

**SSME FA/CIL  
REDUNDANCY SCREEN**

Component Group: Combustion Devices  
 CIL Item: A155-01  
 Part Number: R039080  
 Component: Single Tube Heat Exchanger (Phase II+)  
 FMEA Item: A155  
 Failure Mode: Coil fracture/leakage.

Prepared: A. Kay  
 Approved: T. Nguyen  
 Approval Date: 9/9/99  
 Change #: 1  
 Directive #: CCBO ME3-01-5238

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Phase	Failure / Effect Description	Criticality
SMC 4.1	GCX mixes with fuel-rich hot-gas resulting in ignition, detonation and burning. Burning results in coil, PGM liner, HPOTP turbine, or main injector burn through. Fuel-rich hot-gas enters the downstream side of the coil and combines with oxygen from the bypass system, causing a fire in the discharge line which supplies the Pogo accumulator and the vehicle oxygen pressurization system. Loss of vehicle.	Hazard Reference 1 ME-FB35, ME-FB3A, M.C. ML-I D4S, MF-FB4A C, ME-FB4M
Redundancy Screens: SINGLE POINT FAILURE: N/A		

SSME FMEA/CIL  
DESIGN

Component Group: Combustion Devices  
CIL Item: A155-01  
Part Number: R039060  
Component: Single Tube Heat Exchanger (Phase II+)  
FMEA Item: A155  
Failure Mode: Coil fracture/leakage.

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Design / Document Reference

**FAILURE CAUSE: A: Coil parent material fracture. Fracture due to fatigue.**

THE SINGLE TUBE HEX COIL WITH INTEGRAL END FITTINGS (1) IS FABRICATED FROM 316L CRES MATERIAL. 316L HAS BEEN OXYGEN TESTED AND RATED SATISFACTORY. THE STEEL MATERIAL IS DOUBLE VACUUM MELTED AND SUBJECT TO A STRICT INCLUSION RATING REQUIREMENT TO REDUCE SIZE AND NUMBER OF INCLUSIONS FOR IMPROVED MATERIAL INTEGRITY (2). IT EXHIBITS GOOD DUCTILITY AND FABRICABILITY, CORROSION RESISTANCE, RESISTANCE TO STRESS CORROSION AND RESISTANCE TO HYDROGEN ENVIRONMENT EMBRITTLEMENT (3). TUBE WALL THICKNESS IS LIMITED TO REDUCE THERMAL STRAINS AND EXTEND LOW CYCLE FATIGUE LIFE. TUBE WALL THICKNESS TRANSITIONS GRADUALLY INTO END FITTING THICKNESS TO EXTEND FATIGUE LIFE (4). ARTIFICIAL FLAW TESTS (4) WERE PERFORMED ON THE COIL TUBING. THE TESTS INCLUDED CYCLIC LOADING OF DELIBERATELY INDUCED I.D. AND O.D. SURFACE DEFECTS. THE RESULTS SHOWED FLAWS LESS THAN 50% OF THE TUBING THICKNESS DO NOT PROPAGATE. COIL LOADING IS MINIMIZED BY THE BRACKET MOUNTING SYSTEM WHICH ACCOMODATES THERMAL EXPANSION.

(1) R039041 (2) R0160-07\* (3) RSS-8581-10 (4) NASA TASK 099

**FAILURE CAUSE: B: Loss of channel/bracket supports.**

THE BRACKETS (1) ARE FABRICATED FROM HAYNES 188. HAYNES WAS SELECTED FOR ITS HIGH STRENGTH AT ELEVATED TEMPERATURES AND RESISTANCE TO DEGRADATION IN HIGH PRESSURE HYDROGEN (2). THE BRACKETS ARE COMPOSED OF CHANNELS (3) WELDED TOGETHER INTO A RIGID BOX STRUCTURE WITH REDUNDANT, LIGHTLY LOADED WELDS WHERE REQUIRED.

