MISSION SAFETY EVALUATION REPORT FOR STS-31

Postflight Edition: October 15, 1990

Safety Division

Office of Safety and Mission Quality

National Aeronautics and Space Administration

Washington, DC 20546

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EXECUTIVE SUMMARY

The first attempt to launch Space Shuttle *Discovery* was made on April 10, 1990. The countdown proceeded without problems until approximately 4 minutes before liftoff, when 1 of the 3 Auxiliary Power Units (APUs) exhibited a speed control problem. Technicians determined that there was a blowing leak through the APU #1 Pulse Control Valve. The defective APU was replaced on the pad (which was a first). STS-31 launch was rescheduled for April 24, 1990.

On April 24, 1990, the launch countdown proceeded on schedule to the terminal phase at the T-31 second mark, when the liquid oxygen fill and drain valve in the Orbiter Main Propulsion System (MPS) was determined to be in the wrong position for launch. Countdown was automatically held at T-31 seconds until the console operator repositioned the valve. *Discovery* was launched satisfactorily at 8:33:51 a.m. Eastern Daylight Time (EDT).

All systems performed well, and the Hubble Space Telescope was released 330 nautical miles above the Earth. This was the highest altitude that the Space Shuttle had ever flown. Hubble is an optical, spectrographic, and photometric observatory system designed for extended orbital operation and will provide images of planets, asteroids, and comets. These images will be of significantly higher resolution than can be achieved with earthbound telescope systems and will enable significant data gathering on celestial systems in the outer expanses of the universe.

After 5 days in orbit, *Discovery* touched down on Edwards Air Force Base concrete runway 22 at 9:49 a.m. EDT, April 29, 1990. Plans to land on the lakebed runway had to be abandoned because of high winds. Descent took approximately 15 minutes longer than usual because of the record-breaking altitude for the STS-31 mission.

FOREWORD

The Mission Safety Evaluation (MSE) is a National Aeronautics and Space Administration (NASA) Headquarters Safety Division, Code QS produced document that is prepared for use by the NASA Associate Administrator, Office of Safety and Mission Quality (OSMQ), and the Space Shuttle Program Director prior to each Space Shuttle flight. The intent of the MSE is to document safety risk factors that represent a change, or potential change, to the risk baselined by the Program Requirements Control Board (PRCB) in the Space Shuttle Hazard Reports (HRs). Unresolved safety risk factors impacting STS-31 flight were also documented prior to the STS-31 Flight Readiness Review (FRR) (FRR Edition), the STS-31 Launch Minus Two Day (L-2) Review (L–2 Edition), and prior to the STS-31 Launch Minus One Day (L-1) Review (L–1 Update). This final Postflight Edition evaluates performance against safety risk factors identified in the previous MSE editions for this mission.

The MSE is published on a mission-by-mission basis for use in the FRR and is updated for the L-1 Review. For tracking and archival purposes, the MSE is issued in final report format after each Space Shuttle flight.

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SECTION 1

INTRODUCTION

1.1 Purpose

The Mission Safety Evaluation (MSE) provides the Associate Administrator, Office of Safety and Mission Quality (OSMQ), and the Space Shuttle Program Director with the NASA Headquarters Safety Division position on changes, or potential changes, to the Program safety risk baseline approved in the formal Failure Modes and Effects Analysis/Critical Items List (FMEA/CIL) and Hazard Analysis process. While some changes to the baseline since the previous flight are included to highlight their significance in risk level change, the primary purpose is to ensure that changes which were too late to include in formal changes through the FMEA/CIL and Hazard Analysis process are documented along with the safety position, which includes the acceptance rationale.

1.2 Scope

This report addresses STS-31 safety risk factors that represent a change from previous flights, factors from previous flights that had an impact on this flight, and factors that were unique to this flight.

Factors listed in the MSE are essentially limited to items that affect, or have the potential to affect, Space Shuttle safety risk factors and have been elevated to Level I for discussion or approval. These changes are derived from a variety of sources such as issues, concerns, problems, and anomalies. It is not the intent to attempt to scour lower level files for items dispositioned and closed at those levels and report them here; it is assumed that their significance is such that Level I discussion or approval is not appropriate for them. Items against which there is clearly no safety impact or potential concern were not reported here, although items that were evaluated at some length and found not to be a concern were reported as such. NASA Safety Reporting System (NSRS) issues were considered along with the other factors, but may not be specifically identified as such.

Data gathering is a continuous process. However, collating and focusing of MSE data for a specific mission begins prior to the mission Launch Site Flow Review (LSFR) and continues through the flight and return of the Orbiter to Kennedy Space Center (KSC). For archival purposes, the MSE is updated subsequent to the mission to add items identified too late for inclusion in the prelaunch report and to document performance of the anomalous systems for possible future use in safety evaluations.

1.3 Organization

The MSE is presented in eight sections as follows:

Section 1 - Provides brief introductory remarks, including purpose, scope, and organization.

Section 2 - Provides a summary description of the STS-31 mission, including launch data, crew size, mission duration, launch and landing sites, and other mission- and payload-related information.

Section 3 - Contains a list of safety risk factors/issues, considered resolved or not a safety concern prior to STS-31 launch, that were impacted or repeated by anomalies reported for the STS-31 flight.

Section 4 - Contains a list of safety risk factors that were considered resolved for STS-31.

Section 5 - Contains a list of Inflight Anomalies (IFAs) that developed during the STS-36 mission, the previous Space Shuttle flight.

Section 6 - Contains a list of IFAs that developed during the STS-33 mission, the previous flight of the Orbiter vehicle (OV-103).

Section 7 - Contains a list of IFAs that developed during the STS-31 mission. Those IFAs that are considered to represent safety risks will be addressed in the MSE for the next Space Shuttle flight.

Section 8 - Contains background and historical data on the issues, problems, concerns, and anomalies addressed in Sections 3 through 7. This section is not normally provided as part of the MSE, but is available upon request. It contains (in notebook format) presentation data, white papers, and other documentation. These data were used to support the resolution rationale or retention of open status for each item discussed in the MSE.

Appendix A - Provides a list of acronyms used in this report.

SECTION 2

STS-31 MISSION SUMMARY

2.1 Summary Description of the STS-31 Mission

The first attempt to launch Space Shuttle *Discovery* was made on April 10, 1990. The countdown proceeded without problems until approximately 4 minutes before liftoff, when 1 of the 3 Auxiliary Power Units (APUs) exhibited a speed control problem. Technicians determined that there was a blowing leak through the APU #1 Pulse Control Valve. After the defective APU was replaced on the pad (which was a first) and the Hubble Space Telescope (HST) Nickel-Hydrogen batteries were recharged, the launch was rescheduled for April 24, 1990.

On April 24, 1990, the launch countdown proceeded on schedule to the terminal phase at the T–31 second mark, when the liquid oxygen fill and drain valve in the Orbiter Main Propulsion System was determined to be in the wrong position for launch. The countdown was automatically held at the T-31 seconds until the console operator repositioned the valve and the mission was cleared for launch. Space Shuttle *Discovery* lifted off Pad 39B at 8:33:51 a.m. Eastern Daylight Time (EDT). All systems performed well as *Discovery* reached an altitude of 330 nautical miles (nmi), the highest altitude the Space Shuttle had ever flown.

The first day in orbit was spent preparing the HST for deployment. Power was supplied to the Remote Manipulator System (RMS) at T+2 hours 54 minutes, and checkout of the RMS subsystems and operating modes began. The black-and-white camera at the end of the manipulator arm was used to examine Hubble for any damage that might have occurred during the launch. After the post-ascent checkout was completed, preparations for a possible space walk began. Two crewmembers started breathing 100% oxygen from their helmet assemblies while the orbiter cabin pressure was dropped from 14.7 to 10.2 pounds per square inch (psi). The "prebreathing" procedure is used to shorten the time required to prepare for a spacewalk if trouble with Hubble developed. Umbilical power to Hubble was activated at approximately 4-1/2 hours into the mission. Commands to turn on the Hubble transmitters were sent at 13:21 EDT. Checkout continued through the night.

At the beginning of Flight Day (FD) 2, HST deployment operations went well initially. The first sign of trouble occurred when Hubble's 2 solar arms failed to trip microswitches that signal full deployment. The left-hand solar panel unreeled as planned. Then the right-hand array unlatched, rolled out a single segment on each side, and stopped. Engineers at Goddard Space Flight Center (GSFC) decided to disable the warning system and attempt to deploy the array a third time. This time, the array unfurled until it unreeled to its full length. At 15:37 EDT the crew released the manipulator arm's grip on Hubble.

On FD 3, the Orbiter was positioned in a gravity gradient attitude with the nose pointing toward Earth and the open payload bay doors facing north. The purpose of this position was to test the Orbiter's ability to maintain a stable attitude using the influence of gravity rather than the Reaction Control System (RCS) thrusters. Before the end of FD 3, a small RCS burn was completed that moved *Discovery* within 40 nmi of Hubble by wakeup time on FD 4. Prior to the burn, *Discovery* was trailing Hubble by approximately 54 nautical miles.

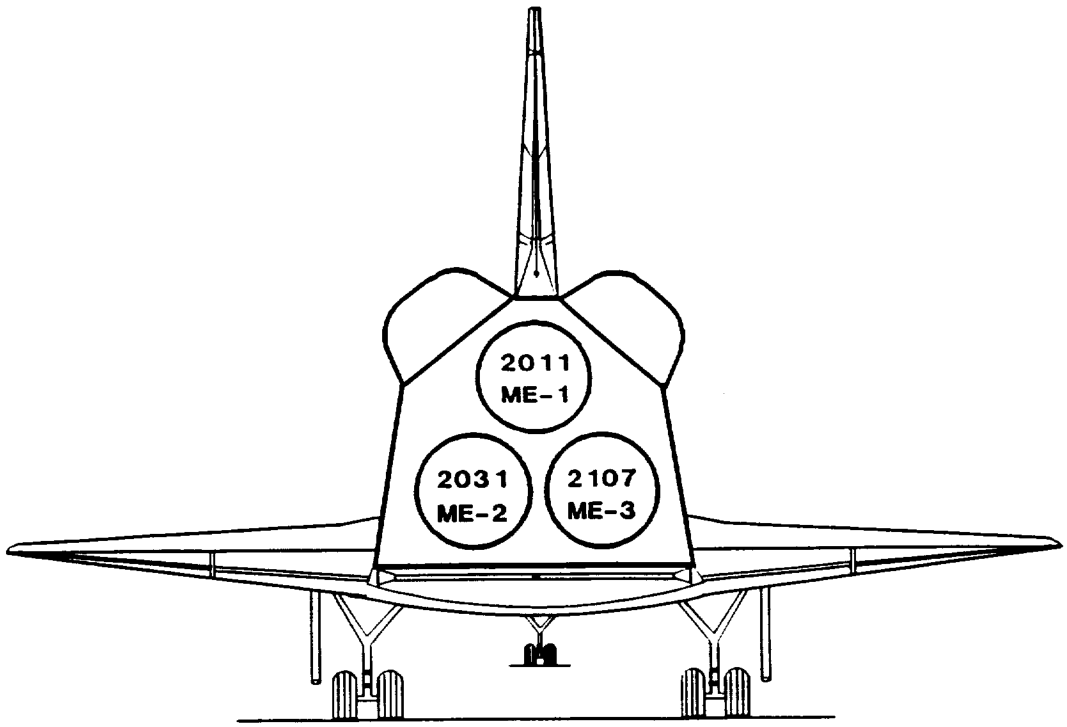
On FD 4, the HST aperture door was opened. If the door failed to reach its full 105° position, 2 crewmembers stood by to perform a space walk to manually open the door. The first attempt to open the aperture door was unsuccessful, because the on-board computer placed Hubble in an inertial hold-safe mode. This safe mode was triggered when the computer detected problems with the high-gain antenna. A second attempt to open the door began at 09:46 EDT. Seventeen minutes later, the aperture door was opened. Mission Control released the crew from escort duty although problems with Hubble's high-gain antennas continued. The crew was trained to support deployment activities, but an unscheduled repair call was not on the agenda. Houston wanted to preserve the supply of "consumables" - oxygen, food, and maneuvering fuel - to accommodate for weather-related landing delays.

On FD 5, the astronauts prepared for landing. Flight Control System (FCS) checkout and hot-fire test of the RCS thrusters were conducted. During FCS checkout, the crew members started an APU; configured the hydraulic system for reentry; examined the guidance sensor systems; and tested *Discovery's* speed brake, rudder, elevons, and body flap. During these tests, a fuel pump heater failed on APU #3; the crew switched to the backup heater which operated satisfactorily for the remainder of the STS-31 mission.

On FD 6, *Discovery* landed at Edwards Air Force Base at 9:49 a.m. EDT. At 08:37:26 EDT, as *Discovery* passed over southern Africa, the 2 Orbital Maneuvering System (OMS) engines were fired for approximately 4 minutes, 48 seconds to slow the vehicle for reentry. At 09:19:21 EDT, over the Pacific Ocean, "Entry Interface" occurred, with the Orbiter travelling at a velocity of 24,700 feet per second. The period of maximum heating during reentry occurred approximately 10 minutes later, soon after the Orbiter had passed north of Hawaii. As *Discovery* slowed to Mach 1, the crew took over control manually for the final portion of the landing. *Discovery* landed on concrete runway 22 after a flight of 5 days, 1 hour, 16 minutes, 6 seconds. Plans to land on a lakebed runway had to be abandoned because of high winds. Descent took approximately 15 minutes longer than usual because of the record-breaking altitude for the STS-31 mission.

2.2 Flight/Vehicle Data

- Launch Date: April 24, 1990
- Launch Time: 8:31 a.m. EDT
- Launch Site: KSC Pad 39B
- RTLS: Kennedy Space Center, Runway 33
- TAL Site: Banjul, The Gambia
- Alternate TAL Site: Ben Guerir, Morocco
- Landing Site: Edwards AFB, CA, Concrete Runway 22
- Landing Date: April 29, 1990
- Landing Time: 9:49 a.m. EDT
- Mission Duration: 5 Days, 1 Hour, 16 Minutes
- Crew Size: 5
- Inclination: 28.5 Degrees
- Altitude: 330 Nautical Miles Circular/Direct Insertion
- Orbiter: OV-103 (10) *Discovery*
- SSMEs: (1) #2011, (2) #2031, (3) #2107
- ET: ET-34
- SRBs: BI-037
- SRMs: RSRM Flight Set #10
- MLP #2



ENGINE	#2011	#2031	#2107
POWERHEAD	#2016	#2028	#2014
MCC*	#4005	#2019	#4002
NOZZLE	#4016	#4017	#4019
CONTROLLER	F24	F27	F25
FASCOS*	#17	#12	#29
HPFTP*	#5203R1	#6102R1	#4011R1
LPFTP*	#2030	#2120R1	#4007
HPOTP*	#2027R1	#4008R1	#2226R1
LPOTP*	#2126	#2120	#4105

* Acronyms can be found in Appendix A.

2.2.1 Remote Manipulator System End Effector Modification

The Remote Manipulator System was the primary deployment method for the Hubble Space Telescope. A new configuration End Effector was the interfacing mechanism used to grapple and deploy the HST. This was the first flight with the modified, -7 configuration end effector. Modifications made reduce the number of Crit 1 failure modes, improve performance, and extend the useable life before refurbishment. To eliminate 6 Crit 1 failure modes, a test connector was added to enable testing of end effector electronic unit fuses and built-in test equipment, brake and clutch enable signals, and heater buses. The previous end effector configuration was susceptible to failure under the launch vibration environment. The end effector carriage-to-frame interface was strengthened by replacing the roller bearing with preloaded slider blocks. These blocks hold the carriage to the frame during launch and reduce vibration effects. Wear on the end effector brakes and clutches required refurbishment after 5 or 6 flights. Modifications to increase brake slip torque (from 35 to 85 ounces) and clutch slip torque (from 35 to 45 ounces) have been made to reduce slipping revolutions. A modification was also made to clutches and brakes to contain friction material debris formed during operation. These modifications increased the useful end effector life between refurbishment to 30 flights.

2.2.2 Carbon Brakes

OV-103/STS-31 was the first flight using carbon brakes on the main landing gear. Carbon brakes are replacing the carbon-lined beryllium brakes used on all Orbiters since the beginning of the Space Shuttle Program. Improved performance margins which lower the safety risk during landings, extended life, and elimination of special handling procedures were the prime reasons for making this change. STS-31 was selected for carbon brake system first flight because needed instrumentation is available on OV-103. The carbon brake assembly comprises 5 rotors and 4 stators, increased from 4 and 3 respectfully, to increase the friction/braking area. The beryllium brake assemblies have carbon liners fastened to beryllium rotors which further reduce the available rotor friction area. One-piece carbon rotors are used in the improved carbon brake assembly. Hydraulic pressure regulation is reduced by 500 psi with the carbon brakes; operating pressure is 2000 psi. Energy absorption capability of the carbon brakes increases from the 18,000,000 foot-pounds (ft-lb) of the beryllium brakes to 82,000,000 ft-lb. This added capability provides a nominal brake life of over 20 landings/stops; much improved over the 5 maximum of the beryllium brakes. This extra energy absorption capability allows an increase in nominal landing speed from 180 knots to 225 knots, lowering the risk associated with Return-To-Launch-Site contingency landings at Kennedy Space Center. In addition to increased performance and extended useful life, elimination of the beryllium brakes decreases the health risks to technicians; beryllium is a highly toxic element.

2.2.3 Highest Orbit Mission

STS-31 was the highest orbit mission of the Space Shuttle Program. A question recently raised concerning the capability to deorbit after an OMS propellant tank failure again brought to light the increased risk of high-orbit missions. Because of the extended OMS-1 and OMS-2 burns required to achieve a 330 nautical mile (nmi) circular orbit, OMS engine propellant reserves are depleted to a point that subsequent loss of access to OMS propellant (fuel or oxidizer in either OMS Pod) would leave insufficient propellant to accomplish deorbit. This is a known condition and is an accepted risk in flying high-orbit missions. The issue of sufficient OMS propellant can become a concern at any altitude. Prelaunch quantity, fuel usage, mission profile (including payload deployment maneuvers and rendezvous), payload mass, and center of gravity maintenance can vary and influence propellant reserves. OMS propellant tanks are made of titanium and operate at a maximum pressure of 313 psi. All tanks are proof-pressure tested prior to installation and leak checked prior to each flight. Tank fracture control requirements require tank proof-pressure testing to be accomplished after 5 flights to protect against possible crack initiation, growth, and tank rupture. There have been no propellant tank failures in flight. The STS-31 OMS propellant tanks successfully passed all acceptance and proof tests required by the tank fracture control plan.

2.3 Payload Data

Payload Bay:

- Hubble Space Telescope (HST)
- IMAX Cargo Bay Camera (ICBC) System (IMAX-04)
- Ascent Particle Monitor (APM) (Get-Away Special)

Middeck:

- IMAX In-Cabin Camera System (IMAX-04)
- Protein Crystal Growth (PCG)
- Air Force Maui Optical Station (AMOS) Calibration Test
- Radiation Monitoring Equipment (RME)
- Investigations into Polymer Membrane Processing (IPMP)
- Investigation of Arc and Ion Behavior in Microgravity (SE 82-16 Ion Arc)

2.4 Hubble Space Telescope Description.

The HST primary objective is to provide a high resolution, optical telescope system that will see planets, asteroids, and comets so clearly that the scientific data recorded will significantly extend the knowledge of the universe. The HST is comprised of 3 major elements: the Optical Telescope Assembly (OTA), the Support System Module (SSM), and a set of Scientific Instruments (SI). The HST is deployed by the RMS. The HST does not have a propulsion system. Attitude control is provided by reaction wheels and magnetic torquers.

The OTA is a 2.4 meter, f/24, Ritchey-Chretien Cassegrain-type telescope with a usable Field-Of-View (FOV) of 14 arc minutes half-angle. The focal plane is divided among 4 axial SIs and 1 radial SI, 3 optical control sensors, and 3 Fine Guidance Sensors (FGSs). The OTA major elements include the primary mirror and main ring, providing the primary structural interface to the SSM; the focal plane structure, supporting the SIs and FGSs; the main and secondary light baffles for stray light absorption; the metering truss and secondary mirror; and the OTA Equipment Section (ES), housing most of the OTA electronics. The ES mounts to the exterior SSM ES. An SSM equipment shelf is provided with the focal plane structure for Fixed Head Star Tracker (FHST) and Rate Sensor Unit (RSU) mounting. All focal plane sensors, as well as the majority of the OTA electronics, are Orbital Replaceable Units (ORUs).

Supporting all other elements of the vehicle, the SSM is the spacecraft portion of the HST. It provides all interfaces to the Orbiter. The SSM contains a very precise pointing and stabilization control subsystem, thermal control subsystem, data management subsystem, and electrical power and communications subsystem. The electrical power required to operate the HST is provided by batteries, recharged and supplemented by Solar Array (SA) blankets during the sunlit portion of its orbit. The major structural components of the SSM are the Aperture Door (AD), the Light Shield (LS) and Forward Shell (FS) (enclosing the OTA), the SSM ES (housing the module subsystems and providing the primary HST load-bearing structure), and the Aft Shroud (AS) (enclosing the SIs, FGSs, and FHSTs). The SSM also provides structural and electrical interfaces to the GSFC Flight Support System (FSS). Electrical interface to the Orbiter is provided via the AS.

The initial complement of SIs on the HST includes 2 imaging cameras, 2 spectrographs, 1 photometer, and the OTA FGSs used as astrometry SIs. The Faint Object Camera (FOC) and High Resolution Spectrograph (HRS) are mounted in the axial position of the OTA focal plane structure. The Wide Field/Planetary Camera (WF/PC) is radially mounted in the OTA, as are the FGSs. All SIs and FGSs are ORUs.

SECTION 3

SAFETY RISK FACTORS/ISSUES IMPACTED BY STS-31 ANOMALIES

This section lists safety risk factors/issues, considered resolved (or not a safety concern) for STS-31 prior to launch (see Sections 4, 5, 6, and 7), that were repeated or related to anomalies that occurred during the STS-31 flight. The list indicates the section of this Mission Safety Evaluation (MSE) Report in which the item is addressed, the item designation (Element/Number) within that section, a description of the item, and brief comments concerning the anomalous condition that was reported.

