

FAILURE MODES EFFECTS ANALYSIS (FMEA) - CRITICAL HARDWARE  
NUMBER: 04-2-LV13-X

SUBSYSTEM NAME: AUXILIARY POWER UNIT (APU)

REVISION: 4 08/09/93

	PART NAME VENDOR NAME	PART NUMBER VENDOR NUMBER
LRU	: AUXILIARY POWER UNIT (APU) SUNDSTRAND	MC201-0001-02XX 729867XX/754949
LRU	: AUXILIARY POWER UNIT (APU) SUNDSTRAND	MC201-0001-03XX 729867XX/754949A
LRU	: AUXILIARY POWER UNIT (APU) SUNDSTRAND	MC201-0001-04XX X742211X
SRU	: VALVE, SOLENOID	5905137 SAME
SRU	: VALVE, SOLENOID	5907038 SAME
SRU	: VALVE, SOLENOID	59906 SAME

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**PART DATA**


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**EXTENDED DESCRIPTION OF PART UNDER ANALYSIS:**

VALVE, SHUTOFF, THREE-WAY SOLENOID, NORMALLY CLOSED. HIGH SPEED CONTROL AND APU SHUTOFF.

QUANTITY OF LIKE ITEMS: 3  
ONE PER APU

**FUNCTION:**

- (1) TO CONTROL APU TURBINE SHUTOFF AND HIGH SPEED WHEN "HIGH SPEED" HAS BEEN MANUALLY SELECTED OR WHEN PC VALVE (LV12) FAILS OPEN.
- (2) TO SHUT DOWN THE APU WHEN DE-ENERGIZED.

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SUBSYSTEM NAME: AUXILIARY POWER UNIT (APU)  
AUXILIARY POWER UNIT (APU)  
ITEM NAME: VALVE, SOLENOID

CRITICALITY OF THIS  
FAILURE MODE: 1/1

**FAILURE MODE:**  
FAILS IN OPEN POSITION

**MISSION PHASE:**

PL PRELAUNCH  
OO ON-ORBIT  
LO LIFT-OFF  
DO DE-ORBIT  
LS LANDING SAFING

**VEHICLE/PAYLOAD/KIT EFFECTIVITY:** 102 COLUMBIA  
103 DISCOVERY  
104 ATLANTIS  
105 ENDEAVOUR

**CAUSE:**

INTERNAL MECHANICAL OR WELD FAILURE, CONTAMINATION OR CORROSION IN THE VALVE OR ARMATURE MECHANISM, SEAT CONTAMINATION, CRACKED SEAT, CONTROLLER LOGIC FAILURE, INTERNAL BINDING OF FLAPPER OR POPPET DUE TO SEAT FRAGMENT CONTAMINATION, CRACKED FLAPPER OR FLEXTUBE, CONTAMINATION IN ARMATURE/MAGNET GAP.

**CRITICALITY 1/1 DURING INTACT ABORT ONLY? NO**

**REDUNDANCY SCREEN** A) N/A  
B) N/A  
C) N/A

**PASS/FAIL RATIONALE:**

A)  
B)  
C)

**- FAILURE EFFECTS -**

**(A) SUBSYSTEM:**

POSSIBLE APU OVERSPEED TO WHEEL BURST RESULTING IN LOSS OF ONE OR MORE APUS. THIS POSSIBILITY IS REDUCED BY AUTOMATIC CLOSURE OF FUEL ISOLATION VALVES WHICH MAY BE EFFECTIVE IN SHUTTING DOWN THE APU DEPENDENT ON HYDRAULIC PUMP LOAD. WHEN THE SAFETY SWITCH IS IN INHIBIT MODE, THIS PROTECTION IS NOT AVAILABLE. LOSS OF SINGLE APU IF SHUTDOWN OCCURS.

**(B) INTERFACING SUBSYSTEM(S):**

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POSSIBLE DAMAGE TO ADJACENT EQUIPMENT AND LOSS OF ONE OR MORE HYDRAULIC SYSTEMS.

**(C) MISSION:**

ABORT DECISION IS REQUIRED IF FAILURE OCCURS PRIOR TO ENTRY COMMITMENT.

**(D) CREW, VEHICLE, AND ELEMENT(S):**

POSSIBLE LOSS OF CREW/VEHICLE IF FIRE AND/OR EXPLOSION OCCURS. LOSS OF SINGLE APU IF SHUTDOWN OCCURS. REMAINING APUS WILL BE SWITCHED TO HIGH SPEED WITH THE SAFETY CIRCUIT INHIBITED, DEPENDING ON MISSION PHASE.