(1) R039045 (2) RSS-8581-10 (3) R039044, R039046

**FAILURE CAUSE: C: Damage due to impact from fragmented liner, turning vane, or brackets.**

THE HEX LINER (1) IS FABRICATED FROM INCONEL 903. INCONEL 903 WAS CHOSEN FOR ITS STRENGTH AND FOR ITS RESISTANCE TO DEGRADATION IN HIGH PRESSURE HYDROGEN. IT IS SEMI-CORROSION RESISTANT AND RESISTANT TO STRESS CORROSION (2). THE TURNING VANE (3) IS MADE FROM A SINGLE INCONEL 625 CASTING WITH ELEVEN ROSSSES, TO ACCOMMODATE MOUNTING PINS THAT ARE WELDED TO THE HEX LINER. THE TURNING VANE SLIDES ON THESE DRY-FILM LUBRICATED PINS WHICH PREVENT BINDING DURING THERMAL EXPANSION. THIS KEEPS OPERATIONAL STRAINS IN THE ELASTIC RANGE, THEREBY ELIMINATING THE NEED TO PROTECT THE INCONEL 625 FROM HYDROGEN ENVIRONMENT EMBRITTLEMENT (2). THE BRACKETS (4) ARE FABRICATED FROM HAYNES 188. HAYNES 188 WAS SELECTED FOR ITS STRENGTH AT ELEVATED TEMPERATURES AND FOR ITS RESISTANCE TO DEGRADATION IN HIGH PRESSURE HYDROGEN (2). THE HEAT EXCHANGER WAS IMPACT TESTED (5).

(1) R039050 (2) RSS-9591-10 (3) RS006684 (4) R039044, R039046 (5) IL 35PHDC67

**FAILURE CAUSE: D: Tube wall wear at support points.**

CLEARANCE IS PROVIDED BETWEEN THE TUBE (1) AND THE BRACKETS (2) AND LINER (3) AT SELECTED LOCATIONS TO PREVENT CONTACT DURING OPERATION. AT ALL OTHER LOCATIONS, THE TUBE IS HELD IN THE BRACKET DIMPLES TO MINIMIZE RELATIVE MOTION. ASSEMBLY OF BRACKETS ONTO THE COIL IS PERFORMED IN SPECIAL TOOLING WHICH MINIMIZES THE POSSIBILITY OF RELATIVE LOOSENESS. INCREASED WALL THICKNESS OVER THE BIFURCATED HEX IS SUCH THAT THE TUBE WEAR WILL NOT BE DETRIMENTAL THROUGHOUT THE OPERATIONAL LIFE OF THE HEAT EXCHANGER.

(1) R039041 (2) R039044, R039046 (3) R039050

**FAILURE CAUSE: E: Tube damage during HPOTP removal and installation.**

THE TUBE (1) IS PROTECTED FROM DIRECT PUMP CONTACT BY THE BRACKETS (2). THE BRACKETS ARE DESIGNED TO PROVIDE CLEARANCE FROM THE PUMP. CHAMFERS ARE PROVIDED ON THE BRACKETS TO PREVENT DAMAGE IF CONTACT DOES OCCUR DURING INSTALLATION OR REMOVAL.

(1) R039041 (2) R039044, R039046

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Component: Combustion Devices  
CIL Item: A155-01  
Part Number: R039060  
Component: Single Tube Heat Exchanger (Phase II+)  
FMEA Item: A155  
Failure Mode: Coil fracture/leakage.

Prepared: K. Ngy  
Approved: T. Ngy  
Approval Date: 9/9/99  
Change #: 1  
Directive #: CGBD ME3-01-5238

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Design / Document Reference

FAILURE CAUSE: F: Coil collapse.

THE HEX COIL (1) IS MADE FROM 316L CRES TUBING. 316L HAS EXCELLENT DUCTILITY AND PROVIDES HIGH DAMAGE RESISTANCE. THICK WALL TUBING MAINTAINS ROUND CROSS SECTION TO MINIMIZE COLLAPSE POTENTIAL. THE ALLOY EXHIBITS GOOD CORROSION RESISTANCE, HIGH RESISTANCE TO STRESS CORROSION AND RESISTANCE TO HYDROGEN ENVIRONMENT EMBRITTLEMENT (2). COLLAPSE PRESSURE CAPABILITY OF THE COIL MEETS CEI REQUIREMENTS (3).

