INDEPENDENT ORBITER ASSESSMENT

FMEA/CIL ASSESSMENT FINAL REPORT

16 SEPTEMBER 1988

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1.0 EXECUTIVE SUMMARY

The McDonnell Douglas Astronautics Company (MDAC) was selected in June 1986 to perform an Independent Orbiter Assessment (IOA) of the Failure Modes and Effects Analysis (FMEA) and Critical Items List (CIL). Direction was given by the Orbiter and GFE Projects Office to perform the hardware analysis and assessment using the instructions and ground rules defined in NSTS 22206, Instructions for Preparation of FMEA and CIL.

The IOA analysis featured a top-down approach to determine hardware failure modes, criticality, and potential critical items. To preserve independence, the analysis was accomplished without reliance upon the results contained within the NASA and Prime Contractor FMEA/CIL documentation. The assessment process compared the independently derived failure modes and criticality assignments to the proposed NASA post 51-L FMEA/CIL documentation. When possible, assessment issues were discussed and resolved with the NASA subsystem managers. Unresolved issues were elevated to the Orbiter and GFE Projects Office manager, Configuration Control Board (CCB), or Program Requirements Control Board (PRCB) for further resolution. An issue generally refers to a disagreement between the NASA FMEA/CIL and the IOA failure mode analysis results. This process was reviewed twice by the National Research Council, Shuttle Criticality Review and Hazard Analysis Audit Committee, and was concluded to be acceptable.

As subsystem FMEA/CIL assessments were completed during the course of the task, separate subsystem assessment reports were published. The remaining assessments were being completed as revised FMEA/CIL documentation became available. The IOA task was brought to a premature conclusion in March 1988 which resulted in several subsystem assessments with open issues. Subsequent authority was received that allowed for the resolution of all the remaining open CIL issues and the identification of those with safety implications. The resulting resolution assessment worksheets are documented in a companion volume to this report, entitled "IOA CIL Issues Resolution Report", dated 16 September 1988 (reference 71). Summaries of each subsystem assessment are provided in Appendix C of this report. Table 1-1 presents an overview of the FMEA/CIL assessments. Resolution of all CIL issues is shown in Table 1-2. All CIL issues have been resolved. Some FMEA issues remain open; however, these do not involve safety or mission critical hardware.

Several Orbiter FMEA/CIL assessment difficulties encountered during the task were attributed to interpretion of NSTS 22206 ground rules and instructions. For example, the Prime Contractor occasionally used a very broad redundancy interpretation approach which caused more 1R and 2R functional criticalities. The definition of redundancy was expanded to include redundancy at the higher assembly and subsystem levels, in addition to like and unlike redundancy to the hardware component being failed. IOA, in its original analysis, limited redundancy to failure items under study, which resulted in less severe functional criticalities. IOA accepted the Prime Contractor's more severe criticalities when exact NSTS 22206 ground rules could not be clearly deciphered.

The most important Orbiter assessment finding was the previously unknown "stuck" autopilot push-button criticality 1/1 failure mode. The worst case effect could cause loss of crew/vehicle when the microwave landing system is not active. The Prime Contractor has been directed by the CCB to add the failure mode to the FMEA/CIL documentation and to implement a software change to bypass a stuck "Auto" switch.

SPAR Aerospace conducted their Remote Manipulator System (RMS) failure mode analysis in a manner similar to IOA and consistent with NSTS 22206. One major assessment difficulty affecting 69 FMEA/CIL items concerned uncommanded motion of the arm while within 2 feet of the Orbiter, payload, or a suited crewman. The arm malfunction detection software design specification calls for a stopping distance of 2 feet. Concern exists that the arm will not be stopped within this 2 foot envelope for all failure modes. However, IOA could not prove conclusively that the uncommanded motion failure modes were a threat and should be assigned a worst case effect criticality of 1/1. Therefore, IOA withdrew the issue and accepted the NASA 2/1R criticality assignments.

The Extravehicular Maneuvering Unit (EMU) FMEA/CIL documentation prepared by Hamilton Standard followed NSTS 22206 ground rules and was in general agreement with IOA. Assessment of the Manned Maneuvering Unit (MMU) was not completed due to the NASA decision to defer review of the MMU FMEA/CIL.

In conclusion, NASA and Prime Contractor Post 51-L FMEA/CIL documentation assessed by IOA is believed to be technically accurate and complete. All CIL issues have been resolved. No FMEA issues remain that have safety implications. Consideration should be given, however, to upgrading NSTS 22206 with definitive ground rules which more clearly spell out the limits of redundancy.

TABLE 1-1
FMEA / CIL ASSESSMENT OVERVIEW

SUBSYSTEM	FMEA			CIL		
	IOA	NASA	ISSUE*	IOA	NASA	ISSUE
Fuel Cell Powerplant (FCP)	50	50	0	24	24	0
Hydraulic Actuators (HA)	112	112	0	59	59	0
Displays and Control (D&C)	171	264	45	21	21	0
Guidance, Navigation & Control (GN&C)	175	148	56	36	36	0
Orbiter Experiments (OEX)	81	191	24	1	1	0
Auxiliary Power Unit (APU)	314	313	2	106	106	0
Backup Flight System (BFS)	33	-	0	15	15	0
Electrical Power, Distribution & Control (EPD&C)	435	435	0	158	158	0
Landing & Deceleration (L&D)	259	267	24	131	131	0
Purge, Vent and Drain (PV&D)	48	46	2	8	8	0
Pyrotechnics (PYRO)	38	38	0	38	38	0
Active Thermal Control System (ATCS) and Life Support System (LSS)	886	813	268	205	205	0
Crew Equipment (CE)	351	422	123	82	82	0
Instrumentation (INST)	107	96	25	18	18	0
Data Processing System (DPS)	78	78	2	24	24	0
Atmospheric Revitalization Pressure Control System (ARPCS)	262	262	0	87	87	0
Hydraulics & Water Spray Boiler (HYD & WSB)	336	301	45	112	112	0
Mechanical Actuation System (MAS)	555	555	0	292	292	0
Manned Maneuvering Unit (MMU)	-	-	0	-	-	0
Nose Wheel Steering (NWS)	68	58	14	38	38	0
Remote Manipulator System (RMS)	821	585	11	390	390	0
Atmospheric Revitalization System (ARS)	223	311	102	84	84	0
Extravehicular Mobility Unit (EMU)	619	619	0	479	479	0
Power Reactant Supply & Distribution System (PRS&D)	296	278	18	89	89	0
Main Propulsion System (MPS)	1365	1230	208	763	763	0
Orbital Maneuvering System (OMS)	262	243	57	118	118	0
Reaction Control System (RCS)	656	623	135	207	207	0
Comm and Tracking (C&T)	1108	729	71	263	263	0
Total as of 16 September 1988	9709	9067	1232	3848	3848	0

* Non Safety and Mission Critical Issues

TABLE 1-2
CIL ISSUE RESOLUTION

SUBSYSTEM	Original IOA CIL Issues	Accepted By NASA	Withdrawn By IOA	Total Remaining Open
Fuel Cell Powerplant (FCP)	1	1	0	0
Hydraulic Actuators (HA)	17	2	15	0
Displays and Control (D&C)	0	0	0	0
Guidance, Navigation & Control (GN&C)	0	0	0	0
Orbiter Experiments (OEX)	1	0	1	0
Auxiliary Power Unit (APU)	25	4	21	0
Backup Flight System (BFS)	12	12	0	0
Electrical Power, Distribution & Control (EPD&C)	0	0	0	0
Landing & Deceleration (L&D)	51	24	27	0
Purge, Vent and Drain (PV&D)	3	0	3	0
Pyrotechnics (PYRO)	4	0	4	0
Active Thermal Control System (ATCS) and Life Support System (LSS)	141	30	111	0
Crew Equipment (CE)	4	0	4	0
Instrumentation (INST)	5	4	1	0
Data Processing System (DPS)	2	0	2	0
Atmospheric Revitalization Pressure Control System (ARPCS)	48	4	44	0
Hydraulics & Water Spray Boiler (HYD & WSB)	23	1	22	0
Mechanical Actuation System (MAS)	310	0	310	0
Manned Maneuvering Unit (MMU)	92	0	92	0
Nose Wheel Steering (NWS)	9	6	3	0
Remote Manipulator System (RMS)	74	0	74	0
Atmospheric Revitalization System (ARS)	36	7	29	0
Extravehicular Mobility Unit (EMU)	40	26	14	0
Power Reactant Supply & Distribution System (PRS&D)	9	0	9	0
Main Propulsion System (MPS)	191	43	148	0
Orbital Maneuvering System (OMS)	60	2	58	0
Reaction Control System (RCS)	241	37	204	0
Comm and Tracking (C&T)	294	101	193	0
Totals	1693	304	1389	0

2.0 INTRODUCTION

The 51-L Challenger accident prompted NASA to readdress safety policies, concepts, and rationale being used in the National Space Transportation System (NSTS). The NSTS Office has undertaken the task of reevaluating the FMEA/CIL for the Space Shuttle design. MDAC is providing an independent assessment of the proposed post 51-L Orbiter FMEA/CIL for completeness and technical accuracy.

The MDAC was initially tasked in June 1986 to conduct an independent analysis and assessment on twenty subsystems. Subsequently, in April 1987, an additional eight subsystems were added which provided complete coverage of all standard Orbiter equipment. Table 2-1 provides a listing of the Orbiter and GFE subsystems identified by NASA to the National Research Council, Shuttle Criticality Review and Hazard Analysis Audit Committee.

The IOA analysis approach is summarized in the following steps 1.0 through 3.0. Step 4.0 summarizes the assessment of the NASA and Prime Contractor FMEA/CIL.

Step 1.0 Subsystem Familiarization
- 1.1 Define subsystem functions
- 1.2 Define subsystem components
- 1.3 Define subsystem specific ground rules and assumptions

Step 2.0 Define Subsystem Analysis Diagram
- 2.1 Define subsystem
- 2.2 Define major assemblies
- 2.3 Develop detailed subsystem representations

Step 3.0 Failure Events Definition
- 3.1 Construct matrix of failure modes
- 3.2 Document IOA analysis results

Step 4.0 Compare IOA Analysis Data to NASA FMEA/CIL
- 4.1 Resolve differences
- 4.2 Review in-house
- 4.3 Document assessment issues
- 4.4 Forward findings to Project Manager

As a result of the preceding steps, general project assumptions and ground rules (Appendix B) were developed to amplify and clarify instructions in <u>NSTS 22206</u>. Also, subsystem specific assumptions and ground rules were defined as appropriate for the subsystems. These assumptions and ground rules are presented in each individual subsystem report.

Table 2-1

ORBITER and GFE SUBSYSTEMS

ORIGINAL TWENTY SUBSYSTEMS (JUNE 1986)

- o Guidance, Navigation & Control (GNC)
- o Data Processing System (DPS)
- o Backup Flight System (BFS)
- o Nose Wheel Steering (NWS)
- o Instrumentation (INST)
- o Electrical Power, Distribution & Control (EPD&C)
- o Main Propulsion System (MPS)
- o Fuel Cell Powerplant (FCP)
- o Power Reactant Supply & Distribution System (PRSD)
- o Orbital Maneuvering System (OMS)
- o Reaction Control System (RCS)
- o Auxiliary Power Unit (APU)
- o Hydraulics & Water Spray Boiler (HYD & WSB)
- o Atmospheric Revitalization System (ARS)
- o Atmospheric Revitalization Pressure Control System (ARPCS)
- o Extravehicular Mobility Unit (EMU)
- o Manned Maneuvering Unit (MMU)
- o Landing & Deceleration (L&D)
- o Hydraulic Actuators (HA)
- o Remote Manipulator System (RMS)

ADDITIONAL EIGHT SUBSYSTEMS (APRIL 1987)

- o Communication and Tracking (C&T)
- o Displays and Controls (D&C)
- o Orbiter Experiments (OEX)
- o Pyrotechnics (PYRO)
- o Purge, Vent and Drain (PV&D)
- o Mechanical Actuation System (MAS)
- o Active Thermal Control System (ATCS), Life Support System (LSS), and Airlock Support System (ALSS)
- o Crew Equipment (CE)

3.0 RESULTS

The IOA task was accomplished in three phases, namely, a review of both the NSTS 22206 and RI 100-2G FMEA/CIL Desk Instructions, an independent subsystem failure modes analysis, and an independent assessment of the NASA and Prime Contractor FMEA/CIL documentation. The NSTS 22206 and RI 100-2G documents were first reviewed and evaluated to determine if any omissions and ambiguities existed that impeded the preparation process or prevented the surfacing of major technical issues. This task was completed and a report was published in October 1986 (Reference 1). Many of the recommendations have been incorporated in subsequent versions of NSTS 22206.

The independent failure mode analysis process used available subsystem drawings and schematics, documentation, and procedures. Each of the 28 subsystems was broken down into lower level assemblies and individual hardware components. Each component was then evaluated and analyzed for credible failure modes and effects. Criticalities were assigned based on the worst possible effect of each failure mode consistent with the NSTS 22206. To preserve independence, the analysis was accomplished without reliance upon the results contained within the NASA FMEA/CIL documentation. The independent analysis of the 28 subsystems was completed and published in separate analysis reports (see Section 6.0, references 2 through 35).

The final phase of the IOA task was to provide an independent assessment of the NASA and Prime Contractor post 51-L FMEA/CIL results for completeness and technical accuracy. This process compared the independently derived analysis results to the proposed NASA post 51-L FMEA/CIL, and investigated any significant discrepancies.

The IOA assessment process resulted in an initial total of 10,735 independently derived failure modes and 4,513 potential critical items. As of 9 March 1988, when the Interim Report (reference 70) was published, a total of 3,193 FMEA issues and 1586 CIL issues remained open due to a lack of revised subsystem FMEA/CIL documentation to be assessed. Several subsystems were still in the Prime Contractor FMEA/CIL revision process during the first quarter of 1988. Subsequently, revised CIL documentation was received and all CIL issues were resolved. Of the overall total of 1,693 CIL issues (the 1,586 remaining as of 9 March 1988, plus 107 that had been resolved previously) NASA accepted 304 recommendations and IOA withdrew 1,389 issues. Many non-CIL issues were not resolved due to lack of revised FMEA documentation. All issues with safety and mission implications were resolved.

The interim assessment results were fully documented in separate assessment reports (references 36 through 69). Final CIL issues resolutions have been documented in reference 71. This final report provides assessment summaries in Appendix C for each subsystem. Appendix D provides a comparison of IOA subsystem assessments and Rockwell CIL packages.

The most significant Orbiter assessment issue was uncovered by the Nose Wheel Steering (NWS) subsystem assessment team. The failure mode was a "stuck" autopilot push-button causing the worst case effect of loss of crew/vehicle (criticality 1/1). The Orbiter autopilot is used for entry, and manually disengaged before landing. The autopilot is engaged by "Roll/Yaw Auto" and "Pitch Auto" push-button indicators (PBIs). If either "Auto" PBI fails closed, the autopilot cannot be permanently disengaged. With the autopilot remaining engaged, the Orbiter will attempt to "Autoland", which requires a Microwave Landing System (MLS) on the ground. The MLS is not required for day landings, and has not been "available" for four of the last seven STS missions. Without the MLS, use of the autoland alone will cause the Orbiter to miss the runway. A single point failure with no redundancy and which threatens loss of crew/vehicle is categorized by NSTS 22206 as a "criticality 1" item. The Prime Contractor has added the failure mode to the FMEA/CIL baseline and is developing a software change to bypass a failed "Auto" switch.

SPAR Aerospace prepared their RMS FMEAs in a manner similar to IOA and consistent with NSTS 22206. The only major difficulty encountered was the use of software routines as unlike redundancy to downgrade the criticalities on FMEAs. The failure mode was uncommanded arm motion. The failure effect is RMS arm impact with the Orbiter, payload, or suited astronauts. Standard arm operations such as berthing/unberthing, grappling, and payload deployment and retrieval, require the arm to approach the Orbiter or payload closer than 2 feet. Any malfunction resulting in uncommanded motion while the arm is within this 2 foot envelope presents the possibility of impact with the Orbiter. The software design specification calls for a stopping distance of 2 feet. Consequently, the IOA originally recommended that the 69 uncommanded arm motion failure modes be upgraded from criticality 2/1R to 1/1. This recommendation was presented to the CCB and rejected. IOA has subsequently readdressed the concern with the NASA Subsystem Manager and withdrawn the issue due to inability to prove conclusively that a criticality 1 threat exists.

4.0 GENERAL CONCLUSIONS AND OBSERVATIONS

The following paragraphs briefly discuss some of the difficulties and observations encountered during the IOA study period.

Ground Rules Interpretation - As a result of ambiguous language used in NSTS 22206, many disagreements arose in analyzing hardware failure modes. Some of the major sources of confusion are discussed briefly below for like and unlike redundancies, redundancy screens, emergency systems, and crew action and its impact on criticalities.

a. Like and Unlike Redundancy - The interpretation of like and unlike redundant items and the definition of a hardware item function are not clearly stated; however, their impact in assigning functional criticality is significant. A broad interpretation creates more 1R and 2R functional criticalities. And most importantly, the discussion of parallel functional paths is not adequate to clarify redundancies. Two examples are discussed below.

Example 1 - One of the single most important difficulties encountered during the assessment of the NASA/Rockwell data was the utilization of multiple scenarios in assigning functional criticalities. In such cases, the Rockwell approach seemed to investigate the redundancies to the effect of the failure of the item under study instead of redundancies to the item itself. For example, failure of the supply water system drain Quick Disconnect (QD) and the drain cap on the supply water system was tied to the failure of the radiators and ammonia boiler systems in the active thermal control system. This was apparently done since loss of the flash evaporator system was seen as an effect of the failure under study, making it a redundant leg to the radiators and ammonia boiler systems. In these cases, the functional criticalities were assigned for potential loss of life/vehicle. The original IOA interpretation was to make the QD and the drain cap redundant to each other and then investigate the functional loss (flash evaporator system) arising from loss of these redundancies. Based on this approach a worst case potential for loss of mission was anticipated by IOA, instead of loss of crew/vehicle.

Example 2 - In certain cases, the Rockwell analysis cites failure of another item as the cause for the failure of the item under study. This approach assumes a failure is already in progress, which seems contrary to the hardware criticality requirements stated in the NSTS 22206. Under the hardware criticality requirements only the singular direct effect of the identified failure mode of a hardware item is to be investigated.

b. Redundancy Screens - Language such as "...capable of check out..." for Screen A, and "...from a single credible event..." for Screen C leave considerable room for conjecture on the part of an analyst. Further, the criteria for complying with the screens are not defined clearly enough to explain them adequately.

c. Emergency Systems - The definition of emergency systems excludes hardware items which are used during nominal mission phases and any intact abort cases. For example, the Launch Entry Helmet oxygen supply panel and the Airlock Support System were assigned emergency status by the subsystem managers. This created a very conservative approach open to individual interpretation and not necessarily consistent with the NSTS 22206.

d. Crew Action - The role of crew action in response to a failure is not clear when assigning hardware criticality as opposed to functional criticality. Also, the terms "off-nominal" versus "nominal" versus "contingency", as applied to crew actions, are used interchangeably throughout the NSTS 22206, creating confusion.

5.0 RECOMMENDATIONS

Based upon the assessment results and independent study of the twenty-eight subsystems, the following recommendations are made:

A. The unassociated multiple failure scenarios and failures already in progress as used by the Orbiter Prime Contractor should be re-evaluated, since they bring a very broad and conservative methodology to the FMEA/CIL process. This approach may reduce visibility into failure modes and effects for some particular items, since the majority of the functional criticality 2s and 3s are replaced by 1Rs and 2Rs, respectively. This approach tends to overload the CIL with less important failure modes, and prevents the genuinely significant failure modes from receiving adequate management attention.

B. Consideration should be given to improving NSTS 22206 by eliminating sources of ambiguities. The document should be rearranged to provide step-by-step procedures and instructions for conducting hardware failure analysis. This would reduce guess work and eliminate differences in philosophy used from one subsystem to another. More specifically, the topics related to redundancies (criticality, screens, like/unlike...etc) should be further expanded to ensure consistent application of methodology and criticality assignments. The document should provide more specific examples of application of the ground rules to specific subsystems.

C. If NASA and Rockwell maintain their current approach to redundancy and unrelated failures, confusion could be avoided in the future by changing the rules in NSTS 22206 so that they agree with this broader interpretation. Sections of NSTS 22206 for which changes might be appropriate include 2.3.2.d, 2.3.3.c, and 2.3.3.d.