**(E) FUNCTIONAL CRITICALITY EFFECTS:**

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**-DISPOSITION RATIONALE-**

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**(A) DESIGN:**

VALVE PROTECTED BY 25-MICRON FILTER IN-LINE UPSTREAM AND FUEL PUMP 25-MICRON FILTER UPSTREAM. VALVE IS CYCLED INFREQUENTLY, ONLY AT HIGH SPEED OR AFTER PULSE CONTROL VALVE FAILURE. CORROSION RESISTANT MATERIALS (17-7, 304L, TUNGSTEN CARBIDE) USED. THE COBALT USED AS A BINDER FOR THE TUNGSTEN CARBIDE SEATS IS LEACHED OUT ON THE SHUT OFF OUTLET SEAT AS IT IS EXPOSED TO AMMONIUM HYDROXIDE (DECOMPOSITION PRODUCT OF HYDRAZINE AND AIR) AFTER APU SHUTDOWN. AN AGE LIFE LIMIT WAS ESTABLISHED BASED ON EXPOSURE TIME USING INSPECTION OF SEATS FROM VALVES USED IN SERVICE.

THE FUEL ISOLATION VALVES WILL BE AUTOMATICALLY CLOSED BY OVERSPEED SIGNAL FROM APU. A COMPUTER SIMULATION OF THE SAFETY SHUTDOWN CAPABILITY HAS INDICATED THAT WHEN THE LEAKAGE AREA OF THE PULSE CONTROL OUTLET IS OVER 25 PERCENT, IN COMBINATION WITH THE SHUTOFF VALVE BEING HELD OPEN OVER 95 PERCENT, ISOLATION VALVE CLOSURE AT OVERSPEED SIGNAL MAY NOT PREVENT OVERSPEED TO WHEEL BURST. THIS OCCURS ONLY WHEN THE HYDRAULIC PUMP IS UNDER LOW LOAD (APPROXIMATELY 10 HORSEPOWER).

IN 1980, THE SEAT AND MANIFOLD WAS REDESIGNED TO REDUCE STRESSES IN THE CRITICAL AREA. ASSEMBLY PROCEDURES REVISED TO AVOID OVERSTRESS OF POPPETS AND INCLUDE X-RAY OF POPPET ASSEMBLIES. SHARP CORNERS AND RECAST LAYER REMOVED IN SOCKET AREA. SUPPLIER HAS ADDED 5-MICRON FILTER IN TEST FACILITY TO AVOID CONTAMINATION.

IN 1990 THE GGVM SEAT DESIGN UNDERWENT EXTENSIVE ANALYSIS AND SEAT DESIGN CHANGES WILL BE INCORPORATED IN THE IAPU ON AN ATTRITION BASIS. PATH A SEAT DESIGN WILL CONSIST OF THE FOLLOWING: ADDITIONAL EDM RECAST LAYER REMOVAL, EXTENSION OF THE SLEEVE, DELETION OF THE O.D. LABYRINTH GROOVES, ADDITION OF STRESS RELIEF CYCLE TO SEAT RAW MATERIALS AND SEAT, AND WIDENING THE SEAT LANDS.

**(B) TEST:**

ACCEPTANCE LEAKAGE TESTS ARE CONDUCTED AT BOTH VALVE AND APU LEVEL. CERTIFICATION TESTS CONDUCTED WERE 27 MISSIONS FOR A TOTAL OF 41.7 HR INCLUDING VIBRATION. IMPROVED VERSIONS OF DESIGN SUCCESSFULLY TESTED TWO SAMPLES FOR OVER 100 HR ON DEVELOPMENT IMPROVED APU. IAPU

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QUALIFICATION TEST (QUAL 1) DEMONSTRATED SUCCESSFUL IGGVM OPERATION FOR OVER 75 HOURS RUNTIME.

PATH A SEAT SUCCESSFULLY PASSED A 20 HOUR CERTIFICATION TEST.

OMRSD: HELIUM GAS LEAK TEST OF SHUTOFF OUTLET IS PERFORMED, AND GGVM PERFORMANCE IS VERIFIED DURING "HOT FIRE", FOR FIRST FLIGHT AND ANY TIME AN APU IS REPLACED. SHUTOFF AND PULSE CONTROL VALVE OUTLET LIQUID HYDRAZINE LEAK CHECK IS PERFORMED PRIOR TO EVERY MISSION. FLIGHT DATA IS USED TO VERIFY GGVM OPERATION EVERY FLOW AFTER THE FIRST FLIGHT. GGVM OPERATION IS VERIFIED DURING CONFIDENCE RUN FOR NEWLY INSTALLED APUS.