(1) R03904; (2) RSS-8581-10; (3) RSS-8546 CP320R0003B

FAILURE CAUSE: ALL CAUSES

THE HEAT EXCHANGER ASSEMBLY PARENT MATERIALS WERE CLEARED FOR FRACTURE MECHANICS/NDE FLAW GROWTH SINCE IT CONTAINS NO FRACTURE CRITICAL PARTS (1). THE FMEA/CIL WELDS ARE CLEARED FOR FRACTURE MECHANICS/NDE FLAW GROWTH BY THE WELD ASSESSMENT (2). TABLE A155 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 (2). THE ANALYSIS FOR HIGH AND LOW CYCLE FATIGUE AND MINIMUM FACTORS OF SAFETY MEET CEI REQUIREMENTS (3).

(1) NASA TASK 117 (2) RSS-8756; (3) CP320R0003B

**SSME FMEA/CIIL**  
**INSPECTION AND TEST**

Component Group: Combustion Devices  
 CIL Item: A155-01  
 Part Number: R039080  
 Component: Single Tube Heat Exchanger (Phase II+)  
 FMEA Item: A155  
 Failure Mode: Coil fracture/leakage.

Prepared: A. Kay  
 Approved: T. Nguyen  
 Approval Date: 9/9/99  
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Failure Causes	Significant Characteristics	Inspection(s) / Test(s)	Document Reference
A, F	COIL		R039041
	MATERIAL INTEGRITY	BAR STOCK MATERIAL INTEGRITY IS VERIFIED PER SPECIFICATION REQUIREMENTS.	R00160-070
		THE STRAIGHT TUBING IS INSPECTED FOR CHEMICAL COMPOSITION, SURFACE FINISH AND DISCONTINUITIES, TENSILE AND BURST STRENGTH EXPANSION, GRAIN SIZE AND SHAPE, SURFACE OXIDIZATION AND SUSCEPTIBILITY TO INTERGRANULAR ATTACK PER SPECIFICATION REQUIREMENTS.	RR0160-077
		THE TUBING IS INSPECTED FULL LENGTH BEFORE AND AFTER PROOF TEST TO VERIFY ALL OUTSIDE DIAMETERS AND WALL THICKNESS ARE PER SPECIFICATION REQUIREMENTS.	
		AFTER CYCLIC PROOF PRESSURE TESTING, STRAIGHT TUBING IS ULTRASONIC INSPECTED FOR INTERNAL DEFECTS, AND THE O.D. IS PENETRANT INSPECTED PER SPECIFICATION REQUIREMENTS.	R00160-077 RA1515-025 RA0115-116
	COIL INTEGRITY	THE COIL IS PENETRANT INSPECTED ON THE O.D. AFTER FORMING AND PROOF TESTING PER SPECIFICATION REQUIREMENTS. FORMED COIL IS INSPECTED FOR WALL THICKNESS AND FORMING DEFECTS TO VERIFY ADEQUATE PROCESS CONTROL PER SPECIFICATION REQUIREMENTS.	R00160-077 RA0115-116 RA0102-003
		COIL IS LEAK TESTED PER SPECIFICATION REQUIREMENTS.	RA0115-105
		COIL IS VISUALLY INSPECTED ON SURFACES SUSCEPTIBLE TO DAMAGE AFTER FABRICATION PER SPECIFICATION REQUIREMENTS AND PER TIME/CYCLE REQUIREMENTS.	R039050 RL01085 OMRSD V-1100-115
		ASSEMBLED COIL IS INSPECTED FOR SECURE BRACKETS AND TUBE SEATING IN CHANNEL DIMPLES PER TIME/CYCLE REQUIREMENTS.	

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Component or: Combustion Devices  
 CII Item: A155-01  
 Part Number: R039060  
 Component: Single Tube Heat Exchanger (Phase II\*)  
 FMEA Item: A155  
 Failure Mode: Coil fracture/leakage.