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APPENDIX A

ACRONYMS

ACRONYMS

ABS	- Ammonia Boiler System
ACA	- Annunciator Control Assembly
ACIP	- Aerodynamic Coefficient Instrumentation Package
ADI	- Attitude Direction Indicator
ADP	- Air Data Probe
ADS	- Audio Distribution System
ADTA	- Air Data Transducer Assembly
ALCA	- Aft Load Control Assembly
AMCA	- Aft Motor Control Assembly
AOA	- Abort-Once-Around
AOS	- Acquisition of Signal
APC	- Aft Power Controller
APU	- Auxiliary Power Unit
ARCS	- Aft Reaction Control System (Subsystem)
ARPCS	- Atmospheric Revitalization Pressure Control System
ARS	- Atmospheric Revitalization System
ASA	- Aerosurface Servo Amplifier
ATCS	- Active Thermal Control Subsystem
ATO	- Abort-To-Orbit
ATVC	- Ascent Thrust Vector Control
B&AS	- Brakes and Antiskid
BF	- Body Flap
BFC	- Backup Flight Control
BFS	- Backup Flight System
BITE	- Built-In Test Equipment
C&W	- Caution and Warning
CCB	- Change Control Board
CCC	- Contaminant Control Cartridge
CCTV	- Closed-Circuit Television
CCU	- Crew Communications Umbilical
CIL	- Critical Items List
CIU	- Communications Interface Unit
CNTLR	- Controller
COAS	- Crew Optical Alignment Sight
COMM	- Communication
CPU	- Central Processing Unit
CRIT	- Criticality
CWS	- Caution and Warning System
D&C	- Displays and Controls
DAP	- Digital Autopilot
DCM	- Display and Control Module
DCN	- Document Change Notice
DDU	- Display Driver Unit
DEU	- Display Electronic Unit
DFI	- Development Flight Instrumentation
DHE	- Data-Handling Electronics
DMA	- Deployed Mechanical Assembly
DOD	- Department of Defense
DPS	- Data Processing System (Subsystem)
DSC	- Dedicated Signal Conditioner

ACRONYMS

ECLSS	-	Environmental Control and Life Support System (Subsystem)
EI	-	Entry Interface
EIU	-	Engine Interface Unit
EMU	-	Extravehicular Mobility Unit
EPA	-	Environmental Protection Agency
EPDC	-	Electrical Power, Distribution and Control
EPG	-	Electrical Power Generator
EPS	-	Electrical Power System
ET	-	External Tank
EVA	-	Extravehicular Activity
EVCS	-	Extravehicular Communications System
FC	-	Fuel Cell
FCA	-	Flow Control Assembly
FCB	-	Fecal Collection Bag
FCL	-	Freon Coolant Loop
FCOS	-	Flight Control Operating System
FCP	-	Fuel Cell Power (Plant)
FCS	-	Flight Control System
FDA	-	Fault Detection and Annunciation
FDM	-	Frequency Division Multiplexing
FES	-	Flash Evaporator System
FFSSO	-	Forward Fuselage Support System for OEX
FLCA	-	Forward Load Control Assembly
FM	-	Failure Mode
FMCA	-	Forward Motor Control Assembly
FMD	-	Frequency Division Multiplexer
FMEA	-	Failure Modes and Effects Analysis
FPC	-	Forward Power Controller
FRCS	-	Forward Reaction Control System (Subsystem)
FSM	-	Fault Summary Message
FSS	-	Flight Support Structure
FSSR	-	Flight Systems Software Requirements
FSW	-	Flight Software
GAS	-	Get-Away Special
GFE	-	Government Furnished Equipment
GMT	-	Greenwich Mean Time
GNC	-	Guidance, Navigation, and Control
GPC	-	General Purpose Computer
GSE	-	Ground Support Equipment
GSTDN	-	Ground Spaceflight Tracking and Data Network
HDC	-	Hybrid Driver Controller
HEX	-	Heat Exchanger
HIRAP	-	High-Resolution Accelerometer Package
HIU	-	Headset Interface Unit
HPFTP	-	High-Pressure Fuel Turbopump
HPOT	-	High-Pressure Oxidizer Turbopump
HUT	-	Hard Upper Torso
HW	-	Hardware
HX	-	Heat Exchanger
HYD	-	Hydraulics

ACRONYMS

ICM - Interface Control Module
ICMS - Intercom Master Station
ICOM - Intercommunications
ICRS - Intercom Remote Station
IFM - In-Flight Maintenance
IMU - Inertial Measurement Unit
IOA - Independent Orbiter Assessment
IOM - Input/Output Module
IUS - Inertial Upper Stage
IVA - Intravehicular Activity
JSC - Johnson Space Center
KBD - Ku-Band Deploy
LCA - Load Controller Assembly
LCC - Launch Control Center
LCVG - Liquid Cooling and Ventilation Garment
LDG/DEC - Landing and Deceleration
LEH - Launch/Entry Helmet
LPS - Launch Processing System
LRU - Line Replaceable Unit
LSS - Life Support Subsystem
LTA - Lower Torso Assembly
MADS - Modular Auxiliary Data System
MAS - Mechanical Actuation System
MCA - Motor Control Assembly
MCC - Mission Control Center (JSC)
MCDS - Multifunction CRT Display System
MDAC - McDonnell Douglas Astronautics Company
MDM - Multiplexer/Demultiplexer
MEC - Main Engine Controller
MECO - Main Engine Cutoff
MET - Mission Elapsed Time
MGSSA - Main Gear Shock Strut Assembly
MIA - Multiplexer Interface Adapter
MLG - Main Landing Gear
MM - Major Mode
MMU - Manned Maneuvering Unit
MMU - Mass Memory Unit
MPL - Minimum Power Level (65%)
MPM - Manipulator Positioning Mechanism
MPS - Main Propulsion System (Subsystem)
MS - Mission Specialist
MSBLS - Microwave Scanning Beam Landing System
MSK - Manual Select Keyboard
MTU - Master Timing Unit
MUX - Multiplex
NASA - National Aeronautics and Space Administration
NGSSA - Nose Landing Gear Shock Strut Assembly
NGTD - Nose Gear Touch Down
NLG - Nose Landing Gear
NSI - NASA Standard Initiator

NSP	- Network Signal Processor
NSTS	- National Space Transportation System
NWS	- Nose-Wheel Steering
OBS	- Operational Bioinstrumentation System
OEX	- Orbiter Experiments
OI	- Operational Instrumentation
OMRSD	- Operational Maintenance Requirements & Specifications Document
OMS	- Orbital Maneuvering System
OTB	- Orbiter Timing Buffer
OWDA	- Operational Water Dispenser Assembly
P/L	- Payload
PASS	- Primary Avionics Software System
PBI	- Push-Button Indicator
PBM	- Payload Bay Mechanical
PCA	- Power Control Assembly
PCI	- Potential Critical Item
PCM	- Pulse Code Modulation
PCMMU	- Pulse Code Modulation Master Unit
PCN	- Page Change Notice
PCS	- Pressure Control System
PDU	- Power Drive Unit
PFR	- Portable Foot Restraint
PHS	- Personal Hygene Station
PI	- Payload Interrogater
PIC	- Pyro Initiator Controller
PLB	- Payload Bay
PLBD	- Payload Bay Door
PLS	- Primary Landing Site
PLSS	- Portable Life Support Subsystem
PMS	- Propellant Management Subsystem
PRCB	- Program Requirements Control Board
PRCBD	- Program Requirements Control Board Directive
PRCS	- Primary Reaction Control System (jet)
PRD	- Payload Retention Device
PROM	- Programmable Read-Only Memory
PRSD	- Power Reactant Storage and Distribution
PRSDS	- Power Reactant Storage and Distribution System
PSA	- Power Section Assembly
PSA	- Provision Stowage Assembly
PSP	- Payload Signal Processor
PTT	- Push-to-talk
PV&D	- Purge Vent & Drain
QD	- Quick Disconnect
R/BPA	- Rudder/Pedal Brake Assembly
RAM	- Random Access Memory
RCS	- Reaction Control System
RFCA	- Radiator and Flow Control Assembly
RFI	- Radio Frequency Interference
RGA	- Rate Gyro Assembly

RHC - Rotation Hand Controller
RHS - Rehydration Station
RI - Rockwell International
RJD - Reaction Jet Driver
RM - Redundancy Management
RMS - Remote Manipulator System
RPA - Ruder Pedal Assembly
RPC - Remote Power Controller
RPTA - Rudder Pedal Transducer Assembly
RSB - Rudder Speed Brake
RTD - Resistance Temperature Device
RTLS - Return-to-Launch Site
RTS - Remote Tracking Station
RVDT - Rotary Variable Differential Transformer
SBTC - Speed Brake Translation Controller
SCB - Steering Control Box
SCM - System Control Module
SCU - Sequence Control Unit
SCU - Service and Cooling Umbilical
SDM - Startracker Door Mechanism
SEADS - Shuttle Entry Air Data System
SFOM - Shuttle Flight Operations Manual
SFP - Single Failure Point
SGLS - Space Ground Link System
SILTS - Shuttle Infrared Leeside Temperature Sensor
SM - Systems Management
SMM - Solar Maximum Mission
SOP - Secondary Oxygen Pack
SOS - Space Operations Simulator
SPA - Steering Position Amplifier
SPFA - Single Point Failure Analysis
SPI - Surface Position Indicator
SRB - Solid Rocket Booster
SSA - Space Suit Assembly
SSME - Space Shuttle Main Engine
SSMEC - SSME Controller
SSO - Space Shuttle Orbiter
SSSH - Space Shuttle Systems Handbook
ST - Star Tracker
STDN - Spaceflight Tracking and Data Network
STS - Space Transportation System
TACAN - Tactical Air Navigation
TAL - Transatlantic Abort Landing
TCS - Thermal Control System (Subsystem)
TD - Touch Down
TDRS - Tracking and Data Relay Satellite
THC - Thruster Hand Controller
THC - Translation Hand Controller
TPS - Thermal Protection System
TVC - Thrust Vector Control

ACRONYMS

UCD	-	Urine Collection Device
UEA	-	Unitized Electrode Assembly
UHF	-	Ultra High Frequency
VDM	-	Vent Door Mechanism
VRCS	-	Vernier Reaction Control System (jet)
WBSC	-	Wide-Band Signal Conditioner
WCCS	-	Window Cavity Conditioning System
WCCU	-	Wireless Crew Communications Umbilical
WMS	-	Waste Management System
WP	-	Working Paper
WRS	-	Water Removal Subsystem
WSB	-	Water Spray Boiler

APPENDIX B

DEFINITIONS, GROUND RULES, AND ASSUMPTIONS

APPENDIX B
DEFINITIONS, GROUND RULES, AND ASSUMPTIONS

B.1 Definitions

Definitions contained in NSTS 22206, Instructions For Preparation of FMEA/CIL, were used with the following amplifications and additions.

INTACT ABORT DEFINITIONS:

RTLS - begins at transition to OPS 6 and ends at transition to OPS 9, post-flight

TAL - begins at declaration of the abort and ends at transition to OPS 9, post-flight

AOA - begins at declaration of the abort and ends at transition to OPS 9, post-flight

ATO - begins at declaration of the abort and ends at transition to OPS 9, post-flight

CREDIBLE (CAUSE) - an event that can be predicted or expected in anticipated operational environmental conditions. Excludes an event where multiple failures must first occur to result in environmental extremes

CONTINGENCY CREW PROCEDURES - procedures that are utilized beyond the standard malfunction procedures, pocket checklists, and cue cards

EARLY MISSION TERMINATION - termination of onorbit phase prior to planned end of mission

EFFECTS/RATIONALE - description of the case which generated the highest criticality

HIGHEST CRITICALITY - the highest functional criticality determined in the phase-by-phase analysis

MAJOR MODE (MM) - major sub-mode of software operational sequence (OPS)

MC - Memory Configuration of Primary Avionics Software System (PASS)

MISSION - assigned performance of a specific Orbiter flight with payload/objective accomplishments including orbit phasing and altitude (excludes secondary payloads such as GAS cans, middeck P/L, etc.)

MULTIPLE ORDER FAILURE - describes the failure due to a single cause or event of all units which perform a necessary (critical) function

OFF-NOMINAL CREW PROCEDURES - procedures that are utilized beyond the standard malfunction procedures, pocket checklists, and cue cards

OPS - software operational sequence

PRIMARY MISSION OBJECTIVES - worst case primary mission objectives are equal to mission objectives

PHASE DEFINITIONS:

PRELAUNCH PHASE - begins at launch count-down Orbiter power-up and ends at moding to OPS Major Mode 102 (liftoff)

LIFTOFF MISSION PHASE - begins at SRB ignition (MM 102) and ends at transition out of OPS 1 (Synonymous with ASCENT)

ONORBIT PHASE - begins at transition to OPS 2 or OPS 8 and ends at transition out of OPS 2 or OPS 8

DEORBIT PHASE - begins at transition to OPS Major Mode 301 and ends at first main landing gear touchdown

LANDING/SAFING PHASE - begins at first main gear touchdown and ends with the completion of post-landing safing operations

B.2 IOA Project Level Ground Rules and Assumptions

The philosophy embodied in NSTS 22206, Instructions for Preparation of FMEA/CIL, was employed with the following amplifications and additions.

1. The operational flight software is an accurate implementation of the Flight System Software Requirements (FSSRs).

   RATIONALE: Software verification is out-of-scope of this task.

2. After liftoff, any parameter which is monitored by system management (SM) or which drives any part of the Caution and Warning System (C&W) will support passage of Redundancy Screen B for its corresponding hardware item.

   RATIONALE: Analysis of on-board parameter availability and/or the actual monitoring by the crew is beyond the scope of this task.

3. Any data employed with flight software is assumed to be functional for the specific vehicle and specific mission being flown.

   RATIONALE: Mission data verification is out-of-scope of this task.

4. All hardware (including firmware) is manufactured and assembled to the design specifications/drawings.

   RATIONALE: Acceptance and verification testing is designed to detect and identify problems before the item is approved for use.

5. All Flight Data File crew procedures will be assumed performed as written, and will not include human error in their performance.

   RATIONALE: Failures caused by human operational error are out-of-scope of this task.

6. All hardware analyses will, as a minimum, be performed at the level of analysis existent within NASA/Prime Contractor Orbiter FMEA/CILs, and will be permitted to go to greater hardware detail levels but not lesser.

   RATIONALE: Comparison of IOA analysis results with other analyses requires that both analyses be performed to a comparable level of detail.

7. Verification that a telemetry parameter is actually monitored during AOS by ground-based personnel is not required.

   RATIONALE: Analysis of mission-dependent telemetry availability and/or the actual monitoring of applicable data by ground-based personnel is beyond the scope of this task.

8. The determination of criticalities per phase is based on the worst case effect of a failure for the phase being analyzed. The failure can occur in the phase being analyzed or in any previous phase, whichever produces the worst case effects for the phase of interest.

   RATIONALE: Assigning phase criticalities ensures a thorough and complete analysis.

9. Analysis of wire harnesses, cables, and electrical connectors to determine if FMEAs are warranted will not be performed nor FMEAs assessed.

   RATIONALE: Analysis was substantially complete prior to NSTS 22206 ground rule redirection.

10. Analysis of welds or brazed joints that cannot be inspected will not be performed nor FMEAs assessed.

    RATIONALE: Analysis was substantially complete prior to NSTS 22206 ground rule redirection.

11. Emergency system or hardware will include burst discs and will exclude the EMU Secondary Oxygen Pack (SOP), pressure relief valves and the landing gear pyrotechnics.

    RATIONALE: Clarify definition of emergency systems to ensure consistency throughout IOA project.

APPENDIX C
SUBSYSTEM ASSESSMENT SUMMARIES

APPENDIX C
SUBSYSTEM ASSESSMENT SUMMARIES

The IOA assessments proved a valuable method of ensuring the proper criticality level be assigned to each FMEA/CIL identified. In many cases the assigned criticality level was changed by the appropriate subsystem manager due to the IOA assessment. As a minimum, this assessment created a deeper awareness of the criticality level assigned and better rationale and understanding. Differences in interpretation and level of detail caused many of the issues generated, along with the lack of updated NASA FMEA/CIL packages. Many non-critical issues remain which should be resolved by the subsystem managers.

C.1 Fuel Cell Powerplant

The IOA analysis of the EPG/FCP hardware initially generated 62 failure mode worksheets and identified 32 PCIs before starting the assessment process (See Fig. C.1). In order to facilitate comparison, five additional failure mode analysis worksheets were generated. These analysis results were compared to the proposed NASA Post 51-L baseline (22 May 1986) of 46 FMEAs and 22 CIL items and to the updated (22 December 1987) version of 43 FMEAs and 23 CILs. The discrepancy between the number of NASA FMEAs can be explained by the different approach used by NASA and IOA to group failure modes. Upon completion of the assessment, and after a discussion with the NASA Subsystem Manager, an agreement between the NASA FMEAs and IOA failure modes was reached. Seven failure modes generated by the IOA analysis were added to the FMEAs, one being a criticality 2/1R CIL item.

C.2 Body Flap/Rudder Speedbrake/Elevon/ME ATVC/Actuations

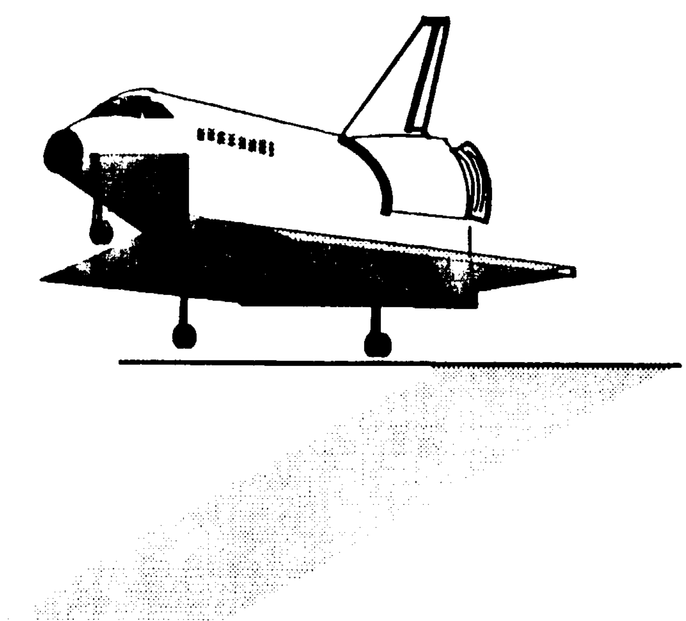
C.2.1 Body Flap Actuator

The overview in Fig. C.2a is a summary of the Body Flap (BF) actuator assessment and presents a comparison of the Pre 51-L baseline and the proposed Post 51-L baseline, with the IOA recommended failures, and any issues. The main reason for differences was that NASA combined failures, whereas IOA prepared separate failure worksheets. Minor differences such as fail or pass of screens were readily resolved. As the result of discussions with the Subsystem Manager and review of the updated FMEA/CIL, all initial issues were resolved, and changes were made to the FMEA/CIL and IOA worksheets.

The IOA effort first completed an analysis of the Body Flap hardware, generating draft failure modes and PCIs. To preserve independence, this analysis was accomplished without reliance upon the results contained within the NASA FMEA/CIL documentation.

EPG/FCP ASSESSMENT OVERVIEW

EPG/FCP ASSESSMENT SUMMARY							
ORIGINAL ASSESSEMENT *				FINAL RESOLUTION**			
	IOA	NASA	ISSUES		IOA	NASA	ISSUES
FMEA	50	43	7	FMEA	50	50	0
CIL	24	23	1	CIL	24	24	0



* NASA PROPOSED BASELINE AS OF 15 DECEMBER 1986

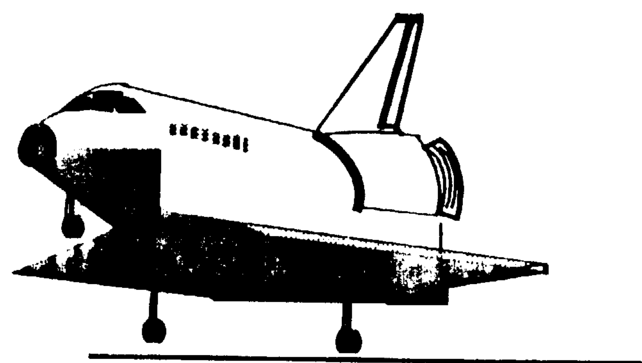
** FINAL NASA BASELINE AS OF 13 MARCH 1987

Figure C.1 - EPG/FCP FMEA/CIL ASSESSMENT

BODY FLAP ACTUATOR ASSESSMENT OVERVIEW

BF ACTUATOR ASSESSMENT SUMMARY

	ORIGINAL ASSESSMENT *			FINAL RESOLUTION **		
	IOA	NASA	ISSUES	IOA	NASA	ISSUES
FMEA	43	36	7	34	34	0
CIL	19	17	7	15	15	0



* NASA PROPOSED BASELINE AS OF 20 MAY 1987
** FINAL NASA CIL ITEMS BASELINE AS OF 7 DECEMBER 1987 AND NASA NON - CIL FMEAS PRE 51 - L BASELINE

Figure C.2a - BF ACTUATOR FMEA/CIL ASSESSMENT

The IOA analysis of the BF hardware initially generated 36 failure mode worksheets and identified 19 PCIs before starting the assessment process. In order to facilitate comparison, seven additional failure mode analysis worksheets were generated.