**(C) INSPECTION:****RECEIVING INSPECTION**

MATERIAL AND PROCESSES CERTIFICATIONS ARE VERIFIED.

**CONTAMINATION CONTROL**

CLEANLINESS TO LEVEL 100 IS VERIFIED BY INSPECTION. FLUID SAMPLES ARE ANALYZED FOR CONTAMINATION AND VERIFIED BY INSPECTION. CORROSION PROTECTION REQUIREMENTS ARE VERIFIED BY INSPECTION.

**ASSEMBLY/INSTALLATION**

MANUFACTURING, ASSEMBLY, AND INSTALLATION REQUIREMENTS ARE VERIFIED BY INSPECTION. CRITICAL DIMENSIONS AND SURFACE FINISHES ARE VERIFIED BY INSPECTION. SOLENIOD IS VERIFIED BY INSPECTION.

**NONDESTRUCTIVE EVALUATION**

PENETRANT INSPECTION OF WELDS AND ASSEMBLIES IS VERIFIED. RADIOGRAPHIC INSPECTION OR CROSS SECTION INSPECTION OF LOT SAMPLE PERFORMED ON SELECTED WELDS. NDE FOR CRITICAL WELDS IS BEING DETERMINED.

**CRITICAL PROCESSES**

WELDING PER SPECIFICATION REQUIREMENTS IS VERIFIED BY INSPECTION. WELDING PROCEDURES, EQUIPMENT AND SCHEDULES ARE UNDER INVESTIGATION FOR POTENTIAL IMPROVEMENTS. DESTRUCTIVE INSPECTION OF CRITICAL WELDS FROM LOT SAMPLES OF PRODUCTION HARDWARE IS UNDER CONSIDERATION. VALVE SEAT FABRICATION IS VERIFIED BY INSPECTION. SCANNING ELECTRON MICROSCOPE (SEM), WHICH SCANS ACROSS EACH SEAT-WEB UPPER SURFACE, IS PERFORMED FOLLOWING INSERTION OF THE SEAT INTO THE SLEEVE. SEM PHOTOGRAPHS OF EACH WEB ARE MADE. DESTRUCTIVE TESTING/INSPECTION OF A SINGLE SEAT SAMPLE, PER EACH MANUFACTURING LOT FOR REMOVAL OF THE EDM RECAST LAYER, IS PERFORMED.

UNITS MANUFACTURED POST AUGUST 1990 WILL HAVE AN ADDITIONAL SEM OF THE ENTIRE INNER AND OUTER SEALING LANDS AND SEM OF THE SEAT SURFACE. A FINAL MAGNIFIED OPTICAL INSPECTION OF THE SEAT WILL BE PERFORMED PRIOR TO FINAL INSTALLATION OF THE SEAT MANIFOLD INTO THE VALVE ASSEMBLY.

**TESTING**

TEST EQUIPMENT AND TOOL CALIBRATION ARE VERIFIED BY INSPECTION. ATP IS WITNESSED AND VERIFIED BY INSPECTION.

**HANDLING/PACKAGING**

HANDLING, PACKAGING, STORAGE, AND SHIPPING PROCEDURES ARE VERIFIED.

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**(D) FAILURE HISTORY:**

NO GGVM FAILURES WITH THIS FAILURE MODE.

RELATED GGVM FAILURES - CAR AC9511 SHUTOFF VALVE SEAT FRACTURE ANALYSIS HAS DISCLOSED THAT THE COBALT BINDER IN THE TUNGSTEN CARBIDE OF THE VALVE SEAT IS LEACHED AWAY FROM THE SURFACE OF THE MATERIAL WHEN EXPOSED TO HOT DEIONIZED WATER (USED IN THE VALVE CLEANING PROCESS). LEACHING IS CAUSED BY THE AMMONIUM HYDROXIDE CREATED BY THE COMBINATION OF AIR AND HYDRAZINE VAPOR DOWNSTREAM OF THE SHUTOFF OUTLET SEAT. NORMAL POPPET CYCLING OF THE SHUTOFF VALVE DISLODGES TUNGSTEN CARBIDE PARTICLES AND RESULTS IN SEAT CRACKING. CORRECTIVE ACTION INCLUDED ELIMINATING THE DEIONIZED WATER CLEANING AND ADDING SEM INSPECTION OF THE SEAT WEBS DURING MANUFACTURING. ALL GGVMs RECEIVED NEW SEATS AND POPPETS FOLLOWING STS-51L.