Approved: T. Nguyen  
 Approval Date: 9/9/99  
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Failure Causes	Significant Characteristics	Inspection(s) / Test(s)	Document Reference
B	STHEX LINER ASSY BRACKET CHANNEL CHANNEL BRACKET SUPPORT PIN		RC39050 R039045 R039044 R039046 R039048
	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER DRAWING AND SPECIFICATION REQUIREMENTS	AMS 6508 R00170-186
	WELD INTEGRITY	ALL WELDS ARE INSPECTED TO DRAWING AND SPECIFICATION REQUIREMENTS PER WELD CLASS. INSPECTIONS INCLUDE: VISUAL, DIMENSIONAL, PENETRANT, RADIOGRAPHIC AND FILLER MATERIAL, AS APPLICABLE.	RL10011 RA01007-071 RA0115-116 RA0115-005
		BRACKET CONTACT WITH HPOTP, HPOTP ENVELOPE, COIL SECURITY WITHIN BRACKET AND BRACKET SECURITY ARE INSPECTED PER TIME/CYCLE REQUIREMENTS.	RL01065 CMRSD V41BU0 126
C	TURNING VANE		RS008684
	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER SPECIFICATION REQUIREMENTS. VANE CASTING IS X-RAY INSPECTED PER DRAWING AND SPECIFICATION REQUIREMENTS	RB0170-197 RF0001 001 RA0115-005
		VANE ASSEMBLY IS PENETRANT INSPECTED AFTER MACHINING TO VERIFY ABSENCE OF CASTING DEFECTS PER SPECIFICATION REQUIREMENTS	RA0115-116
	VANE INTEGRITY	VANE IS INSPECTED FOR THICKNESS AND LEADING EDGE RADIUS PER DRAWING REQUIREMENTS. DRY-FILM LUBE IS INSPECTED PER SPECIFICATION REQUIREMENTS. THE VANE IS INSPECTED FOR CLEARANCE AND DAMAGE PER TIME/CYCLE REQUIREMENTS.	RS008684 RB0140-017 R039050 RL01065 CMRSD V41BU0 115
	HEAT EXCHANGER LINER		R039047
	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER SPECIFICATION REQUIREMENTS. MATERIAL IS PENETRANT INSPECTED AFTER CHEM MILL, ANNEAL, AND HEAT TREAT PER SPECIFICATION REQUIREMENTS.	RB0170-196 RA0115-116
	HEAT TREAT	HEAT TREAT IS VERIFIED PER DRAWING AND SPECIFICATION REQUIREMENTS	RE39047 RAC011-020
	WELD INTEGRITY	ALL WELDS ARE INSPECTED TO DRAWING AND SPECIFICATION REQUIREMENTS PER WELD CLASS INSPECTIONS INCLUDE: VISUAL, DIMENSIONAL, PENETRANT, RADIOGRAPHIC AND FILLER MATERIAL, AS APPLICABLE.	RA1500-071 RA0115-116 RA0115-006
	STHEX LINER ASSY BRACKET CHANNEL CHANNEL BRACKET SUPPORT PIN		R039050 R039045 R039044 R039046 R039048

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Component Group: Combustion Devices  
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 Part Number: R039060  
 Component: Single Tube Heat Exchanger (Phase II-)  
 FMEA Item: A155  
 Failure Mode: Coil fracture/leakage.

Approved: T. Nguyen  
 Approval Date: 9/9/99  
 Change #: 1  
 Directive #: CCBD ME3-01-6238

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Failure Causes	Significant Characteristics	Inspection(s) / Test(s)	Document Reference
C	MATERIAL INTEGRITY	MATERIAL INTEGRITY IS VERIFIED PER DRAWING AND SPECIFICATION REQUIREMENTS	AMS 5608 RB0173-186
		BRACKETS ARE INSPECTED FOR SECURITY AND CLEARANCES PER TIME/CYCLE REQUIREMENTS	RL01065 OMRSD V41BU.115
	WELD INTEGRITY	ALL WELDS ARE INSPECTED TO DRAWING AND SPECIFICATION REQUIREMENTS PER WELD CLASS. INSPECTIONS INCLUDE VISUAL, DIMENSIONAL, PENETRANT, RADIOGRAPHIC AND FILLER MATERIAL AS APPLICABLE	RL10011 RA1607-071 RA0115-115 RA0115-009
	UNVERIFIABLE ROOT WELDS R039045/R039050	UNVERIFIABLE ROOT WELDS ARE INSPECTED PER DRAWING AND SPECIFICATION REQUIREMENTS AS APPLICABLE. ALL CIFS ARE THROUGH FLAWS WHICH CAN BE DETECTED BY THE IIA PENETRANT INSPECTION OF THE FACE SIDE.	RA0115-116
D	ASSEMBLY INTEGRITY	ASSEMBLED COIL IS INSPECTED FOR SECURE BRACKETS, TUBE SEATING AND CLEARANCES, AND COIL MOVEMENT AFTER ASSEMBLY AND PER TIME/CYCLE REQUIREMENTS.	RL01065 OMRSD V41BU.115
E	COIL INTEGRITY INSPECTION	COIL AND BRACKETS ARE INSPECTED FOR DEFORMATION AND DAMAGE. BRACKET TO PUMP CLEARANCE ENVELOPE IS INSPECTED TO ASSURE NO INTERFERENCE BETWEEN PUMP AND COIL ASSEMBLY WHENEVER HPOTP IS REMOVED.	RL01065 OMRSD V41BU.125
ALL CAUSES	ASSEMBLY INTEGRITY	THE HOT FIRE TESTING AND 2ND E & M INSPECTIONS VERIFY ASSEMBLY INTEGRITY.	RL00050-04 RL00056-06 RL00056-07
		COIL IS LEAK TESTED PRIOR TO EACH FLIGHT (LAST TEST). HEAT EXCHANGER IS PROOF TESTED AFTER EVERY HPOTP INSTALLATION.	OMRSD V41BP0.020 OMRSD V41BP0.030