The IOA results were then compared to the NASA FMEA/CIL baseline with proposed Post 51-L updates included. A resolution of each discrepancy from the comparison was provided through additional analysis as required. Upon completion of the assessment, all of the IOA and NASA failure modes were in agreement.

C.2.2 Rudder/Speedbrake Actuator

The overview in Fig. C.2b is a summary of the Rudder/Speed Brake (RSB) actuator assessment and presents a comparison of the Pre 51-L baseline and the proposed Post 51-L baseline, with the IOA recommended failures, and any issues. The main reason for differences was that NASA combined failures, whereas IOA prepared separate failure worksheets. Minor differences such as fail or pass of screens were readily resolved. As the result of discussions with the Subsystem Manager and review of the updated FMEA/CIL, all initial issues were resolved, and changes were made to the FMEA/CIL and IOA worksheets.

The IOA effort first completed an analysis of the RSB hardware, generating draft failure modes and PCIs. To preserve independence, this analysis was accomplished without reliance upon the results contained within the NASA FMEA/CIL documentation.

The IOA analysis of the RSB hardware initially generated 38 failure mode worksheets and identified 27 PCIs before starting the assessment process. No additional failure mode worksheets were generated during the comparison. The IOA results were then compared to the NASA FMEA/CIL baseline, with the proposed Post 51-L CIL updates included. A resolution of each discrepancy produced by the comparison was provided through additional analysis as required. Upon completion of the assessment, all of the IOA and NASA failure modes were in agreement.

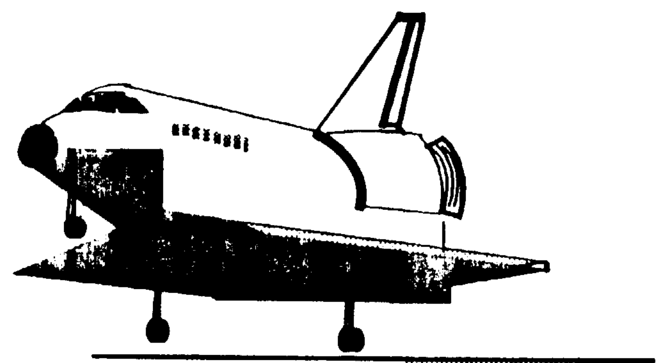
C.2.3 Elevon Actuator

The overview in Fig. C.2c is a summary of the elevon actuator assessment and presents a comparison of the Pre 51-L baseline and the proposed Post 51-L baseline, with the IOA recommended failures, and any issues. The main reason for differences was that NASA combined failures, whereas IOA prepared separate failure worksheets. Minor differences such as fail or pass of screens were readily resolved. As the result of discussions with the Subsystem Manager and review of the updated FMEA/CIL all initial issues were resolved, and changes were made to the FMEA/CIL and IOA worksheets.

The IOA effort first completed an analysis of the elevon subsystem

RSB ACTUATOR ASSESSMENT OVERVIEW

RSB ACTUATOR ASSESSMENT SUMMARY							
ORIGINAL ASSESSMENT *				FINAL RESOLUTION **			
	IOA	NASA	ISSUES		IOA	NASA	ISSUES
FMEA	38	33	5	FMEA	34	34	0
CIL	27	20	7	CIL	18	18	0

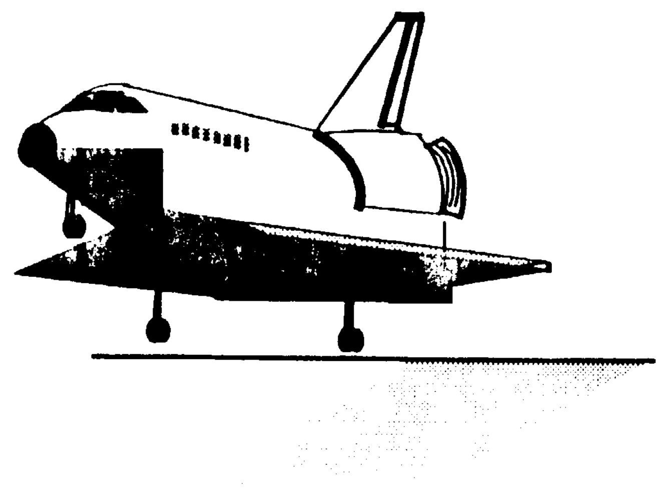


* NASA PROPOSED BASELINE AS OF 20 MAY 1987
** FINAL NASA CIL ITEMS BASELINE AS OF 7 DECEMBER 1987 AND NASA NON - CIL FMEAS - PRE 51 - L BASELINE

Figure C.2b - RSB ACTUATOR FMEA/CIL ASSESSMENT

ELEVON ACTUATOR ASSESSMENT OVERVIEW

ELEVON ACTUATOR ASSESSMENT SUMMARY						
	ORIGINAL ASSESSMENT *			FINAL RESOLUTION **		
	IOA	NASA	ISSUES	IOA	NASA	ISSUES
FMEA	25	23	4	23	23	0
CIL	17	13	4	13	13	0



* NASA PROPOSED BASELINE AS OF 5 MAY 1987
** FINAL NASA CIL ITEMS BASELINE AS OF 7 DECEMBER 1987 AND NASA NON-CIL FMEAS - PRE 51-L BASELINE

Figure C.2c - ELEVON ACTUATOR FMEA/CIL ASSESSMENT hardware, generating draft failure modes and PCIs. To preserve independence, this analysis was accomplished without reliance upon the results contained within the NASA FMEA/CIL documentation. The IOA analysis of the elevon actuator hardware initially generated 25 failure mode worksheets and identified 17 PCIs before starting the assessment process. No additional failure mode worksheets were generated during the comparison. The analysis results were compared to the proposed NASA Post 51-L baseline of 23 FMEAs and 13 CIL items. A resolution of each discrepancy from the comparison was provided through additional analysis as required. Upon completion of the assessment, all of the IOA and NASA failure modes were in agreement.

C.2.4 Main Engine (ATVC) Actuator

The overview in Fig. C.2d is a summary of the main engine actuator assessment and presents a comparison of the Pre 51-L baseline and the proposed Post 51-L baseline, with the IOA recommended failures, and any issues. The main reason for differences was that NASA combined failures, whereas IOA prepared separate failure worksheets. Minor differences such as fail or pass of screens were readily resolved. As a result of discussions with the Subsystem Manager and review of the updated FMEA/CIL, all initial issues were resolved, and changes were made to the FMEA/CIL and IOA worksheets.

The IOA effort first completed an analysis of the Ascent Thrust Vector Control (ATVC) actuator hardware, generating draft failure modes and PCIs. To preserve independence, this analysis was accomplished without reliance upon the results contained within the NASA FMEA/CIL documentation.

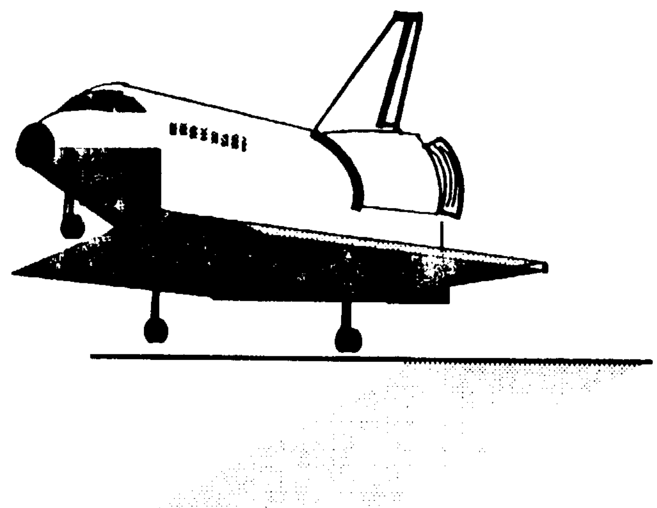
The IOA analysis of the ATVC actuator hardware initially generated 25 failure modes worksheets and identified 16 PCIs before starting the assessment process. The results were compared to the proposed NASA Post 51-L baseline (5 May 1987) of 21 FMEAs and 15 CIL items and the updated (7 December 1987) version of 21 FMEAs and 13 CIL items. A resolution of each discrepancy from the comparison was provided through additional analysis as required. Upon completion of the assessment, all of the IOA and NASA failure modes were in agreement.

C.3 Displays and Control Subsystem

The IOA product for Displays and Controls (D&C) analysis consisted of 134 failure mode worksheets that resulted in 8 PCIs being identified. In order to facilitate comparison, 37 additional failure mode worksheets were generated. Comparison was made to the NASA baseline of 4 January 1988, which consisted of 264 FMEAs and 21 CIL items. The comparison determined if there were any results which had been found by the IOA but were not in the NASA baseline. This comparison produced agreement on all but 45 FMEAs, which caused no differences in the CIL items

MAIN ENGINE (ATVC) ACTUATOR ASSESSMENT OVERVIEW

ATVC ACTUATOR ASSESSMENT SUMMARY						
	ORIGINAL ASSESSMENT *			FINAL RESOLUTION **		
	IOA	NASA	ISSUES	IOA	NASA	ISSUES
FMEA	25	21	4	21	21	0
CIL	16	13	3	13	13	0



* NASA PROPOSED BASELINE AS OF 5 MAY 1987
** FINAL NASA CIL ITEMS BASELINE AS OF 7 DECEMBER 1987 AND NASA NON - CIL FMEAS - PRE 51 - L BASELINE

Figure C.2d - MAIN ENGINE ACTUATOR FMEA/CIL ASSESSMENT (reference Figure C.3).

The issues arose due to different interpretation of NSTS 22206, the FMEA and CIL preparation instructions. IOA analyzed the electrical circuits as black boxes, and NASA analyzed the components within the black boxes. Of the 45 differences with the FMEAs, all were minor and did not affect criticality assessments. In conclusion, IOA is in full agreement with the revised NASA CIL baseline.

C.4 Guidance, Navigation and Control System

The IOA product for the Guidance, Navigation and Control (GNC) analysis consisted of 141 failure mode worksheets that resulted in 24 PCIs being identified. In order to facilitate comparison, 34 additional failure mode worksheets were generated. Comparison was made to the NASA baseline (as of 4 January 1988) which consisted of 148 FMEAs and 36 CIL items. The comparison determined if there were any results which had been found by the IOA that were not in the NASA baseline. This comparison produced agreement on all but 56 FMEAs, with no differences in CIL items (reference Figure C.4).

The issues arose due to different interpretation of NSTS 22206, the FMEA and CIL preparation instructions. IOA analyzed the components of the electrical circuits, generating 56 worksheets more than NASA, who treated the electrical circuits as black boxes. Of these 56 differences with the FMEAs, all were minor and did not affect criticality assessments. Three of the FMEA issues were with the Solid Rocket Booster Rate Gyro Assembly EPD&C. No drawings were available to assess these FMEAs. In conclusion, IOA is in full agreement with the revised NASA CIL baseline.

C.5 Orbiter Experiments

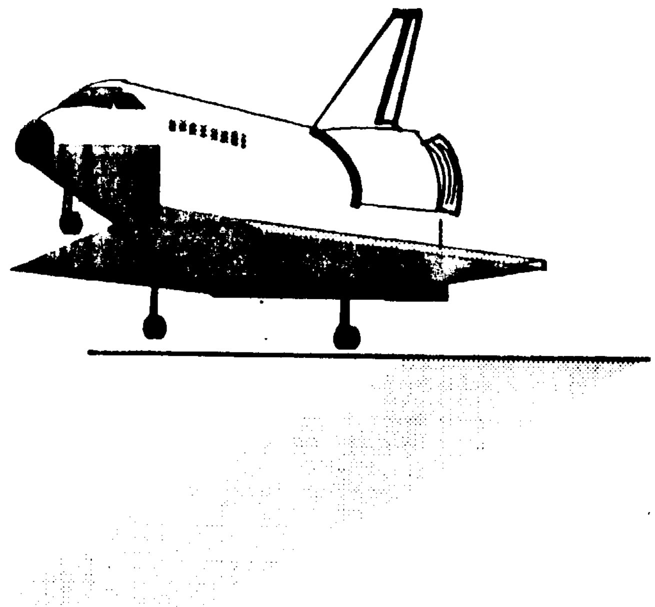
The IOA analysis of the Orbiter Experiments (OEX) hardware initially generated 82 failure mode worksheets and identified 2 PCIs before starting the assessment process (Fig. C.5). These analysis results were compared to the proposed NASA Post 51-L baseline of 191 FMEAs and 1 CIL item, which was generated using the older FMEA/CIL instructions. Upon completion of the assessment, 167 of the 191 FMEAs were in agreement. Of the 24 that remained, 21 were IOA 3/3 FMEAs on components not addressed by NASA. Of the remaining three, two issues were with FMEA criticality levels. The remaining issue concerned a FMEA on a component which no longer exists; thus, no FMEA was needed, and the issue was withdrawn.

C.6 Auxiliary Power Unit

Comparison of the IOA Auxiliary Power Unit (APU) analysis product

D & C ASSESSMENT OVERVIEW

D&C ASSESSMENT SUMMARY *	IOA	NASA	ISSUES
FMEA	171	264	45
CIL	21	21	0

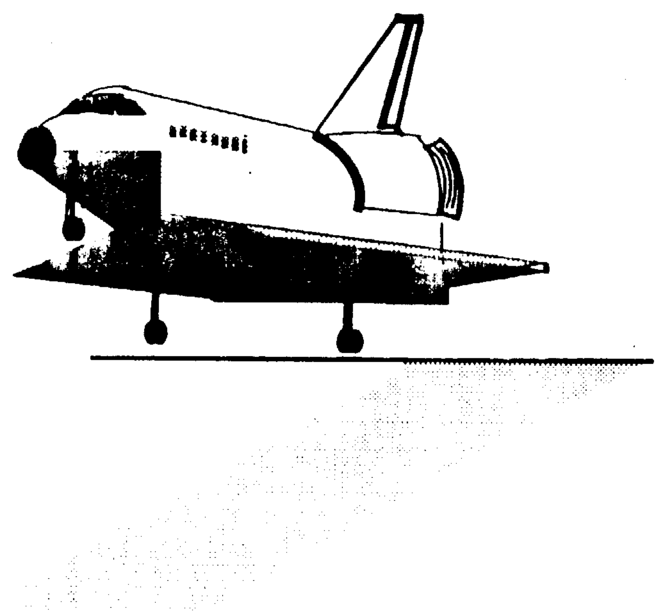


* FINAL NASA BASELINE AS OF 4 JANUARY 1988.

Figure C.3 - D&C FMEA/CIL ASSESSMENT

GNC FMEA/CIL ASSESSMENT OVERVIEW

GNC ASSESSMENT SUMMARY *	IOA	NASA	ISSUES
FMEA	175	148	56
CIL	36	36	0

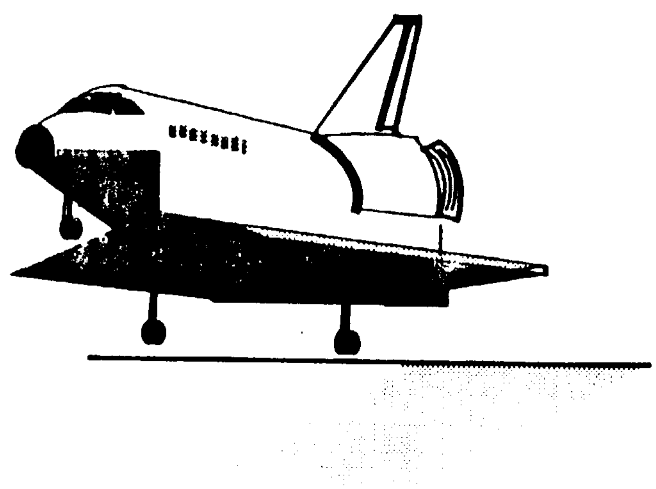


* FINAL NASA BASELINE AS OF 4 JANUARY 1988.

Figure C.4 - GNC FMEA/CIL ASSESSMENT

OEX ASSESSMENT OVERVIEW

OEX ASSESSMENT SUMMARY							
ORIGINAL ASSESSMENT *				FINAL RESOLUTION **			
	IOA	NASA	ISSUES		IOA	NASA	ISSUES
FMEA	82	191	25	FMEA	81	191	24
CIL	2	1	1	CIL	1	1	0



* NASA PROPOSED BASELINE AS OF APRIL 1987
** FINAL NASA BASELINE AS OF 1 JANUARY 1988

Figure C.5 - OEX FMEA/CIL ASSESSMENT

with the NASA APU FMEA/CIL baseline which emerged from the NASA FMEA/CIL review process produced numerous discrepancies. Discussions of these discrepancies with the NASA Subsystem Manager resulted in the identification of 28 issues, which were taken to the NASA/Rockwell FMEA review working group meetings for consideration. These reviews resulted in the addition of four new hardware FMEAs to the APU FMEA baseline, three of which are CIL items.

Two IOA issues remain for the APU subsystem at the completion of the assessment (Fig. C.6). The first issue is a carryover from the original 28 issues, and involves a fuel line temperature sensor which is not covered by the existing FMEA baseline. The APU Subsystem Manager agreed that this sensor, the fuel pump bypass line temperature sensor (MDAC ID 417X), should be covered since loss of it could lead to curtailment of orbit activities (if one other sensor is lost), but stated that consideration of APU instrumentation FMEAs had been deferred indefinitely to allow completion of the review of higher-criticality FMEAs. IOA recommends adding a FMEA to cover failure of this sensor at criticality 3/2R. IOA recommends a criticality of 3/1R for FMEA 04-2-518A-2 (lube oil heater thermostat failed closed), to match the effect of possible loss of an APU due to lube oil overheating cited in APU electrical FMEAs 05-6N-2048-2, 05-6N-2050-2, and 05-6N-2051-2. This discrepancy between hardware FMEAs and electrical FMEAs did not emerge during the initial assessment of the hardware FMEAs.

C.7 Backup Flight System

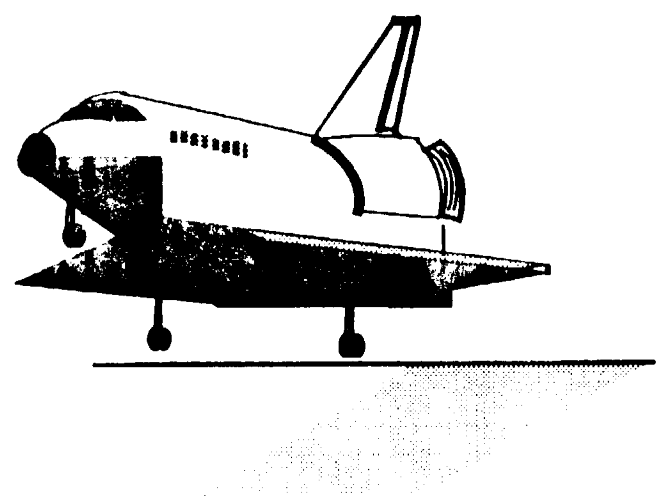
The IOA product for the Backup Flight System (BFS) analysis consisted of 29 failure mode worksheets that resulted in 21 PCIs being identified. This product was originally compared with the proposed NASA BFS baseline as of October 1986, and subsequently compared with the applicable (as of 19 November 1987) Data Processing System (DPS), Electrical Power Distribution and Control (EPD&C), and Displays and Controls NASA CIL items. The comparisons determined if there were any results which had been found by the IOA that were not in the NASA baseline.

The original assessment determined there were numerous failure modes and PCIs in the IOA analysis that were not contained in the NASA BFS baseline. Conversely, the NASA baseline contained three FMEAs (Inertial Measurement Unit (IMU), Air Data Transducer Assembly (ADTA), and Air Data Probe) for CIL items that were not identified in the IOA product. The IOA prepared worksheets and agreed with the NASA analysis for the three items. This increased the IOA worksheets from 29 to 32 and the PCIs from 21 to 24 for the original assessment as shown in Figure C.7.

NASA and Rockwell conducted several reviews and completed a substantial rewrite of all CILs between December 1986 and November 1987. This effort included eliminating BFS as a unique subsystem by integrating BFS CILs with primary DPS CILs.

