFICATION AND DRAWING REQUIREMENTS.	RA0611-020 RS008601
	SURFACE FINISH	THE LINER DRY FILM LUBRICATION IS VERIFIED PER DRAWING REQUIREMENTS.	RS008601
	ASSEMBLY INTEGRITY	INNER RADII ARE INSPECTED PER DRAWING REQUIREMENTS.	RS008601
	FLEX JOINT		RS008601
	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 JOINT IS GIMBAL TESTED PER DRAWING REQUIREMENTS.	RS008601
		FLEX JOINT IS ACCEPTANCE TESTED PER SPECIFICATION REQUIREMENTS.	RL00208

Componen ıp:	Ducts and Lines	Prepared:	D. Early
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FMEA Item:	K201	Directive #:	CCBD ME3-01-5638
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Failure Causes	Significant Characteristics	Inspection(s) / Test(s)	Document Reference
C	PLATE		RS007167
	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER DRAWING REQUIREMENTS.	RS007167
	ASSEMBLY INTEGRITY	THE DUCT ASSEMBLY IS PROOF PRESSURE TESTED PER DRAWING REQUIREMENTS.	RS007015
ALL CAUSES	LPOTP DISCHARGE DUCT		RS007015
	COMPONENT CLEANLINESS	ASSEMBLY IS VERIFIED CLEAN PER SPECIFICATION REQUIREMENTS.	RA1610-002 RA1610-004
	FLIGHT FLOW TESTING	THE EXTERNAL SURFACE IS VISUALLY INSPECTED PRIOR TO EACH LAUNCH.	OMRSD V41BU0.030
		A HELIUM SIGNATURE LEAK TEST IS PERFORMED PRIOR TO EACH LAUNCH. (LAST TEST)	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
WELD JOINTS

Component Group: Ducts and Lines
CIL Item: K201
Part Number: RS007015
Component: LPOTP Discharge Duct
FMEA Item: K201

Prepared: D. Early
Approved: T. Nguyen
Approval Date: 7/25/00
Change #: 1
Directive #: CCBD ME3-01-5638

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
DUCT	RS007015	1	GTAW	I				
DUCT	RS007015	2	GTAW	I	X			
DUCT	RS007015	3	GTAW	I	X			
DUCT	RS007015	4	GTAW	I	X	X		
DUCT	RS007015	5	GTAW	I	X			
DUCT	RS007015	6	GTAW	I	X			
DUCT	RS007015	7	GTAW	I	X	X		
DUCT	RS007015	8	GTAW	I	X	X	X	
DUCT	RS007015	9	GTAW	I		X		
DUCT	RS007015	10	GTAW	I				
DUCT	RS007015	11	GTAW	I	X			
DUCT	RS007015	12	GTAW	I				
DUCT	RS007015	13	GTAW	I	X			
FLEX JOINT	RS008601	1	GTAW	III	X	X		
FLEX JOINT	RS008601	2	GTAW	II	X			
FLEX JOINT	RS008601	3	GTAW	III	X			
FLEX JOINT	RS008601	4-9	GTAW	I				
FLEX JOINT	RS008601	10-15	GTAW	I				
FLEX JOINT	RS008601	16	GTAW	I				
FLEX JOINT	RS008601	17	GTAW	II	X			
FLEX JOINT	RS008601	18	GTAW	I		X		
FLEX JOINT	RS008601	25-28	GTAW	II				
FLEX JOINT	RS008601	33	GTAW	I		X		
FLEX JOINT	RS008601	34	GTAW	I				
FLEX JOINT	RS008601	35	GTAW	I				
FLEX JOINT	RS008601	36	GTAW	I				
FLEX JOINT	RS008601	52	GTAW	II		X		
FLEX JOINT	RS008601	18 PLCS	GTAW	III	X			
BELLOWS	RS008893	1-3	GTAW	I				
BELLOWS	RS008893	4,5	EBW	I				
BELLOWS	RS008893	6,7	GTAW	I				