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Failure History: Comprehensive failure history data is maintained in the Problem Reporting database (PRMS/PRACA)  
 Reference: NASA letter SA21/88/309 and Rocketdyne letter 88RC09761.  
 Operational Use: Not Applicable.

**SONIC FINEAVAIL  
WELD JOINTS**

Component Group: Combustion Devices  
 CIL Item: A155  
 Component: R039050  
 Part Number: Single Tube Heat Exchanger (Phase II-)  
 A155

Prepared: A. Kay  
 Approved: T. Nguyen  
 Approval Date: 9/9/99  
 Change #: 1  
 Directive #: CCBD ME3-01-8238  
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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	ICF	
STHEX COIL ASSEMBLY	R039040	1	EBW	I				
STHEX COIL ASSEMBLY	R039040	2	EBW	I				
STHEX BRACKETS	R039045	1-3	GTAW	II	X			
STHEX BRACKETS	R039045	3-4	GTAW	II	X			
STHEX BRACKETS	R039045	9-10	GTAW	II	X			
STHEX LOWER LINER	R039047	4	EBW	II	X	X	X	
STHEX LOWER LINER	R039050	1-11	GTAW	II	X	X	X	
STHEX LOWER LINER	R039050	156	GTAW	I				
STHEX LOWER LINER	R039050	157	GTAW	I				
STHEX LOWER LINER	R039050	12-139, 158- 173	GTAW	II	X			
STHEX LOWER LINER	R039050	140-147, 148- 155	GTAW	I	X			
STHEX STRUCTURAL SHELL	R039051	5	EBW	I				
STHEX BYPASS LINE	R039054	12	GTAW	I				
STHEX OXID TANK PRESSURANT	R039060,R039051	1,1						
STHEX OXID TANK PRESSURANT	R039060	2	GTAW	II	X	X		
STHEX OXID TANK PRESSURANT	R039060,R039051	3,	GTAW	II	X	X	X	
STHEX OXID TANK PRESSURANT	R039060,R039051	4,	GTAW	II	X	X	X	

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SSME - A/CIL  
**FIELD CONFIGURATION VARIANCES FROM CIL RATIONALE**

Component Group: Combustion Devices  
 Item Name: Single Tube Heat Exchanger (Phase II+)  
 Item Number: A155  
 Part Number: R039050

Prepared: A. Kay  
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Base Line Rationale	Variance	Change Rationale	Variation Dash Number
1 NO RATIONALE EFFECTED	CUTBACK TURNING VANE MODIFICATION EXISTS ON ONE POWERHEAD ASSEMBLY.	CUTBACK DESIGN WAS IMPLEMENTED TO STOP CRACKING OBSERVED WHEN ATD HPOTP WAS USED. USE AS IS RATIONALE:	R008584-025
2 NO RATIONALE EFFECTED	R039051 WELDS 3 & 4 EXIST ON 5 POWERHEAD ASSEMBLIES.	STRUCTURAL ANALYSIS SHOWS NO HFE PROTECTION REQUIRED	R039051-11

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