APU ASSESSMENT OVERVIEW

APU ASSESSMENT SUMMARY							
ORIGINAL ASSESSMENT *				FINAL RESOLUTION **			
	IOA	NASA	ISSUES		IOA	NASA	ISSUES
FMEA	316	304	28	FMEA	314	313	2
CIL	101	102	25	CIL	• 106	106	0



* NASA PROPOSED BASELINE AS OF 17 DECEMBER 1986 (EPDC BASELINE AS OF 10 JULY 1987).
** NASA BASELINE AS OF 2 OCTOBER 1987

Figure C.6 - APU FMEA/CIL ASSESSMENT

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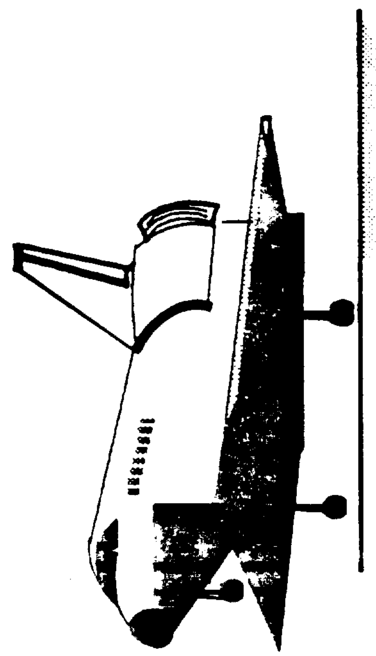
BFS ASSESSMENT OVERVIEW

BFS ACTUATOR ASSESSMENT SUMMARY

	ORIGINAL ASSESSMENT *			FINAL RESOLUTION **		
	IOA	NASA	ISSUES	IOA	NASA	ISSUES
FMEA	32	16	16	33	-	-
CIL	24	12	12	15	15	0



* NASA PROPOSED BASELINE AS OF OCTOBER 1986
** FINAL NASA CIL ITEMS BASELINE AS OF 19 NOVEMBER 1987

Figure C.7 - BFS FMEA/CIL ASSESSMENT

The revised NASA baseline contained four more FMEAs for CIL items that were not identified in the original IOA BFS product, deleted the IMU FMEA mentioned in the previous paragraph, and moved the ADTA and Air Data Probe CILs also mentioned in the previous paragraph to the GNC subsystem. Once again, the IOA prepared worksheets and agreed with the NASA analysis of the additional failures. This increased the IOA worksheets from 32 to 33 and the PCIs from 24 to 25 for the final assessment. The IOA assessment of the final updated baseline (19 November 1987) resulted in agreement on all BFS CIL items, even though there are differences in number of items and assigned criticalities. Figure C.7 presents an overview of the assessment results.

The differences in assigned criticalities are due to different interpretation and application of the FMEA/CIL preparation instructions contained in NSTS 22206. The IOA analyzed BFS hardware failures with the assumption the BFS had been or would be engaged. NASA analyzed BFS hardware failures as an integral part of the DPS or EPD&C and, therefore, counted generic Primary Avionics Software System failures when assigning criticalities to BFS hardware failure modes. The IOA interpretation neither added to nor subtracted from the CIL.

C.8 Electrical Power Distribution and Control

The IOA product for the Electrical Power Distribution and Control analysis consisted of 1,671 failure mode analysis worksheets that resulted in 468 PCIs being identified. Comparison was made to the proposed NASA Post 51-L baseline (as of 31 December 1987), which consisted of 435 FMEAs and 158 CIL items. Differences between the number of IOA worksheets and NASA FMEAs resulted from different levels of analysis (e.g., grouping components into one FMEA versus a worksheet for each component), failure modes not being identified within the original analysis, and the fact that two different schematic sets were used (NASA used Rockwell International assembly drawings and IOA used the Rockwell International integrated schematics). Figure C.8 presents a comparison of the Post 51-L NASA baseline with the IOA recommended baseline.

The issues arose due to differences between the NASA and IOA interpretation of the FMEA/CIL preparation instructions, different definitions of screen detectability, and some ignorance of flight procedures on the part of IOA. After comparison, there were no discrepancies found that were not already identified by NASA, and the remaining issues were the result of the differences in the schematics used by NASA and IOA.

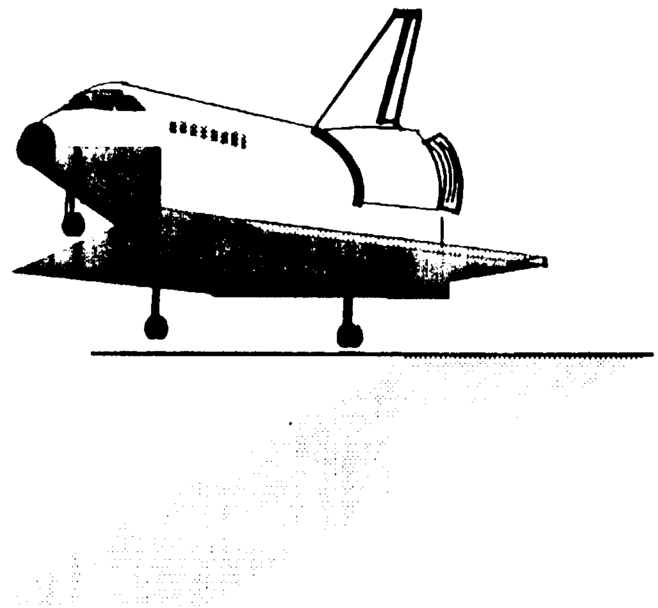
C.9 Landing/Deceleration Subsystem

The IOA analysis of the Landing/Deceleration (LDG/DEC) hardware initially generated 246 failure mode worksheets and identified 124 Potential Critical Items (PCIs) before starting the

EPD&C ASSESSMENT OVERVIEW

EPD&C ASSESSMENT SUMMARY *

	IOA	NASA	ISSUES
FMEA	435	435	0
CIL	158	158	0



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* FINAL NASA BASELINE AS OF 31 DECEMBER 1987

Figure C.8 - EPD&C FMEA/CIL ASSESSMENT

assessment process. In the analysis report, the Landing/Deceleration Subsystem was divided into six separate functional areas according to hardware and function. Difficulty was encountered in the hardware analysis due to the large amounts of proprietary hardware contained in the tires and wheels, and in many of the mechanisms of the landing gear and the hydraulics systems. The initial NASA document, STS 82-0013, consisted of five separate functional areas which included 118 FMEAs. After the initial definition of the subsystem the 32 NWS FMEAs were removed and a separate group was initiated to prepare the analysis for that subsystem. A decision was made to include the EPD&C data for the subsystem, and 122 electrical FMEAS were added to the subsystem. Later, eight additional FMEAS were added to the EPD&C portion of the subsystem. In November 1986, 44 hydraulics FMEAs were added to the subsystem. After the initial IOA analysis was completed in January 1987, a decision was made to remove the pyrotechnic devices from the subsystem, which removed six FMEAs from the Nose Landing Gear and Main Landing Gear subsystems. At the time of this report there are six subsystems that have been evaluated, including 267 NASA FMEAs and 120 CIL items. There were 75 issues between the NASA documentation and the IOA data.

The IOA analysis did not include 14 of the NASA FMEAs due to the lack of data to support the evaluation, and many of the FMEAs were evaluated using documentation such as training manuals and component procurement specification documents. The general lack of documentation and the proprietary nature of the data presented major problems for the analysts.

The majority of the hardware issues were prepared on portions of the subsystem for which the NASA FMEAs covered a whole assembly with a limited number of FMEAs. The IOA analysis concluded that a single NASA FMEA was covering several 1/1 failures that were within the single FMEA. Several major components appeared to be overlooked or considered to be a part of an assembly by the NASA assessment. The IOA assessment also uncovered several functional FMEAs that were discussed with the NASA Subsystem Manager. Only the initial FMEA data on the hardware subsystems was analyzed and the assessment reflects only the analysis of that data.

The majority of the electrical (EPD&C) issues arose due to operational discrepancies or evaluation differences on the criticality of the function or hardware capability. This portion of the document was completely analyzed and the assessment includes the final resolution of the EPD&C data.

The interim IOA assessment report indicated 51 Landing/Deceleration CIL issues. These issues represented a broad spectrum of differences between the IOA and NASA/Rockwell regarding documented hardware failure modes, criticality assessments, and redundancy verification.

The IOA studied the revised Landing/Deceleration subsystem FMEA/CIL hardware documentation presented to the NSTS Level I/II

Review Board in April 1988. The IOA also examined the documentation presented to the CCB in January 1988 for hydraulic actuators and LDG/DEC EPD&C components. All this data was factored into a re-evaluation of the 51 CIL issues. As a result, all issues have been resolved (Figure C.9). The resolutions represent either an agreement between the IOA and NASA/Rockwell or a concession by IOA to a more conservative analysis by NASA/Rockwell. There are no hardware failure modes considered to be CIL items by the IOA but not by NASA/Rockwell.

Rationale for the resolution of each landing/deceleration issue is contained on the applicable assessment worksheets in the companion volume to this report, the CIL Issues Resolution Report.

C.10 Purge, Vent and Drain System

The IOA product for the Purge, Vent and Drain (PV&D) independent analysis consisted of 62 failure mode worksheets that resulted in 16 PCIs being identified. A comparison was made of the IOA product to the NASA FMEA/CIL dated 20 November 1987, which consisted of 42 FMEAs and 8 CIL items. The difference in the number of IOA analysis worksheets and NASA FMEAs can be explained by the different levels of analysis detail performed to identify failure modes. The comparison determined if there were any results found by the IOA that were not included in the NASA FMEA/CIL.

The original assessment produced agreement on all but five failure modes. Three failure modes for components were not identified by the NASA FMEAs, one being a CIL item. Two failure modes identified by IOA and NASA had differences in criticality, resulting in two new CIL items. Subsequent research and discussions with the NASA Subsystem Manager resulted in the withdrawal of the three CIL issues. Figure C.10 presents a comparison of the NASA PV&D FMEA/CIL baseline as presented to the NSTS Level I/II Review Board on 8 April 1988, with the IOA recommended baseline and any issues. Detailed discussion of IOA issues and recommendations are provided in subsequent paragraphs.

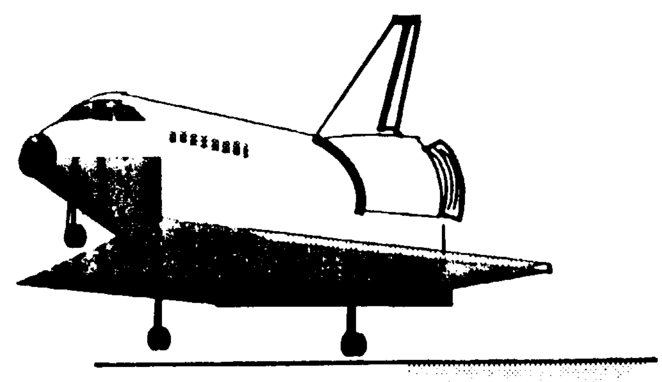
The assessment between the IOA purge system worksheets and NASA Post 51-L FMEA/CIL baseline produced one issue. IOA recommends the addition of a FMEA to the NASA baseline for the failure mode "check valve leakage", as identified in IOA worksheet 9009. The criticality for this failure mode is 3/3.

The original assessment between the IOA Window Cavity Conditioning System (WCCS) worksheets and NASA Post 51-L FMEA/CIL produced three issues. IOA recommended the addition of a FMEA to the NASA baseline for the failure mode "WCCS outer cavity tubing clogging", as identified in IOA worksheet 9036. The criticality for this failure mode was 1/1 and, therefore, would have required NASA to generate a CIL. Further research and discussion with the NASA Subsystem Manager resulted in this failure mode being

LDG/DEC FMEA/CIL ASSESSMENT OVERVIEW

LANDING/DECELERATION ASSESSMENT SUMMARY

	ORIGINAL ASSESSEMENT *			FINAL RESOLUTION**		
	IOA	NASA	ISSUES	IOA	NASA	ISSUES
FMEA	259	267	75	259	267	24
CIL	124	120	51	131	131	0



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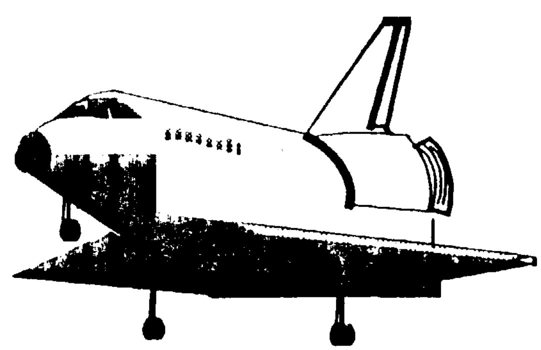
* NASA PROPOSED BASELINE AS OF 19 NOVEMBER 1986
** FINAL CIL RESOLUTION AS OF 15 APRIL 1988

Figure C.9 - LDG/DEC FMEA/CIL ASSESSMENT

PV&D ASSESSMENT OVERVIEW

PV&D ASSESSMENT SUMMARY

	ORIGINAL ASSESSMENT *			FINAL RESOLUTION **			
	IOA	NASA	ISSUES		IOA	NASA	ISSUES
FMEA	62	46	11	FMEA	48	46	2
CIL	16	8	3	CIL	8	8	0



* NASA PROPOSED FMEA BASELINE AS OF 20 NOVEMBER 1987.
** NASA CIL ITEMS BASELINE AS OF 8 APRIL 1988

Figure C.10 - PV&D FMEA/CIL ASSESSMENT

declared non-credible, and the issue was withdrawn. IOA agreed to a 1/1 criticality for NASA Baseline FMEA/CIL 01-5-332404-5, "WCCS desiccant filter outer cavity leakage". However, NASA Baseline FMEA/CIL 01-5-332404-6 describes the same component, same failure, and same results, but with different windows, as a criticality 3/3. IOA recommended combining the two NASA FMEAs with a criticality of 1/1. IOA disagreed with NASA Baseline FMEA 01-5-332406-5, designated criticality 3/3. IOA worksheet 9037 for the same failure mode, "WCCS outer cavity tubing leakage", identifies the criticality as 1/1. NASA Baseline FMEA 01-5-332403-1 identifies the same failure mode for the tubing, but for a different set of windows, as a criticality 1/1. Discussion with the NASA Subsystem Manager revealed that NASA FMEAs 01-5-332404-6 and 01-5-332406-5 are designated criticality 3/3 because the forward and middle windows have a different venting scheme and different delta pressure margins, which allow them to experience these two failure modes without exceeding their delta pressure margins.

The assessment between the External Tank/Orbiter (ET/ORB) Purge Disconnect Network IOA worksheets and NASA Post 51-L FMEA/CIL baseline produced one issue. IOA recommends the addition of a FMEA to the NASA baseline for the failure mode, "ET/ORB Purge Disconnect external leakage", as identified in IOA worksheet 9060. The criticality for this failure mode is 3/3. IOA recognizes this as a credible failure mode.

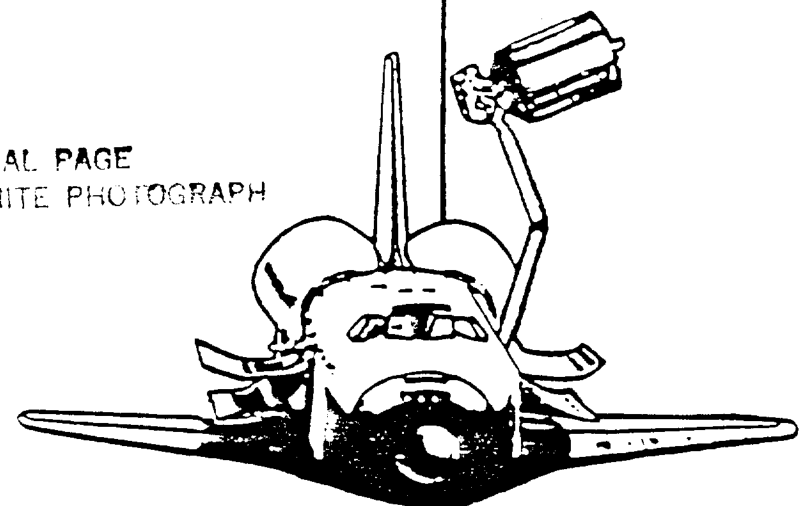
In conclusion, discussions with the NASA Subsystem Manager resulted in the resolution of all IOA issues involving the PV&D Subsystem CIL. Two issues remain with the PV&D non-CIL FMEAs.

C.11 Pyrotechnics

The IOA analysis of the Pyrotechnics hardware initially generated 41 failure mode worksheets and identified 41 PCIs before starting the assessment process. No additional failure mode analysis worksheets were generated to facilitate comparison. These analysis results were compared to the proposed NASA Post 51-L baseline of 37 FMEAs and 37 CIL items, which were generated using the NSTS-22206 FMEA/CIL instructions. Upon completion of this assessment, there were four IOA issues involving items which were not part of the original NASA FMEA/CIL. Re-evaluation of items using the NSTS Level I/II Review Board Presentation SSV88-71, presented on 22 April 1988, resulted in the revising of the CIL assessment items to 38 NASA items, 38 IOA items, and no issues (Figure C.11). Three new FMEA/CIL items were generated and two deleted by NASA. The additional three items satisfied the four original IOA issues, while the deletions were accepted by IOA after additional system evaluation found the failure modes not to be credible.

PYROTECHNICS ASSESSMENT SUMMARY *

	IOA	NASA	ISSUES
FMEA	38	38	0
CIL	38	38	0



LANDING/DECELERATION

	IOA	NASA	ISSUES
FMEA	9	9	0
CIL	9	9	0

ORBITER/ET SEPARATION

	IOA	NASA	ISSUES
FMEA	12	12	0
CIL	12	12	0

CREW STATION & EQUIPMENT

	IOA	NASA	ISSUES
FMEA	6	6	0
CIL	6	6	0

P/L RETN/DEPLOY

	IOA	NASA	ISSUES
FMEA	6	6	0
CIL	6	6	0

RENDEZVOUS RADAR ANTENNA

	IOA	NASA	ISSUES
FMEA	5	5	0
CIL	5	5	0

*** NASA CIL ITEM BASELINE AS OF 22 APRIL 1988.**

Figure C.11 - PYROTECHNICS FMEA/CIL ASSESSMENT

C.12 Thermal Control System

C.12.1 Active Thermal Control System

The IOA analysis and assessment of the Active Thermal Control System (ATCS) consisted of an evaluation of hardware in the following subsystems: the Freon Coolant Loop (FCL), the Radiator Flow Control Assembly (RFCA), the Flash Evaporator System (FES), and the Ammonia Boiler System (ABS). The original assessment produced agreement on all but 30 CIL issues and 101 non-CIL issues. The re-evaluation process involved the 30 CIL issues. All issues have been resolved.

Re-evalualtion by NASA of three of the items resulted in criticalities which either agreed with IOA's completely or removed it from the CIL list and from the issue list. A group of CIL issues were resolved by accepting NASA's more conservative groupings of failures or NASA's more conservative definition of function and redundancy. Three CIL issues were resolved when the failures were found in other NASA FMEA packages or as a subset of existing ATCS failures.

During the original assessment, IOA had recommended higher criticalities for four of the CILs. After re-evaluation and consideration of all redundancy paths, IOA returned to the original criticalities and agreed with NASA. Also, after re-evaluation, IOA agreed with the non-credibility of the failures proposed by NASA.

Eleven of the CIL issues were discussed with the Subsystem Manager. In seven cases, the discussion revealed sufficient redundancy for IOA to agree with the lower criticalities. Three of the issues (ATCS-3079, 3079A, 3067) produced agreement, in theory, with the IOA criticalities. However, the Subsystem Manager described current Level II guidelines which require the assignment of dual criticalities. One issue resulted in a new criticality being assigned after joint agreement by NASA and IOA.

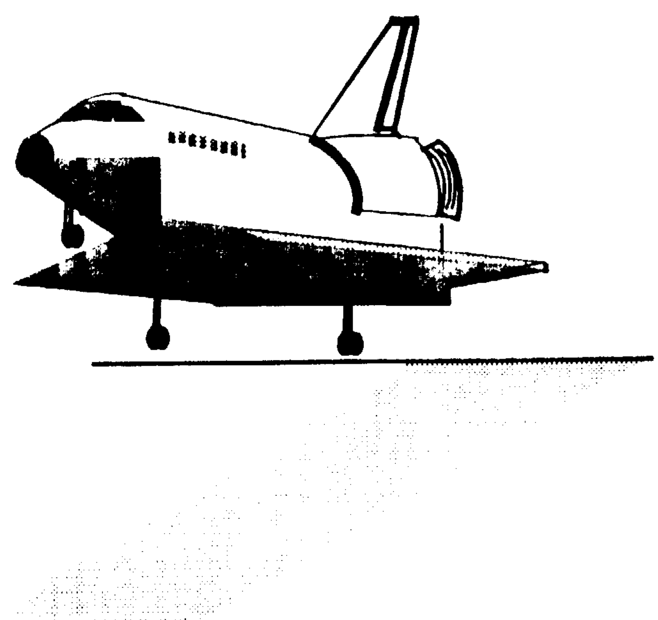
In conclusion, all ATCS CIL issues have been resolved as shown in Figure C.12a.