	ITEM	COMMENT
Section 5: STS-36 Inflight Anomalies		
Orbiter 3	Reaction Control System (RCS) Thruster R3D failed off during External Tank (ET) separation. (IFA No. STS-36-04)	Two RCS thruster anomalies were reported on STS-31. Thruster L3A failed "off" during post-Main Engine Cutoff (MECO), Main Propulsion System (MPS) dump, +X maneuver; the oxidizer injector valve did not open. Approximately 7 hours after this failure, thruster L3A oxidizer temperature dropped from 90°F to 21°F, indicating that the oxidizer injector valve was leaking. These failures were similar to thruster anomalies experienced on STS-5, STS-29, and STS-30. The failure mechanism was attributed to nitrate formation/contamination of the oxidizer valve pilot poppet. Expedited procurement is in process for a universal throat plug designed to eliminate the potential for water intrusion into RCS thrusters. (See Section 7, Orbiter 2 for more details.) (IFA No. STS-31-03A and STS-31-03B)
Orbiter 7	Water Spray Boiler (WSB) #2 vent system "A" heater failed. (IFA No. STS-36-07)	While on-orbit and during STS-36 entry, WSB #2 vent system heater "A" operated erratically. WSB controller testing at the vendor failed to duplicate the anomaly. This was a repeat of IFA No. STS-34-18, which was closed as unexplained because it could not be repeated. Troubleshooting of the STS-34 anomaly included operation of "A" and "B" heaters for a number of cycles and shaking of wiring and connectors. STS-31 WSB #2A heater operated erratically before launch and failed to respond when power was applied on-orbit. WSB #2B heater was turned on and functioned properly for the remainder of the mission. Heater "A"

ITEM		COMMENT
Section 5: STS-36 Inflight Anomalies		
Orbiter 7 (Continued)		was reselected for entry; operated slower than normal in increasing temperature, and cycled irregularly. Postflight temperature profile tests at Kennedy Space Center (KSC) found tiles in contact with the WSB vent nozzle; the tiles acted as heat sinks. Previous failures also occurred on STS-33 and STS-34. (IFA No. STS-31-05)
SRB 6	Right Solid Rocket Booster (SRB) frustrum Marshall Trowellable Ablator No. 2 (MTA-2) debonds. (IFA No. STS-36-B-07)	During postflight inspection of the right SRB frustrum, MTA-2 debonds were found at 16 ramp locations. The voids occurred between MTA-2 layers. Material analyses performed on MTA-2 sections removed from 2 fasteners found that the voids were air bubbles introduced during material application; these voids were too small to initiate loss of MTA-2. As a corrective action, MTA-2 processing enhancements are being evaluated. This was the first instance of an MTA-2 debond since it was first used. Evidence indicated that the debonds occurred during or after frustrum separation. Postflight assessment of STS-31 found missing Thermal Protection System (TPS) material on the left-hand aft skirt. Areas with missing TPS material were either missing K5NA over MTA-2 or MTA-2 over MTA-2 applications. It was determined that the loss of MTA-2 on STS-31 occurred during descent or at water impact. (See Section 7, SRB 4 for details.) (IFA No. STS-31-B-04)

ITEM		COMMENT
Section 6: STS-33 Inflight Anomalies		
Orbiter 10	Erratic temperature indications from Auxiliary Power Unit (APU) #1 and #3 bypass line "A". (IFA No. STS-33-16)	Bypass line "A" temperature sensors on both APU #1 and #3 demonstrated erratic behavior. This was indicated by erratic bypass line heater operation. The temperature sensors, or thermostats, are mounted on the APU bypass lines. It is believed that these lines experienced vibration which led to loosening of the sensor mounts. APU #3 fuel pump bypass heater "A" failed "on" during Flight Control System (FCS) checkout prior to STS-31 reentry. This heater operated erratically during STS-33, but a decision was made not to replace the thermostat prior to STS-31. Therefore, this anomaly was expected. (See Section 7, Orbiter 6 for details.) (IFA No. STS-31-08)

SECTION 4

RESOLVED STS-31 SAFETY RISK FACTORS

This section contains a summary of the safety risk factors that were considered resolved for STS-31. These items were reviewed by the NASA safety community. A description and information regarding problem resolution are provided for each safety risk factor. The safety position with respect to resolution is based on findings resulting from System Safety Review Panel (SSRP) and Program Requirements Control Board (PRCB) reviews (or other special panel findings, etc.). It represents the safety assessment arrived at in accordance with actions taken, efforts conducted, and tests/retests and inspections performed to resolve each specific problem.

SECTION 4 INDEX

RESOLVED STS-31 SAFETY RISK FACTORS

SECTION 4 INDEX - CONTINUED

RESOLVED STS-31 SAFETY RISK FACTORS

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
INTEGRATION		
1	STS-34 Auxiliary Power Unit (APU) fuel pump carbon bearing crack. HR No. ORBI-100 INTG-149 ***No APU anomalies attributed to pump bearing cracks were reported on STS-31.***	During postflight inspection of Hydraulic Power Unit (HPU) fuel pump Serial Number (S/N) R6C004, a single longitudinal crack was found on the cover side of the driven carbon gear bearing. S/N R6C004 was installed on APU S/N 181, which flew on STS-34. APU system performance was nominal; actual fuel pump performance data is not obtainable during flight. This failure mode was similar to the cracked carbon bearing which led to rapid hydrazine decomposition in fuel pump S/N R8B003 at Sundstrand on November 1, 1989. Note that STS-34 and fuel pump S/N R6C004 flew before the November pump failure, failure,investigation, and subsequent screening procedures development. (See STS-33 Mission Safety Evaluation Report, Section 4, Integration 3, for details of the investigation and findings.) All acceptance and certification test traces for fuel pump S/N R6C004 were reviewed. From the calibration testing performed on June 27, 1988, indication of bearing distress was obvious during steady-state operation. Bearing distress was indicated by the 3 factors determined in the November 1989 investigation to be signals of fuel pump bearing cracks: torque increase, fuel flow decrease, and discharge pressure decrease. An additional calibration run was made on September 4, 1988; however, traces from this run did not show signs of a bearing crack. It is believed that a longitudinal crack relieved stresses in the bearing so that no distress was evident during the September calibration run; therefore, fuel pump calibration testing continues to be the best screen for carbon bearing cracks.

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE

INTEGRATION

1 (Continued)

Rationale for STS-31 flight was:

- There were a total of 7 cracked carbon bearings found in the Space Shuttle Program; all had test traces that recorded the 3 key bearing distress indicators.
- Assembly records were reviewed for fuel pumps on the STS-31 Solid Rocket Boosters (SRBs) and the Orbiter; no anomalies were found. Fuel pumps on the STS-31 Orbiter APUs were not removed after STS-33 flight and are considered to be in good health.
- Orbiter APU fuel pump Acceptance Test Procedures (ATPs) provide adequate screening.
- Bearings in STS-31 SRB HPU fuel pumps were visually inspected prior to installation.
- Flight operation is less severe than the fuel pump ATPs.
- Test traces for each STS-31 SRB HPU fuel pump were reviewed; no anomalies were indicated.

This risk factor was resolved for STS-31.

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
INTEGRATION		
2	Main Propulsion System (MPS) to Main Engine (ME) #2, engine #2031, 12" seal leak. HR No. ME-D3 (All Phases) ***No similar anomaly or related problem was reported on STS-31 after the seal was removed and replaced.***	During STS-31 ME helium signature tests, a significant leak was detected at the F1 joint between the Orbiter MPS and ME #2, engine #2031, Low-Pressure Fuel Turbopump (LPFTP). The F1 joint is in the 12" fuel line to engine #2031, and a teflon-coated metal seal is used. Upon seal removal and inspection, it was reported that a silver metal sliver was found across the teflon seal that most likely caused the leak. Other silver particles were found around the seal. The sliver was probably from the coating on the bolts used in the seal area; the silver coating serves as a lubricant. The seal area was cleaned, and no anomalies were reported for the sealing surfaces of the LPFTP or the 12" line from the MPS. The seal was removed and replaced. A helium signature test of the Liquid Hydrogen (LH_2) side of the ME #2 MPS system was performed with good results. ***This risk factor was resolved for STS-31.***
3	Failure of Snap-On torque wrench. HR No. INTG-051A ***No anomalies attributed to torque wrench problems were reported on STS-31.***	A LH_2 8" disconnect insert bolt failed during torquing to 55 inch-pounds (in-lb). The wrench was a Snap-On click-type (model Q2150R, Z#50667), 5-150 in-lb range, pre-1970 vintage with a calibration date of December 12, 1989. Six other OV-103 uses of Snap-On torque wrench Z#50667 were identified as having a suspect overtorque condition. Problem Report (PR) V070-3-10-0308 was written to document the suspect condition. Investigation found all uses of the wrench acceptable per engineering evaluation/torque checks. The wrench was found to have angular misalignment of its internal mechanism. By reducing the indicator setting to less than minimum, all preload on the triangular metal pivot was lost. If preload is zero and the wrench is shaken or bumped, the pivot may dislodge and come to rest on 1 of its 3 sides. When the pivot comes to

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
INTEGRATION		
3 (Continued)		rest on 1 incorrect side, the applied torque is approximately 130% of the set value. On the other incorrect side, the applied torque is approximately 224% of the set value. Identical results were obtained with Utica torque wrenches. Both Utica and TCI wrenches have the same triangular pivot as the Snap-On wrench. The root cause was determined to be broken, displaced, or missing mechanical stops (C-clips or pins). The purpose of the stop is to prevent reduction of the wrench setting to a point where the spring force is insufficient to prevent pivot repositioning due to jarring of the wrench. Eight similar Snap-On wrenches were removed from use on March 7, 1990. A torque analyzer check was made on click-type wrenches in the Orbiter Processing Facility (OPF) and the wheel and tire shop. A total of 166 wrenches were checked on the analyzer, and only 1 wrench failed to click. A Director's Bulletin was issued on March 13, 1990 for click-type torque wrenches that requires exercise of all torque wrenches after checkout prior to use, check of the wrenches on a torque analyzer, and leaving a preload of approximately 10% of the torque wrench range. The Calibration Laboratory implemented verification of the safety stop during the calibration cycle. Kennedy Space Center (KSC) issued a NASA TWX to alert other Centers about the problem with Snap-On, TCI, and Utica torque wrenches. All Centers initiated plans to ensure that no hardware in use would be negatively impacted by this problem. Review found no usage where flight safety was compromised, except for fasteners in the carrier panel, elevon hoist joint, and 8" fill and drain areas. These fasteners were removed and replaced. All Program Elements either cleared the torque wrenches used to process flight hardware or provided adequate rationale to accept the integrity of the fasteners on their hardware. ***This risk factor was resolved for STS-31.***

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>INTEGRATION</u>		
4	Difference between the Primary Flight Software (PFS) and Backup Flight Software (BFS) could lead to recontact between the Orbiter and External Tank (ET) after separation. HR No. INTG-010 ***No Orbiter/ET separation problems were encountered on STS-31.***	It was recently discovered that a difference exists between the PFS and BFS requirements which, under certain conditions, could lead to recontact of the Orbiter and ET at the forward attach point after separation. The PFS inhibits all rotational commands during the first 3 seconds (sec) of the ET separation maneuver; BFS does not. In the case where the BFS is in control prior to the ET separation maneuver and a negative pitch rate command is issued as the -Z translation burn begins (ET separation maneuver), recontact is possible. The required pitch rate to overcome the -Z translation can be achieved by either 2 Reaction Control System (RCS) jets failing "on" after the negative pitch rate command is issued, or by a transient induced by a Space Shuttle Main Engine (SSME) failure close to Main Engine Cutoff (MECO). The probability of either of these occurrences is extremely low. If a negative pitch rotational command is received as the -Z maneuver starts, the Orbiter nose will move toward the ET. The forward RCS would then have no -Z jets firing, and recontact would occur at the forward strut. Damage on recontact would be minimal, if any, due to the slow closing rate. Positive pitch rate commands are not a problem because the result would be to move the Orbiter away from the ET. Plans are to implement a fix in the BFS source code in the OI-21 build. Discussions among the technical community have concluded that implementation of a crew workaround procedure or software fix at this time would result in a higher risk than flying as is. A crew user note has been prepared cautioning against negative pitch commands during ET separation while in the BFS mode. Safety concurs with the assessment that there is a low probability of the required sequence of events occurring and agrees that nothing more should be done until OI-21 is available. A waiver has been approved accepting this condition through STS-50, the first planned flight with OI-21. ***This risk factor was acceptable for STS-31.***

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
INTEGRATION		
5	Contamination in OV-102 Hydrogen (H_2) system lines. HR No. INTG-023 ***No anomalies attributed to contamination in the OV-103 H_2 system were reported on STS-31.***	During STS-35/OV-102 turnaround activities, the LH_2 outboard fill and drain valve relief valve and the engine #2 prevalve relief valve were replaced due to leakage. A black fibrous contamination was discovered in these relief valves and in the recirculation valve seat area. A sample of the contamination was sent to the materials laboratory for analysis and was found to comprise corundum and calcite; this material is similar to that used in 80-grit sandpaper. Because this was the first use of Mobile Launch Platform (MLP) #3, it was initially considered the prime source of the contamination. Inspection of MLP #3 H_2 system filter found the vehicle side very clean. Some particles were found in the horizontal line upstream of the filter. Small particles, metal shavings, and several strands of thread were found in the lower flex hose on the Tail Service Mast (TSM). The line between the filter and the TSM was cleaned. The source of the contamination was not determined. An investigation was performed of the condition of STS-31/OV-103 and MLP #2 (supporting STS-31). An MLP filter that was removed in May 1989 was flushed. Particles too numerous to count were found on the vehicle side of the filter. Borescope inspection of the horizontal line from the filter to the vehicle found several particles, but no gross contamination. These particles were removed and found to be 400 to 750 microns in size. Material analysis identified the particles to comprise 300-series stainless steel and traces of corundum. Borescope inspection of the lower flex hose to the TSM found some minor contamination, which was removed. Inspection of the MLP #2 Liquid Oxygen (LO_2) system found no contamination. STS-31/OV-103 LH_2 prevalve screens were inspected prior to STS-33, with no abnormal materials found. All OV-103 launches commencing with STS-26 were from MLP #2, and prevalve screen inspections found no contamination. ***This risk factor was resolved for STS-31.***

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
INTEGRATION		
6	SRB Rate Gyro Assembly (RGA) workmanship and inspection discrepancies. HR No. INTG-144A INTG-165 B-50-18 Rev. C DCN-1 ***No anomalies associated with either SRB or Orbiter RGAs were reported on STS-31.***	The NASA Shuttle Logistic Depot (NSLD) recently began refurbishment of SRB RGAs after every flight. Previously, SRB RGAs were flown new from the vendor, Northrup; not refurbished. Orbiter RGAs are also flown new; however, they are manufactured at a different Northrup facility. During receiving inspection at NSLD, 13 SRB RGAs were found to have a number of workmanship and quality inspection discrepancies. NSLD analysis of the discrepancies led to the conclusion that the condition occurred during the previous refurbishment and was not related to flight. This placed doubt on the integrity of the RGAs on the STS-31 SRBs. Seven other RGAs were inspected by NSLD after this discovery; however, no discrepancies were found. There were 4 previous inflight failures of RGAs; there was no record of Orbiter RGA inflight failures. Discrepancies found by NSLD included bent terminals, missing screws, damaged and exposed wires, cracked or broken connectors, loose wire clippings, missing or incorrect part numbers, and miscellaneous contamination. All noted discrepancies were found by visual inspection; no failures were recorded which led to a discrepancy discovery. SRB RGAs are supplied by the Orbiter Project as Government Furnished Equipment (GFE) and are very similar to those used on the Orbiter (the Orbiter RGAs also have a roll axis). The Orbiter Project coordinated an investigation to determine how such obvious quality inspection escapes could have occurred. Teardown inspection and tests were performed on the discrepant RGAs at NSLD. Results of this investigation determined that none of the discrepancies would lead to an inflight failure. SRB RGAs are Criticality 1R2; Orbiter RGAs are Criticality 1R3. Shuttle software processes the data input from each of the 4 SRB RGAs. Software selects 1 of 4 inputs, usually the second highest value, for further processing. If an SRB RGA failure is detected, software deselects that RGA and chooses the middle input from the remaining 3. Deselection of failed RGAs can be made until 1 remains. Note that SRB RGA input is used until SRB separation, approximately 2 minutes (min) after launch.

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>INTEGRATION</u>		
6 (Continued)		The Orbiter Project reported at the Launch Minus Two-Day (L–2 Day Review that acceptance tests are run prior to installation of the RGAs on the SRBs. Acceptance tests include vibration and thermal cycling. Proper function of the RGAs is verified after installation. The Orbiter Project stated that, because all Orbiter RGAs had flown previous missions with no anomalies, there was no reason to believe that problems exist similar to those found at NSLD. Rationale for flight was based on the redundancy of both SRB and Orbiter RGAs, and passing of tests performed before and after RGA installation with no reported problems. ***This risk factor was acceptable for STS-31.***

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
INTEGRATION		
7	ET LO_2 outboard elbow heater short. HR No. INTG-008A ***No ice debris problems were reported on STS-31 subsequent to disabling the shorted ET LO_2 elbow heater prior to flight.***	During preflight testing, it was determined that the ET LO_2 outboard elbow heater was not drawing current. Troubleshooting found a blown fuse in the Pad Terminal Connection Room on the elbow heater circuit, indicating a possible short. The cable that contains wiring to the failed heater also carries wiring for 2 other heater circuits and AC motor valves. The concern was that a hard short in the elbow heater wires could affect other circuits. All other heater circuits were checked and found to be operating normally, and AC motor valves were cycled nominally. Measurements taken at the TSM verified a short on the Orbiter side of the heater circuit and cleared the ground side. Prior to the launch scrub, a decision was made to fly "as is" because further troubleshooting would require entry into the aft compartment. Because the ET LO_2 outboard elbow heater does not have a redundant backup, loss of this heater could lead to ice formation at the elbow after ET fill operations. Ice could become debris during launch and impact the Orbiter; however, because the ET LO_2 elbow is near the aft of the ET, any dislodged ice would probably not impact the Orbiter. Due to the potential, however, calculations were made to determine the ice acreage that would cause problems if impacted on the Orbiter lower aft Thermal Protection System (TPS) tiles and/or body flap. The calculated ice acreage was approved as an additional Launch Commit Criteria (LCC). The Ice/Frost Inspection Team was given instructions to look for ice formation in excess of the LCC acreage at the elbow area. Little to no ice formed in the LO_2 elbow area during the first launch attempt, due in part to the ambient temperature. The launch scrub and extended turnaround provided an opportunity for further troubleshooting. The short was isolated to the ET side of the heater wiring. The decision was made to cut the wires at the monoball interface, insulate exposed conductors, and tie the wires back for flight. ***This risk factor was acceptable for STS-31.***

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>ORBITER</u>		
1	Metal chips found in the carbon brake assembly (OV-103). HR No. ORBI-050 ***No brake system anomalies were reported on STS-31.***	During visual inspection of the brake bleed port, metal chips were found in 1 of 4 brakes prior to installation on OV-103. The most probable cause was determined to be the rod used to clean drilled fluid passageways. Chips were found trapped in a blind corner of the piston housing. Ten additional carbon brakes were inspected and 3 were found to be contaminated. At KSC, 2 were found with chips in the housing; at Wright Patterson Air Force Base (WPAFB), 1 was found with chips in 4 pistons. (The brake completed over 30 successful stops, and no piston seal damage occurred.) One B.F. Goodrich 747 carbon brake was found with chips in the piston housing. That brake was similar in design to the Orbiter brakes (including orifices) and had successfully completed approximately 200 landings. Loss of 1 brake is a 1R2 criticality. (A change is in process to make this a 1R3 criticality based upon an interim modification to the steering system.) A spare ship set was inspected/acceptance tested at B.F. Goodrich and contained no chips. This unit was installed on OV-103 and verified as clean. ***This risk factor was resolved for STS-31.***

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
2	RCS thruster weld issue. HR No. ORBI-119 *No RCS thruster anomalies attributed to weld defects were reported on STS-31.*	The RCS thruster weld issue raised during STS-36 preflight reviews was evaluated for impact on STS-31/OV-103. Technical assessment and failure analysis results arrived at prior to STS-36 were applicable to STS-31. Rationale for STS-31 flight was: • The worst-case thruster for STS-31/OV-103 was a long thruster in the forward RCS that flew 9 missions. Analysis showed a 68-mission projected life, assuming a reasonable worst-case 30% weld penetration. A short thruster in the aft RCS flew 12 missions, but in a more benign stress environment. • It was established that the only reasonable failure consequence of a weld with 30% or greater weld penetration is a leak, not a total failure or burst. The wire wrap will shut down a thruster leaking through one of these welds in sufficient time to prevent further damage to the thruster or adjacent thrusters. The wire wrap modification was installed on all OV-103/STS-31 RCS thrusters. • RCS thrusters are redundant. *This risk factor was resolved for STS-31.*

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>ORBITER</u>		
3	Elevon cove leak test failure on STS-31. HR No. ORBI-003 ORBI-099 ***No elevon cove leaks were reported on STS-31 after repair of the seal damage areas originally detected due to failure of Operational Maintenance Requirements and Specifications Document (OMRSD) leak tests.***	The elevon cove failed OMRSD leak tests on STS-31. Maximum allowable leaks are 110 standard cubic feet per minute (scfm) for the inboard elevons and 65 scfm for the outboard elevons. Backpressure measurements are taken and should be 0.5 psi. Backpressure on OV-103/STS-31 was measured at 0.25 pounds per square inch (psi), indicating a leak. The last leak check of OV-103 was performed prior to STS-26. Postflight inspections are required after every flight, but not leak checks. Some damage is usually detected after every flow. Contamination buildup was found on the primary elevon seal. Some areas without visible damage were found to be leaking. The probability exists that these elevon cove seals leaked during the last flight. Rationale for STS-31 flight was: • All elevon cove seal leak damage areas were identified and repaired. • OMRSD leak test results were satisfactory. ***This risk factor was resolved for STS-31.***