CAR AC3326 FLEXTUBE FAILURE WAS DISCOVERED DURING F&D AFTER ATP HOT FIRE. EXAMINATION OF THE FAILED FLEXTUBE DISCLOSED AN INCLUSION. THE CONCLUSION WAS THAT THE INCLUSION CREATED A STRESS CONCENTRATION POINT AND THE TUBE CRACKED DUE TO FATIGUE UNDER NORMAL OPERATING LOADS. CORRECTIVE ACTION WAS TO ADD AN X-RAY INSPECTION FOR SCREENABLE FLAWS IN NEW PRODUCTION TUBES AND REPLACEMENT TUBES FOR REWORKED GGVM'S REQUIRING THEM. APU 009 FLEXURE TUBE CRACK IN WELD, HEAT AFFECTED ZONE AFTER 186 HOURS. BOTH OF THE ABOVE FAILURES CAN RESULT IN A FAILED OPEN VALVE.

CAR 07F010 UNDERSPEED SHUTDOWN DUE TO FOREIGN CONTAMINATION (KEL-F PARTICLE) ON BYPASS SEAT OF PULSE CONTROL VALVE. THIS CONTAMINATION COULD HAVE RESULTED IN A PULSE CONTROL AND/OR SHUTOFF FAILED OPEN. CONTAMINATION BELIEVED TO HAVE ENTERED VALVE DURING ITS MANUFACTURING CYCLE. CORRECTIVE ACTION INVOLVED DISASSEMBLY AND CLEANING OF THE GGVM TEST STAND AT THE MANUFACTURER AND AN INCREASED NUMBER OF CLEANING AND CLEANLINESS VERIFICATION OPERATIONS.

CAR 31RF01 APU RAN AT HIGH SPEED WITH LOW CHAMBER PRESSURE WHILE NORMAL SPEED WAS SELECTED. THE PULSE CONTROL VALVE OUTLET SEAT WAS CRACKED AND A FRAGMENT OF THE OUTER SEALING LAND WAS BROKEN. THIS ANOMALY WAS DETECTED AT APU START AS THE LEAKAGE WAS PRESENT WITH THE FIRST CLOSING PULSE OF THE PULSE CONTROL VALVE. INTERIM CORRECTIVE ACTION INCLUDES LIMITING THE PULSE CONTROL VALVE OPERATING LIFE, PERFORMING A LIQUID LEAK CHECK OF THE VALVE OUTLET SEATS PRIOR TO EVERY FLIGHT, AND MANDATORY SEM INSPECTION OF THE SEAT SEALING SURFACES DURING CRITICAL MANUFACTURING PROCESSES. FINAL CORRECTIVE ACTION IS THE PATH A SEAT DESIGN AS DESCRIBED IN THE DESIGN SECTION. THE PATH A SEAT HAS SUCCESSFULLY PASSED A 20 HOUR CERTIFICATION TEST WITH NO SEAT LAND CRACKS. THE SHUTOFF OUTLET SEAT HAD ONE CRACK IN EACH OF THE THREE WEBS. THEREFORE THE PATH A SEAT IS NOT CONSIDERED A SOLUTION TO THE WEB CRACKING PROBLEM. TO SOLVE THIS PROBLEM, SPECIFIC CHANGES TO THE SEAT WEBS ARE BEING PROPOSED. THIS IS PART OF THE PATH B SEAT REDESIGN.

CAR AD7195 HELIUM GAS LEAKAGE OF THE SHUTOFF OUTLET SEAT DETECTED DURING APU REFURBISHMENT. THREE WEBS WERE CRACKED. EXPOSURE TIME WAS 17.5 MONTHS PRIOR TO DETECTING LEAKAGE. PROPOSED CORRECTIVE ACTION IS A

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MATERIAL CHANGE FOR THE SHUTOFF OUTLET POSITION ONLY. THIS IS PART OF THE PATH B SEAT REDESIGN.