C.12.2 Life Support and Airlock Support System

The final Life Support System (LSS) and Airlock Support System (ALSS) analysis and assessments were performed to establish a criticality that was agreed to by both NASA and the IOA study. These analyses were performed only on the items where issues existed between the previous NASA and IOA criticalities. Further, the analyses were limited to those issues which were CIL related. All issues have been resolved, based on IOA internal review and discussions with the NASA Subsystem Manager. A note of interest is that across the system items which were previously not strictly identified as issues were revisited. These were related to previous assessments where a detailed assessment was

ATCS ASSESSMENT OVERVIEW

ATCS ASSESSMENT SUMMARY							
ORIGINAL ASSESSMENT *				FINAL RESOLUTION **			
	IOA	NASA	ISSUES		IOA	NASA	ISSUES
FMEA	252	357	101	FMEA	252	357	101
CIL	109	147	30	CIL	109	109	0



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* JANUARY 1988
** MAY 1988

Figure C.12a - ATCS FMEA/CIL ASSESSMENT

not made due to the lack of NASA information at that time. The following paragraph gives insight to the resolution of the issues that previously existed.

The supply water subsystem had 34 CIL issues resolved. Twenty-four issues were withdrawn when the NASA criticality was accepted, six issues were changed to the IOA criticalities, and four were revised to new criticalities.

The most significant issue was related to external leakage of H2O from the H2 separators in the water line from the fuel cells to the supply water tanks. Initial criticalities were based upon two separate scenarios. The NASA scenario considered a loss of FES situation that could result in a 1R/2 criticality if a subsequent ABS or radiator failure occured. The IOA scenario took the approach that water management protects against the usage of FES water until entry, but the loss of orbit FES operation and drinking water results in a 2/2 criticality. Upon reanalysis the IOA analyst took a third approach which was later formalized by the NASA Subsystem Manager. The question to answer considered what happened to the H2O as it went overboard through the vacuum vent line. Final determination was that an uncontrollable buildup of ice would result, which could seriously damage the vehicle upon entry. Thus a revised criticality of 1/1 was agreed upon. Three other criticalities were revised to mission critical within the galley supply water lines, based upon leak isolation capabilities.

The six criticalities which were revised to match IOA were based upon unisolatable supply water leaks which resulted in free water in the cabin, thus resulting in mission termination. The 24 issues where IOA accepted the NASA criticality were based upon further understanding of fuel cell H2O dead head conditions (7), effects of H2 in the Extravehicler Mobility Unit (EMU) H2O (2), ice build up conditions at the H2O servicing ports (6), effects of supply tank outlet plumbing failures on FES operations (8), and water dump redundancy considerations (1).

In the Waste Management Subsystem, 27 issues were resolved. Seventeen were withdrawn when the IOA task accepted the NASA criticality. Seven resulted in the NASA Subsystem Manager agreeing with the IOA recommended criticality, and three were resolved through further discussion which revised the criticalities to a new position from that previously held by either party.

In the case of the issues withdrawn in favor of the NASA criticalities, seven were based upon the definition of redundancy and the fact that the Fecal Collection Bag (FCB) and Urine Collection Device (UCD) only provide for a one day extension, rather than providing actual redundancy. The remaining 10 were based upon the final agreement on the worst case scenario. The worst case scenarios were related to the interpretation of leak isolation redundancy, UCD redundancy considerations, usage of the contingency cross-tie, and hazardous atmospheres created by vacuum vent line blockage.

The seven IOA criticalities agreed to by NASA were associated with consistency within the waste water dump system. Two of the revised criticalities also were in this category. The remaining revised criticality was related to the purpose of the vacuum line heater and the fact that the assessment was initially made against the wrong NASA FMEA.

Twenty issues were resolved related to the Smoke Detection and Fire Suppression subsystem. Fifteen issues were resolved when the IOA task accepted the NASA criticalities and withdrew the issues. Five issues were resolved when further NASA analysis lead to the criticalities matching the IOA analysis presented in the assessment report for this subsystem (reference 56). The bases for these resolutions are discussed in the following paragraphs.

Justification for withdrawing the IOA issues were derived from the following considerations. The first justification was based upon the determination of failure detectability (screens A & B) and the passing or failing of the screens. When this was an issue the higher criticality was accepted, since more visibility is given to the item. Eight items, five of which were CIL items and three that were CIL vs Non-CIL, were in this category. The second justification was based upon analysis data where the IOA criticality relied upon the usage of portable fire bottles to suppress avionics bay fires prior to main engine ignition. Upon further investigation, the concerns of the NASA Subsystem Manager on the difficulty of reaching the ports were determined to have merit. Five items were in this category.

Finally, two issues were withdrawn because the IOA failures within components were determined to be non-credible. The data used to determine this came from sources external to the NASA Subsystem Manager.

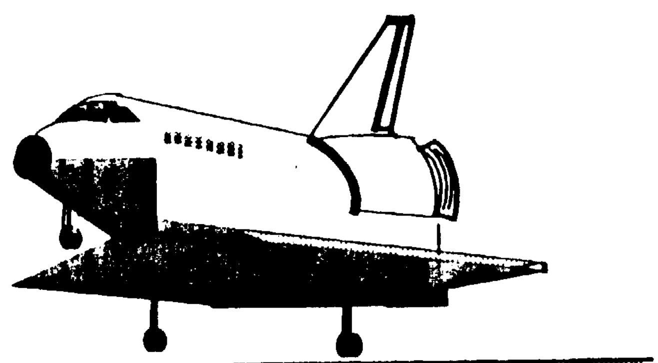
Five issues were resolved based upon further analysis. These analyses led to NASA criticalities that matched the IOA data presented in the assessment report (reference 56).

In the Airlock Support System (ALSS) 53 items were reviewed. This was one of the major subsystems where detailed NASA data was not available when the original assessments were performed. Except in one case, all ALSS issues were withdrawn. The one case resulted in a revised criticality to provide consistency with components in the same circuit. The withdrawn issues were mostly based upon IOA accepting the philosophy that the airlock must support contingency extravehicular activity (20), and that EMU provisions are redundant (18). Other justifications were based upon different interpretations of remaining success paths, various erroneous assumptions on airlock operations, and a more conservative approach taken by NASA.

Figure C.12b documents the final results of the IOA assessment.

LSS/ALSS ASSESSMENT OVERVIEW

LSS/ALSS ASSESSMENT SUMMARY							
ORIGINAL ASSESSMENT *				FINAL RESOLUTION **			
	IOA	NASA	ISSUES		IOA	NASA	ISSUES
FMEA	694	456	301	FMEA	634	456	167
CIL	171	101	111	CIL	96	96	0



* NASA BASELINE AS OF 1 OCTOBER 1987

** NASA BASELINE AS OF 4 MAY 1988

Figure C.12b - LSS AND ALSS FMEA/CIL ASSESSMENT

C.13 Crew Equipment

The IOA analysis and assessment of crew equipment examined hardware associated with Extravehicular Activity (EVA) equipment, EVA tethers, EVA tools, Intravehicular Activity (IVA) tools, food assemblies, and miscellaneous Orbiter hardware. The original assessment process produced agreement on all but four CIL issues. During the secondary assessment, all cases were re-examined and withdrawn. The cases where NASA had been recommending a higher criticality than that suggested by IOA were agreed with by recognizing the validity of stricter definitions of function and redundancy. The items where IOA had not originally identified a corresponding NASA FMEA were re-examined and implicit matches were identified. In conclusion, all CIL issues were withdrawn. Issues still remain with 123 non-CIL failure modes. Figure C.13 documents the final results.

C.14 Instrumentation

The IOA analysis of the Instrumentation hardware initially generated 88 failure mode worksheets and identified 8 PCIs before starting the assessment process (Fig. C.14). These analysis results were compared to a NASA baseline which was frozen as of 1 January 1988, with 14 Post 51-L FMEAs included in a total of 96 FMEAs and 18 CIL items, which were generated using the referenced FMEA/CIL instructions. Upon completion of the assessment, 82 of the 107 FMEAs were in agreement. Of the 25 that remained, 4 are 2/2 criticality and not currently on the NASA CIL list and 7 new FMEAs were generated which had no NASA match. The remaining 14 FMEAs are of a different criticality than the NASA interpretation. None of these 14 FMEAs affect the CIL listing.

The four CIL items were for failures of the Operational Instrumentation MDMs OF1, 2, and 3. The Instrumentation CCB meeting of 2 March 1988 reflected that all MDMs were addressed by the Data Processing System (DPS) CIL presentation of 14 December 1987. Upon subsequent contact, the DPS personnel referred the IOA analysts to the fuel cell subsystem. Analysis by fuel cell personnel revealed that the failures identified were not CIL items. The IOA's initial concerns were with redundancy for the fuel cell measurements that these MDMs provide. The fuel cell analysis revealed that redundancy is provided.

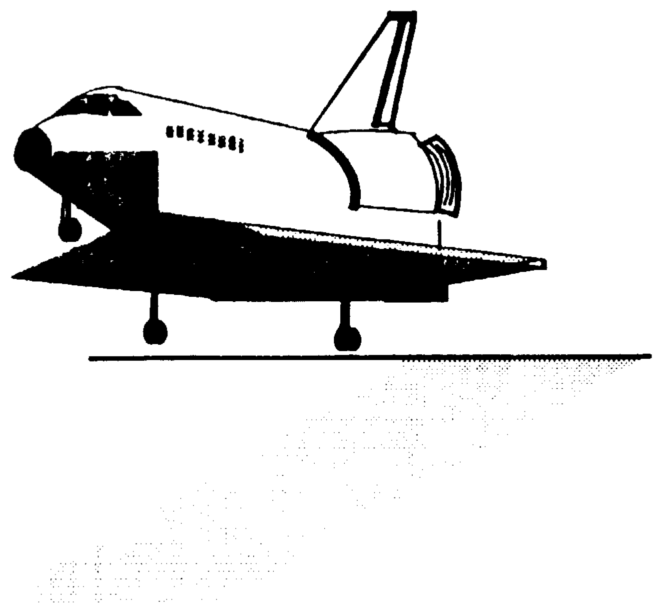
C.15 Data Processing System

The IOA analysis of the Data Processing System (DPS) hardware initially generated 85 failure mode worksheets and identified 2 PCIs before starting the assessment process. In order to facilitate comparison, 37 additional failure mode analysis worksheets were generated (See Fig. C.15). These analysis results were compared to the proposed NASA Post 51-L baseline of 78 FMEAs and 25 CIL items, which was generated using the <u>Rockwell</u>

CREW EQUIPMENT ASSESSMENT OVERVIEW

CREW EQUIPMENT ASSESSMENT SUMMARY

	ORIGINAL ASSESSMENT *			FINAL RESOLUTION **		
	IOA	NASA	ISSUES	IOA	NASA	ISSUES
FMEA	351	422	123	351	422	123
CIL	82	80	4	82	82	0

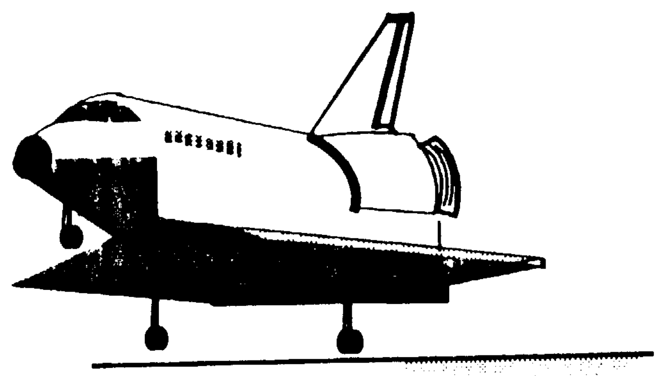


* DECEMBER 1987.
** APRIL 1988.

Figure C.13 - CREW EQUIPMENT FMEA/CIL ASSESSMENT

INSTRUMENTATION FMEA/CIL ASSESSMENT OVERVIEW

INSTRUMENTATION ASSESSMENT SUMMARY							
ORIGINAL ASSESSMENT *				FINAL RESOLUTION **			
	IOA	NASA	ISSUES		IOA	NASA	ISSUES
FMEA	107	96	25	FMEA	107	96	25
CIL	22	18	4	CIL	13	18	0

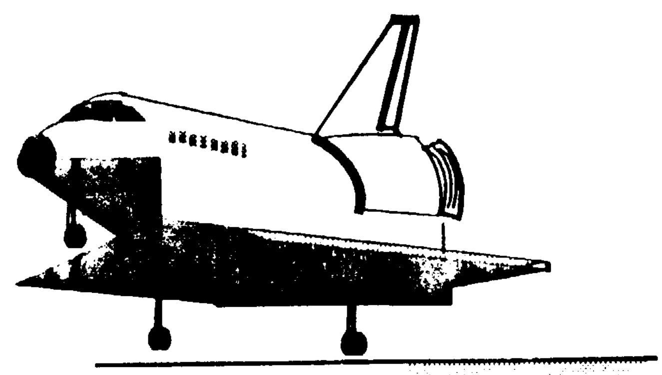


* NASA BASELINE OF 1 JANUARY 1988.
** FINAL NASA BASELINE AS OF 2 MARCH 88 CCB MEETING.

Figure C.14 - INSTRUMENTATION FMEA/CIL ASSESSMENT

DPS FMEA/CIL ASSESSMENT OVERVIEW

DPS ASSESSMENT SUMMARY							
	ORIGINAL ASSESSMENT *				FINAL RESOLUTION **		
	IOA	NASA	ISSUES		IOA	NASA	ISSUES
FMEA	78	78	4	FMEA	78	78	2
CIL	23	25	2	CIL	24	24	0



* NASA PROPOSED BASELINE AS OF NOVEMBER 1986
** FINAL NASA CIL RESOLUTION AS OF 4 APRIL 1988

Figure C.15 - DPS FMEA/CIL ASSESSMENT

00-2G FMEA/CIL instructions. Upon completion of the assessment, 60 of the 78 FMEAs were in agreement. Of the 18 that remained, 14 had minor discrepancies that did not affect criticality. Of the remaining four, two issues were with FMEAs (05-5-B03-1-1 and 05-5-B03-2-1) that had considered failure modes outside the DPS subsystem, and caused inflated criticalities. These criticalities placed both FMEAs on the CIL. The other two issues were also with FMEAs (05-5-B01-1-1 and 05-5-B02-1-1) that considered failure modes outside the DPS subsystem. However, when the correct failure mode is included, the current criticalities will remain unchanged. In summary, all issues may be attributed to differences between ground rules in Rockwell 100-2G and NSTS 22206 instructions.

The two remaining DPS CIL issues shown in the IOA Interim Report (reference 70) concerned FMEAs 05-5-B03-1-1 and 05-5-B03-2-1, loss of output from FA and FF MDMs respectively. The IOA considered these failures to be non-CIL items with 3/1R criticality. In the November 1986 version of the proposed post 51-L baseline, both FMEAs were considered by NASA/Rockwell to be 2/1R, which categorized them as CIL items. NASA and Rockwell conducted several reviews during 1987 and substantially revised all CILs. FMEA 05-5-B03-2-1, "MDM FF1-4 loss of output", was downgraded to 3/1R, which agrees with the IOA analysis. NASA/Rockwell chose to retain the 2/1R criticality for FMEA 05-5-B03-1-1. The criticality assessment difference for this FMEA is withdrawn as an issue since the NASA/Rockwell value represents a more conservative application of the NSTS 22206 instructions than that imposed by the IOA.

C.16 Atmosphere Revitalization Pressure Control System

The original analysis and assessment of the Atmosphere Revitalization Pressure Control System (ARPCS) yielded issues with 124 of the NASA FMEAs and 48 of the NASA CILs. During the second phase of the assessment process, the 48 CIL issues were re-examined and resolved.

Re-evaluation by NASA of the EPD&C failures resulted in revised criticalities for four of the CIL issues. These revised criticalities matched IOA's recommendations and the issues were closed.

IOA's original analysis was completed before the decision to remove the auxiliary O2 tank was made. The knowledge of this design change led to a re-evaluation of IOA's assigned criticalities and withdrawal of a second group of issues.

Two issues were withdrawn when they were found to be subsets of existing NASA CILs. Additionally, another group of issues were withdrawn when IOA accepted NASA's more conservative definition of redundancy and credible failure modes.

Sixteen issues were discussed with the NASA Subsystem Manager, John Whelan, on 23 May 1988. Four of these involved oxygen flow to the Launch/Entry Helmets. The issues were withdrawn when it was learned that a "Y" connection is flown permitting two crewmembers to utilize one connection. This permitted a downgrading of the criticality from 1/1 to 2/1R. Eight issues involved the N2 system. NASA utilized a ground rule, accepted by both the PRCB and the CCB, which placed cabin integrity as a backup to the N2 systems. Accepting this philosophy permits a criticality downgrade from 2/1R to 3/1R. IOA withdrew these issues. The remaining issues were closed when the Subsystem Manager gave IOA a clearer understanding of the system and component design and operation.

In summary, all CIL issues have been resolved. Figure C.16 presents the final resolution of the ARPCS assessment.

C.17 Hydraulic/Water Spray Boiler

The IOA product for the Hydraulic/Water Spray Boiler (HYD/WSB) analysis consisted of 447 failure mode worksheets that resulted in 183 PCIs being identified. An initial comparison was made to the NASA baseline (as of 19 November 1986) which consisted of 364 FMEAs and 111 CIL items. The comparison determined if there were any results which had been found by the IOA that were not in the NASA baseline. This comparison produced agreement on all but 68 FMEAs, which caused differences in 23 CIL items. A second comparison was made to the NASA FMEA/CIL baseline as documented in the NSTS Level I/II Review Board Presentation of 30 March 1988. This comparison, and further investigation, resulted in the withdrawal of 18 of the CIL issues. The remaining five CIL issues were discussed with the NASA Subsystem Manager on 26 April 1988. As a result of this meeting, four issues were withdrawn, and one issue was accepted by the Subsystem Manager. No IOA issues remain with respect to the Hydraulic/WSB CIL. Forty-five discrepancies remain involving non-CIL items. Figure C.17 presents a comparison of the NASA baseline with the IOA recommended baseline, and any issues.

Details of the resolution of all the CIL issues are provided in the companion volume to this report, the CIL Issues Resolution Report (reference 71).

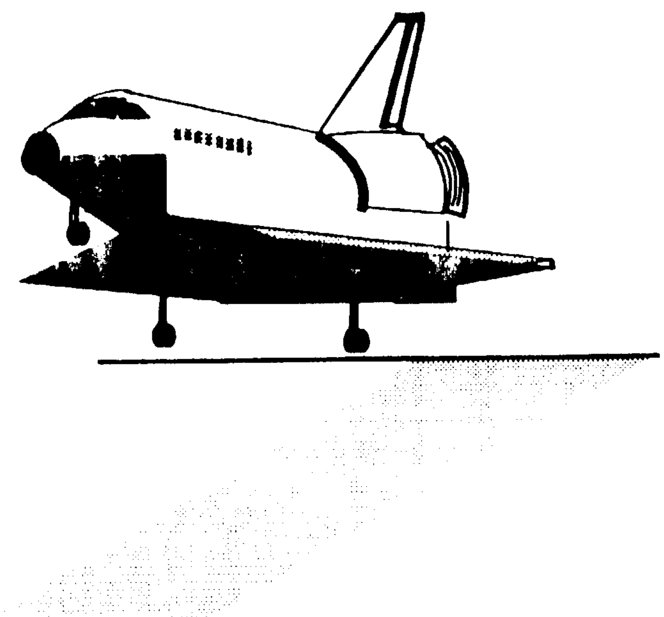
C.18 Mechanical Actuation Subsystem

Hardware assigned to the Mechanical Actuation Subsystem (MAS) includes mechanisms of nine Orbiter subsystems. They include the air data probes, elevon seal panels, ET umbilicals, Ku-Band deploy mechanism, payload bay doors, payload radiators, personnel hatches, vent door mechanisms, and star tracker door mechanisms. The IOA analysis of this hardware initially generated 685 failure mode worksheets and identified 476 PCIs before starting the assessment process. In order to facilitate comparison, 28 additional failure mode analysis worksheets were generated.

ARPCS ASSESSMENT OVERVIEW

ARPCS ASSESSMENT SUMMARY

	ORIGINAL ASSESSMENT *			FINAL RESOLUTION **		
	IOA	NASA	ISSUES	IOA	NASA	ISSUES
FMEA	262	273	124	262	262	0
CIL	87	73	48	87	87	0



* JANUARY 1988.
** MAY 1988.