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
4	Fuel Cell (FC) separator plate plating defects. HR No. ORBI-282A ***No FC anomalies attributed to separator plate defects were reported on STS-31.***	FC separator plate plating defects were an issue of great concern during the STS-33 preflight reviews. During teardown of STS-33 FCs S/N 104 and S/N 115 for operational improvements, plating blisters were found on 46 separator plates [Oxygen (O_2)-to-H_2), and H_2-to-coolant]. FC operating times were approximately 1000 hours (hr); they had 3 flights each (STS-9, STS-61C, and STS-26). All of the plates were from a single lot of 255 manufactured from December 1982 through December 1983. The blisters were due to separation of the gold and nickel layers from the magnesium base material. No corrosion was observed through to the magnesium. Potassium hydroxide, used as an electrolyte with water, passivates the bare magnesium, and no corrosion occurs. Corrosion pits may develop if material impurities are present at the blister site. Explosive mixing of H_2 and O_2 through the separator plate could lead to a catastrophic event; indication of H_2 and O_2 mixing requires immediate FC shutdown and safing. Mixing of H_2 and coolant is more benign, resulting in slow degradation in FC performance. Separator plates from this suspect lot were identified to be in STS-33/OV-103 FCs. An accounting of these plates follows: • 2 in FC #1, H_2-to-O_2 plate, with 411 hr of operation. • 1 in FC #2, H_2-to-coolant plate, with 519 hr of operation. • 45 in FC #3, 2 in H_2-to-O_2 plate, 43 in H_2-to-coolant plate, with 854 hr of operation. Orbiter Program Management directed that FCs #1 and #3 on OV-103 be changed out after STS-33. This action was completed during the STS-31 turnaround process; therefore, suspect H_2-to-O_2 plates were no longer on OV-103. ***This risk factor was resolved for STS-31.***

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>ORBITER</u>		
5	OV-103/STS-31 Right-Hand (RH) main landing gear upstop tripod assembly problem. HR No. ORBI-179 ORBI-182 ORBI-188 ***No landing gear anomalies were reported on STS-31.***	During removal of the RH brakes to deal with the carbon brake contamination problem, the brake accelerometers were taped to the main strut. This is the exact location where the strut contacts the upstop. During retraction of the gear assembly to support TPS work, the accelerometers were caught between the uplock and strut, resulting in damage to the upstop assembly. Measurements and inspection of the airframe and structural brackets revealed that no damage was caused by this incident. Stress analysis indicated that the uplock mechanism and the upstop backup structure were not overloaded. Further analysis and inspection confirmed that all damage was isolated to the upstop mechanism and accelerometers. All damaged hardware and instrumentation were replaced. Inspection of OV-102 found the main landing gear uplock hooks deformed and not to print. OV-102 uplocks were removed and replaced. Based on this finding, OV-103 uplock hooks were also checked. OV-103 uplock hooks showed no deformation and were cleared for flight. ***This risk factor was resolved for STS-31.***

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
6	OV-103 aft fuselage hydraulic fluid leak. HR No. ORBI-036 ORBI-047A ***After cleanup operations were performed, no anomalies attributed to hydraulic fluid leakage were reported on STS-31.***	Approximately 2.8 gallons of hydraulic fluid leaked onto the aft fuselage and right wing areas of Orbiter OV-103 during the holiday standdown period from December 23, 1989 through January 2, 1990 due to a seal failure in the hydraulic Ground Support Equipment (GSE) Quick Disconnect (QD) coupling. Pre-holiday hydraulic operations were performed on December 21, 1989 to position aerosurfaces for tile repair access. The hydraulic system was configured with onboard reservoirs filled to approximately 65%, and system pressure was at 75 pounds per square inch absolute (psia) (nominal shutdown configuration). Leakage was caused by the failure of GSE QD coupling seals. The QD was removed and returned to the vendor for analysis. Failure analysis of the removed QD found that both O-rings failed; the outer O-ring was rolled within the gland, and the inner O-ring was extruded between the seal sleeve and the QD body. These O-rings were found to be more than 10 years old. General cleaning, repair/replacement, and inspection of suspected contaminated areas were completed prior to going vertical. After mating the Orbiter to the ET, inspection of the Orbiter aft compartment was performed to look for evidence of hydraulic fluid from the oil spill that occurred during the Christmas holiday standdown period. The inspection revealed that approximately 1/2 cup of fluid had seeped out of the hollow box beam, down toward one of the engine base heat shields. Contamination was limited to a temporary tank cover and adjacent structure. Cleaning operations were performed. ***This risk factor was resolved for STS-31.***

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>ORBITER</u>		
7	OV-103 APU #3 turbine wheel limited-life issue. HR No. ORBI-031 ***No anomalies attributed to turbine wheel failure were reported on any STS-31 APUs.***	A determination was made that APU #3 would violate the turbine wheel limited-life requirement during this flight. APU turbine wheels are life limited due to blade cracks induced by High-Cycle Fatigue (HCF). OMRSD inspection requirements were established based on the number of APU starts and high-speed run time. The OMRSD requirement is 14 starts maximum; APU #3 had 15 starts, with a minimum of 2 additional starts during the STS-31 mission. A similar limited-life issue arose during the STS-36 prelaunch reviews, where APU #1 was found with 19 hot starts. Since establishment of the OMRSD requirements, additional high-speed testing was been performed. This data was evaluated by Rockwell International (RI), Sundstrand, and Southwest Research Institute [a Johnson Space Center (JSC) contractor]. The consensus, based on results of recent analyses and tests, was that the original life limit established for new turbine wheels is conservative. For STS-36 APU #1, S/N 307, the Level II Program Requirements Control Board (PRCB) approved an increase in the turbine wheel limit to 24 starts or 69 min of high-speed operation for that flight only. The confidence level for 0.999 reliability at 69 min of high-speed operation for a new wheel was determined to be 95%. High-speed APU operation is not planned during a nominal mission. If a contingency requires high-speed operation in excess of the life limit, the reliability of this wheel would be 0.995 with 95% confidence. OMRSD Waiver S53139A was approved to fly APU #3 "as is" on STS-31. ***This risk factor was resolved for STS-31.***

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
8	Nose wheel bearing retainer nut issue. HR No. ORBI-179 *No Nose Landing Gear (NLG) anomalies were reported on STS-31.*	During installation of the nose wheel assembly on OV-102/STS-35, a quality inspector noticed wheel assembly free play of approximately 0.007". Further inspection with Menasco representatives (nose and main landing gear assembly vendor) found that the nose wheel bearing retainer nuts on each side of the bearing housing were cocked. Discoloration was also noted on the axle and bearing housing. The bearing retainer nut is an aluminum alloy, male-threaded nut, used to retain axle landing gear roller bearings. There is a retainer nut on each end of the housing. Records indicated that bearing retainer nuts installed on all vehicles had not been removed or replaced since the original build of the NLG assemblies. Inspection of other NLG assemblies was undertaken to determine if similar problems existed. OV-104 inspection found the bearing retainer nuts to be cocked and evidence of freeplay similar to OV-102 was seen. No discoloration of the axle or housing was found. Inspection of the OV-099 NLG assembly stored at Dryden found cocked retainer nuts. Because OV-103 was stacked at this time, access to check the condition of the retainer nuts was not available. Review of nose wheel compartment closeout documentation found no record of free play. It is not believed that "cocking" of the retainer nuts was a result of crossthreading. The initial theory was that nose wheel slapdown loads caused the axle to flex and put side loads on the nuts. The side loads may have caused displacement or stripping of the nut threads across the housing threads. The nose wheel is a crit 1 assembly.

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
8 (Continued)		In evaluating this situation, the Orbiter Project Office could not define a credible scenario that would result in a catastrophic event. Independent safety assessment found 2 possible hazardous scenarios: • Loose bearings could overheat and freeze up. It is not clear what the full extent of damage would be; however, as a minimum, nonrepairable destruction of the nose wheel assembly could result. • Nose wheel assembly collapse could result in serious damage and perhaps loss of the vehicle. Attempts to remove the OV-102 left nut at KSC failed. Application of 300-350 in-lb torque could not move the nut. Use of a hammer resulted in only a 1/8" circumferential turn. Continued application of the hammer found that the nut was harder to turn and was discontinued. Based on this action, it was thought that a "cocked" retainer nut is unlikely to fall off. The OV-102 axle assembly was shipped to Menasco for further analysis. At Menasco, the retainer nuts were removed by milling the inner diameter, thus preserving the nut threads. Inspection of the bearings and bearing races found no degradation. Discoloration, which would indicate binding or unusual external forces, was not seen. The bearing housing threads were found to be in excellent condition. The first retainer nut thread was found to be rolled approximately 0.009" at the 12:00-o'clock position. Bearings and bearing grease were in near-new condition. Magnetic particle inspection of the axle housing verified that there were no cracks. An area of untempered martensite, approximately 2" long x 0.22" wide x 0.41" deep, was found on the axle housing. (See Section 4, Orbiter 9 for details concerning the potential for untempered martensite.)

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
8 (Continued)		Stress analysis of this condition verified slapdown loads as the cause of nut cocking. Slapdown loads of 90,000 pounds force (lbf) or greater are sufficient to provide radial forces on the retainer nuts to displace the top of the nut and cause it to "jump" 1 thread. Slapdown loads sufficient to cause a retainer nut to "jump" 2 or more threads would fail the NLG structure and result in a catastrophic event. Analysis of possible loads, coupled with visual inspection of the OV-102 retainer nuts, led to the determination that after a "1-thread" lateral displacement the nut will stay in a wedged-in position without further radial motion. OV-102 nuts were found with the top of the nut, or 12:00-o'clock position, displaced by 1 thread; radial forces caused crossthreading of the first thread at the 3:00- and 9:00-o'clock positions; the threads at the 6:00-o'clock position were in place and in good condition. Stress analysis of effects of axle freeplay on the bearings determined that freeplay of up to 0.012" is acceptable without degradation. Based on the evaluation of the OV-102 axle assembly and bearings, and the lack of recorded free play during nose wheel well closeout, OV-103/STS-31 was cleared for flight. ***This risk factor was resolved for STS-31.***

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
9	Potential for untempered martensite in the NLG axle housing. HR No. ORBI-179 ***No NLG anomalies were reported on STS-31.***	During investigation of the NLG retainer nut problem at Menasco, teardown and inspection of the OV-102 NLG were performed. An area of untempered martensite 2" long x 0.22" wide x 0.41" deep was found on the inside of the 300M steel axle housing. It was determined that the untempered martensite area resulted from the raised area of the rotating Inconel 718 axle contacting the housing during touchdown. This contact raised the temperature of the 300M steel axle housing sufficiently to form untempered martensite. The raised area was in the center of the axle and was used to center the axle by viewing the raised area through a vent hole in the housing. Inspection of OV-104 and OV-099 NLGs found no untempered martensite. In both cases, however, contact was made with the housing; OV-104 contact did not penetrate the housing paint, OV-099 did. Corrective action was taken to remove the raised area and replace it with a painted strip on all NLG assemblies. The untempered martensite area was reworked and removed prior to shipping the OV-102 NLG back to KSC. Untempered martensite is more brittle than the surrounding steel. Because stress loading capabilities are lower, localized flaw growth of stress cracks in the housing results when tensile stress is applied. Stress analysis of the OV-102 area determined that positive structural margins exist with 0.1667" depth of untempered martensite after removal. Analysis also indicated that the area in which the untempered martensite was found is in compression under touchdown load conditions. Analysis determined that frictional forces, caused by axle-to-housing contact on OV-102, produced local temperatures in excess of 1500°F. Local areas of residual stress could remain after cooldown. Any cracks resulting from residual stress caused by friction would grow only if external tensile stress is applied. There are also unknown residual stresses in the area due to the original forging and manufacturing of the housing. Fracture analysis theory indicates that a flaw would be self-arresting in the residual compression stress zone. Due to the high toughness of 300M steel, it is not anticipated that a crack in untempered martensite would propagate into virgin 300M.

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>ORBITER</u> 9 (Continued)		Menasco stated that the presence of untempered martensite was not acceptable because there was no known experience with flying with this condition. It was their experience that resulting critical flaws in untempered martensite are too small to detect and the potential for complete failure always exists. This is especially critical in commercial aircraft landing gear where untempered martensite is a source for stress corrosion cracks. Menasco's experience demonstrated that landing gear failures due to untempered martensite do not occur without the addition of outside forces, such as tension loading or stress corrosion. Untempered martensite areas, whenever discovered by Menasco, are always removed. However, Menasco representatives stated at the STS-31 Flight Readiness Review (FRR) that, based on the analyses performed relative to the Orbiter NLG, flying STS-31/OV-103 "as is" presented a low risk. Review of NLG touchdown loadings for various Orbiter missions found that OV-102 had experienced the highest load, 90,600 pounds (lb). Untempered martensite on OV-103, if any, was expected to be less than that seen on OV-102 due to lower landing loads experienced to date. Because OV-103 and OV-099 had similar NLG touchdown loadings, approximately 70,000 lb, inspection of OV-099 provided an indication of the potential for untempered martensite on OV-103. No untempered martensite was found on OV-099. By comparison of landing loads only, a case was made that there was little possibility that untempered martensite existed in the OV-103 axle housing. However, if the worst-case clearance of 0.025" existed between the axle raised area and the housing, it would only take a landing load of 49,200 lb to achieve contact. Minimum clearance measured for OV-099, OV-102, and OV-104 NLGs was 0.047" (on OV-099). While there was no reason to believe OV-103 had the minimum clearance condition, analysis of possible tolerance buildups demonstrated that the potential was there.

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>ORBITER</u>		
9 (Continued)		A test program was conducted to determine the effects of untempered martensite in 300M steel. Using 0.174" thick 300M steel, friction-induced untempered martensite was achieved using a dull drill bit. The untempered zone formed was 0.033" deep. Subsequent metallurgical tests found no cracks in the untempered martensite. Weld-torch induced untempered martensite did produce cracks; however, no cracks were found beyond the untempered zone. The results of these tests verified that cracks are not easily produced by either heat or friction and that any cracks formed should be contained within the untempered martensite zone. Because of the risk of possible untempered martensite in the OV-103 NLG, certain landing constraints were formulated. In the contingency that the Hubble Space Telescope (HST) was not deployed, the concrete runway at Edwards Air Force Base (EAFB) was the designated primary landing site. Nominal end-of-mission landing without HST would use the EAFB lakebed, primarily based on the first use of the carbon brakes. Nose wheel steering and crosswind landing Development Test Objectives (DTOs) were cancelled for STS-31. Rationale for STS-31 flight was: • Axle-to-housing clearance was probably nominal. • OV-103 highest landing load was equivalent to OV-099; OV-099 had no martensite and slightly below-nominal clearance. Therefore, there was a low probability that significant axle/housing contact had occurred on OV-103. • Analysis demonstrated that slapdown and rollout stresses in the potential contact area were compressive; tensile stresses are required to propagate cracks and cause further damage.

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
9 (Continued)		• Expected NLG loads for STS-31 could cause axle/housing contact due to minimum clearance assessment; however, there was a low probability that minimum clearance existed on OV-103. • There was very low risk of catastrophic housing failure. Additional risk imposed by planned landing DTOs was eliminated by landing constraints. • Operational history on OV-102 and other Orbiter vehicles lent credibility to analysis results; however, it is not a proof test. ***This risk factor was acceptable for STS-31.***

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>ORBITER</u>		
10	STS-31 Left-Hand (LH) NLG tire leak rate. HR No. ORBI-018 ORBI-185 ***No further tire problems were reported on STS-31.***	Instrumentation indicated that the LH NLG tire was leaking at a rate of 0.69 psi/day; the allowable leak rate is 0.4 psi/day over a 20-day period. The Orbiter tires cannot be accessed for any reason while the Orbiter is mated to the ET. Nominal top-off pressure for NLG tires is 345-350 psi prior to OPF rollout. Prior to rollout, weekly measurements of this tire established a leak rate of 0.18 psi/day. Pressure readings were taken with a mechanical gage prior to gear stowage. The Tire Pressure Measurement System (TPMS), which employs strain gages, was used to record tire pressure prior to launch. Tire leak rate was calculated based on recorded pressures. While not as accurate as mechanical pressure measurements, the TPMS has historically shown good trending. The Orbiter Project reported at the STS-31 L–2 Review on April 8, 1990, that an OMRSD waiver was approved for the higher leak rate. Approval was based on the projection that, at the current leak rate, the flight rule requirement for minimum landing pressure of 260 psi would not be violated unless STS-31 launch was delayed until after June 6, 1990. ***This risk factor was acceptable for STS-31.***

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
SSME		
1	SSME High-Pressure Fuel (HPF) duct weld proof-pressure test failure issue. HR No. ME-D3 (All Phases) ***No anomalies attributed to HPF duct weld problems were reported on STS-31.***	HPF ducts used on the SSMEs are manufactured by RI and proof-tested upon delivery to Rocketdyne, Canoga Park. One of these ducts recently failed the proof-pressure test by rupturing at a weld. Failure investigation found O_2 contamination in the failed weld. A complete review was performed of the fabrication pedigree of HPF ducts on STS-36/OV-104 and STS-31/OV-103, resulting in the removal and replacement of a High-Pressure Fuel Turbopump (HPFTP) on STS-36/OV-104. The Material Review Board (MRB) cleared all HPF ducts on STS-31/OV-103. ***This risk factor was resolved for STS-31.***
2	Uralite in G-15 joint on engine #2031, nozzle #4017. HR No. ME-D3C ME-D3M ***No anomalies attributed to improper application of Uralite were reported on STS-31.***	Prior to STS-33, evaluation of a Uralite sample used in the G-15 joint revealed that the material had not been properly applied and had not set up properly. Uralite is used to fill minor surface imperfections in Main Combustion Chamber (MCC) and nozzle interfaces to the G-15 seal. The joint is mated with Uralite in the liquid phase. Uralite flows onto bellows surfaces; the quantity is insufficient to fill the cavity. Nozzle #4017 on engine #2031 was lowered, and Uralite was reapplied. The G-15 seal and the Flow Recirculation Inhibitor (FRI) were replaced, and acceptability was verified by testing. Analysis and evaluation of the Uralite indicated compliance with the bellows. Uralite does not preclude proper seal installation and will not restrict bellows seal movement (in the cured state). Uralite will compress/extrude under bellows loading. Nozzle #4017 was not removed from engine #2031 during the STS-31 turnaround process; therefore, the sealing properties of the G-15 joint were considered to be good. ***This risk factor was resolved for STS-31.***

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
SSME		
3	A dent was found in feedline #2 on engine #2031 prior to STS-33. *No anomalies attributed to feedline problems were reported on STS-31.*	Inspection of engine #2031 prior to STS-33 found a dent in feedline #2. This is the 1-1/2" feedline that runs outside the full length of the nozzle. X-ray inspection found no wall thinning in the area of the dent. No adverse effects were expected as a result of the dent. This condition was processed through the MRB and approved for unlimited use prior to STS-33 launch. *This risk factor was resolved for STS-31.*
4	SSME controller software anomaly. HR No. INTG-165 *No anomalies attributed to SSME controller software problems were reported on STS-31.*	Just prior to STS-36, an anomaly associated with the SSME controller software was discovered. A determination was made at that time to fly "as is". During mainstage, with engine limits inhibited, coupled with both channels of a redline exceeding limits with 1 of the 2 channels disqualified, the engine status word will change from "limit exceedance" to "major component failed". This condition leads to a change in the cockpit engine status display from "red" to "clear", giving the crew the false indication that exceedances are not back within the redline. Engine redline inhibit is issued by the General Purpose Computer (GPC), either automatically when one engine is detected in shutdown, or manually when an engine is stuck in the thrust bucket, leading to an abort gap condition. In either case, limits will not be reenabled until single-engine abort or safe abort capability is achieved. In the worst-case condition, where the limits are inhibited by the GPC due to a failed engine, limit reenable will not be accomplished except by a call from the Mission Control Center (MCC) (crew procedure). This means that the status of the engine status cockpit display is not required for safe continuance of the flight. If the crew elects to manually reenable the limits after engine shutdown, limits would not be reenabled until after the existence of a safe abort capability. If reenable was accomplished and this anomaly occurred, the result would be an immediate shutdown of the engine with redline exceedances. This is the same

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>SSME</u>		
4 (Continued)		result as if the MCC made a reenable call, and the current flight rules are written this way. In this case, fail safe is maintained with or without the correct status word. Current plans are to fix this problem as soon as possible; earliest implementation is expected to be STS-38. The crew was briefed on this possibly anomalous situation prior to STS-31 launch. ***This risk factor was acceptable for STS-31.***
5	Eccentric ring fold-over found on STS-32, engine #2028. HR No. ME-C1 (All Phases) ***Postflight inspection of STS-31 engines found no similar anomalies.***	Postflight inspection of STS-32 engine #2028 revealed that the eccentric ring had folded over during installation of the High-Pressure Oxidizer Turbopump (HPOTP. The concern was that crimped metal could cause a decrease in capability of pressure-assisted seals. This could ultimately lead to a hot-gas path from the oxidizer preburner to the hot-gas manifold. This condition results in loss of turbine power, opening of the Oxidizer Preburner Oxidizer Valve (OPOV), and exceedance of the HPOTP turbine discharge temperature redline. There was also concern relative to hydrogen strut coolant loss (warming), resulting in leaks to the hot-gas manifold and possible turbine failure. There were no on-vehicle inspection techniques available to determine if this condition existed on the STS-31 engines. If it occurs during startup, an on-pad abort will result. However, this condition may not be experienced until mainstage, in which case it is an accepted risk. Past incidents have not resulted in anomalous operation; seals expanded to take up the additional distance left by the fold-over. Based on flight and test experience, little or no leakage was expected. ***This risk factor was acceptable for STS-31.***

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
SSME		
6	Heat exchanger weld contamination (generic). HR No. ME-D2 (All Phases) ME-D3 (All Phases) ***No anomalies attributed to heat exchanger weld contamination were reported on STS-31.***	During leak testing of a new powerhead build, a crack was found in the heat exchanger liner. A leak was first detected at weld #2 at a rate of less than 0.0002 cubic centimeters per second (cc/sec), one-to-two orders of magnitude higher than previous experience. It was later confirmed that the leak was in the Haynes 188 fitting side of weld #2, 0.010" in the heat-affected zone. A crack, 0.060" long at the inner diameter and 0.025" at the outer diameter, was found to be the leak source. Propagation of the crack occurred under additional strain, probably during handling or adjacent heating. This heat exchanger had previously passed the heat exchanger coil proof test. Investigation found evidence of a high-temperature fracture at the surface. Auger analysis revealed a small amount of tin at the fracture surface. The weld with the crack, along with another weld, were identified during fabrication as being wider than normal welds. A wide weld is indicative of significant heating or rewelding. It was noted that this heat exchanger coil was one of the first coils to be welded at the new Wintec facility, and new equipment/procedures were considered to be a factor. The coil was installed in the heat exchanger liner assembly at Rocketdyne. A leak was detected at Rocketdyne near weld #2 during normal liner assembly mass spectroscopy tests, and it was isolated by removal of the sleeve. Initial fabrication x-rays and dye penetration tests did not detect the crack. Subsequent to finding the leak, single-wall x-ray did detect the crack. Metallurgical failure analysis found the crack to be in the weld heat-affected zone, approximately 0.014" from the fusion line. Tin and zinc were also found. Investigation and analysis of preweld tools, fixtures, solvents, and procedures revealed no source of elemental tin and zinc. Silicon molds used to verify final inner-diameter weld width were found to have tin and zinc as constituents of the mold catalyst. Twenty percent of all outlet welds that do not meet minimum weld width are rewelded to within requirements after a deionized water rinse and

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
SSME		
6 (Continued)		an isopropyl alcohol swab. Weld width data from 92 outlet welds were examined. The cracked fitting was found to have 2 pre-ream molds and was rewelded; the widest documented weld had 3 pre-ream molds and subsequent reweld. Inspection of 41 additional welds from 21 units, using dye penetrant, found no additional anomalies. A series of laboratory tests concluded that contaminants promote crack propagation only when plastically deformed at elevated temperature (>2000°F). The most probable cause of the crack was a combination of a hot tear starter crack followed by intergrannular crack growth due to mold contamination and strain. This failure most probably occurred in a single event during reweld of joint #2 in the presence of mold contamination. The failure mechanism requires significant strain, temperature, and the presence of tin, iron, or carbon to form the contaminants. The investigation concluded that the key factors in the failed heat exchanger at weld #2 included a wide weld compounded by remelt and the presence of mold material prior to reweld. Rationale for the flight of STS-31 heat exchangers included: • Low likelihood of producing cracks; 41 welds from 21 units were inspected and did not have cracks; 43 weld samples were prepared with no cracks. • Review of OV-103 heat exchanger fabrication records found no indication of wide welds and only 3 instances of reweld; all were within specification and were leak checked. • All OV-103 heat exchangers passed multiple proof, acceptance, leak, and hot-fire tests. The brittle nature of the fracture was expected to be detectable by such testing. Critical flaw size in embrittled material can be screened by 1 hot-fire test.