CAR AD7069 A CIRCUMFERENTIAL CRACK IN THE OUTER SEALING LAND OF THE SHUTOFF VALVE OUTLET SEAT DETECTED DURING SEAT INSPECTION. THE VALVE HAD 22 MONTHS OF HYDRAZINE EXPOSURE. THE 5 MINUTE HIGH SPEED RUN TIME ACCRUED AS A RESULT OF THE PULSE OF THE PULSE CONTROL VALVE FAILURE (31RF01) IS BELIEVED TO BE A CONTRIBUTOR TO THE CRACK. CORRECTIVE ACTION INVOLVES REMOVAL OF THE APU ONCE ANY HIGH SPEED TIME IS ACCRUED DURING FLIGHT AND REDUCING THE LIFE LIMIT.

CAR AD7547 CIRCUMFERENTIAL BREAK OF OUTER SEALING LAND DURING VENDOR TESTING. TEST INVOLVED RUNNING THE APU AT NORMAL SPEED FOR 10 HOURS AND HIGH SPEED FOR 1.5 HOURS. LIQUID LEAKAGE OF SHUTOFF OUTLET WAS DETECTED FOLLOWING THE 1.5 HOUR HIGH SPEED TIME. APU PERFORMANCE WAS NOMINAL. THE EXPOSURE TIME WAS APPROXIMATELY 18 MONTHS AND THE SHUTOFF VALVE HAD ACCUMULATED 12,000 CYCLES.

CAR AD7703 GGVM S/N 3004 SHUTOFF OUTLET FAILED LIQUID LEAK TEST DUE TO ERODED SEAT LAND. TWO WEBS WERE FOUND CRACKED. GGVM HAD 21 MONTHS EXPOSURE AND 188 MINUTES OF HIGH SPEED RUNTIME.

CAR AD7543 GGVM S/N 4003 BROKEN FRAGMENT DURING ATP (SIMILAR TO 31RF01) WITH APPROXIMATELY ONE HOUR RUNTIME ON P/C SEAT.

CAR AD7327 LEAKING PULSE CONTROL OUTLET SEAT DUE TO OUTER LAND CRACKS. THREE WEBS WERE CRACKED. SHUTOFF VALVE OUTLET SEAT HAD THREE WEBS CRACKED AND PASSED LEAKAGE REQUIREMENTS. THE PULSE CONTROL VALVE HAD 72,000 CYCLES AND THE SHUTOFF EXPOSURE WAS 26 MONTHS.

CAR AD7310 PULSE CONTROL VALVE OUTLET SEAT LAND CRACKED AND ONE WEB CRACKED. VALVE PASSED LEAKAGE REQUIREMENTS. RUNTIME WAS 40,000 CYCLES.

CAR AD8625 GAS GENERATOR AVERAGE PEAK PRESSURE MEASURED 1040 PSIA. ATP SPECIFICATION LOW LIMIT IS 1150 PSIA. GGVM S/N 3001 WAS FOUND TO BE LEAKING GROSSLY TO PULSE CONTROL BYPASS. EXAMINATION OF THIS SEAT FOUND APPROXIMATELY 45 DEGREES OF THE SEALING LAND TO BE DAMAGED WITH IMPACT MARKS FROM CONTAMINATION OR MISALIGNED POPPET. FAILURE ANALYSIS IS CONTINUING.

CAR AD8626 SHUTOFF VALVE OUTLET SEAT WEBS FOUND CRACKED AFTER THE 20 HOUR CERTIFICATION TEST FOR THE PATH A SEATS. THE PATH B SEAT IS THE PROPOSED CORRECTIVE ACTION. VERIFICATION BY TESTING IS TO BE PERFORMED.

CAR AD8687 GGVM/IGGVM EB WELDS FOUND TO BE UNDER PRINT REQUIREMENT FOR WELD PENETRATION IN SOME LOCATIONS. WELD CRACKS FOUND IN FLEXTUBE TO FLAPPER WELDS. INTERIM REMEDIAL ACTION INVOLVES LIMITING GGVM RUNTIME. ANALYSIS AND CORRECTIVE ACTION IS IN WORK.

CAR 43RF10 APU S/N 305 CHAMBER PRESSURE DID NOT RETURN TO ZERO LEVEL AFTER EACH PULSE FOR 35 SECONDS DURING RE-ENTRY. EXAMINATION OF GGVM S/N 3003 DISCOVERED A BROKEN PULSE CONTROL OUTLET SEAT.

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PRINT DATE: 09/07/93

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(E) OPERATIONAL USE:  
NONE

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- APPROVALS -

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EDITORIALLY APPROVED : RI  
EDITORIALLY APPROVED : JSC  
TECHNICAL APPROVAL : VIA CR

*Handwritten signature and date: 9/17/93*  
: S50270L