Figure C.16 - ARPCS FMEA/CIL ASSESSMENT

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HYDRAULICS/WATER SPRAY BOILER ASSESSMENT OVERVIEW

HYD/WSB ASSESSMENT SUMMARY *

	IOA	NASA	ISSUES
FMEA	336	301	45
CIL	112	112	0

WATER SPRAY BOILER

	IOA	NASA	ISSUES
FMEA	89	70	9
CIL	39	39	0

EPD&C - WATER SPRAY BOILER

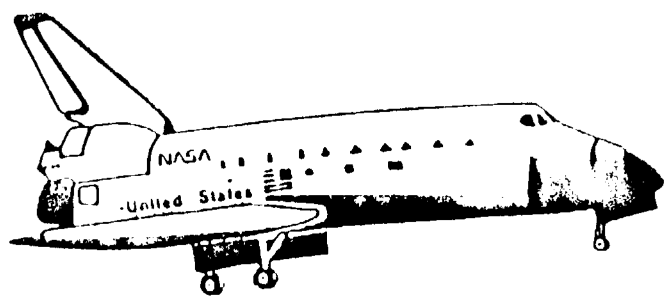
	IOA	NASA	ISSUES
FMEA	27	27	0
CIL	4	4	0

HYDRAULICS SUBSYSTEM

	IOA	NASA	ISSUES
FMEA	112	90	22
CIL	48	48	0

EPD&C - HYDRAULICS

	IOA	NASA	ISSUES
FMEA	128	114	14
CIL	21	21	0



* NASA FMEA/CIL BASELINE AS OF 30 MARCH 1988

Figure C.17 - HYDRAULICS/WATER SPRAY BOILER FMEA/CIL ASSESSMENT

These analysis results (Fig. C.18) were first compared to the proposed NASA Post 51-L baseline of 510 FMEAs and 252 CIL items as documented in the NSTS Level I/II Review Board Presentations through 5 February 1988. The IOA assessment of this baseline generated 310 issues.

During the subsequent re-evaluation review of these 310 issues, two additional subsystem mechanisms were added. They are cabin seals with 30 CILs and separation mechanisms with 10 CILs. This makes the NASA Post 51-L Baseline 555 FMEAs and 292 CILs for the MAS Subsystem. The 310 issues and the two additional mechanisms involving the MAS CIL items were subjected to further IOA internal review.

The IOA internal review revealed that the issues arose due to differences between the NASA and IOA FMEA/CIL interpretation and implementation of NSTS 22206. After comparison, there were no discrepancies found that were not already identified by NASA; all issues may be attributed to differences in ground rules. Therefore all issues are withdrawn by IOA. Likewise, failures in the Orbiter/ET mechanical separation mechanisms and cabin seals were not initially analyzed by IOA due to differences between the NASA/Rockwell and IOA interpretation and implementation of NSTS 22206. IOA has no issues with the NASA CILs presented to the Review Board for these subsystems on 9 October 1987.

IOA also evaluated the NASA CIL package for the Manipulator Positioning Mechanism (MPM) and Manipulator Retention Latch (MRL) as presented to the NSTS Level I/II PRCB on 22 April 1988, and has no issues with those CILs.

As a result of the IOA internal review, all issues were withdrawn. Upon completion of the assessment, no IOA issues remain with regard to the NASA MAS CIL.

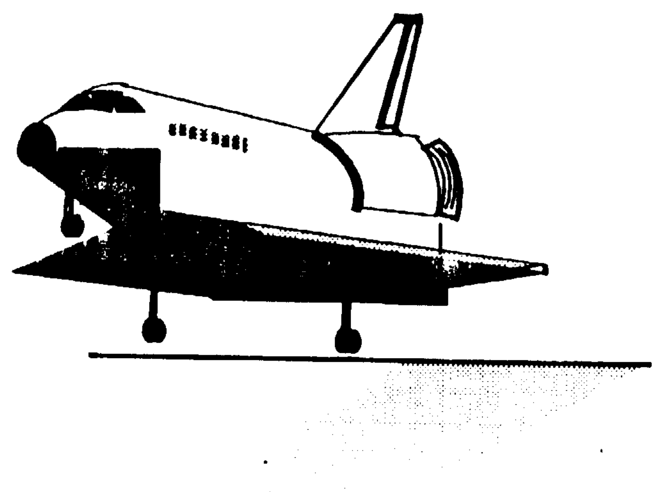
C.19 Manned Maneuvering Unit

The IOA analysis of the Manned Maneuvering Unit (MMU) hardware initially generated 136 failure mode worksheets and identified 69 PCIs before starting the assessment process. In order to facilitate comparison, 57 additional failure mode analysis worksheets were generated. These analysis results were compared to the proposed Martin Marietta Post 51-L baseline of 179 FMEAs and 110 CIL items. Upon completion of the assessment, 121 of the 204 IOA failure modes remained as issues to be resolved. A summary of the FMEA/CIL counts for IOA and NASA is provided in Figure C.19, and some of the significant issues follow.

The Martin Marietta analysis format lacked a comprehensive definition of the flight phases, screens, and the item(s) under study. All the flight phases were not always analyzed for Prep, Ops, and Post-Ops for each failure mode. The screens A and B were not specifically designated per NSTS 22206. IOA had to interpret their status based on very limited information

MECHANICAL ACTUATION SYSTEM FMEA/CIL ASSESSMENT OVERVIEW

MAS ASSESSMENT SUMMARY							
ORIGINAL ASSESSMENT *				FINAL RESOLUTION **			
	IOA	NASA	ISSUES		IOA	NASA	ISSUES
FMEA	713	528	472	FMEA	555	555	0
CIL	512	261	310	CIL	292	292	0



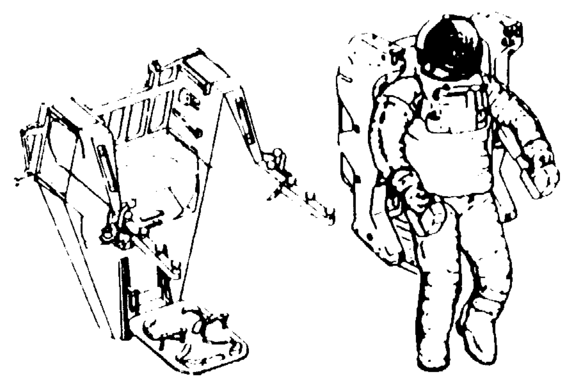
* NASA PROPOSED BASELINE AS OF 5 FEBRUARY 1988.
** FINAL CIL RESOLUTION AS OF 2 JUNE 1988

Figure C.18 - MAS FMEA/CIL ASSESSMENT

MMU ASSESSMENT OVERVIEW

MMU ASSESSMENT SUMMARY

	IOA	NASA*	ISSUES
FMEA	204	-	-
CIL	95	-	-



* NASA POST 51 - L FMEA/CIL REVIEW DEFERRED.

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Figure C.19 - MMU FMEA/CIL ASSESSMENT

provided. Screen C was not addressed; and it was, therefore, left blank throughout the assessment.

The Martin Marietta analysis did not address a specific hardware item in some cases, but used an assembly instead. This made it very difficult to investigate failure modes and effects of a particular item and its impact on the overall system.

The MMU Prep and Post-Ops definitions were not too clear, and it was consequently difficult to match their criticalities. IOA considered every MMU activity to begin with Pre-Ops activities and end with Post-Ops activities prior to the start of the next MMU operations. The Martin Marietta definition seems to suggest that the Prep activities start with the first MMU Pre-Ops and stop after the last MMU Ops activity. The period after the last planned MMU Ops will then be Post-Ops.

There were a number of issues related to the treatment of multi-position switches. Martin Marietta used a more broad and general failure mode approach, such as open or closed. IOA considered and investigated the failure of single contact positions for open and closed and assigned the worst case criticality. Multi-position switches failing open or closed were, in general, considered to be unreasonable.

Electrical items, such as diodes, resistors, relays, etc. associated with a Line Replaceable Unit circuit were not studied by Martin Marietta. IOA provided analysis for these items to be incorporated into the final FMEA/CIL study.

The MMU assessment was not part of the subsequent CIL issue resolution effort, because of the NASA decision to defer indefinitely the review of the MMU FMEA/CIL.

C.20 Nose Wheel Steering Subsystem

The IOA analysis of the Nose Wheel Steering (NWS) hardware initially generated 78 failure mode worksheets and identified 42 Potential Critical Items (PCIs). As a result of the assessment process, 15 NWS failure mode worksheets were deleted and an additional 5 analysis worksheets were generated and added to the assessment package. The assessment comparison also gave rise to 14 issues between the IOA NWS analysis and the corresponding NASA FMEAs (Fig. C.20).

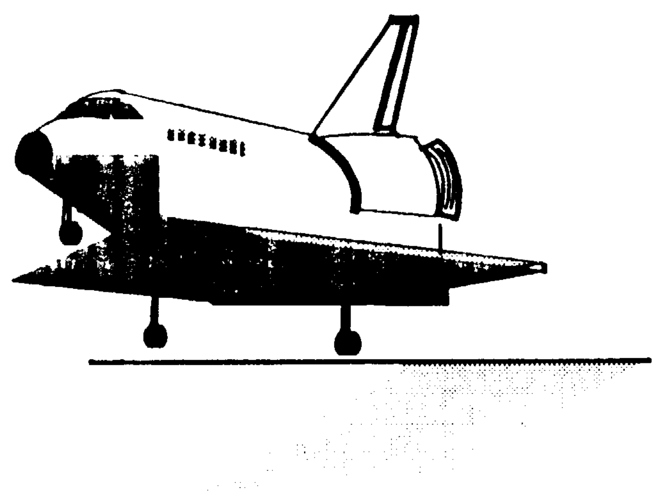
Of these issues, nine are the result of failure modes generated by the IOA that did not have corresponding NASA FMEAs. The remainder of the issues are the result of differences in the NWS subsystem failure mode assigned hardware/functional criticalities.

The most significant Orbiter assessment issue was uncovered during the NWS subsystem analysis. The failure mode was a "stuck" autopilot pushbutton causing the worst case effect of

NWS ASSESSMENT OVERVIEW

NWS ASSESSMENT SUMMARY

	ORIGINAL ASSESSMENT *			FINAL RESOLUTION **		
	IOA	NASA	ISSUES	IOA	NASA	ISSUES
FMEA	68	58	14	68	58	14
CIL	41	34	9	38	38	0



* NASA BASELINE AS OF 23 OCTOBER 1987
** NASA BASELINE AS OF 15 APRIL 1988

Figure C.20 - NWS FMEA/CIL ASSESSMENT

loss of crew/vehicle (criticality 1/1). The Orbiter autopilot is used for entry, and manually disengaged before landing. The autopilot is engaged by "Roll/Yaw Auto" and "Pitch Auto" pushbutton indicators (PBIs). If either "Auto" PBI fails closed, the autopilot cannot be permanently disengaged. With the autopilot remaining engaged, the Orbiter will attempt to "autoland", which requires a Microwave Landing System (MLS) on the ground. The MLS is not required for day landings, and has not been "available" for four of the last seven STS missions. Without the MLS, use of the autoland alone will cause the Orbiter to miss the runway. A single point failure with no redundancy and which threatens loss of crew/vehicle is categorized by <u>NSTS 22206</u> as a "criticality 1" item. Rockwell is adding the failure mode to the FMEA/CIL baseline and developing a software change to bypass a failed "Auto" switch.

The IOA assessment of the existing CILs gave rise to nine issues. Of these issues, eight were the result of IOA identifying additional Potential Critical Items. One PCI concerned the generation of independent FMEA/CILS for like critical hardware as recommended by <u>NSTS 22206</u>. A second PCI was the result of an IOA recommended criticality upgrade. The remainder of the eight PCIs concerned hardware or failure modes excluded by the NASA analysis. IOA also recommended the deletion of one NASA CIL.

The NWS PRCB Presentation of the Hardware/EPD&C presented no issues with the IOA Assessment. The nine CIL issues were with the "stuck" PBI and the Hydraulic/Mechanical CIL's. These issues were presented by IOA at the 21 December 1987 NWS CCB. The Chairman directed the Subsystem Manager and Rockwell to work these issues. The stuck PBI was addressed at the GNC PRCB of 8 April 1988. IOA agrees with NASA's criticality assignment of this issue. Five of the remaining Hydraulic issues were resolved with the NWS presentation of 15 April 1988. The remaining three issues (1. filter fails to filter, 2. hose assembly leakage, 3. check valve closed) were withdrawn by IOA. Number 1 was withdrawn as a non-credible failure, and numbers 2 and 3 were considered covered in other CILs.

C.21 <u>Remote Manipulator System</u>

The IOA analysis of the Remote Manipulator System (RMS) consisted of an analysis of the RMS EPD&C and an analysis of the RMS hardware. The analysis of the RMS hardware encompassed the end effector, the RMS Displays and Controls, the Manipulator Control Interface Unit (MCIU), the Arm Based Electronics (ABE), and the mechanical arm. At the end of the original assessment phase, 453 FMEAs had been identified as well as 324 CILs. IOA and NASA disagreed on the criticality of 69 of the CILs.

During the second phase of the assessment, these 69 issues were re-examined by IOA. The issues involve the problem of uncommanded motion of the arm in the vicinity of the Orbiter. IOA originally recommended this failure type be assigned a 1/1 criticality due to the possibility of the arm colliding with the Orbiter. NASA had recommended a 2/1R criticality due to the presence of software routines which can check for and stop the arm's uncommanded motion. Upon re-evaluation and a better understanding of these software routines, including the fact that arm motion is considerably slowed within a predefined envelope of the Orbiter, IOA accepts this definition of software as unlike redundancy and agrees with the NASA criticalities. All 69 issues are therefore withdrawn.

The original assessment of the RMS EPD&C hardware produced 368 IOA FMEAs and 124 IOA CILs. These were compared to 132 NASA FMEAs and 66 NASA CILs. The difference in numbers was due to differences in ground rules. The original comparison produced 11 FMEA issues and five CIL issues. During the second phase of the assessment, these five CIL issues were re-examined. The issues, which were all withdrawn, fell into two distinct categories. The first category was withdrawn due to the existence of a "worst case" failure for the item in NASA's data base. There is no reason to duplicate a failure and assign it a lower criticality based on less than worst case conditions. The second category was withdrawn after IOA re-evaluation produced a better definition and understanding of the function of the part. Figure C.21a shows the final resolution of the RMS hardware assessment while figure C.21b shows RMS/EPD&C results.

C.22 Atmospheric Revitalization System

The original assessment and analysis of the Atmospheric Revitalization System (ARS) yielded issues with 36 of the NASA CILs. These issues were re-examined and resolved during the second phase of the assessment project. All CIL issues were resolved for the following reasons.

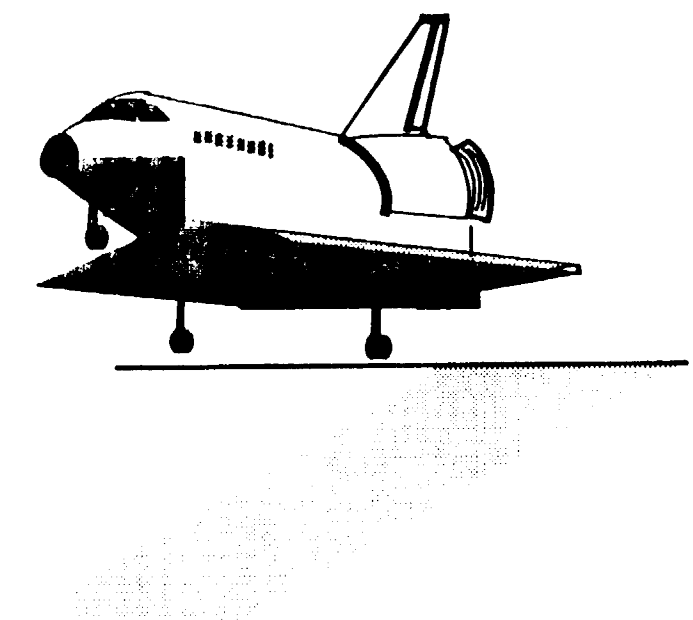
Re-evaluation by NASA of the EPD&C failures resulted in criticality assignments which either agreed with IOA's or removed the item from the CIL and resolved the CIL issue for four of the items. Additionally, development by NASA of an Orbiter seal package allowed IOA to determine matching CILs for three of the originally unmatched IOA CILs.

Eight CIL issues were resolved when closer examination revealed that they were subsets of existing NASA FMEAs. A better understanding of the hardware allowed IOA to accept a lower criticality on one NASA FMEA.

A group of issues was closed when IOA accepted NASA's more conservative definitions of redundancy or NASA's more conservative grouping of failures. Nine issues involved NASA CILs which IOA had originally deemed non-credible. A more conservative definition of the permissible failure modes and a consideration of the effects allowed IOA to remove these items from the issues list.

RMS ASSESSMENT OVERVIEW (HARDWARE)

RMS ASSESSMENT SUMMARY							
ORIGINAL ASSESSMENT *				FINAL RESOLUTION **			
	IOA	NASA	ISSUES		IOA	NASA	ISSUES
FMEA	453	453	69	FMEA	453	453	0
CIL	324	324	69	CIL	324	324	0



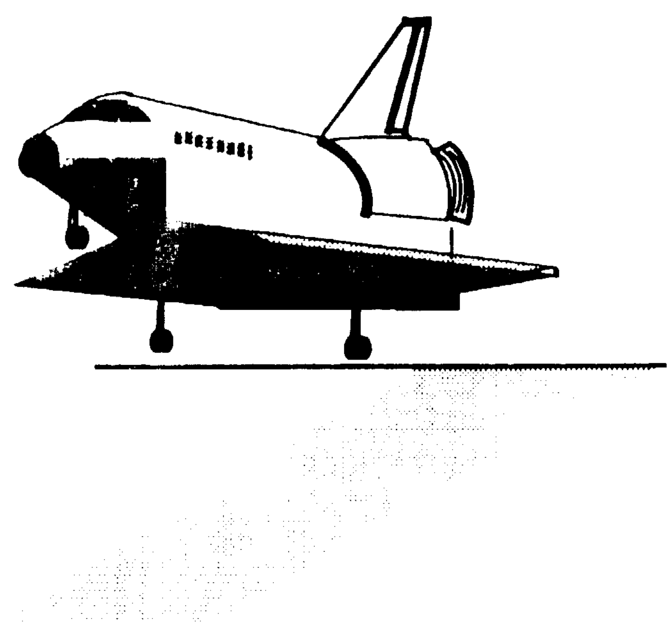
* DECEMBER 1987.
** JUNE 1988.

Figure C.21a - RMS FMEA/CIL ASSESSMENT

EPD&C/RMS ASSESSMENT OVERVIEW

EPD&C/RMS ASSESSMENT SUMMARY

	ORIGINAL ASSESSMENT *			FINAL RESOLUTION **		
	IOA	NASA	ISSUES	IOA	NASA	ISSUES
FMEA	132	368	11	132	368	11
CIL	66	124	5	66	66	0



* JANUARY 1988.
** APRIL 1988.

Figure C.21b - EPD&C/RMS FMEA/CIL ASSESSMENT

Five issues were discussed with the Subsystem Manager. Four were withdrawn after a better understanding of the system operations and NASA's philosophical ground rules were obtained. One was resolved when NASA agreed to issue a new FMEA with a mutually agreed upon criticality.

In summary, all ARS CIL issues have been resolved. Figure C.22 shows the final resolution of the ARS assessment.

C.23 Extravehicular Mobility Unit

The IOA analysis of the Extravehicular Mobility Unit (EMU) hardware initially generated 497 failure mode worksheets and identified 390 Potential Critical Items (PCIs) before starting the assessment process. In order to facilitate comparison, additional failure mode analysis worksheets were generated. These analysis results were compared to the proposed NASA Post 51-L baseline as of 1 January 1988 (Fig. C.23). The discrepancy between the number of IOA and NASA FMEAs can be explained by the different approach used by NASA and IOA to identify failure modes, or simply by errors of omission. Fifty-three failure modes were identified by the IOA analysis that were not covered by the NASA FMEAs; 42 were considered issues due to CIL impacts.

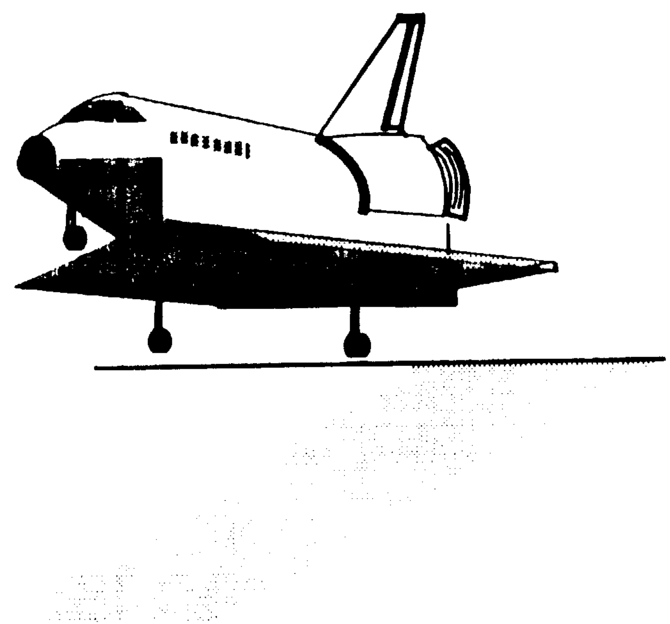
With regard to the issues, the IOA identified a total of 153. Ninety of these were concentrated in the Portable Life Support System (PLSS) and the Display and Control Module (DCM). This was not unexpected due to each subsystem's complexity and significant use of redundancy. These features resulted in different levels of analysis and in different determinations of redundancy by both the IOA and the NASA. Another area of PLSS and DCM issues resulted from differing usage of screen B detectability requirements. The NASA established an interpretation that so long as the crewmember could obtain safe haven upon detection the screen would be passed; however, the IOA disagreed with the use of an emergency system (the Secondary Oxygen Pack or SOP) to support obtaining safe haven.