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>SSME</u>		
6 (Continued)		• OV-103 units had greater than 4 engine tests and 12 proof-test cycles (some at 109% power level); only 5 units in the fleet had more engine tests. • There were no known contamination or cracks found within the history of 50 hot-fired heat exchanger coils. ***This risk factor was resolved for STS-31.***
7	STS-31 engine #2107, Main Engine Controller (MEC) Unit Number (U/N) F11 failure. HR No. INTG-165 ***All SSME MECs performed satisfactorily on STS-31.***	During engine Flight Readiness Test (FRT), MEC F11 experienced a hard failure. The problem occurred when the controller was commanding movement of the Main Fuel Valve (MFV) using channel "A", while channel "B" was monitoring. F11 posted a channel "B" "self test out" failure, which indicated that the self-test system was not able to identify a difference in the MFV position from a preprogrammed false value. Rerun of the test step resulted in identification of the same problem on channel "B". This type of failure would result in loss of redundancy in the controller by disqualification of channel "B". A subsequent failure in engine #2107 could result in hydraulic lockup or pneumatic shutdown, depending on the secondary failure. A similar failure occurred during STS-51C/OV-103; MEC F9 on engine #2 indicated a MFV servoactuator self-test failure. The failure was isolated to an integrated switch and was determined to be an isolated occurrence. Repair was made, and MEC F9 was put back in service. MEC F11 was removed, and F25 was installed in its place. MEC F11 was sent to Honeywell, the vendor, for further failure analysis. Extensive system-level testing at Honeywell would not reproduce the failure. The testing included exercising the MFVs at room temperature with flight and acceptance test software, exercising the

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>SSME</u>		
7 (Continued)		valves during 8 thermal cycles, and exercising the channel "B" MFV during vibration. Although a polycarbonate capacitor was suspected as the most likely cause of the problem, it could not be confirmed. Therefore, this was considered to be an isolated failure (non-generic). (However, as a product improvement, all polycarbonate capacitors used in low-energy applications are being replaced with an improved polycarbonate capacitor with a demonstrated significantly lower failure rate whenever a controller is opened up.) The FRT for engine #2107 and F25 was successfully performed on March 31, 1990. ***This risk factor was resolved for STS-31.***

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>SRB</u>		
1	STS-31 SRB aft skirt Factor of Safety (FOS). HR No. INTG-013A A-60-17 Rev. C DCN3 ***No anomalies associated with aft skirt strength were reported on STS-31. Also, no launch delays were experienced due to the predicted 1.25 FOS that was accepted for STS-31.***	The FOS initially calculated for the STS-31 stack was 1.26, based on initial/preliminary load measurements with baselined wind conditions. The minimum FOS for the aft skirt is currently waived from 1.40 to 1.28. An STS-31 load increase was caused by rotation of the Holddown Post (HDP) eccentric bushing/spherical bearings. Bushing rotation reduces biasing and relieves the aft skirt compression preload. Integration reported its assessment of the STS-31 load conditions. The assessment resulted in a recommendation to reduce the liftoff surface wind constraint of 20 knots from the south to 13 knots to retain an FOS of 1.28. Integration assessed the FOS at 20 knots from the south to be 1.25. A Change Request (CR) to limit surface winds from the south in order to increase the FOS to 1.28 was approved by the Level II PRCB on March 29, 1990. At the STS-31 FRR on March 30 and 31, 1990, Associate Administrator, Office of Space Flight (AA/OSF) gave an action item to JSC, Marshall Space Flight Center (MSFC), and Rockwell to review the current aft skirt FOS assessment methodology to identify and assess the areas and degree of conservatism. Code Q was also directed to present an independent assessment relative to conservatism in developing FOS values. The Program reviewed this action item at the Level I PRCB/FRR Action Item Closeout teleconference on April 5 and 6, 1990. Areas of conservatism and their associated contribution to underestimation of the actual FOS for the aft skirt were identified. JSC and MSFC were tasked by the Space Shuttle Program Manager to prepare summaries of these results for presentation to AA/OSF on April 7, 1990.

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>SRB</u>		
1 (Continued)		AA/OSF convened a special STS-31 Delta FRR on April 7, 1990. The FRR decided that the assumptions upon which the aft skirt FOS calculation is based are conservative, and an additional degree of conservatism is provided by the fact that the FOS is also based on failure defined by crack initiation rather than ultimate skirt collapse. Therefore, a 1.25 FOS represents a conservative estimate for STS-31. The consensus of the senior personnel at the meeting, and those polled via teleconference, was that a wind limit of 20 knots from the south was acceptable for STS-31. This provided a predicted FOS of 1.25 or greater. The change to the LCC showing the associated wind rose was directed by AA/OSF, who also limited the authority to change the wind speed LCC to AA/OSF or the NASA Administrator. ***This risk factor was acceptable for STS-31.***
2	SRB HDP Debris Containment System (DCS) frangible link. HR No. B-60-12 Rev. B ***Debris containment was satisfactory, and there were no reports of stud hangup on STS-31.***	During the STS-36 preflight reviews, HDP debris containment was again an issue. For the first time since STS-30, a large amount (approximately 7 lb) of debris escaped from the HDP DCS during STS-32 liftoff. This was directly attributed to removal of the frangible link from the DCS. For the first 3 missions since reflight, debris escaped from the DCS in large quantities. Concern was raised relative to the possibility of this debris striking the Space Shuttle Vehicle (SSV). The frangible link modification was installed prior to STS-28 and was successful in achieving nearly 100% debris containment. Beginning with STS-34, HDP stud hangups and broaching were experienced. This problem was again experienced on STS-33. The concern was that adverse loads were introduced into the aft skirt and SSV due to multiple HDP stud hangup. For this reason, it was recommended that the frangible link modification should be removed from the STS-32 HDP DCS. While HDP stud hangup was not a problem on STS-32, HDP debris escape was.

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>SRB</u>		
2 (Continued)		For STS-36, the Level II PRCB decided to install the A-286 frangible link used from STS-26 through STS-30. While the A-286 link increased debris risk compared to the NP35N link, no stud hangups were reported when it was used. Postflight inspection found that 7 of 8 HDP DCSs contained at least 96% of the formed debris; HDP #8 contained 64%. There were no reports of stud hangup and only minimal signs of thread impressions on 2 of 8 aft skirt HDP stud holes. The alternatives for frangible link installation for STS-31 included the following: • Install the A-286 frangible link used from STS-26 through STS-30 and STS-36 (allows minor debris escape). • Install the NP35N frangible link used on STS-28 through STS-33 (captured over 99% of debris formed). • Do not install either frangible link. The decision for STS-31 by the Space Shuttle Program Management was to install the A-286 frangible link modification. This decision was based on no experience of broaching or stud hangup on STS-36 and containment of an acceptable amount of STS-36 launch debris. ***This risk factor was resolved for STS-31.***

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>SRB</u>		
3	Potential for unlocked pins in Instrumentation and Electronic Assembly (IEA) Deutsch block. ***No anomalies attributed to IEA operation were reported on STS-31.***	An open circuit was found during pre-acceptance testing of an IEA at Allied Signal. The open circuit was isolated to the SRB Operational Instrumentation (OI) "A" bus return 4. Failure in this case was found to be the direct result of unlocked pin 1Y on the Deutsch Block ATB1. Pin retention testing on ATB1 identified a second unlocked pin, 2T, on the SRB OI "A" bus return 2. Pins 1Y and 2T were inspected and reinserted. Subsequent retention testing conclusively confirmed that the pins were not locked initially. No problems were found with the locking mechanism. This particular IEA, S/N 065, flew on STS-27, most probably with pins 1Y and 2T unlocked. There was no anomaly reported, and no rework required. The original pin retention test requirement was a qualitative "tug" test performed after the technician seated the Deutsch block pin. In 1983, MSFC developed MSFC-STD-781 to specify a set of quantitative pull test requirements. Pull tests were found, however, to be an unreliable detection method for unlocked pins in certain wiring configurations. In the case of this Deutsch block, there is a low probability that frictional forces will exceed the allowable pull-test force and result in undetected unlocked pins. Pull-test forces are 2.3-3.0 lb (2.5 lb nominal test tool setting) compared to an actual unlocked pin identification force of 1.8 lb (average, 2.7 lb maximum). Good results are obtained with a finger push-pull test. Review of problem records indicated that out of approximately 55,000 Deutsch block connections in the IEA fleet only 10 unlocked pins were found after acceptance testing. Of the 10 found, only 1 pin, ATB1 1Y, did not function properly. All critical functions of the forward and aft IEAs are redundant. Redundancy is verified at each test level. IEA pin retention testing was performed at the specified 3.0-3.5 lb on all crit 1R contacts with no wire failure. To date, all STS-31 IEAs passed pin retention, pre-acceptance, acceptance, assembly checkout, and system integration tests. Functions of all IEAs were reconfirmed during STS-31 prelaunch testing. ***This risk factor was acceptable for STS-31.***

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>SRM</u>		
1	STS-31 nozzle internal joint leak test investigation. HR No. BN-03 Rev. B ***No anomalies attributed to Solid Rocket Motor (SRM) nozzle joint leakage were reported on STS-31.***	Engineering review of STS-31/Redesigned Solid Rocket Motor (RSRM) Flight Set #10B nozzle joint leak test results determined that the leak test on nozzle joint #3 was not properly performed. Leak checks of nozzle joint seals are performed by pressurizing the volume between the 2 O-ring seals and recording pressure leak rates. Two pressure tests are performed on each joint; high and low pressure. The high-pressure test is employed to check for contamination and major seal defects. Low-pressure tests identify possible minor seal/surface damage, assembly damage, and minor contamination. Using Boyle's Law, calculations are made to determine the joint volume, based on the known volume of the test equipment, the recorded initial pressure of the test equipment, and the final pressure of the test equipment and pressurized joint. In the case of the original RSRM Flight Set #10B nozzle joint #3, calculations indicated that the joint was not pressurized. Under both high- and low-pressure tests, the final volume of joint #3 was calculated to be near 0; 0.1 and -0.07 cubic inch (in^3), respectively. Average low-pressure volume of joint #3 is 0.87 in^3, and the average high-pressure volume is 1.45 in^3. Without tearing the joint apart, no definite cause could be found to explain the low joint volume. For this reason, Space Shuttle Program Management directed that STS-31/RSRM Flight Set #10B aft segment/nozzle be destacked and replaced. This effort delayed the launch date of STS-31 approximately 3 weeks. ***This risk factor was resolved for STS-31.***

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
SRM		
2	Use of Avtex restart rayon on SRM components. HR No. BC-10 Rev. B ***Avtex restart rayon SRM nozzle liners operated satisfactorily on STS-31. No associated problems were reported.***	Rayon is the precursor material used to make carbon fabric for the SRM nozzle ablative liner. The primary source for the rayon material is [was, because they were shut down by the Environmental Protection Agency (EPA) in late 1989, early 1990] Avtex in Virginia. Avtex ran the production of rayon as a continuous process until October 1988, when they shut down due to financial problems. A bailout of Avtex was made by NASA and the Department of Defense (DoD), and production of rayon resumed in late 1988. Restart rayon (restart here means the rayon produced after the bailout) was installed on STS-31 SRM aft exit cones, cowl, and outer boot rings. Material testing indicated that the restart rayon is comparable to the originally qualified rayon; however, subtle differences exist. Some problems occurred during the carbonization process used to produce the carbon fabric. Because of these problems, and because the restart rayon was qualified by similarity with the original rayon, the Space Shuttle Program Management directed that restart rayon components be ground tested in a flight thermal environment prior to the STS-31 launch. A full-scale test motor firing (TEM-6) using Avtex restart rayon nozzle parts was performed on March 15, 1990. Post-test inspection found no anomalous degradation of restart rayon due to thermal effects. ***This risk factor was resolved for STS-31.***

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>SRM</u>		
3	STS-31 potential SRM thrust imbalance. HR No. BC-06 Rev. B ***No problems attributed to SRM thrust imbalance were reported on STS-31. Data relative to measured thrust imbalance on RSRM Flight Set #10/STS-31 indicated that the actual imbalance was in the range of 20,000 lbf.***	Due to an inadequate leak check of the nozzle joint #3 seals, Flight Set #10B aft segment was replaced with Flight Set #11B aft segment. As a result of the swapout, reassignment was made of aft segments for Flight Sets #10 through #13. The reassignment created predicted worst-case thrust imbalances for Flight Sets #10 through #13 which exceed the Contract End Item (CEI) specification limits. The current Flight Set #10 had a potential thrust imbalance which exceeds the CEI maximum thrust imbalance of 85,000 lbf by a maximum of 30,000 lbf at the 98-103 sec time interval (115,000-lbf worst-case potential imbalance). Waivers were written for Flight Sets #10, #11, and #12 to allow the out-of-specification condition. Although the predicted potential thrust imbalance for these flight sets exceeds the CEI limits, it is within the thrust imbalance differential of 120,000 lbf allowed by NSTS 07700, Volume X. Worst-case predictions of potential thrust imbalance on Flight Sets #10 , #11, and #12 were within the performance capability of the Space Shuttle without additional risk to flight safety. ***This risk factor was acceptable for STS-31.***

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>SRM</u>		
4	Putty found on both sides of TEM-5 inner igniter Gask-O-Seal. HR No. BC-02 Rev. B BC-03 Rev. B ***No anomalies attributed to SRM igniter gasket seals were reported on STS-31.***	Post-test inspection of TEM-5 igniter gaskets found vacuum putty on both sides of the inner igniter Gask-O-Seal. Putty was found in the metal retainer and the rubber cavities of the seal and was in a 150° arc on the forward side, 185° arc on the aft. There were no putty blow holes identified, and no blowby or damage of the seal was reported. The concern was that vacuum putty on both sides of the Gask-O-Seal could degrade the gasket resiliency and lead to hot-gas blowby. Putty had been seen on the inner edge of the inner igniter Gask-O-Seal; however, this was the first time putty had been found on both sides of the seal. This has not occurred on flight hardware, and a recent examination of RSRM Fight Set #13B found no putty on the inner seal. The igniters for both the flight motors and Test and Evaluation Motors (TEMs) are assembled essentially in the same way. However, there are significant differences. The igniter adapter (110 lb) is lifted into position by 2 people and guided into place. The TEM motor igniter adapter has an additional 20 lb added for the quench port, and it makes the weight unsymmetrical. Misalignment and jiggling of the adapter probably wipes the putty onto the gasket, and unsymmetrical loading of the TEM adapters complicates the process. It must be assumed that the STS-31 inner gaskets were contaminated with putty. The gaskets are required to seal only until the motor pressure and igniter chamber pressure have equalized, about 400 millisecond (msec). New, very conservative dynamic tests conducted by Thiokol indicated that a minimum LCC temperature of 95 ±1°F is required to assure a seal tracking FOS of 1.4 for a TEM-5 type 2 groove fill. This requires a higher heater operating temperature of 105 ±1°F to account for cooling after heater shutdown at T–9 min and prior to T–0. The heaters were qualified to 122 ±2°F on TEM motors. In the event of a hold at T–5 min, heaters were to be reactivated. In this case, heaters were again to be turned-off 1 min prior to resuming the count.

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
SRM		
4 (Continued)		Other considerations included the potential for putty conditions worse than TEM-5. Although it has never occurred, the condition of putty in 3 of 4 voids in the seal still yielded an FOS greater than 1.0 at the recommended new LCC. Special tests that attempted to place putty on the crown resulted in the putty squeezing off the crown, and a good footprint was achieved. The seals were not physically damaged. Rationale for STS-31 flight was: • The TEM-5 type of inner seal putty contamination had not been found before on flight hardware. • The seal is required to function for a very short time. • Heater temperature LCC was adjusted to assure a 1.4 FOS, even with 2 seal cavities contaminated with putty. • The Stat-O-Seals on the adapter-to-igniter case bolts provide redundancy. ***This risk factor was resolved for STS-31.***

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>KSC</u>		
1	Momentary power outage at the Launch Control Center (LCC) and Pad B during STS-31 prelaunch activities. ***No power outage problems were experienced during the April 24, 1990, STS-31 prelaunch and launch operations.***	On April 2 1990, a water pipe was broken in the Vehicle Assembly Building (VAB) utility annex causing momentary power loss to the LCC and at Pad B. At the instant of power loss, power to Pad B and the LCC was maintained via Uninterruptable Power Supply (UPS) #1, #2, and #3. However, the water deluge caused an electrical short circuit, which created a power spike. The spike caused shutdown of the UPSs because they are protected by design against surges above 10%. The power loss created by UPS shutdown halted all prelaunch operations in the LCC and at Pad B. HST battery charging was also interrupted. Power was subsequently rerouted through UPS #4, #5, and #6 for continued Pad B operations. Because of this single-point failure in the power supply to the LCC and at Pad B, an initial decision was made to continue through STS-31 launch with UPS #4, #5, and #6 as backup. An analysis conducted by the KSC Safety Office revealed 3 potential single-point failure modes using UPS #4, #5, and #6. The probability of any 1 of these 3 single-point failures occurring during launch countdown was considered to be greater than the failure mode which created the April 2, 1990, power loss. The events leading to the April 2 power loss (momentary loss of power and subsequent power spike) had not occurred previously. This event was considered unique. Therefore, UPS #1, #2, and #3 were used for the STS-31 launch. ***This risk factor was acceptable for STS-31.***

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
PAYLOAD		
1	HST transponder Radio Frequency (RF) radiation inhibit. HR No. ICHR-005 *No anomaly was reported on STS-31.*	During the safety review process for the HST, it was discovered that in normal operation on-orbit there was only one inhibit between the multiple-access transponder and a high-gain antenna which could radiate down into the cargo bay. The problem was that one specific failure could expose the payload bay to an electric field intensity exceeding the allowable limit of 20 volts/meters (V/m). This failure can only occur on-orbit when the multiple access transponder has been powered. In the event that extravehicular activity took place, a warning statement was added to the flight data file that tells the crew to stay outside of specified zones; 3 feet (ft) from the low-gain antenna and 50 ft from the high-gain antenna faces. The radiation level calculated at the closest avionics box was 37 V/m. The payload bay avionics controllers were successfully tested to 55 V/m with no upsets recorded. Engineering reported that, if an upset occurred, the avionics controller would reset during the next scan and operation would continue. A Noncompliance Report (NCR) was approved by the Payload Safety Panel and the Level II PRCB. *This risk factor was resolved for STS-31.*

RESOLVED STS-31 SAFETY RISK FACTORS

ELEMENT/ SEQ. NO.	RISK FACTOR	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>GFE</u>		
1	Extravehicular Mobility Unit (EMU) arm bladder exceeds life limit. ***No contingency requiring EMU use occurred on STS-31.***	A review of the elements that comprise the EMU to be used on STS-31 in a contingency found that both upper arm bladders, S/N 073 and S/N 074, had exceeded the 6-year life limit. The 6-year limit was based on Military Standard criteria to protect against possible moisture-induced degradation of the bladder bonding adhesive. Adhesive bonded tape is applied over heat-sealed seams in the arm bladders. The bladder seam design ensures that little or no load is applied to the seam. There have been no reported adhesive-bonded bladder failures. The bladders had seen considerable use; at least 6 arm-bladder pairs were used in the Water Evaluation Tank Facility at JSC over an 8-year period. These 6 had seen 250-400 hr of pressurized operation; the STS-31 arm bladders had less than 8 hr. Pull/load-testing of 6 taped bladders with over 8 years of life resulted in material failure instead of adhesive debond. Inspection of the arm bladders on the STS-31 EMU was performed 30 days prior to the review with no problems identified. Evaluation by the technical community determined that there was little likelihood of problems resulting from this life exceedance. An effort was initiated to extend the life limit to 8 years. A Level II waiver was approved for STS-31 EMU bladders. ***This risk factor was acceptable for STS-31.***

SECTION 5

STS-36 INFLIGHT ANOMALIES

This section contains a list of Inflight Anomalies (IFAs) arising from the OV-104/STS-36 mission, the previous Space Shuttle flight. Each anomaly is briefly described, and risk acceptance information and rationale are provided.

SECTION 5 INDEX

STS-36 INFLIGHT ANOMALIES

SECTION 5 INDEX - CONTINUED

STS-36 INFLIGHT ANOMALIES

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
INTEGRATION		
1	Engine #2027, nozzle #2027 bluing. IFA No. STS-36-I-01 HR No. ME-B7 (All Phases) ***No Main Engine (ME) nozzle bluing was reported on STS-31.***	During STS-36 postflight inspection, approximately 3" of bluing was noted on nozzle #2027 aft manifold adjacent to the High-Pressure Oxidizer Turbopump (HPOTP) primary drain exit line. This bluing was similar to that seen on STS-33 (IFA No. STS-33-I-01) and was believed to be due to a new nozzle phenomenon. On STS-33, the nozzles on both engines #2031 and #2107 were new; however, only the nozzle on engine #2107 showed bluing. Rocketdyne found through Rockwell hardness tests that there was no annealing in the area of the discoloration. They approved the nozzle for further flight use. Causes resulting from contamination, ascent heating, improper material properties, and flight profile were all ruled out. The most probable cause of the bluing was descent heating during a steep reentry profile. Both STS-33 and STS-36 were Department of Defense (DoD) missions with high inclinations (actual inclinations are classified). All nozzles on STS-31 had flown previously, and STS-31 was a low inclination (28.5°) mission; therefore, further bluing was not expected. ***Not a safety concern for STS-31.***

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>ORBITER</u>		
1	Fuel Cell (FC) #2 Alternating Current (AC) phase "A" inverter failure. IFA No.STS-36-01 HR No. ORBI-127A ***No FC anomaly attributed to inverter failure was reported on STS-31.***	During the first launch attempt, FC #2 AC phase "A" experienced numerous voltage and current fluctuations in a 2-minute (min) period. Fluctuations were from 112 volts AC (VAC) to 122.8 VAC; the Operational Maintenance Requirements and Specifications Document (OMRSD) limit is 110-120 VAC. Inverter #4, Serial Number (S/N) 51, was removed from avionics bay #2 and replaced with S/N 42. FC #2 was retested satisfactorily prior to the next launch attempt. S/N 51 was returned to the vendor for failure analysis. The vendor was able to repeat the failure mode. The problem was isolated to loose connections within the inverter. Four screws were found improperly torqued and loose. It was determined that there were no suspect inverters on OV-103/STS-31. ***This anomaly was resolved for STS-31.***
2	Liquid Hydrogen (LH_2) 17" disconnect "B" open indication intermittent. IFA No. STS-36-02 HR No. ORBI-306 ***No anomaly attributed to the LH_2 17" disconnect system was reported on STS-31.***	The LH_2 17" disconnect open indication dropped out for approximately 12 seconds (sec) during fast fill. The ground launch sequencer software issued an LH_2 stop fill command. No explanation was found for the dropout. Because the Launch Commit Criteria (LCC) requires only 1 of 2 indications and the "A" indication was good, the LH_2 fast fill was resumed. The indication was normal for the remainder of the launch preparations. ***Not a safety concern for STS-31.***

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
3	Reaction Control System (RCS) thruster R3D failed "off" during External Tank (ET) separation. IFA No. STS-36-04 HR No. INTG-172 *Two RCS thruster anomalies were reported on STS-31 (IFA No. STS-31-03A and STS-31-03B). Thruster L3A failed "off" during post-Main Engine Cutoff (MECO), Main Propulsion System (MPS) dump, +X maneuver; the oxidizer injector valve did not open. Approximately 7 hours (hr) after this failure, thruster L3A oxidizer temperature dropped from 90° F to 21° F, indicating that the oxidizer injector valve was leaking. These failures were similar to thruster anomalies experienced on STS-5, STS-29, and STS-30. The failure mechanism was attributed to nitrate formation/contamination of the oxidizer valve pilot poppet. (See Section 7, Orbiter 2 for more details.)*	Chamber pressure in thruster R3D, S/N 228, did not reach the required pressure within the specified time period; therefore, the Redundancy Management (RM) system deselected the thruster. This failure occurred during ET separation and is a Crit 1R/3 failure [there are 3 redundant, down-firing thrusters on each Orbital Maneuvering System (OMS) pod]. Previous experience indicated that this failure was due to the oxidizer valve poppet not opening. A "varnish" type deposit of nitrates was found on oxidizer valve poppets of other failed thrusters. This contamination is created when the oxidizer [Nitrogen Tetroxide (N_2O_4)] comes in contact with moisture. It was previously noted that the rain cover was found missing from R3D prior to launch. A puddle of water was found in the R3D thruster throat and was successfully educed. The presence of water could be a contributor to R3D failure. The thruster was removed and sent to the vendor for failure evaluation. Visual inspection at Dryden Flight Research Center (DFRC) found no contamination in the thruster throat. Failure analysis at Marquardt determined that nitrates were formed on the oxidizer valve poppet, preventing the valve from opening in the allotted time. Rationale for STS-31 flight was based on RCS thruster redundancy. *This risk factor was acceptable for STS-31.*

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
4	Right RCS manifold #1 oxidizer isolation valve position indication intermittent. IFA No. STS-36-06A HR No. ORBI-244 ***No similar anomaly was reported on STS-31.***	At L–4 sec, the right RCS aft oxidizer manifold #1 isolation valve open indication changed to not open. This mission indication caused RCS RM software to annunciate an "RM DLMA MANF" message and to override the right RCS manifold #1 closed indication at Solid Rocket Booster (SRB) separation. The right RCS manifold #1 was overridden to open via the override display after ET separation. The open indication returned when the crew moved the right RCS manifold #1 switch from "GPC" to "OPEN" after the OMS-2 burn. Troubleshooting at Kennedy Space Center (KSC) found no wiring anomalies. The isolation valve actuator was changed out. Rationale for STS-31 flight included redundant valves and satisfactory preflight checkout. ***Not a safety concern for STS-31.***
5	Left RCS 3/4/5 "B" oxidizer tank isolation valve open position indication intermittent. IFA No. STS-36-6B HR No. ORBI-244 ***No similar anomaly was reported on STS-31.***	At L–7 sec, the left RCS 3/4/5 "B" oxidizer tank isolation valve open indication changed to not open; the indication returned to open during a 2-sec period. The valve position indication worked well for the remainder of the mission. This failure was not representative of previous contaminated switch problems that occurred on-orbit and did not clear. This could have been an erroneous data problem or loss of telemetry. Rationale for flight of STS-31 included redundant valves and satisfactory preflight checkout. ***Not a safety concern for STS-31.***

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>ORBITER</u>		
6	Left RCS 1/2 oxidizer crossfeed valve closed position indication intermittent. IFA No. STS-36-6C HR No. ORBI-244 ***No similar anomaly was reported on STS-31.***	At L–45 sec, the left RCS 1/2 oxidizer crossfeed valve closed indication changed to not closed, identifying the loss of closed position. This loss of position indication occurred during a high-vibration period. The closed indication returned when the crew performed the post-OMS-2 burn reconfiguration, moving the left RCS 1/2 crossfeed switch from "GPS" to "CLOSED". This failure was not representative of previous contaminated switch problems that only occurred on-orbit and did not clear. A potential failure mode is that the Launch Process Sequencer (LPS) command could equal the maximum valve travel time (1.3 sec); therefore, the valve was potentially not driven into the stops/detent. Corrective action would be to increase the LPS command to 2.0 sec. Rationale for STS-31 flight included redundant valves and satisfactory preflight checkout. ***Not a safety concern for STS-31.***

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>ORBITER</u>		
7	Water Spray Boiler (WSB) #2 vent system "A" heater failed. IFA No. STS-36-07 HR No. ORBI-244 ***STS-31 WSB #2A heater operated erratically before launch, and failed to respond when power was applied on-orbit (IFA No. STS-31-05). WSB #2B heater was turned on and functioned properly for the remainder of the mission. Heater "A" was reselected for entry; operated slower than normal in increasing temperature, and cycled irregularly. Postflight temperature profile tests at KSC found tiles in contact with the nozzle vent; the tiles acted as heat sinks. Previous failures also occurred on STS-33 and STS-34.***	WSB #2 vent system heater "A" began to degrade about 75 min after initial activation. Heater "B" was selected and operated nominally. Heater "A" was reselected for entry, was slow to come up, and operated erratically during entry. This was a repeat of IFA No. STS-34-18, which was closed as unexplained because it could not be repeated. Troubleshooting of the STS-34 anomaly included operation of "A" and "B" heaters for a number of cycles and shaking of wiring and connectors. Rationale for flight of STS-31 included adequate inflight workarounds. The heaters are redundant, and the mission can be completed on a single heater string. Loss of a heater can be detected in flight through temperature measurement. ***This risk factor was acceptable for STS-31.***

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
8	STS-36 Auxiliary Power Unit (APU) #1 hydraulic flex hose anomaly. IFA No. STS-36-08 HR No. ORBI-036 ORBI-047A ORBI-184 ORBI-188 ***No APU hydraulic flex hose problems were reported on STS-31.***	Hydraulic system #1 exhibited anomalous indications during STS-36 ascent. The reservoir pressure dropped as expected after SRB ignition, but unexpectedly continued to drop. The reservoir temperature increased as expected, but the 6% volume increase due to temperature rise did not materialize. Early during reentry, flight controllers concluded that hydraulic system #1 was leaking at a rate that would likely deplete the fluid and cause system #1 shutdown prior to landing. Controllers directed the crew to temporarily select "low pressure" on system #1 in order to reduce the leakage rate in an attempt to ensure availability of system #1 during the approach and landing at DFRC. The action was successful, but the reservoir volume had decreased to 27% by the early postlanding APU shutdown. Postflight inspection found hydraulic fluid sprayed over most of the aft compartment components. Hydraulic leakage was tracked to a high-pressure flex hose, S/N 153, which was removed and sent to Rockwell International (RI) for failure analysis. The flex hose, Part Number (P/N) ME271-0079-1129, is certified to MIL-H-38360A. It has a teflon liner, 0.045" thick, surrounded by 2 braids of stainless steel and covered by a 1/8" rubber chaffing strip. The hose is 42" long with an inner diameter of 1". Installation is supported by a saddle with a slight bend. This type of flex hose is proof-pressure tested at 6000 pounds per square inch (psi). A 1/2" split was initially found in the stainless steel braid at the leak site. This cut indicated that the leak was not caused by external forces (i.e., twisting). Failure analysis at RI found a pin hole in the teflon liner, 19" from the swage fitting. Additionally, 2 kinks were found on the teflon liner about 1-1/2" from the pin hole and were considered contributors to the leak. X-ray inspection found no cracks in the metal end fitting. RI performed a pneumatic test of the flex hose, submerged in water, to verify the leak. Subsequent to leak verification extensive teardown was performed.

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>ORBITER</u>		
8 (Continued)		Titeflex, the vendor, assisted RI with the failure analysis. Similar uses of flex hoses were reviewed in NASA, DoD, and commercial aircraft applications. No other similar failures of high-pressure flex hoses were found in any application to date. All leaks were found to have originated at the hose fitting end(s). Three flex hose leaks had occurred in Orbiter Program applications. All leaks were in fittings, not in the liner. The first was in August 1975, where a flex hose failed proof test due to a thin fitting wall. The second, experienced in November 1979, found an indication of a fitting leak; however, further examination and subsequent use found no repeated problem. The third was found during postflight inspection of STS-1 hydraulic systems. A crack was found in a fitting that had previously passed proof tests. Subsequent failure analysis found that this was a surface crack which did not leak or degrade the performance of the fitting. The failed hose was initially installed on OV-104 during original production at Palmdale. High-pressure flex hoses on OV-104 had seen the least amount of operating time, approximately 9 hr, of all Orbiter vehicles. OV-103 flex hoses had been used the most; approximately 14 hr operation. The actual leak originated at the center of the flex hose, approximately 16" from the crimp sleeve on the elbow end. External leakage was through a longitudinal split in the chafe guard, occurring approximately 12" from the leak in the teflon liner. The area around the split appeared as a blister in the extrusion skin. An area of permanent deformation, or kink, was also observed approximately 1" from the leak site. Microscopic examination confirmed that the leak was at a longitudinal surface crack, originating in the inner diameter of the liner. A semi-elliptical shaped flaw, 0.180" x 0.036", had grown and broken through the teflon liner to a leak site of 0.020". X-ray examination found no break or disturbance in the braid layers.

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
8 (Continued)		Laboratory tests using fractography were performed on three 1/2" sections of the failed teflon liner. The sections were used as test coupons and subjected separately to monotonic loads with and without a 0.180" x 0.036" notch, and to fatigue cycling. Results of fractographic analyses and comparison to the failed area of the flex hose determined that the initial surface crack or flaw formation mechanism was unknown; it could not be conclusively tied to overload, fatigue, or sustained stress. In addition, the internal surface crack was determined to be extended by Low-Cycle Fatigue (LCF) from pressure rippling effects associated with pump operational characteristics; this led to final flaw breakthrough and a stable leak. In another test, a remnant portion of the failed hose was bent to a radius of approximately 5" to evaluate kinking and buckling characteristics. This radius produced 2 transverse buckles on the compression side and 1 longitudinal buckle on the tension side. Compression-side buckles were found to have a similar appearance to buckles found approximately 1" from the STS-36 flex hose leak site. Because longitudinal craze damage, or "whitening", was observed near all buckles of the failed flex hose liner, effects of flex hose pulsing on the craze area were also examined. This was initiated because of the theory that mishandling or unacceptable bending of the flex hoses had occurred and, with the pulsing effects induced by normal operation, led to the failure on STS-36. Fatigue tests were performed. After 1.3 million cycles, no cracks were found in the craze area. This represented only half the number of cycles in a single flight for one of these hoses; however, the tests were performed using a much higher load profile. Similar tests were performed with a teflon hose liner notched to simulate the surface flaw on the failed hose. Through the cycling of the hose, growth of this flaw or crack was achieved.

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
8 (Continued)		The results of these tests led to the conclusion that a crack cannot occur as a result of bending or mishandling alone, and that a crack initiated by improper sintering or other flaws can be grown as a result of mishandling and operational cycling. Chemical properties of the failed teflon liner were analyzed and compared to reference properties for unsintered teflon, minimally sintered teflon, and teflon after maximum sintering. These inputs were provided by duPont, the teflon manufacturer. Analyses of the failed teflon through infrared spectrophotometry and differential scanning calorimetry techniques – comparison of the melting point, specific gravity, heat of transition, and tensile strength to reference properties – determined that the failed teflon liner was minimally sintered. "Bump extrudate" occurs during manufacture after the liner is extruded but not yet cured. The liner may bump against the side of the extrusion machine. This results in a bump that, when cured, will not achieve proper temperature. The bump extrudate phenomenon causes minimum sintering, believed to be the originating factor leading to the STS-36 flex hose failure. This type of flaw should be caught during quality inspection testing after manufacture through a crush-and-roll test. The crush-and-roll test flattens the teflon liner under glass for observation and detection of similar flaws. The lot from which the failed STS-36 flex hose was manufactured did not have a quality stamp, or buyoff, next to the crush-and-roll test on the buyoff sheet. All other required tests had the appropriate quality stamp of approval next to the test step. It is believed, therefore, that either the crush-and-roll test was not performed on this lot of teflon liner, or that an anomaly was discovered which the quality inspector could not accept.

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
8 (Continued)		The results of the failure analysis and investigation previously described were as follows: • The leak resulted from a single crack in the teflon liner, which grew by fatigue from a surface flaw on the inner diameter. • The surface flaw formation and growth was facilitated by the combination of: – Local incomplete sintering in the flaw area, probably because of a phenomenon called bump extrudate. – Minimally complete sintering of the entire liner. – Buckling of the hose, possibly caused by mishandling. – Stressing (LCF) induced by the operational environment. • It was probable that a test was omitted which would have detected the lack of sintering. • There was a low probability that the combination of the factors which led to the STS-36 flex hose failure will be repeated. • There was no indication that this was a generic teflon liner problem.

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
8 (Continued)		Relative to the high-pressure flex hoses on STS-31/OV-103, acceptability for flight was based on the following: • There was an excellent history of performance of this type of flex hose throughout DoD and NASA; the STS-36 failure of this type was the first. • Buckling of a non-flawed area of a flex hose would not initiate or propagate a crack in a flight environment. • There was no indication of a generic problem with high-pressure flex hoses. • High-pressure flex hoses on STS-31/OV-103 were not from the same lot as that which failed. The Johnson Space Center (JSC) Safety Division researched the concern for fire resulting from a hydraulic fluid leak into the aft compartment. Two locations on each APU exceeded the autoignition point of MIL-H-83282A hydraulic fluid used in the Orbiter. These were the injector well (1200°F) and the interface area of exhaust duct-to-APU housing (1100°F). These surfaces are covered with insulation and stainless steel foil, except the injector well that has Kao-wool insulation which is also a liquid barrier. Except for "smart leaks", it was not credible for the hydraulic fluid to come in contact with the high-temperature areas. The number and location of hydraulic fluid autoignition temperature exceedences on the MEs had not been completely catalogued. There were several which might have approached or exceeded the autoignition temperature and were not insulated or isolated.

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
8 (Continued)		Tests performed at White Sands showed that spraying a hydraulic mist at 3000 psi at an oxy-acetylene torch, or at an arcing energy source at 150 amps, would cause the hydraulic fluid to ignite. Varying the distance to the ignition source varied the size of the flame cone, but the flame did not propagate upstream. No spray test onto a hot surface was performed, so the potential for lowering the autoignition temperature due to a fine spray was unknown. Therefore, it was necessary to consider other mitigations to the potential for igniting a hydraulic fluid leak in the aft compartment. APU/hydraulics operation is limited to ascent and entry phases. On a straight line basis, assuming no purge effects, hydraulic fluid combustion is oxygen dependent and could be sustained in a practical sense only to an altitude of 80,000 feet (ft). Because the autoignition temperature increases with decreasing pressure, autoignition temperatures rise such that the threat would no longer exist. The threat, both on ascent and descent, is mitigated by purge effects. The Gaseous Nitrogen (GN_2) prelaunch purge dilutes possible air intrusion and remains positive during ascent due to decreasing pressure as the Space Shuttle climbs. During reentry, an MPS helium purge is initiated at approximately 80,000 ft and continues until wheel stop plus 100 sec. While there was a finite probability of ignition of the hydraulic fluid, the mitigation measures make the probability low and a secondary risk to the potential of losing the use of a hydraulic system due to depletion of the hydraulic fluid. The flex hose on OV-103 hydraulic system #2, S/N 003 from lot #20W598C, did not have each individual test step, such as crush-and-roll Quality Control (QC), stamped. Instead, the acceptance test sheet for lot #20W598C had the Quality Assurance Director's signature and stamp. Titeflex provided assurance to JSC Safety, Reliability, and Quality Assurance (SR&QA) that this indicated all tests

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>ORBITER</u>		
8 (Continued)		were performed and passed. This procedure is sometimes used if the "traveler" sheet that accompanies the flex hose lot through each test has the appropriate test steps stamped. ***This risk factor was resolved for STS-31.***
9	Cathode Ray Tube (CRT) #4 screen went blank. IFA No. STS-36-09 ***No CRT anomalies were reported on STS-31.***	CRT #4 screen went blank during on-orbit operations. Power cycling provided only temporary recovery of the CRT. The unit was inoperative for the remainder of the flight. CRT #4 was removed at KSC and sent to the vendor for failure analysis. Troubleshooting by the vendor determined that the failure resulted from a fractured solder joint at a capacitor in the horizontal deflection amplifier. There are 4 CRTs available; 2 or more CRTs must fail before there is a mission impact. ***Not a safety concern for STS-31.***

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>ORBITER</u>		
10	Oxygen (O_2) bleed orifice leak. IFA No. STS-36-10 HR No. ORBI-299 ***No anomaly was reported on STS-31.***	During cabin operations at 10.2 psi, the crew manually controls the O_2 content of the atmosphere. Presleep O_2 partial pressure was 2.85 psi. Per procedures, the crew connected the bleed orifice, resulting in a rise of O_2 partial pressure to 2.9 psi during the sleep period. The crew tightened the elbow B-nut in an attempt to slow any possible leak, and the bleed orifice functioned nominally. It is thought that the rise in O_2 partial pressure may have been due to a lag effect of manual control. The OV-103 O_2 bleed orifice was checked prior to STS-31 flight. ***Not a safety concern for STS-31.***
11	Free water found near humidity separator "A". IFA No. STS-36-11 HR No. ORBI-051 ORBI-254 ORBI-321A ***Humidity separators operated normally on STS-31.***	The crew reported finding 1 to 2 cups of water outside humidity separator "A" during required inspection procedures. The Waste Water Management System (WWMS) wand was used to recover the free water. The crew reconfigured to use humidity separator "B" for the remainder of the mission. Because of recent free water problems experienced on STS-32/OV-102, a decision was made to remove the humidity separator package and send it to the vendor for failure analysis. Vendor inspection at DFRC found contamination in an area of the separator where it had not previously been seen or experienced on other problem humidity separators. While the free water failure mode had not yet been defined, crew procedures were in place which required periodic inspection of the humidity separators and surrounding areas for free water. Contingency deorbit can be implemented should both separators and workaround fail. OV-103 humidity separators flew on STS-33 without any problems. ***This risk factor was acceptable for STS-31.***