The largest remaining block of issues (40) were distributed throughout the Hard Upper Torso (HUT), helmet, air assemblies, gloves, and the Lower Torso Assembly. Although many of these issues were similar in cause to those of the PLSS and the DCM (namely different levels of analysis or different interpretation of redundancy), a large group of these resulted from a common failure mode - loss of pressure integrity. The NASA "qualified" the failure mode as loss of pressure maintenance capability in excess of SOP make-up capability. The IOA's concern was that it automatically assumed loss of the SOP in assigning a 1/1 criticality; the IOA preferred a 2/1R with a failure of screen B and screen C to reflect the failure scenario.

The IOA participated in a series of meetings during June and July of 1988 with representatives of the NASA Subsystem Manager, Hamilton Standard, ILC-Dover, and Boeing Reliability to resolve

ARS ASSESSMENT OVERVIEW

ARS ASSESSMENT SUMMARY							
ORIGINAL ASSESSMENT *				FINAL RESOLUTION **			
	IOA	NASA	ISSUES		IOA	NASA	ISSUES
FMEA	223	311	102	FMEA	223	311	102
CIL	84	113	36	CIL	84	84	0

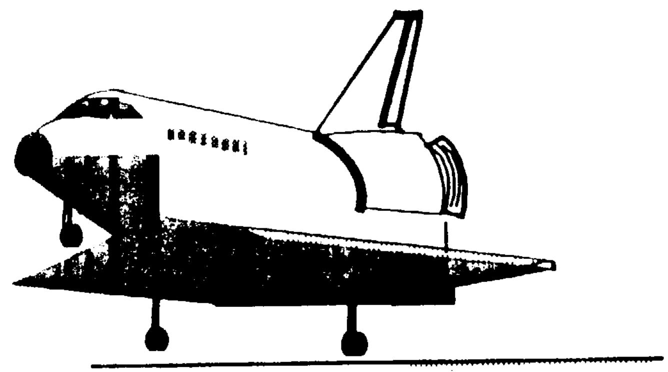


* JANUARY 1988.
** MAY 1988.

Figure C.22 - ARS FMEA/CIL ASSESSMENT

EMU ASSESSMENT OVERVIEW

EMU ASSESSMENT SUMMARY							
ORIGINAL ASSESSMENT *				FINAL RESOLUTION **			
	IOA	NASA	ISSUES		IOA	NASA	ISSUES
FMEA	688	614	153	FMEA	619	619	0
CIL	547	474	40	CIL	479	479	0



* NASA PROPOSED BASELINE AS OF 1 JANUARY 1988
** NASA PROPOSED BASELINE AS OF 16 SEPTEMBER 1988 (APPROXIMATE COUNTS)

Figure C.23 - EMU FMEA/CIL ASSESSMENT

these issues. As a result of these meetings, all but 2 of the 153 issues were resolved. With regard to the 40 CIL issues, the NASA accepted 24 IOA recommendations, and 14 IOA issues were withdrawn.

The IOA accepted NASA's use of the SOP to support obtaining a safe haven, allowing Screen B to be passed in those instances. The NASA also established that loss of pressure integrity failures could exceed SOP make-up capability, even with the SOP functioning normally. Thus, the IOA accepted NASA's 1/1 criticality for those loss of pressure integrity failure modes.

The remaining two CIL issues concerned failure modes 100-FM1 (separation of the PLSS from the HUT) and 300-FM7 (separation of the DCM from the HUT). The NASA considered these failure modes credible for ascent and entry phases only, and gave them a criticality of 2/2. The IOA asserted that the failure modes could occur during EVA also, and recommended a higher criticality (loss of crewmember would result if all redundancy were lost).

These two issues were presented to Clay McCullough/VP on 1 September 1988 for resolution. In that meeting, the NASA decided to perform appropriate analyses to determine the credibility of these failure modes due to EVA impact loads. The results of the analyses will be used to determine the appropriate criticality for these failure modes. The IOA considers these two issues to be accepted by NASA, by virtue of the actions being taken.

C.24 Power Reactant Storage and Distribution System

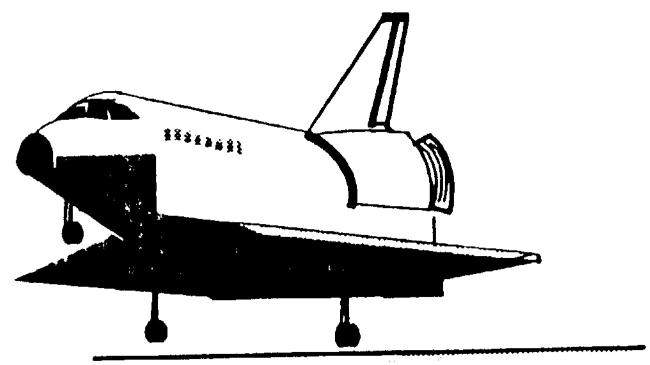
The IOA analysis of the Electric Power Generation/Power Reactant Storage and Distribution (EPG/PRSD) hardware initially generated 162 failure mode worksheets and identified 82 PCIs before starting the assessment process. In order to facilitate comparison, four additional failure mode analysis worksheets were generated. These analysis results (Fig. C.24a) were first compared to the proposed NASA Post 51-L baseline of 92 FMEAs and 58 CIL items, and then to the updated version of 66 FMEAs and 39 CIL items. They were finally compared to the baseline configuration of 64 FMEAs and 39 CIL items for the two tank baseline, and 67 FMEAs and 42 CIL items for the three and four tank baselines as documented in the NSTS Level I/II Review Board Presentation SSV88-10, presented on 19 January 1988.

The nine issues involving the EPG/PRSD CIL items were subjected to further IOA internal review. As a result of this internal review, two issues were withdrawn. These were issues involving CIL 04-1B-LV031-1 (MDAC ID 252, 264) and CIL M4-1B1-LV012-1 (MDAC ID 278, 281). The first issue was withdrawn because the NASA 2/1R criticality is based on the assumption that loss of two fuel cells during ascent constitutes loss of crew and vehicle. The second issue was withdrawn because existence of a valve position indicator driven by solenoid position cannot guarantee detection of all valve internal leaks, thus screen B is failed.

EPG/PRSD ASSESSMENT OVERVIEW

EPG/PRSD ASSESSMENT SUMMARY *

	IOA	NASA	ISSUES
FMEA	85	67	18
CIL	42	42	0



* FINAL NASA BASELINE AS OF 19 JANUARY 1988.

Figure C.24a - EPG/PRSD FMEA/CIL ASSESSMENT

The remaining issues were presented to the NASA Deputy Subsystem Manager on 12 April 1988, and were withdrawn as a result of this meeting.

Issues involving CILs M4-1B1-TK030-1 (MDAC ID 216, 217) and M4-1B1-TK010-1 (MDAC ID 330, 331) were withdrawn because cryo tank leakages are covered by CILs 04-1B-A01FSO-1 and 04-1B-A01FSH-1.

Issues involving CILs M4-1B1-RV031-1 (MDAC ID 231, 234), 04-1B-LV-045-1 (MDAC ID 267), M4-1B1-RV011-1 (MDAC ID 307, 310), 04-1B-LV015-1 (MDAC ID 275), and 04-1B-LV011-1 (MDAC ID 292, 295) were withdrawn because the time available for crew action to close the manifold valves after a worst case external leak is too short (7 seconds) for the CILs to credit the crew action as requiring an additional failure (i.e., manifold valves fail open) before loss of all fuel cells will occur. Thus, these CILs are criticality 2/1R rather than 3/1R. Upon completion of the assessment, and after discussions with the Deputy Subsystem Manager, no IOA issues remain with regard to the NASA EPG/PRSD CIL. Eighteen discrepancies remain involving non-CIL FMEAs. Figure C.24a presents the final resolution if the EPG/PRSD assessment.

The IOA analysis of the EPD&C/EPG hardware initially generated 263 failure mode worksheets and identified 60 Potential Critical Items (PCIs) before starting the assessment process. In order to facilitate comparison, 42 additional failure mode analysis worksheets were generated. These analysis results were compared to the proposed NASA Post 51-L baseline of 211 FMEAs and 47 CIL items, which was generated using the NSTS 22206 FMEA/CIL instructions (Fig. C.24b). Upon completion of the assessment, all of the 211 FMEAs were in agreement.

C.25 Main Propulsion System

The IOA MPS analysis generated 690 FMEA worksheets, 371 of which were PCIs. Of the total, 438 FMEAs were generated for mechanical components and 252 for electrical components (Fig. C.25).

General differences of opinion and interpretation between the IOA MPS Group and the Rockwell/NASA MPS team resulted in different criticality assignments. The Rockwell/NASA team, for example, tended to have a broader view of an item's function than did IOA. A related difficulty was the matter of redundancy. Again, the Rockwell/ NASA team adopted a broader view of redundancy than did IOA. Rockwell/NASA viewed sequential main engine failures as loss of redundancy. IOA believes engines are not redundant to each other because, while they perform identical functions, they do not perform the same function.

Another area of differing opinions was the Rockwell/NASA practice of introducing criticality 1/1 failures, such as line breaks or leaks, as a second failure, thereby creating a 2/1R criticality regardless of the first failure. IOA concludes that, in most

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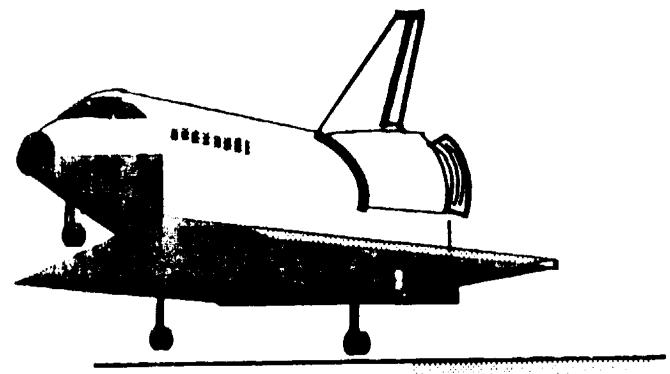
EPD&C/EPG ASSESSMENT OVERVIEW

EPD&C/EPG ASSESSMENT SUMMARY *			
	IOA	NASA	ISSUES
FMEA	211	211	0
CIL	47	47	0

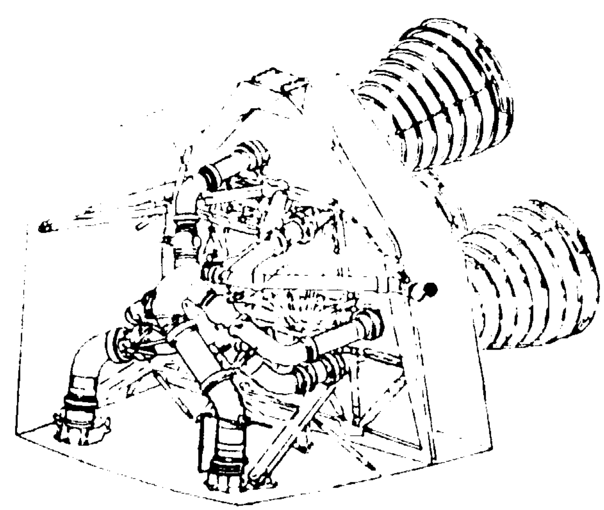


* FINAL NASA BASELINE AS OF 4 JANUARY 1988

Figure C.24b - EPD&C/EPG FMEA/CIL ASSESSMENT

MPS ASSESSMENT OVERVIEW

MPS ASSESSMENT SUMMARY							
ORIGINAL ASSESSMENT *				FINAL RESOLUTION **			
	IOA	NASA	ISSUES		IOA	NASA	ISSUES
FMEA	1365	1264	399	FMEA	1365	1230	208
CIL	711	749	191	CIL	763	763	0



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* NASA PROPOSED BASELINE AS OF 1 JANUARY 1988
** NASA PROPOSED BASELINE AS OF 16 SEPTEMBER 1988 (FMEA COUNTS ARE APPROXIMATE).

Figure C.25 - MPS FMEA/CIL ASSESSMENT

cases, this is not consistent with the NSTS 22206 methodology or definitions.

The Rockwell/NASA approach tended to drive criticalities higher than those determined by IOA. On the basis that a higher criticality is more conservative and consistent with a worst case approach, IOA was able to resolve many issues by accepting the higher criticality of the Rockwell/NASA results.

The CIL issues were resolved by IOA internal review and by meetings conducted in August and September of 1988 with representatives of the Subsystem Manager. Final resolution of the 191 CIL issues resulted in the withdrawal of 148 issues and acceptance by Rockwell/NASA of the IOA recommendation in 43 cases. Of these, 37 were CILs that Rockwell/NASA agreed to drop because they were redundant to other analyses, 3 CILs were added, and 3 were modified.

Details of issue resolution can be found in the companion volume to this report, the CIL Issues Resolution Report (reference 71).

C.26 Orbital Maneuvering System

The IOA Orbital Maneuvering System (OMS) analysis generated 284 hardware and 667 EPD&C failure mode worksheets. Of these, 160 were hardware potential critical items (PCIs) and 216 were EPD&C PCIs. A comparison was made of the IOA product to the NASA FMEA/CIL baseline as of 23 December 1987 which consisted of 101 hardware FMEAs, 68 hardware CILs, 142 EPD&C FMEAs, and 49 EPD&C CILs. In order to facilitate comparison, additional IOA analysis worksheets were generated as required. IOA mapped 138 hardware FMEAs, 93 hardware CILs and PCIs, 147 EPD&C FMEAs, and 47 EPD&C CILs and PCIs into the NASA FMEAs and CILs. The IOA and NASA FMEA/CIL baselines were compared, and discussions were held with the NASA Subsystem Managers in an effort to resolve the identified issues. A majority of the initial hardware issues were resolved; however, 47 hardware issues, 29 of which concerned CIL items, and 70 EPD&C issues, 31 of which concerned CIL items, remained unresolved. The unresolved issues concerned NSTS 22206 interpretation differences, redundancy string definition differences, failure modes identified by IOA which were not addressed in the NASA FMEA/CIL baseline, and differences in assigned criticalities, redundancy screens, and failure effects. All unresolved FMEA and CIL issues were documented in the IOA OMS assessment report (reference 50).

The 60 OMS hardware and EPD&C CIL issues documented in the assessment report were resolved during the IOA CIL issues resolution effort. IOA met with J. Hooper (OMS Subsystem Manager (SSM)) on 16 May 1988 to resolve the IOA CIL issues. The SSM accepted two IOA issues. The first concerned a valve housing for which there was no "structural failure" mode in the OMS FMEA/CIL. The SSM agreed to add this valve housing to the prop line/valve housing "structural failure" CIL (03-3-2101-1). The second accepted issue concerned a two-pole toggle switch failure mode. NASA failed only one pole and considered the other pole to be redundant, whereas IOA considered an internal switch failure which caused both poles to fail simultaneously. The NASA failure mode required that the switch be placed in a certain position before it could fail in that position, while the IOA failure mode allowed a short across any set of contacts with the switch in any position. The SSM accepted the IOA failure mode and rationale and upgraded the criticality from a 3/1R to a 2/1R CIL. The SSM stated that these issues would be incorporated into the OMS FMEA/CIL during the next update activity. IOA withdrew the remaining 58 CIL issues after in-house reviews and inputs from the OMS hardware and OMS TVC SSMs, but maintains concerns and recommendations on many of them. Refer to the individual IOA assessment sheets in section C.17 of the companion volume to this report (reference 71) for the withdrawal rationale for each of these 58 issues.

Figures C.26a and C.26b present the interim and final OMS FMEA/CIL assessment results for the hardware and EPD&C, respectively. All of the IOA OMS CIL issues have been resolved. However, IOA maintains some concerns, which are presented in the following paragraphs.

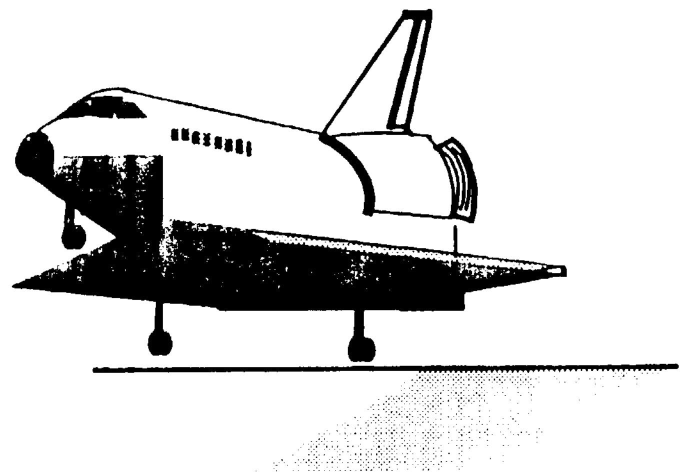
OMS FMEA 03-3-4002-2 (structural failure of the OMS engine inlet filter) is classified as a 3/3, but could cause plugging of the OMS engine injector and subsequent burn-through of an OMS engine. This failure mode was classified as a 2/1R in the pre-51L OMS FMEA/CIL baseline, but was downgraded by NASA and Boeing reliability to a 3/3 because it is also listed as a cause on 03-3-4004-2 (restricted flow of the OMS engine injector, 1/1). This action was taken to reduce the number of OMS CIL items. As a result, this failure mode with potentially catastrophic effects is now classified as a 3/3 and will not receive the safety attention it deserves. IOA contends that the criticality assigned to this failure mode should reflect the fact that it could ultimately result in loss of crew/vehicle. To have a criticality assigned which does not reflect the worst-case effects of a failure mode is misleading and could allow life and vehicle-threatening failures to go unrecognized. The criticality assigned to a failure mode on a FMEA should not be downgraded to a 3/3 because that failure is also listed as a cause on a separate FMEA. IOA could find no support for such a practice in NSTS 22206, but withdrew the issue after Boeing reliability stood by this downgrading practice. However, IOA strongly recommends that the criticality on 03-3-4002-2 be reinstated to a 1 or 1R CIL, and that downgrading a failure mode to a 3/3 for this reason be discontinued.

Another IOA concern involves the 3/3 criticalities currently assigned to failure modes which allow the backflow of OMS propellants from the propellant tanks into the helium pressurization subsystem. IOA recommends that the "failed open" and "internal leakage" failure modes for the quad check valve assemblies and vapor isolation valves be classified as functional

OMS HARDWARE ASSESSMENT OVERVIEW

OMS HARDWARE ASSESSMENT SUMMARY

	ORIGINAL ASSESSMENT *			FINAL RESOLUTION		
	IOA	NASA	ISSUES	IOA	NASA	ISSUES
FMEA	138	101	47	117	101	18
CIL	93	68	29	• 68	68	0



* NASA BASELINE AS OF 23 DECEMBER 1987.

IOA AND NASA HARDWARE TOTALS DO NOT INCLUDE INSTRUMENTATION AND THERMAL CONTROL ITEMS. IOA ANALYZED AND ASSESSED THESE ITEMS AS EPD&C ITEMS.

Figure C.26a - OMS HARDWARE FMEA/CIL ASSESSMENT

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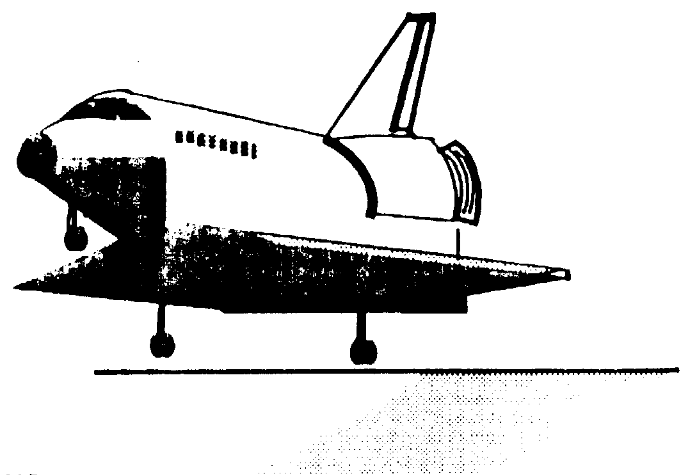
OMS EPD&C ASSESSMENT OVERVIEW

OMS EPD&C ASSESSMENT SUMMARY

	ORIGINAL ASSESSMENT *			FINAL RESOLUTION		
	IOA	NASA	ISSUES	IOA	NASA	ISSUES
FMEA	147	142	70	145	142	39
CIL	47	49	31	50	50	0



* NASA BASELINE AS OF 23 DECEMBER 1987.