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
12	Thruster R4R failed "off" during pre-entry hot-fire test. IFA No. STS-36-12 HR No. ORBI-119 ***(See the discussion of STS-31 RCS thruster anomalies associated with Orbiter 3 of this Section.)***	During firing of thruster R4R, S/N 235, the chamber pressure did not reach the required pressure within the specified time. The thruster was deselected by the RCS RM system. This was a failure mode similar to thruster R3D failure. Contamination of the oxidizer valve poppet was suspected. Prior to launch, the rain cover of thruster R4R was found soaked with water. The thruster was removed and sent to the vendor for analysis. Visual inspection at DFRC found no contamination in the thruster throat. There are 4 redundant yaw firing thrusters on each OMS pod, and the aft RCS can handle any 2 thruster failures. ***This risk factor was acceptable for STS-31.***
13	Flash Evaporator System (FES) controller "A" shutdown. IFA No. STS-36-14 HR No. ORBI-276B ***FES operation was normal on STS-31.***	FES controller "A" shut down during on-orbit operations. The shutdown occurred when the water dump mode was initiated. The crew selected the high radiator set point in an attempt to correct the problem. A transducer sensed inadequate FES cooling which resulted in FES controller "A" shutdown. The crew then cycled the radiator switch twice; the FES came online and performed nominally. OMRSD requirements verify the integrity of the FES prior to launch. There are adequate redundancy, and crew workaround procedures are available. ***This risk factor was acceptable for STS-31.***

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
14	STS-36 hydraulic system depressurization anomaly. IFA No. STS-36-17 HR No. ORBI-036 ORBI-047A ORBI-184 ORBI-188 ***No similar hydraulic system anomaly was reported on STS-31.***	During reentry, hydraulic system #1 pump pressure did not respond properly when commanded to the low-pressure mode to reduce the rate of a suspected hydraulic leakage. Initially, pressure dipped to 2100 psi, and then leveled off at 2600 psi for 5 min before dropping to 650 psi; nominal low pressure is 800 psi (500 to 1000 psi range). The low-pressure mode is normally required only for APU start. This was the first time to command a hydraulic system to "low" during entry; however, periodic load tests verify this capability. Pressure was returned to normal shortly before landing and shutdown after wheel stop. Teardown of this pump revealed severe scoring in the piston cap through the entire bore, 360° in circumference. Additionally, 6 score marks were found through the housing bore hardcoat anodize. Burnishing was also indicated on the piston. This pump previously flew on OV-099 and was removed after 5 flights to investigate an anomalous APU vibration. APU pump testing at JSC determined that the vibration was caused by the APU. After being subjected to this anomalous vibration environment on OV-099 and testing at JSC, the pump went through acceptance tests prior to installation on OV-104. STS-36 was the fourth flight for this pump on OV-104. In addition to operation on OV-099 and OV-104, and testing at JSC, the pump was used with 3 other hydraulic systems at Abex (the vendor), the KSC Orbiter Processing Facility (OPF), and at Sundstrand. This was significant because analysis of cap and piston fluid samples found 73 particles larger than 100 microns; the largest were found to be 300-series Corrosion Resistant Steel (CRES), MP35N, and iron oxide, ranging from 125 to 360 microns. None of these materials are used in the cap or piston. The source of the contamination was unknown; however, because the pump operated with several different hydraulic systems, contamination could

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
14 (Continued)		have been introduced to the cap or housing bore anywhere along the way. Because contamination was found, a possible scenario for the STS-36 anomaly was that a particle lodged between the large end of the depress piston and the housing bore. To do this, the particle would have had to penetrate the hardcoat temporarily and prevent the piston from completing the stroke. It is believed that the piston finally overcame the resistance of the contamination and returned to nominal depressurization mode operation at 600 psi. In addition to use on the Orbiter, this type of hydraulic pump is also used with the SRB Hydraulic Power Units (HPUs) and in many commercial applications. All available pumps have been examined for similar scoring. Examination of SRB HPU pumps found light localized scoring at the inner edge of the piston cap and light indications of wear further inside. This scoring was not nearly as bad as that seen on the anomalous STS-36 pump. Note that the SRB HPU pumps are operated for a relatively short time period, but operate in a higher vibration environment than the Orbiter pumps. Examination of 2 spare Orbiter pumps found only light localized scoring at the piston cap inner edge. This scoring did not compare with that seen on the anomalous STS-36 pump and was slightly less than the scoring found in the SRB pumps. These 2 pumps were located at Abex and had only seen operation during acceptance testing. No indication of wear was found in 2 test stand pumps located at JSC. These 2 pumps were considered in good shape; however, there was no record of operating time. A key factor in determining whether the scoring and wear are operating-time related was the examination of the 3 pumps operating in the Flight Control Hydraulics Laboratory (FCHL). The FCHL pumps had total operating times ranging from 682 to 916 hr. These pumps experienced thousands of depressurization/pressurization cycles and hundreds of hours of operation in the

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
14 (Continued)		depressurization mode. Examination found only indications of incipient wear and no scoring. The pumps were considered to be in good condition. The vibration environment experienced by the FCHL pumps was extremely low compared to flight environments on the Orbiter and SRB. The results of the STS-36 pump anomaly investigation and examination of available pumps formed the rationale for STS-31 flight: • The STS-36 depress anomaly was not a hard failure. – The anomaly cleared itself. – The anomaly occurred during off-nominal operations. – There was no prior history of depressurization problems with this or other pumps. • Examination of other pumps determined that the piston cap and housing bore scoring found in the anomalous pump was by far the worst case. • The anomalous pump had been subjected to an unique set of operating environments: – Exposure to excessive vibration on OV-099. – Exposure to 6 different hydraulic systems increased the opportunity for introduction of contamination.

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
14 (Continued)		• Piston cap scoring did not appear to be operating-time related. – FCHL pumps indicated slight scoring of the piston caps. – JSC test stand pumps indicated very little evidence of scoring. – SRB pumps indicated the beginnings of localized wear after a relatively short operating time. • Anomaly characteristics and failure analysis evidence were consistent with transient contamination. • Similar conditions existing on the OV-103/STS-31 pump would result in inability to start the APU at T–5 min and cause a launch scrub. For the on-orbit start, redundant capability exists among hydraulic systems for reentry. ***This risk factor was acceptable for STS-31.***

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
SRB		
1	Left SRB Ordinance ring pin embedded in External Tank Attach (ETA) ring foam. IFA No. STS-36-B-01 HR No. INTG-081A ***Postflight disassembly of STS-31 did not reveal any embedded ordnance pins. However, all of the ordnance ring-to-frustum fastener assemblies on the Right-Hand (RH) SRB were found to be loose; 20 of the same fasteners were loose on the Left-Hand (LH) SRB (IFA No. STS-31-B-02). Reduction in preload, attributed to washer deformation caused by descent loading, was considered to be the principal factor responsible for the loose fasteners.***	Postflight disassembly of STS-36 SRBs found 3 pins missing from the forward skirt frustum attach ordnance ring area. One pin was found embedded in the ETA ring foam. Loss of these pins had been seen before and was attributed to water impact; however, this was the first time that a pin had been found. Inspection of the pin retainers, P/N 10172-0010-001, found that the ends of some of the clips were bent or spread in a way that compromised pin retention. Inspection of 180 retainers revealed that 4 had been spread to the point of losing all pin retention capabilities. Three others were found bent almost to this point, and 30 additional pin retainers were deformed but not to the same extent. Retainers are reused after inspection in accordance with United Space Boosters, Inc., (USBI) refurbishment specification 10SPC-0131C. The refurbishment specification requires inspection with no reuse if the pin retainer is "bent out of print". A determination has not been made whether the dimension in question is measured prior to reuse. For STS-31 and STS-35, ordnance pins will be positively locked in place using a fastener/daisy chain lockwire configuration per Engineering Change Proposal (ECP) 2779. A maximum of 6 pins in series will be lockwired together. Thermal qualities of the Inconel lockwire to be used exceed the maximum heating conditions experienced during flight. For STS-38 and subsequent flights, a new design retainer clip will be used which maintains the pin in place throughout the flight profile. ***This risk factor was resolved for STS-31.***

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
SRB		
2	Left SRB frustum Main Parachute Support System (MPSS) restraint strap bolt missing a nut. IFA No. STS-36-B-02 ***No anomaly was reported on STS-31.***	Postflight inspection of the left STS-36 SRB found a nut missing from an MPSS restraint bolt. The main parachute associated with this nut performed nominally. There are 28 additional restraint links on top of the deployment bag and 16 supports on the bottom. Photographic evidence confirmed that the nut was properly installed at assembly. Analysis indicated that the nut was on the bolt at one time, but was not properly torqued. This was determined by comparison of the threads on this fastener with adjacent fasteners that still had nuts installed. It was not known when the nut came off (the bolt threads did not show distress). Neither the drawings nor the assembly manual allow for removal of the nut after installation of the parachutes. No corrective action was required for this design or the associated assembly documentation. Technicians and inspectors were briefed regarding proper installation of the fasteners. The SRB decelerator subsystem is a Crit 3 function. Because failure would only impact reuse, this was not a safety-of-flight issue. ***Not a safety concern for STS-31.***
3	Safety wire missing from GN_2 purge line in RH aft skirt. IFA No. STS-36-B-03 HR No. B-00-15 ***No anomaly was reported on STS-31.***	During postflight inspection of the RH SRB aft skirt, safety wire was found missing from a B-nut in the GN_2 purge line assembly. It was believed that the safety wire was never installed. USBI analysis determined that the installation torque of 480 inch-pounds (in-lb) results in a safety factor of 11.55 against the B-nut backing off without the safety wire installed. Build paper indicated that the B-nut was installed and properly torqued. Preload was 5.8 times the flight load. The B-nut qualified without safety wiring. There was no record of a B-nut backing off on prior flights. Inspection of STS-31 B-nuts found that the safety wire was correctly installed.

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>SRB</u>		
3 (Continued)		A specific flagnote will be added to the drawing to clearly define lockwire requirements. A design change will require drilling the B-nut for lockwiring; this will be in effect for STS-41. ***This risk factor was resolved for STS-31.***
4	Left SRB drogue parachute first stage reefing line cutter failure. IFA No.STS-36-B-04 ***All parachute systems operated normally on STS-31.***	During descent of the left SRB after separation, the drogue parachute first stage reefing line cutter failed to fire. The 2 cutters in the first stage reefing line are redundant; the redundant cutter operated properly. This was the first occurrence of this failure since STS-26 and was identical to failures experienced on STS-1 and STS-8. Postflight inspection found the unfired cutter with the shear pin still in the housing, and the cutter actuation lanyard was missing. The lanyard was not recovered. Closeout photographs showed that the lanyard was in place prior to flight. Test data demonstrated that parachute deployment which causes the lanyard to pull on the shear pin at an angle greater than 140° will result in cutter failure. However, this condition was considered to have a low probability of occurrence (3 failures out of 1052 cutters flown). The packing procedures were refined after STS-11. The result was that the probability of 2 cutters failing in the same reefing line fell from 0.00132 (on STS-8) to 0.0000295 (on STS-36). Reefing line cutters are Crit 3R2 hardware. Line cutter failure is a reuse issue and is not considered a safety-of-flight issue. Redundant cutters provide backup in the case of a single cutter malfunction. ***Not a safety concern for STS-31.***

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>SRB</u>		
5	Right and left SRB ETA ring found with cable tie-wraps disengaged from electrical cable assemblies. IFA No.STS-36-05 ***No anomaly was reported on STS-31.***	During postflight inspection of both left and right SRB ETA rings, several cable tie-wraps were found disengaged from the electrical cable assemblies. Three were found disengaged on the right SRB ETA ring (1 near the aft IEA end cover and 2 on the cable bundles between the upper and lower struts). One was also disengaged on the left SRB ETA ring upper strut cable bracket. The failure mode was slippage through the locking ratchet at the head of the tie-wrap. Disengagement was attributed to water intrusion during towback that weakened the tie-wraps. DuPont design data predicts a loss of material strength due to water saturation; this was verified by USBI Materials Laboratory tests. Accessible tie-wraps on STS-31 SRBs were inspected for proper engagement prior to launch. ***This risk factor was acceptable for STS-31.***

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>SRB</u>		
6	Right SRB frustum Marshall Trowellable Ablator No. 2 (MTA-2) debonds. IFA No. STS-36-B-07 HR No. B-60-12 Rev. C-DCN4 C-00-04 Rev. B-DCN2 ***Postflight assessment of STS-31 found missing Thermal Protection System (TPS) on the LH aft skirt (IFA No. STS-31-B-04). Areas with missing TPS material were either missing K5NA over MTA-2 or MTA-2 over MTA-2 applications. It was determined that the loss of MTA-2 on STS-31 occurred during descent or at water impact. (See Section 7, SRB 4 for additional details on this anomaly.)***	During postflight inspection of the right SRB frustum, MTA-2 debonds were found at 16 ramp locations. The voids occurred between MTA-2 layers. Material analyses performed on MTA-2 sections removed from 2 fasteners found that the voids were air bubbles introduced during material application; these voids were too small to initiate loss of MTA-2. As a corrective action, MTA-2 processing enhancements are being evaluated. This was the first instance of MTA-2 debond since it was first used. Evidence indicated that the debonds occurred during or after frustum separation. ***Not a safety concern for STS-31.***

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
SRM		
1	Right Solid Rocket Motor (SRM) igniter/forward dome boss interface surface metal pitting and Gask-O-Seal damage. IFA No. STS-36-M-01 HR No. BC-02 Rev. B BC-03 Rev. B ***No similar anomalies were reported on STS-31.***	During disassembly of the STS-36 booster assemblies, a blow hole was found at the 175° position in the igniter vacuum putty. This putty is laid-up between the igniter and the forward dome as a thermal barrier to stop hot gas excursion to the igniter-to-case sealing surfaces. The blow hole measured 0.3" circumferentially at the igniter adapter and widened to 2.5" circumferentially at a position 4" below the adapter. Blow holes through the putty have been experienced on approximately 65% of all flight and test SRMs/Redesigned Solid Rocket Motors (RSRMs); however, the results have not been as severe as those witnessed on the STS-36 LH SRM. Significant to this occurrence was the discovery of a depression, or pitting, in both the inner diameter of the forward dome and the outer diameter of the igniter chamber body, as well as a missing portion of cadmium plating on the inner igniter gasket seal. Sooting was also seen around the outside of the inner igniter gasket seal, extending approximately 100° in either direction from the blow hole. Blow holes observed on the STS-27 RH SRM and on Transient Pressure Test Article (TPTA) 1.2 also resulted in corroded metal surfaces and cadmium plating similar to the STS-36 LH SRM. In these cases, the minimum blow hole circumferential measurement was 0.16". This supported the belief that corrosion is not worse with smaller blow holes. The blow hole was large enough to allow sufficient hot gas to pass to clean the putty off the surfaces of the forward dome and igniter case. Pitting of both of these surfaces was believed by Marshall Space Flight Center (MSFC) and Thiokol Corporation metallurgists to be due to "corrosion" as opposed to hot gas "erosion". The hot propellent gases contain a large amount of chlorine, hydrogen chloride, and other corrosive materials. Chlorides were believed to be the primary cause of the corrosion; however, the corrosion process was continued by sea water after splashdown. The pitting was refurbishable; igniter chamber pitting was measured to be 1-2 mils in depth.

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>SRM</u>		
1 (Continued)		In addition to pitting of the forward dome and igniter case, examination found missing cadmium plating from the Gask-O-Seal over an area of 1.5" circumferentially by 0.15" radially in the area of the blow hole. Metallurgical analysis found powdery cadmium chloride. The melting point of cadmium is 610°F, and it oxidizes when heated. From hardness testing, observations of metal corrosion, and removal of cadmium plating from the Gask-O-Seal, it was estimated that the igniter joint experienced a temperature in the range of 450°F to 550°F. This finding indicated that the cadmium was removed through corrosion as opposed to melting. Thiokol engineers stated that cadmium stripping is acceptable as long as there is no damage or degradation of the elastomer seal. In this case, no degradation of the elastomer was found. Analysis by Thiokol showed that exposure to temperatures up to 800°F are acceptable for seal performance. The volume on the seal side of the blow hole was very small (3.8 in^3 versus 15 in^3 for a field joint and nozzle-to-case joint). It had a 0.61-sec fill time, and there was no circulation producing additional flow in this area. Therefore, the temperature rise was limited to less than 800°F. Flow/thermal analysis of a worst-case blow hole, measuring 0.1" circumferentially, was performed. A blow hole of 0.1" was considered worst-case because no blow hole had been observed to be less than 0.16", and blow holes less than 0.1" would tend to self-plug. For this size blow hole, the void fill time was determined through this analysis to be 2.4 sec. No damage to the seal would result because the seal surface temperature would be below 450°F, well within the 800°F limit. Analysis did show, however, that the cadmium on the retainer would be exposed to temperatures greater than 610°F, the melting point of cadmium, for a period of 1.2 sec until flow stagnation occurs. It was determined that, even if the cadmium melted, no embrittlement or damage to the elastomer was expected. The fact that

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
SRM		
1 (Continued)		damage seen on STS-27 and TPTA, with a blow hole of 0.16", was similar to that seen on STS-36 was an indicator that the analysis results are conservative. Worst-case thermal analysis of the igniter chamber steel indicated that the surface temperature rose to 2750°F. This prediction was based on the pitting seen, less than 2 mils in depth. At 2750°F, analysis showed that there was no loss in structural margins of safety. Stresses in the heat-affected zone range from 40-140 ksi. The overall joint capability was determined not to be compromised by the localized heat-affected zone. The joint Factor of Safety (FOS) was demonstrated by burst tests to be greater than 1.8. Based on the localized heat-affected zone experienced on STS-36, the remaining margin of safety was greater than 0.3. The only resulting concern with a localized heat-affected zone was reuse, because of the loss of corrosion protection on the metal surface. A thorough analysis of the likelihood of circulation flow found no mechanism to generate circulation within the igniter joint. The joint is unlike the nozzle-to-case joint, where nozzle gimballing occurs, or the field joints. In both cases, the dynamic environment provides the potential for creation of a delta pressure in the joint, leading to circulation. In addition, of all SRM igniter joints experiencing putty blow holes, none had been seen with more than 1 blow hole.

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
SRM		
1 (Continued)		Rationale for STS-31 flight included: • Blow holes through the igniter joint putty were witnessed on the majority of flight and test SRMs, with no damage to the sealing capability of the joint (no evidence of blowby or damage of the elastomer and no damage to the structural components). • Worst-case blow hole of 0.1" would result in no damage to the elastomer seal. • Worst-case analysis predicted a positive structural margin of safety. • There was no known mechanism which would lead to hot-gas circulation in the igniter joint. ***This risk factor was acceptable for STS-31.***

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STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>SRM</u>		
2	Secondary O-ring damage to igniter plug. IFA No. STS-36-M-02 HR No. BN-03 Rev. B ***The STS-31 igniter plugs passed leak tests and were checked for no gap with a feeler gage prior to ordnance installation. Igniter operation was normal on STS-31.***	During disassembly of the LH SRM, a flaw was found in the secondary O-ring on the igniter port plug. The port plug secures the hole in the igniter adapter formerly used for the igniter pressure transducer. Primary and secondary seals are redundant. The flaw consisted of material separation, resembling a slit, on the inner diameter of the O-ring. The slit was verified by Thiokol to be 0.7" long x 0.060" deep and extended around approximately 50% of the O-ring circumference. A similar material separation was found on an O-ring on the STS-34 RH igniter. The damaged secondary O-ring on STS-36 had passed leak tests at 2159 pounds per square inch absolute (psia), the maximum environmental operating pressure of the igniter. The most probable cause of the slit was damage at assembly by the edge of the dovetail groove used to hold the O-ring, due to excessive grease in the groove. Excessive grease was found in the dovetail groove of the failed port plug. Excessive grease causes an overfill condition, trapping the O-ring between the edge of the dovetail and the igniter adapter. Circumferential separations of this type are on the inner diameter of the O-ring; therefore, the top and bottom sealing surfaces should not be compromised. Damage seen to O-ring surfaces was in the face seal, with no gap opening. A pressure test was performed on the damaged O-ring without the primary seal in place. The damaged seal passed the pressure test. Analysis of the flaw found that these material separations are circumferential and are not on the sealing foot print. This type of circumferential defect does not affect sealability and has no impact on flight operation or flight safety. STS-31 igniter port plugs passed vacuum bell leak tests. In addition, STS-31 plugs were checked prior to ordnance part II installation with a 0.003" feeler gage for no gap. ***This risk factor was resolved for STS-31.***

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>KSC</u>		
1	Missing washer on Debris Containment System (DCS) Holddown Post (HDP) #6. IFA No. STS-36-K-01 HR No. B-60-12 Rev. C-DCN4 ***Washer installation on all HDPs was verified for STS-31 as part of the bolt installation.***	Postlaunch inspection of HDP #6 found that the required washer was missing. It was later determined that 2 washers were on another HDP; only 1 is required. It was believed that the technician inadvertently installed 2 washers on 1 of the HDPs, thinking that he had installed 1 on each, per the drawing. It should be noted that both Lockheed and NASA quality control inspectors certified that the washer installation was correct. Analysis showed no performance degradation with either no washer or 2 washers installed on any bolt. Installation procedures were changed to state that "1 washer is required on 1 bolt". Washer installation on all HDPs was verified for STS-31 as part of the bolt installation. ***Not a safety concern for STS-31.***

STS-36 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>MCC</u>		
1	Space Shuttle Main Engine (SSME) post-powerdown hardware failure indicated. IFA No. STS-36-MOC-01 ***No similar anomaly was reported on STS-31.***	Two erroneous SSME hardware failure identifiers were annunciated approximately 9 minutes after SSME controller powerdown. The SSME controller cannot generate failure identifiers once it has been powered down. Suspect was a data recording anomaly in the Mission Operational Computer (MOC). Troubleshooting was performed to determine susceptibility to erroneous data. This was not a safety-of-flight issue. ***Not a safety concern for STS-31.***

SECTION 6

STS-33 INFLIGHT ANOMALIES

This section contains a list of Inflight Anomalies (IFAs) arising from the STS-33 mission (previous flight of OV-103). Each anomaly is briefly described, and risk acceptance information and rationale are provided.