IOA AND NASA TOTALS INCLUDE INSTRUMENTATION AND THERMAL CONTROL ITEMS.

Figure C.26b - OMS EPD&C FMEA/CIL ASSESSMENT criticality 1Rs. These failures would allow propellants to reach the helium pressure regulator assemblies where contamination could cause the assemblies to fail closed. Subsequent inability to repressurize the OMS propellant tanks and use or deplete propellants could result in loss of crew/vehicle. These failures are currently also listed as causes on the regulator "fails closed" FMEA (03-3-1004-2). The criticalities assigned to these check valve and vapor isolation valve failure modes should reflect the fact that they could ultimately result in loss of crew/vehicle. IOA withdrew these issues after discussions with the SSM, but maintains the recommendation.

On the current NASA OMS FMEA/CIL, one CIL sheet may include several components and/or failure modes. The criticality and screens assigned reflect only the worst case component failure mode. IOA is concerned that this lumping of components and failure modes on CILs reduces insight into the effects of individual OMS subsystem component failures and may lessen the attention given to critical failure modes. The components and failure modes lumped together on one CIL could have different criticality and screen assignments if they were separated onto individual FMEAs and CILs, and better insight would be obtained. For example, the bipropellant valve assembly FMEAs (03-3-4001) include the engine control valve, pneumatic actuator, rack & pinion assembly, bipropellant valves, and bipropellant valve cavity pressure relief valve. IOA recommends that these components be addressed on individual FMEAs and CILs and assigned unique criticalities. This would provide better insight into the effects of each of these component failures and would help ensure that the critical failures receive the appropriate amount of individual attention.

Some OMS subsystem failures do not exist as "failure modes" on current FMEAs and CILs. Instead, they are listed only as causes on FMEAs and CILs for other failure modes. IOA is concerned that a failure mode is not adequately addressed by only listing it as a cause on a FMEA or CIL. For example, the "failed closed" and "failed open" failure modes for the bipropellant valve cavity pressure relief valve are addressed only as causes on 03-3-4001-6. All critical failures should be listed as failure modes on FMEAs and CILs to help ensure that they receive the appropriate amount of attention.

Many of the IOA EPD&C CIL issues involved the definition of redundancy. The NASA-applied definition of the redundancy string allowed the selection of specific failures which were required to cause known problems, e.g., failures required to cause continuous power to a valve. IOA considers many redundancy strings to include multiple failures, but withdrew related issues since the NASA approach tended to be more conservative.

The final IOA concern involves electrical components within valves (microswitches, diodes, etc.) which are not specifically addressed on the current NASA OMS FMEA/CIL. IOA recommends that the EPD&C components within a valve be addressed individually on FMEAs and

CILs to provide better insight into the effects of their failures, and to help ensure that critical failures receive the proper amount of attention. Failures of valve EPD&C components are not visible on the current valve hardware FMEAs.

The IOA CIL issues resolution effort initiated after the OMS interim report was published involved only the resolution of CIL issues. Therefore, the 57 IOA OMS FMEA (non-CIL) issues documented in the interim report remain unresolved. IOA also maintains all recommendations and concerns put forth in the interim report. The interim report may add to or supplement information presented in the final report.

Several changes have been made to the 23 December 1987 NASA OMS FMEA/CIL baseline since the assessment report was completed. However, IOA has found no changes which created new CIL issues.

The OMS hardware results include the OMS TVC subsystem results. Five of the 60 OMS CIL issues were OMS TVC subsystem CIL issues and were withdrawn by IOA.

The IOA analysis and assessment effort resulted in the following changes to the NASA OMS FMEA/CIL: the addition of a new 1/1 CIL for blockage of the quad check valve assembly inlet filter (03-3-1007-3), upgrades of flight criticalities on four FMEA/CILs, upgrades to 1/1 abort criticalities on four FMEA/CILs, redundancy screen changes on six FMEA/CILs, and the additions of eight failure modes, eleven items, and eight causes to the NASA OMS FMEA/CIL.

C.27 Reaction Control System

The IOA Reaction Control System (RCS) analysis generated 208 hardware and 2064 EPD&C failure mode worksheets. Of these, 141 were hardware potential critical items (PCIs) and 449 were EPD&C PCIs. A comparison was made of the IOA product to the NASA FMEA/CIL baseline as of 23 December 1987 which consisted of 99 hardware FMEAs, 62 hardware CILs, 524 EPD&C FMEAs, and 144 EPD&C CILs. In order to facilitate comparison, additional IOA analysis worksheets were generated as required. IOA mapped 166 hardware FMEAs, 133 hardware CILs and PCIs, 597 EPD&C FMEAs, and 116 EPD&C CILs and PCIs into the NASA FMEAs and CILs. After comparison of the IOA and NASA FMEA/CIL baselines and discussions with the NASA Subsystem Manager (SSM), 96 hardware issues, 83 of which concerned CIL items, and 280 EPD&C issues, 158 of which concerned CIL items, remained unresolved. The unresolved issues concerned NSTS 22206 interpretation differences, redundancy string definition differences, failure modes identified by IOA which were not addressed in the NASA FMEA/CIL baseline, and differences in assigned criticalities, redundancy screens, and failure effects. All unresolved FMEA and CIL issues were documented in the IOA RCS assessment report (reference 51).

The 241 RCS hardware and EPD&C CIL issues documented in the assessment report were resolved during the IOA CIL issues resolution effort. IOA met with G. Grush (RCS SSM) on 19 May 1988 and 2 June 1988 to resolve the IOA CIL issues. The SSM accepted 37 IOA issues. Sixteen of the accepted issues concerned the fact that the "internal leakage" and "restricted flow" failure modes did not exist for several forward and aft RCS components. The other accepted issues involved the addition of the "structural failure", "rupture", and "external leakage" failure modes for 21 RCS component housings which were not previously covered. The SSM stated that these issues would be incorporated into the RCS FMEA/CIL during the next update activity. IOA withdrew the remaining 204 CIL issues after in-house reviews and inputs from the SSM, but maintains concerns and recommendations on many of them. Refer to the individual IOA assessment sheets in section C.18 of the companion volume to this report (reference 71) for the withdrawal rationale for each of these 204 issues.

Figures C.27a and C.27b present the interim and final RCS FMEA/CIL assessment results for the hardware and EPD&C, respectively. All of the IOA RCS CIL issues have been resolved. However, IOA maintains some concerns, which are presented in the following paragraphs.

The current NASA RCS FMEA/CIL does not address the loss of forward RCS propellant dumping capability. Many flights include a nominal FRCS propellant dump after the deorbit burn in order to achieve an improved X axis center-of-gravity (cg) condition for entry. Some flights may be planned such that a post-deorbit FRCS propellant dump is **required** to move the X cg of the Orbiter back within the allowable forward X cg limit for entry (1076.7 inches). Inability to complete a required dump could, therefore, result in possible loss of entry control. In assigning criticalities to FRCS subsystem failures, IOA considered the possible effects of the inability to complete a planned post-deorbit FRCS dump. The NASA RCS FMEA/CIL review did not. As a result, IOA assigned 2/1R criticalities to many FRCS subsystem failures which NASA currently classifies as 3/1R. Failures which result in loss of propellant tank repressurization capability, loss of propellant flow paths, or loss of primary thrusters are the types of failures which result in the inability to dump FRCS propellant.

The above IOA concern is underscored by GNC CIL # 05-1-FC6242-1 (loss of output from a FRCS reaction jet driver). This failure results directly in the loss of a FRCS primary thruster. The NASA GNC FMEA/CIL review also classified this failure as a 2/1R because of the loss of FRCS dumping capability and possible loss of entry control due to violation of the entry X cg limit. Yet, the RCS FMEA which addresses loss of a FRCS primary thruster is classified as a 3/1R because the FRCS dumping effects were not considered. IOA urges that this inconsistency between criticalities assigned to failures with identical effects be corrected. The RCS criticalities assigned to FRCS subsystem failures which result in loss of FRCS dumping capability should be upgraded to be consistent with the IOA and NASA GNC approaches.

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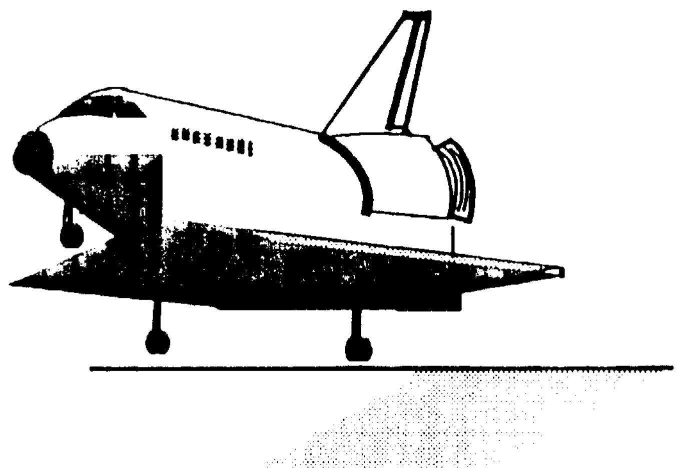
RCS HARDWARE ASSESSMENT OVERVIEW

RCS HARDWARE ASSESSMENT SUMMARY

	ORIGINAL ASSESSMENT *				FINAL RESOLUTION		
	IOA	NASA	ISSUES		IOA	NASA	ISSUES
FMEA	166	99	96	FMEA	109	99	13
CIL	133	62	83	CIL	63	63	0



* NASA BASELINE AS OF 23 DECEMBER 1987.

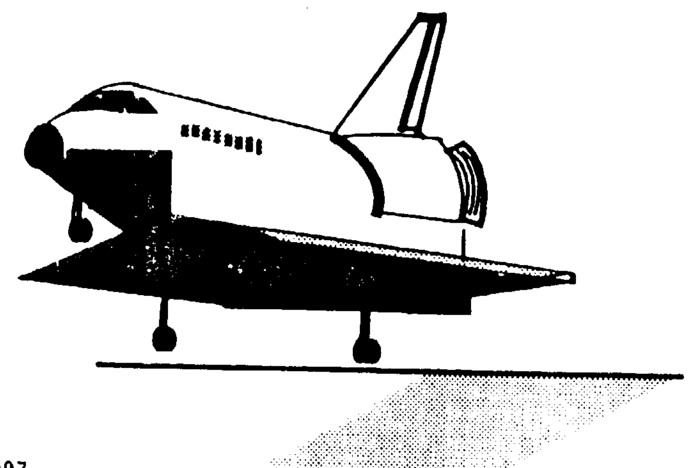
IOA AND NASA TOTALS DO NOT INCLUDE INSTRUMENTATION AND THERMAL CONTROL ITEMS. IOA ANALYZED AND ASSESSED THESE ITEMS AS EPD&C ITEMS.

Figure C.27a - RCS HARDWARE FMEA/CIL ASSESSMENT

RCS EPD&C ASSESSMENT OVERVIEW

RCS EPD&C ASSESSMENT SUMMARY

	ORIGINAL ASSESSMENT *			FINAL RESOLUTION		
	IOA	NASA	ISSUES	IOA	NASA	ISSUES
FMEA	597	524	280	547	524	122
CIL	116	144	158	144	144	0



* NASA BASELINE AS OF 23 DECEMBER 1987.
IOA AND NASA TOTALS INCLUDE INSTRUMENTATION AND THERMAL CONTROL ITEMS.

Figure C.27b - RCS EPD&C FMEA/CIL ASSESSMENT

IOA held a meeting on 2 June 1988 with the RCS SSM and personnel from the Mission Operations Directorate, Rockwell, and Boeing reliability to discuss the above IOA concern and related issues, and to make propulsion and mass properties planning and operations personnel aware of the IOA findings. Participants concluded that the IOA concern was valid. During the meeting it was confirmed that a nominal post-deorbit FRCS propellant dump could be required on some missions. If the dump could not be completed as required due to a subsystem failure(s), the forward X cg entry limit would be violated resulting in possible loss of crew/vehicle. There is currently no flight rule which prohibits dependence on a nominal post-deorbit FRCS propellant dump in order to meet the forward X cg limit for entry. For these reasons, IOA contends that the inability to complete a planned post-deorbit FRCS dump should be considered in NASA RCS FMEA/CIL criticality assignments, and recommends upgrades on many FRCS subsystem failures. IOA withdrew the issues related to this concern (see applicable assessment sheets), but maintains the concern and the above recommendations.

To summarize this concern, a major use of the FRCS subsystem is management of Orbiter mass properties through propellant dumping. This function may be critical and should not be neglected in FMEA/CIL criticality assignments.

Another IOA concern involves the 3/3 criticalities currently assigned to failure modes which allow the backflow of RCS propellant from the propellant tank into the helium pressurization subsystem. IOA recommends that the "failed open" and "internal leakage" failure modes for forward and aft quad check valve assemblies be classified as functional criticality 1Rs. These failures would allow propellant to reach the helium pressure regulator assemblies where contamination could cause the assemblies to fail closed. Subsequent inability to repressurize the RCS propellant tank and use or deplete propellant could result in loss of crew/vehicle. These failures are currently also listed as causes on the forward and aft regulator "fails closed" FMEAs (03-2F-101030-2 and 03-2A-201030-2). The criticalities assigned to these check valve failure modes should reflect the fact that they could ultimately result in loss of crew/vehicle. IOA withdrew these issues after discussions with the SSM, but maintains the recommendation.

On the current NASA RCS FMEA/CIL, one CIL sheet may include several components and/or failure modes. The criticality and screens assigned reflect only the worst case component failure mode. IOA is concerned that this lumping of components and failure modes on CILs reduces insight into the effects of individual RCS subsystem component failures and may lessen the attention given to critical failure modes. The components and failure modes lumped together on one CIL could have different criticality and screen assignments if they were separated onto individual FMEAs and CILs, and better insight would be obtained. For example, the vernier thruster assembly FMEAs (03-2F-131310 and 03-2A-231310) include the inlet valves, injector, thrust chamber,

C-2

nozzle extension, heater, insulation, pressure transducer, and temperature transducer. IOA recommends that these components be addressed on individual FMEAs and CILs and assigned unique criticalities. This would provide better insight into the effects of each of these component failures and would help ensure that the critical failures receive the appropriate amount of individual attention.

Some RCS subsystem failures do not exist as "failure modes" on current FMEAs and CILs. Instead, they are listed only as causes on FMEAs and CILs for other failure modes. IOA is concerned that a failure mode is not adequately addressed by only listing it as a cause on a FMEA or CIL. All critical failures should be listed as failure modes on FMEAs and CILs to help ensure that they receive the appropriate amount of attention.

Many of the IOA EPD&C CIL issues involved the definition of redundancy. The NASA-applied definition of the redundancy string allowed the selection of specific failures which were required to cause known problems, e.g., failures required to cause continuous power to a valve. IOA considers many NASA redundancy strings to include multiple failures, but withdrew related issues since the NASA approach tended to be more conservative.

The final IOA concern involves electrical components within valves (microswitches, diodes, etc.) which are not specifically addressed on the current NASA RCS FMEA/CIL. IOA recommends that the EPD&C components within a valve be addressed individually on FMEAs and CILs to provide better insight into the effects of their failures, and to help ensure that critical failures receive the proper amount of attention. Failures of valve EPD&C components are not visible on the current valve hardware FMEAs.

The IOA CIL issues resolution effort initiated after the RCS interim report was published involved only the resolution of CIL issues. Therefore, the 135 IOA RCS FMEA (non-CIL) issues documented in the interim report remain unresolved. IOA also maintains all recommendations and concerns put forth in the interim report. The interim report may add to or supplement information presented in the final report.

Several changes have been made to the 23 December 1987 NASA RCS FMEA/CIL baseline since the assessment report was completed. However, IOA has found no changes which created new CIL issues.

C.28 Communication and Tracking

The initial IOA and NASA FMEA/CIL comparison analysis of the Communication and Tracking (C&T) hardware and functions resulted in 294 CIL issues. These issues were subsequently resolved in several ways:

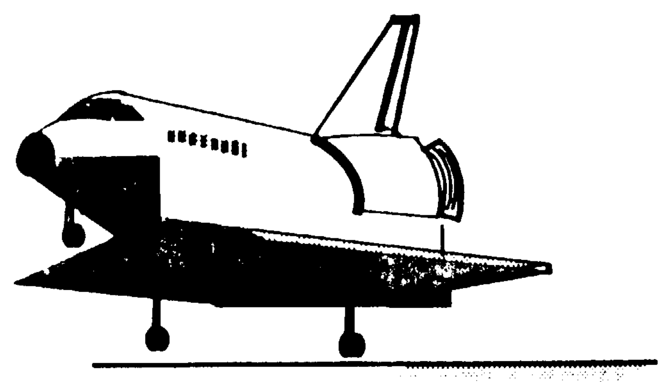
- o Through discussions and agreements with NASA Subsystem Managers of the C&T subsystem component elements.

- NASA generated new FMEAs.
- Discovery of additional NASA FMEA/CILs not analyzed in the initial assessment.
- NASA changed criticality designations.
- NASA agreed to generate new FMEAs to address IOA identified failure modes.
- IOA withdrew failures which were considered non-credible.
- IOA accepted the more conservative NASA CIL criticality designations when IOA and NASA CILs were at variance.
- IOA accepted NASA use of unlike redundancies not previously considered by IOA.

Rationale for resolution of each CIL issue appears under the "remarks" section on the applicable assessment work sheets contained in the companion volume to this report, the CIL Issues Resolution Report. Figure C.28 provides a numerical overview of the C&T FMEA/CIL assessment.

COMMUNICATIONS AND TRACKING FMEA/CIL ASSESSMENT OVERVIEW

COMM/TRK ASSESSMENT SUMMARY							
ORIGINAL ASSESSMENT *				FINAL RESOLUTION **			
	IOA	NASA	ISSUES		IOA	NASA	ISSUES
FMEA	1108	697	407	FMEA	1108	729	71
CIL	298	239	294	CIL	263	263	0



* TABULATION OF INTERIM ASSESSMENT BASED ON FMEA/CIL's GENERATED PRIOR TO 1 JANUARY, 1988.

** TABULATION OF FINAL ASSESSMENT BASED ON FMEA/CIL's AND ISSUES AS OF 24 MAY, 1988.

Figure C.28 - COMM & TRACKING FMEA/CIL ASSESSMENT

APPENDIX D

Comparison of IOA Subsystems To Rockwell CIL Packages

A comparison of Orbiter subsystems assessed by IOA and corresponding Rockwell CIL packages is presented in Table D-1. IOA assessed several subsystems which are not part of the Rockwell Orbiter CIL packages. Likewise, several of the Rockwell CIL packages were outside the scope of the IOA analysis. This category included mission-specific equipment, and emergency egress equipment added to the Orbiter pursuant to the recommendations of the Presidential Commission.

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TABLE D-1
IOA TO ROCKWELL CIL PACKAGE COMPARISON

SUBSYSTEM	Rockwell CIL Package ID
Fuel Cell Powerplant (FCP)	55,56
Hydraulic Actuators (HA)	14,15
Displays and Control (D&C)	79,80
Guidance, Navigation & Control (GN&C)	61,62
Orbiter Experiments (OEX)	N/A
Auxiliary Power Unit (APU)	59,60
Backup Flight System (BFS) / DPS	83,84
Electrical Power, Distribution & Control (EPD&C)	85
Landing & Deceleration (L&D)	5,6,7,8,12,13
Purge, Vent and Drain (PV&D)	2
Pyrotechnics (PYRO)	31,40,108-112
Active Thermal Control System (ATCS) and Life Support System (LSS)	91-96,99-101
Crew Equipment (CE)	102,103
Instrumentation (INST)	81,82
Data Processing System (DPS) - Included in BFS	-
Atmospheric Revitalization Pressure Control System (ARPCS)	89,90
Hydraulics & Water Spray Boiler (HYD & WSB)	41,42,97,98
Mechanical Actuation System (MAS)	1,3,4,16-30, 33, 34
Manned Maneuvering Unit (MMU)	N/A
Nose Wheel Steering (NWS)	9-11
Remote Manipulator System (RMS)	37, 38, 39
Atmospheric Revitalization System (ARS)	86-88
Extravehicular Mobility Unit (EMU)	N/A
Power Reactant Supply & Distribution System (PRS&D)	57,58,105,106
Main Propulsion System (MPS)	43-48
Orbital Maneuvering System (OMS)	51-54
Reaction Control System (RCS)	49,50
Comm and Tracking (C&T)	63-78
Not in IOA Scope	32, 35, 36, 104, 107,113-115