SECTION 6 INDEX

STS-33 INFLIGHT ANOMALIES

STS-33 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>INTEGRATION</u>		
1	Space Shuttle Main Engine (SSME) #2107 nozzle bluing. IFA No. STS-33-I-01 HR No. ME-B7 (All Phases) ***No Main Engine (ME) nozzle bluing was reported on STS-31.***	Postflight visual inspection of the ME #2107 nozzle revealed discoloration or "bluing" on the front face of the aft manifold. The discoloration was centered about the lower centerline [±1.5 feet (ft)], low reentry heating region. The nozzle structure is uninsulated in this region (Inconel 718). No discoloration was evident on the ME #2031 nozzle. Discoloration in this region had not been observed in previous flight experience. The nozzle discoloration could not be explained by the predicted heating environment. The time/cause of the discoloration is not yet understood. Worst-case recurrence would impact nozzle reuse. This Flight Problem Report was approved at the Level II noon Program Requirements Control Board (PRCB) on February 8, 1990. Per Associate Administrator, Office of Space Flight (AA/OSF) at the STS-36 Flight Readiness Review (FRR), this Inflight Anomaly (IFA) was reopened. Further data was requested from other flights using new ME nozzles. ***Not a safety concern for STS-31.***

STS-33 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
1	Auxiliary Power Unit (APU) #1 lube oil output pressure was high. IFA No. STS-33-01 HR No. ORBI-036 ***No APU lube oil pressure anomaly was reported on STS-31.***	APU #1 experienced higher than normal lube oil output pressure during ascent. Pressure peaked at approximately 85 pounds per square inch (psi), 25 psi higher than normal. The pressure returned to normal just prior to Main Engine Cutoff (MECO). Two waivers, 1 for high APU gearbox delta pressure and the other for high APU gearbox blanket pressure, were approved prior to STS-33 launch. The seal cavity pressure was higher than the gearbox pressure due to a procedural error, allowing hydrazine seepage into the gearbox. A wax substance, pentaerythritoral, is formed when hydrazine is mixed with lube oil. This substance goes back into solution between 175-200°F, the nominal APU operating temperature. Kennedy Space Center (KSC) performed oil flush and drain, as well as lube oil filter changeout per Operational Maintenance Requirements and Specifications Document/Operations and Maintenance Instruction (OMRSD/OMI) V10078, prior to the next OV-103 flight. KSC was directed to double-bag the filter and send it to Rockwell International (RI)/Downey for analysis. Oil samples were taken prior to system flush. ***Not a safety concern for STS-31.***

STS-33 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
2	Cabin air leak through the Waste Collection System (WCS). IFA No. STS-33-02 HR No. ORBI-077 ***No anomaly was reported on STS-31.***	Cabin pressure decreased to 14.28 pounds per square inch absolute (psia) before the leak was isolated. The crew isolated the leak to coincide with WCS usage. The leak was verified when the commode slide valve was opened and no discernable air flow was noted. Air transportation of fecal matter was also lost. The crew performed inflight maintenance to manually move the vacuum ball valve from vacuum position to FAN SEP position. Cabin pressure was restored as well as full WCS operation. Inspection of the OV-103 WCS at Dryden by Johnson Space Center (JSC)/Hamilton Standard personnel found a broken pin on the linkage between the handle and the relief valve. Further investigation determined that the wrong pin was installed. OV-102 was checked prior to STS-32 and found to be correct. OV-104 was inspected at KSC prior to STS-36. OV-103/STS-31 WCS was removed and replaced, and was determined to be operating properly. ***Not a safety concern for STS-31.***
3	Reaction Control System (RCS) F1U pressure transducer failure. IFA No. STS-33-04A HR No. ORBI-203 ***No RCS pressure transducer anomaly was reported on STS-31.***	The RCS F1U chamber pressure transducer failed during Flight Control System (FCS) checkout in preparation for reentry. Indications were that the jet fired properly on ascent. For reentry, F1U was deselected due to the low chamber pressure indication and was not required for the remainder of the mission. Similar instances of low RCS thruster chamber pressure were experienced on 3 previous flights on all Orbiters. A decision was made not to repair this transducer until after STS-31 because this jet is mainly used for proximity missions only; STS-31 was not a rendezvous mission. ***Not a safety concern for STS-31.***

STS-33 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
4	Commander's airspeed mach indicator out of specification. IFA No. STS-33-05 ***No anomaly was reported on STS-31.***	During FCS checkout, the Commander's airspeed mach indicator read 20,500 feet per second (fps); the specification is 20,000 fps. This problem was also reported on the two previous OV-103 missions since reflight. On STS-26, it read 22,250 fps; on STS-29, 22,050 fps. This anomaly was isolated to OV-103. ***Not a safety concern for STS-31.***
5	Hydraulic systems #1 and #2 accumulator ascent pressure locked-up low. IFA No. STS-33-07 HR No. ORBI-052 ***No hydraulic system anomaly was reported on STS-31.***	During ascent, hydraulic systems #1 and #2 accumulator pressure locked-up low. This anomaly was similar to a problem on STS-26 and STS-29 (IFA No. STS-29-26) where priority valves #1 and #2 experienced low reseats at APU shutdown. The valves are required to lock-up at 2600-pounds per square inch differential (psid) pressure (referenced to reservoir pressure). After STS-33 ascent, priority valve #1 locked-up at 2420 psid; valve #2 locked-up at 2340 psid. Lockups have been repeatable during the 3 OV-103 flights since reflight and show no sign of further degradation. During special testing at KSC, 2 of the 6 lockups were below specification. There was no immediate system concern; therefore, these valves were allowed to fly "as is" for STS-33. However, the valves were known to be out-of-specification. It is believed that the valves were set low during acceptance testing at the vendor or changed with time. These valves had never flown prior to STS-26. There has been no evidence of problems with the priority valves on OV-102 and OV-104 missions since reflight. The two OV-103 valves were removed and replaced. ***Not a safety concern for STS-31.***

STS-33 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
6	Power Reactant Storage and Distribution (PRSD) Oxygen (O_2) tank #1 had a sticky Check Valve (CV). IFA No. STS-33-08 HR No. ORBI-094 ***No anomaly was reported on STS-31.***	PRSD O_2 tank #1 CV stuck twice during the mission. This O_2 tank was not in use when the anomalies occurred. When a 20-psid pressure difference built up across the CV, it opened and operated nominally. Nominal cracking pressure is 3-5 psid. This particular CV experienced a large 180-psid closing force after high O_2 flow associated with the pressure leak through the WCS (see Orbiter 2 above). Stopping the high O_2 flow caused Liquid Oxygen (LO_2) to be trapped in the manifold. Environmental heat converted the LO_2 to gas and pressurized the manifold until the relief valve opened. The CV operated nominally for the remainder of the mission. Sticking CVs were observed on previous flights subsequent to large closing forces. No remedial action was required. It is believed that this anomaly was caused by transient contamination, compounded by the high checking force during the pressure leak through the WCS. ***Not a safety concern for STS-31.***
7	Forward attach point system A and system B connectors found damaged. IFA No. STS-33-10 HR No. ORBI-289 ***No pyro connector anomaly was reported on STS-31.***	During Orbiter inspection at Dryden, it was found that the tangs on both system A and system B pyro connectors were clocked incorrectly. Clocking was at 30° aft instead of straight-up. One connector (20V77W11J13) had a broken strain relief; the other connector (20V77W12J12) had a loose backshell. A known interference problem existed between these connectors and the forward attach pyro bolt; it is very alignment sensitive. All connectors and harnesses in this area are replaced prior to each flight. JSC and RI engineers prepared a design change to replace these connectors with 90° backshell connectors. This change will correct the interference problem. ***Not a safety concern for STS-31.***

STS-33 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
8	"Y" Star Tracker door thermal blanket detached. IFA No. STS-33-11 HR No. ORBI-011A ***The thermal blankets were removed prior to STS-31 launch, thereby precluding recurrence of this anomaly.***	The "Y" Star Tracker door thermal blanket was found totally detached from the door and lying loose on the bottom of the Star Tracker cavity. The blanket was not damaged at the attach points. A small tear on the top of the blanket indicated that it was detached when the door closed. No fastener damage was observed. Investigation of problems during Star Tracker door cycling on OV-104, prior to rollout for STS-34, found that the thermal blankets interfered with the bright-object sensor. Redesigned thermal blankets were installed on all Orbiters. There were no reported problems with the modified blankets on STS-34. Worst-case effects of loose thermal blankets are related to jamming the Star Tracker doors open during reentry. This would allow plasma flow through the cavity resulting in damage to the Star Tracker. Recent RI thermal analysis indicated that the thermal blankets in the Star Tracker cavity were not necessary, based on redefined heating environments. A recommendation was made by RI at the STS-32 FRR to remove these blankets prior to launch. The recommendation was subsequently approved by the PRCB, and the blankets were removed. ***This anomaly was resolved for STS-31.***

STS-33 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
9	Flash Evaporator System (FES) B outlet temperature oscillation. IFA No. STS-33-13 HR No. ORBI-276B ORBI-300 *No FES anomaly was reported on STS-31.*	During FES B deorbit preparation, when FES B was reconfigured from the "PRI B ON" to the "PRI B GPC" position, it shut down because FES B was above the temperature limits. This was due to the inability of FES B to bring control band temperatures within shutdown logic limitations. A similar occurrence was experienced on STS-29 (IFA No. STS-29-14). Prior to STS-33, the midpoint sensors were repacked due to a lag that existed between the midpoint temperature sensor and actual Freon Coolant Loop (FCL) temperature. This was caused by a midpoint sensor manifold design change for OV-103 only, which should have rectified this problem. After the first occurrence of this anomaly on STS-33, FES B was recycled; this successfully brought the temperature into the control band before the shutdown logic timed out. FES B operated nominally for the remainder of the flight. This anomaly was believed to have been caused by a tolerance build-up in the lead/lag times of controller "B" and its 3 temperature sensors. *This anomaly was resolved for STS-31.*

STS-33 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>ORBITER</u>		
10	Erratic temperature indications from APUs #1 and #3 bypass line "A". IFA No. STS-33-16 HR No. ORBI-250 *APU #3 fuel pump bypass heater "A" failed "on" during FCS checkout prior to STS-31 reentry. This heater had operated erratically during STS-33, but a decision was made not to replace the thermostat prior to STS-31. Therefore, this anomaly was expected. (See IFA No. STS-31-08 in Section 7, Orbiter 6 of this MSE for more details.)*	Bypass line "A" temperature sensors on both APUs #1 and #3 demonstrated erratic behavior. This was indicated by erratic bypass line heater operation. The temperature sensors, or thermostats, are mounted on the APU bypass lines. It is believed that these lines experienced vibration which led to loosening of the sensor mounts. A determination was made to replace the "A" and "B" temperature sensors on both APUs. APU #1 temperature sensors were replaced and tested satisfactorily. A decision was made to delay the replacement of APU #3 temperature sensors until after STS-31, when the entire APU was to be replaced. *This anomaly was resolved for STS-31.*

STS-33 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>ORBITER</u>		
11	Hydraulic system #2 Water Spray Boiler (WSB) Gaseous Nitrogen (GN_2) leakage was out-of-specification. IFA No. STS-33-17 HR No. INTG-072 INTG-113 ***No excessive WSB GN_2 leakage was reported on STS-31.***	During STS-33 on-orbit operations, the hydraulic system #2 WSB demonstrated excessive GN_2 leakage. Some decay in GN_2 tank pressure is expected. Leakage on STS-33 was at a rate of 0.36 pounds per square inch/hour (psi/hr); the specification limit is 0.30 psi/hr. A similar anomaly was experienced during STS-29 on WSB #1. ***Not a safety concern for STS-31.***

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>SRB</u>		
1	Holddown Post (HDP) anomalies. IFA No. STS-33-B-01 IFA No. STS-33-B-02 HR No. INTG-164 B-00-15 B-00-17 ***No HDP stud hangup anomaly was reported on STS-31.***	Orbiter accelerometer readings at STS-33 Solid Rocket Booster (SRB) ignition indicated a holddown bolt anomaly. The launch film showed the stud at HDP #3 hung-up, similar to the occurrence on STS-34. The stud extended approximately 8" and contacted the aft skirt stud hole wall. This may have caused a piece of the Epon shim to pull loose and separate from the skirt foot. An area of Epon shim material (approximately 34 square inches) on the bottom of the right SRB HDP #3 was observed falling off during the launch. An RI evaluation of this type of anomaly concluded that the probability of shim material ricocheting and impacting the vehicle is extremely remote as the primary forces acting on the shim particles are gravity, plume impingement, and aspiration. Postflight inspection of the Right-Hand (RH) aft skirt found that it had been broached on the aft side of the HDP #3 bolt hole. Thread impressions were also visible on the forward side of the same hole. One of the 2 pyrotechnic charges used on each frangible nut did not appear to explode properly on HDPs #3, #4, and #8. The frangible nut separation area showed a ductile separation. Nominal operation of the pyrotechnics causes splintering of the nut material at the explosion site. The cause of ductile separation seen on these nuts was inconclusive. It could indicate explosion was either less powerful than desired or late. The anomalous pyro action might have contributed to the stud hangup at HDP #3. HDP broaching occurred on several previous flights, most recently on STS-34. Rationale for STS-33 launch, the next flight after STS-34, was that a Marshall Space Flight Center (MSFC) and RI integration analysis indicated that all 8 HDP bolts could hang-up with no deleterious liftoff performance effects, provided that all frangible nuts are released. However, the potential problem experienced with the skewed firing of the frangible nut pyrotechnic charges identified the need for further

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>SRB</u>		
1 (Continued)		analysis relative to the influence and contribution of the bolt hangup at HDP #3 and liftoff performance degradation. Further analysis found the following: • Worst-case hangup was defined as the hangup of all 4 studs on 1 SRB. • Worst-case hangup has a minimal effect on post and tower clearance. • Worst-case hangup has a negligible effect on flight controllability. • Worst-case hangups could cause the limit load to be exceeded on some External Tank (ET) and/or SRB hardware based on a conservative quick-look analysis (4 stud hangups could possibly reach 1.2 to 1.4 times the limit load). One, 2, or 3 stud hangups yields loads within limit loads. • The probability of a worst-case 4-stud hangup is less than 2 x 10^{-5} with removal of the plunger-to-stud frangible bolt. • RI load analysis concluded that the structure can withstand a 4-post worst-case load plus 3σ dispersed loads. Some SRB personnel believe that stud hangup can be minimized by incorporating a 0.030" bias in the alignment of the skirt to the Mobile Launch Platform (MLP) support post. Incorporation of this bias before assembly is expected to compensate for flexure of the structure due to the loading of the aft skirt during assembly. The MLP spherical bearings would then be properly aligned and allow maximum clearance between the holddown bolt and the bolt hole, thereby significantly reducing the likelihood of holddown bolt hangup. ***This anomaly was resolved for STS-31.***

STS-33 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
SRB		
2	Left-Hand (LH) ET Attachment (ETA) ring Integrated Electronic Assembly (IEA) end cover and cable sooted. IFA No. STS-33-B-03 HR No. B-60-24 Rev. C ***No IEA sooting was reported on STS-31.***	Upon removal of the LH IEA covers, sooting was noted on 16 cables and interior painted surfaces of the end cover. Examination of the cable jacket indicated no heating effects (no erosion, clouding of material, or degradation). It was determined that the gap in the RTV-133 sealant allowed hot gases to enter the ETA ring and the IEA cable areas through the aft side of the IEA end cover. The gases entered at the aft side of the end cover, traveled across the wire bundles, and exited through the opposite (forward) side of the end cover. This was determined by the heaviest sooting deposits on the aft side of the IEA end cover and the flow pattern. The direction of hot gas flow entering the end cover indicated that this condition occurred during reentry or descent. The RTV-133 material was missing at the area of soot entry and exit. All cables functioned properly during the mission. There was not adequate heat present to damage the cables or impair the cable function. Corrective action consisted of an engineering change [Field Engineering Change (FEC)-10266] effective for STS-32, STS-36, STS-31, and STS-35; Engineering Change Proposal (ECP)-2670 will make this revision to the closeout procedures permanent. This change clarifies the Thermal Protection System (TPS) closeout, thereby assuring proper closeout and preventing recurrence of this anomaly. ***This anomaly was resolved for STS-31.***

STS-33 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
KSC		
1	Improper installation of cable connector assemblies. IFA No. STS-33-K-01 STS-33-K-02 STS-33-K-03 ***No cable connector assembly anomaly was reported on STS-31.***	During STS-33 postflight assessment, 2 cable connectors were found incorrectly installed, and 2 ground straps were loose due to omitted washers. • The RH forward skirt Range Safety System (RSS) Ground Support Equipment (GSE) cable [Radio Frequency (RF) signal to the Integrated Receiver/Decoder (IRD)] was not fully seated on its mating connector at the forward feedthrough. The connector was engaged only 3/4 of a turn; 3-1/2 turns are required for full engagement. The connector was lockwired correctly. The connector insert showed signs of moisture and contained K5NA debris. This cable is not used in flight, but is used during range safety ground checkout. • The LH upper strut separation ordnance connector was finger-loose. The connector was lockwired correctly. The jam nut was retorqued to determine the relationship of the lockwire to the properly-torqued connector. Slack in the lockwire indicated that the connector had not been properly torqued prior to lockwire installation. • Two ground straps located between the RH SRB aft IEA bracket and the SRM were loose. The ground strap fasteners bottomed out due to omitted washers. Some washers had not been installed on the fasteners on the forward end of the IEA, but those fasteners had not bottomed out and the ground straps were not loose. All 4 bolts were torqued properly [125-150 inch-pound (in-lb)]. The LH brackets had washers installed. ***This anomaly was resolved for STS-31.***

SECTION 7

STS-31 INFLIGHT ANOMALIES

This section contains a list of Inflight Anomalies (IFAs) arising from the OV-103/STS-31 mission. Each anomaly is briefly described, and risk acceptance information and rationale are provided.

SECTION 7 INDEX

STS-31 INFLIGHT ANOMALIES

STS-31 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
1	Auxiliary Power Unit (APU) #1 speed control failure. IFA No. STS-31-01 HR No. ORBI-031 ORBI-040	During the launch attempt on April 10, 1990, APU #1 exhibited speed control problems shortly after startup. Indications were that low speed could not be maintained. The crew manually commanded APU #1 to high speed that was successfully maintained. Upon cycling back to low speed, the same erratic speed behavior occurred. A decision was made to scrub the launch attempt and to plan for an extended turnaround. The controller was sent to Sundstrand, the APU vendor, for failure analysis. The analysis indicated that all APU controller functions were nominal. Because failure analysis cleared the APU controller as the source of the speed control failure, APU #1 removal and replacement was directed. APU removal was required because the Gas Generator Valve Module (GGVM) cannot be removed with the APU installed in the Orbiter. Failure analysis of the APU at Sundstrand confirmed that the problem was in the Pulse Control Valve (PCV) and cleared the Shutoff Valve (SOV). Sundstrand ran 1900 cycles of the PCV and determined that there was a blowing leak through the valve, indicating a flow path through the valve seat. Failure modes include cracking or chipping of the valve seat. Because the GGVM is sealed, it was sent to Eaton Consolidated Controls, the valve vendor, for failure analysis. Failure analysis at Eaton included teardown of the GGVM. Teardown revealed missing material from the PCV seat: 0.040" x 0.150" x 0.050". A particle that was believed to be the missing seat material was found in the valve. Damage to the PCV housing was also noted. The condition which resulted in the loss of valve seat material has not been determined. A record review found that this GGVM was installed on APU #1 prior to STS-26 and had flown on all subsequent OV-103 missions.

STS-31 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
1 (Continued)		Removal and replacement of the APU was completed on April 17, 1990; a hot-fire test of APU #1 was successfully conducted on April 18, 1990. Post hot-fire inspection of the aft compartment found no problems. Review of recorded data indicated that the APU performed nominally during the hot fire.
2	Reaction Control System (RCS) thruster L3A anomalies. IFA No. STS-31-03A STS-31-03B HR No. ORBI-056	RCS thruster L3A failed "off" during post-Main Engine Cutoff (MECO), Main Propulsion System (MPS) dump, +X maneuver. This thruster was deselected from further use by Redundancy Management (RM) when the chamber pressure did not reach 36 pounds per square inch absolute (psia) in the 265-millisecond (msec) time period. Initial indications were that the oxidizer injector valve was not open. Approximately 7 hours (hr) after this failure, thruster L3A oxidizer temperature dropped from 90°F to 21°F, indicating that the oxidizer injector valve was leaking. It is believed that frozen propellant plugged the thruster throat approximately 45 minutes (min) after the oxidizer leak initiation. This was demonstrated by the cycling of chamber pressure between 2 and 42 psia with corresponding fluctuations of oxidizer temperature. Manifold #3 isolation valves were closed to isolate further leakage and to avoid propellant loss. Oxidizer temperature and chamber pressures continued to oscillate until the frozen propellant blockage melted. These failure modes were similar to thruster anomalies experienced on STS-5, STS-41G, STS-29, and STS-30; however, there was no previous indication of throat blockage. The failure mechanism for the previous anomalies was attributed to nitrate formation/contamination of the oxidizer valve pilot poppet.

STS-31 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
2 (Continued)		Thruster L3A has had problems since installation on OV-103 in 1988. In January 1988, a helium leak check found a valve leak rate of 450 standard cubic centimeters per minute (sccm) at 250 pounds per square inch gage (psig); allowable leak rate is 350 sccm. This condition was waived prior to STS-26. Post-STS-26 return to Kennedy Space Center (KSC) found Nitrogen Tetroxide (N_2O_4) vapors emanating from L3A at a concentration of 25 parts per million (ppm). L3A performance on STS-29 was good with no anomalies. Postflight inspection of L3A at KSC found it was dripping liquid that was believed to be nitric acid. More dripping liquid was later seen, and inspection found deposits inside the nozzle. During September/October 1989, heavy vapors were witnessed coming from L3A. More dripping liquid was seen in October 1989. In all cases of dripping liquid, the liquid was not analyzed because it was felt that the liquid was nitric acid, the result of hydrazine (thruster fuel) contacting moisture, most likely from the ambient air. Prior to STS-33, manifold #3 was evacuated to service the thruster propellant. Previous failure analysis determined that evacuation of the manifold leads to drawing of moisture through the thruster valves and results in contamination of valve poppets. Valve contamination is the primary cause of nearly all thruster failures. STS-33 thruster L3A operation was nominal. In December 1989, visible vapors were seen emanating from L3A. Vapor concentrations were deemed borderline nominal; however, visible vapor is a rare occurrence. Failure analysis of L3A at Marquardt, the thruster vendor, confirmed valve leakage using helium at low pressure. A computer-enhanced x-ray showed something between the pilot poppet and seat, causing the poppet to be held open approximately 0.004". A force deflection test demonstrated normal mainstage movement, but higher than normal force on the pilot stage. Dragging was also witnessed during closing of the pilot stage. Initial failure analysis found "gelatinous"

STS-31 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
2 (Continued)		iron nitrate contamination in the valve assembly. The valve was cut open, revealing gross metallic nitrates deposits around the pilot poppet. A tiger team was convened to review thruster failures and to formulate recommendations to reduce future problems. One fix already in work is the universal throat plug. The plug has been designed to completely seal the thruster throat from water/moisture intrusion and is considered to be the primary means for eliminating thruster problems.
3	Supply water tank "C" bellows anomaly. IFA No. STS-31-04	During prelaunch, water tank "D" normally drains into tank "C". On orbit, tanks "C" and "D" failed to equalize quantities per normal operation. It was suspected that the tank "C" bellows was stuck in the fill position. Water was drained from tanks "C" and "D" through Flash Evaporator System (FES) "B" in an attempt to free the stuck bellows. This worked, and the water quantities equalized. Water tank "C" was tested at KSC with no repeat of the on-orbit anomaly. Tank troubleshooting found minor sticking of the bellows at the 100% position.
4	Water Spray Boiler (WSB) #2 vent heater "A" did not respond on orbit. IFA No. STS-31-05 HR No. ORBI-170	After operating erratically before launch, WSB #2A heater failed to respond when power was applied on-orbit. After attempting to cycle the heater commands, WSB #2B heaters were turned on and functioned properly for the remainder of the mission. Heater "A" was used for entry; it operated but was slower than normal in increasing temperatures and cycled irregularly. Previous failures occurred on STS-33, STS-34, and STS-36. Postflight troubleshooting of WSB #2 heaters and controllers at KSC found tile in contact with the nozzle. Temperature profile tests showed tile acting as heat sinks.

STS-31 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
5	Fuel Cell (FC) #2 Oxygen (O_2) flow rate was high during purge. IFA No. STS-31-06 HR No. ORBI-285	During FC #2 purge operations, the O_2 flow rate was high for approximately 22 seconds (sec), reaching a maximum rate of 12 pounds per hour (lb/hr). O_2 flow rates returned to normal after this short excursion. A problem with the integrated dual gas regulator was suspected. Resolution of this anomaly and failure analysis required removal and replacement of FC #2. Regulator teardown and inspection at the vendor found minor contamination, but nothing that should cause this failure. The regulator was reassembled and installed in a fuel cell for further testing.
6	APU #3 fuel pump bypass heater "A" failed "on". IFA No. STS-31-08 HR No. ORBI-250	During Flight Control System (FCS) checkout prior to reentry, APU #3 fuel pump bypass heater "A" temperature ramped up to approximately 196°F and tripped a fault detection alarm. The system was reconfigured to heater "B", and the bypass temperature returned to the normal range. APU #3 bypass heater "A" had operated erratically during STS-33. A decision was made not to replace the thermostat prior to STS-31 because APU #3 was scheduled for replacement after this mission. Therefore, this anomaly was expected. Heater/thermostat repair was subsequently performed by the vendor.

STS-31 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
ORBITER		
7	Air Data Transducer Assembly (ADTA) #3 circuit breaker contamination. IFA No. STS-31-12	During checkout prior to reentry, ADTA #3 was bypassed on transition to software mode OPS 8. Indications were that ADTA #3 had no power. The crew cycled the associated circuit breaker 5 times with no success. An additional 5 cycles were required to restore power to ADTA #3. The circuit breaker worked as designed during the remainder of reentry preparations. The additional cycles violated Flight Rules and Operational Maintenance Requirements and Specifications Document (OMRSD) requirements that were established to clear possible contamination in circuit breakers. Contamination problems had been experienced several times during flight and turnaround operations. Since Flight Rule and OMRSD limits of 5 cycles to restore power through a circuit breaker were exceeded, and the ADTA is a Crit 1 function; removal and replacement was required.
8	Missing seal material from trailing edge of elevon flipper doors #5 and #6. IFA No. STS-31-15 HR No. ORBI-003	Postflight inspection of OV-103 found seal material missing from the trailing edge of Right-Hand (RH) elevon flipper doors #5 and #6. Further inspection found the bulb seal from flipper door #5 in the upper elevon cove area. The ring retainer for flipper door seal #6 was not found. Retainer hardware on flipper doors #5, #6, #12, and #13 were found to be installed backwards. An inspection of flipper doors #5 and #6 for heat effects was performed. Inspection of OV-104 revealed that Left-Hand (LH) door #2 seal was backwards. Retainers on doors #4 and #6 of OV-102 were also found to be backwards. Repairs were to be made to OV-104 and OV-102 prior to flight. An investigation is underway to determine why retainers have been incorrectly installed. The associated job card has been modified to include an installation diagram.

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ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
SSME		
1	Engine #2031 High-Pressure Fuel Turbopump (HPFTP) seal fragments. IFA No. STS-31-E-02 HR No. ME-D3 (All Phases)	During postflight inspection of STS-31/OV-103 Main Engine (ME)-2, engine #2031, disassembly of HPFTP #6102R1 revealed 2 different sections of the pump-end outboard static seal were missing: 3.3" and 0.7" circumferential lengths, respectively. The HPFTP mount ring static seal has an approximate total circumferential length of 39.9" and is fabricated of Inconel X-750 with gold plating. One piece of the missing seal material, measuring 0.47" long x 0.45" wide x 0.026" deep, was found and removed from joint G3 of the High-Pressure Oxidizer Turbopump (HPOTP). This piece is believed to have migrated to the HPOTP (turbine side) subsequent to engine shutdown (zero-g environment, post-MECO). During operation, fragments from the static seal could enter the hot gas flow. Fragments of the size missing from the HPFTP #6102R1 seal would not affect HPFTP performance and would be of insufficient mass to cause downstream damage. It is postulated, however, that fragments have the potential to migrate to the Liquid Oxygen (LOX) hot-gas manifold in a zero-g environment. This migration could result in damage to the heat exchanger coil when the engine is next started. The scenario needed to result in this damage requires a "smart" particle to strike a turbine blade in such a way as to gain sufficient velocity to impact the heat exchanger. Heat exchanger impact tests showed potential coil punctures with fragment masses greater than 0.06 grams. Of the total seal material missing, 2 pieces were found in the main injector plus the piece found at HPOTP joint G3, accounting for a net mass of 0.25 grams. A net mass of 0.35 grams remained unaccounted for.

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
SSME		
1 (Continued)		A review of the static seal test history found 53 cases of cracked outboard seal cracks, with 5 cases where seal segments were missing. These cases were determined from a data base of 83 dual pilot housing builds with a total of 434 starts and 168,638 sec of operation. Missing pieces ranged from 0.5" on HPFTP #2105 with 7 starts and 3,432 sec of operation, to 6.0" on HPFTP #4204 with 6 starts and 2,323 sec of operation. HPFTP #6102R1 had 6 starts and 3,135 sec of operation.

STS-31 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
SRB		
1	LH Solid Rocket Booster (SRB) Integrated Electronic Assembly (IEA) dislodged at water impact. IFA No. STS-31-B-01	The LH SRB aft IEA was torn loose from its mounting brackets due to water impact forces. The IEA is held in place by attached electrical cables. The STS-31 ascent profile was the highest in flight history resulting in the SRBs achieving a greater altitude than previously experienced. Because of the higher altitude, descent speeds were greatly increased. Increased speeds led to high water impact loads. Damage to the IEA will most probably take it out of flight status. The damage included: • Fractured IEA mounting flanges (internal IEA pressure was maintained). There was also visible deformation of both the forward and aft ET attach ring webs at the IEA location. • All of the cables on the strut side and 10 of the 19 cables on the tunnel side were severed, leaving the IEA attached by only 9 cables. These cables were then purposely cut by the divers. • Loss of 3 ET attach ring IEA box covers, 2 angle brackets, and 1 cable tie bracket. Analysis of the failure mechanisms supports water impact as the cause. Shear patterns were seen on IEA cover bolts, and the fracture orientation of the IEA flanges was indicative of high-impact loads. Evaluation of IEA flanges found brittle cleavages across the entire flange, and there was no indication of an old crack or defective casting. Analysis of the applied loads indicated that forces originated aft of the IEA, forcing it forward. This is a reuse issue only.

STS-31 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>SRB</u>		
2	Loose SRB ordnance ring-to-frustum fastener assemblies. IFA No. STS-31-B-02 HR No. INTG-081A	During postflight disassembly of STS-31 SRBs, all of the ordnance ring-to-frustum fastener assemblies on the RH SRB were found loose. Twenty of the same fasteners were found to be loose on the LH SRB. Preliminary investigation found the frustum flange thickness to be 0.450" to 0.491"; engineering drawing requirements call for the flange to be 0.490" to 0.510". Data indicated that the cause of the loose fasteners might be associated with this out-of-specification flange thickness. Further evaluation exonerated the flange thickness because adequate fastener grip was maintained. The reduction in preload was considered to be the principal factor responsible for this anomaly. The reduction in preload was attributed to washer deformation caused by descent loading (drogue loads put the fastener assemblies in tension which reduces preload). The nuts were fully engaged on the bolts with at least 2 protruding threads. Ascent loads are compressive; therefore, the integrity of this joint is not dependent on preload during ascent. Loss of preload during descent has no effect on joint integrity. This determination was based on worst-case Design Certification Review (DCR) of deployment loads which resulted in determination of a Factor of Safety (FOS) greater than 4.0 for the fastener assemblies.

STS-31 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
SRB		
3	Range Safety System (RSS) crossover box and cable discoloration. IFA No. STS-31-B-03 HR No. B-60-12 Rev. C-DCN5	Postflight assessment of the STS-31 SRBs found that the RSS crossover brackets on both SRBs were sooted in the area of the P2 connector jam nut. The left P2 connector backshell was also sooted. Ballooning of the heat shrink tubing was also observed on 1 cable in the right SRB RSS transition housing. Thermal analysis of the sooted area showed that there was not sufficient heating during ascent to cause the effects seen inside the RSS transition housing. Sooting was evident on areas of connectors and other housing components that could only occur during descent. This condition was noted on previous missions and was documented in the SRB postflight assessment manual for STS-41G. This problem is listed as an STS-31 IFA to record this first-time event since return to flight. The concern is that discoloration could occur during ascent. The worst-case effect would be loss of cross-strapping capability of the RSS. However, it was determined that there is no way that the RSS can be initiated due to this anomaly. It was also determined that there is neither sufficient heating nor physical evidence to support the occurrence of sooting during ascent. Ballooning at the heat shrink tubing can occur during ascent due to delta pressure and is not considered a problem. Analysis has determined that corrective action is not required. An enhancement of the RSS transition housing is being evaluated. This problem is a Crit 3 failure.

STS-31 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
<u>SRB</u>		
4	Left SRB aft skirt missing some Thermal Protection System (TPS). IFA No. STS-31-B-04 HR No. B-70-02 Rev. C C-70-07 Rev. A-DCN4	STS-31 postflight assessment of the SRBs found missing TPS on the LH aft skirt. Areas with missing TPS were either missing K5NA over Marshall Trowellable Ablator (MTA)-2 or missing MTA-2 over MTA-2 applications. These areas, ranging in size up to 4" x 10", were between the cork ramps of the mid-ring fastener head closeouts. Evaluation of the MTA-2 losses showed small affected areas with clean or lightly-sooted MTA-2 substrate. This condition is consistent with a late descent or water impact occurrence. Evaluation of K5NA losses showed small spalling-affected areas with sooted and/or heat-affected MTA-2 substrate. Thermal analyses and verification indicated that minor K5NA spalling can occur in flight, beginning at T+80 sec, due to aft skirt radiant heat loads on a thin K5NA application. There is a very low potential that minor K5NA loss could become a debris source subsequent to T+80 sec. There are no similar radiant heat loads experienced on SRB forward assemblies; no forward assemblies have this type of thin K5NA closeout. Application of K5NA over MTA-2 was discontinued in December 1989. Aft struts on STS-35 and STS-40 are the only struts remaining with this type application. It was determined that the loss of MTA-2 on STS-31 occurred during descent or at water impact. The loss of K5NA occurred at T+80 sec or later and was not considered a probable debris source.

STS-31 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
SRM		
1	RH Solid Rocket Motor (SRM) nozzle cowl/outer boot ring separation. IFA No. STS-31-M-01 HR No. BC-10	During postflight inspection of the right SRM nozzle, the cowl/outer boot ring joint was separated, showing a gap of 1.8" at 216° decreasing to 0" at 120°. The separation was greater than that seen on previous flight motors. Cowl/outer boot ring bond line separations typically occur during SRM static tests and in flight nozzles at the end of motor tailoff. Separation gaps are typically 0.1-0.2". Indications are that the separation occurred after motor burnout, based on the observation that there was no evidence of flow, erosion, or heat effects within the separation and no soot or slag in the separation gap. Additionally, the phenolic edges on the cowl and the outer boot ring were sharp; heat effects during motor burn would round and dull the edges. Of 25 SRMs built and tested/flown, 2 had separations beyond what is considered typical (0.1"-0.2"); STS-34 SRM #10B which had a 0.58" bond line separation (max) at 225° and this STS-31 instance with 1.8" separation (max). Ten of 55 high-performance motors have had displaced outer boot rings. Displaced outer boot rings are usually caused by delta pressure in the flex boot cavity during motor tailoff. The cowl vent holes tend to plug with slag such that cavity pressure cannot track chamber pressure during the rapid motor depressurization that occurs during tailoff. Displaced rings can also be caused by heat soak and thermal stresses which can fail the adhesive bond during reentry. Splashdown load can aggravate the condition, causing greater separation opposite the actuators. The STS-31 SRMs/SRBs probably experienced the highest splashdown loads to date. The function of the outer boot ring is to provide thermal protection to the flex bearing and adjacent O-ring seals. By design, the outer boot ring need only retain hoop continuity and remain attached to the cowl until motor tailoff.

STS-31 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
SRM		
1 (Continued)		Conservative thermal analysis performed by Thiokol showed that outer boot ring adhesive separation after 110 sec will not affect flex bearing safety margin or reuse. The Configuration End Item (CEI) specification was updated to reflect the functional requirements of the outer boot ring. The requirement is that the outer boot ring retain hoop continuity and remain attached to the cowl until the beginning of motor tailoff (110 sec). The outer boot ring can be unbonded and broken after 110 sec and meet all CEI specification requirements. A deviation (RDW-0601) was approved for all SRMs to allow the 2.0 FOS requirement for the outer boot ring adhesive bond to be violated after 70 sec; RDW-0601 indicates that the worst-case FOS for the adhesive bond after 70 sec can be as low as 1.0. The STS-31 nozzle condition is understood and has no impact on flight safety. STS-31 nozzle hardware met all CEI specifications. There were no materials or processes anomalies identified. The only discriminator identified was water impact (geyser over 200-feet tall) which does not affect the safety of future flights.

STS-31 INFLIGHT ANOMALIES

ELEMENT/ SEQ. NO.	ANOMALY	COMMENTS/RISK ACCEPTANCE RATIONALE
KSC		
1	MPS Liquid Oxygen (LO_2) outboard fill and drain valve close failure. IFA No. STS-31-K-01 HR No. INTG-085A	During the second STS-31 launch attempt, the ground launch sequencer issued a command at T-48 sec to close the outboard fill and drain valve. This command was not sent to the vehicle because prerequisite control logic was active which verifies that the LO_2 transfer feed line purge valve is closed. The result was a hold at the T-31 sec point because confirmation of outboard fill and drain valve closure was not available. This was not a software problem as previously reported. Subsequently, the fill and drain valve was manually commanded closed and was verified by software, and the count was resumed. As a result of the power outage experienced during the STS-31 pad testing, it was decided to activate the feedline purge on the LO_2 transfer feedline to prevent any hammer effect if power was lost and the External Tank (ET) had to be drained. This purge was manually activated at approximately T-100 sec. A deviation to S0007 was written and approved to allow the manual activation of the purge. However, the fix to the potential power loss problem, approved in the deviation, was not tested prior to the launch attempt. Corrective action is in work for future flights to determine an alternative for protecting against hammer effects at loss of power.

SECTION 8

BACKGROUND INFORMATION

This section contains pertinent background information on the safety risk factors and anomalies addressed in Sections 3 through 7. It is intended as a supplement to provide more detailed data if required. This section is available upon request.

APPENDIX A

LIST OF ACRONYMS

AA/OSF	Associate Administrator, Office of Space Flight
AC	Alternating Current
AD	Aperture Door
ADTA	Air Data Transducer Assembly
AFB	Air Force Base
AMOS	Air Force Maui Optical Site
APM	Ascent Particle Monitor
APU	Auxiliary Power Unit
AS	Aft Shroud
ATP	Acceptance Test Procedure
BFS	Backup Flight Software
CA	California
cc/sec	Cubic Centimeters Per Second
CEI	Contract End Item Configuration End Item
CR	Change Request
CRES	Corrosion Resistant Steel
CRT	Cathode Ray Tube
CV	Check Valve
DCR	Design Certification Review
DCS	Debris Containment System
DFRC	Dryden Flight Research Center
DoD	Department of Defense
DTO	Development Test Objective
EAFB	Edwards Air Force Base
ECP	Engineering Change Proposal
EDT	Eastern Daylight Time
EMU	Extravehicular Mobility Unit
EPA	Environmental Protection Agency
ES	Equipment Section
ET	External Tank
ETA	External Tank Attach External Tank Attachment

LIST OF ACRONYMS - CONTINUED

F	Fahrenheit
FASCOS	Flight Acceleration Safety Cutoff System
FC	Fuel Cell
FCHL	Flight Control Hydraulics Laboratory
FCL	Freon Coolant Loop
FCS	Flight Control System
FD	Flight Day
FEC	Field Engineering Change
FES	Flash Evaporator System
FGS	Fine Guidance Sensor
FHST	Fixed Head Star Tracker
FMEA/CIL	Failure Modes and Effects Analysis/Critical Items List
FOC	Faint Object Camera
FOS	Factor of Safety
FOV	Field-of-View
fps	Feet Per Second
FRI	Flow Recirculation Inhibitor
FRR	Flight Readiness Review
FRT	Flight Readiness Test
FS	Forward Shell
FSS	Flight Support System
ft	Feet
ft-lb	Foot-Pound
GFE	Government Furnished Equipment
GGVM	Gas Generator Valve Module
GN_2	Gaseous Nitrogen
GPC	General Purpose Computer
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
H_2	Hydrogen
HCF	High-Cycle Fatigue
HDP	Holddown Post
HPF	High-Pressure Fuel
HPFTP	High-Pressure Fuel Turbopump
HPOTP	High-Pressure Oxidizer Turbopump
HPU	Hydraulic Power Unit
HR	Hazard Report
hr	Hour
HRS	High Resolution Spectrograph
HST	Hubble Space Telescope

APPENDIX A

LIST OF ACRONYMS - CONTINUED

ICBC	IMAX Cargo Bay Camera
IEA	Integrated Electronic Assembly
	Instrument and Electronic Assembly
IFA	Inflight Anomaly
in-lb	Inch-Pound
in^3	Cubic Inch
INTG	Integration
IPMP	Investigations into Polymer Membrane Processing
IRD	Integrated Receiver/Decoder
JSC	Johnson Space Center
KSC	Kennedy Space Center
L-2	Launch Minus 2 Days (Review)
lb	Pound
lb/hr	pounds per hour
lbf	Pounds Force
LCC	Launch Commit Criteria
	Launch Control Center
LCF	Low-Cycle Fatigue
LH	Left-Hand
LH_2	Liquid Hydrogen
LO_2	Liquid Oxygen
LOX	Liquid Oxygen
LPFTP	Low-Pressure Fuel Turbopump
LPOTP	Low-Pressure Oxidizer Turbopump
LPS	Launch Process Sequencer
LS	Light Shield
LSFR	Launch Site Flow Review
MCC	Main Combustion Chamber
	Mission Control Center
ME	Main Engine
MEC	Main Engine Controller
MECO	Main Engine Cutoff
MFV	Main Fuel Valve
min	Minute
MLP	Mobile Launch Platform
MOC	Mission Operations Center
	Mission Operational Computer
MPS	Main Propulsion System
MPSS	Main Parachute Support Structure
MRB	Material Review Board

APPENDIX A

LIST OF ACRONYMS - CONTINUED

MSE	Mission Safety Evaluation
msec	Millisecond
MSFC	Marshall Space Flight Center
MTA	Marshall Trowellable Ablator
MTA-2	Marshall Trowellable Ablator No. 2
N_2O_4	Nitrogen Tetroxide
NASA	National Aeronautics and Space Administration
NCR	Noncompliance Report
NLG	Nose Landing Gear
nmi	Nautical Mile
NSLD	NASA Shuttle Logistics Depot
NSRS	NASA Safety Reporting System
O_2	Oxygen
OI	Operational Instrumentation
OMI	Operations and Maintenance Instruction
OMRSD	Operational Maintenance Requirements and Specifications Document
OMS	Orbital Maneuvering System
OPF	Orbiter Processing Facility
OPO	Orbiter Project Office
OPOV	Oxidizer Preburner Oxidizer Valve
ORBI	Orbiter
ORU	Orbital Replaceable Unit
OSMQ	Office of Safety and Mission Quality
OTA	Optical Telescope Assembly
OV	Orbiter Vehicle
P/N	Part Number
PCG	Protein Crystal Growth
PCV	Pulse Control Valve
PFS	Primary Flight Software
ppm	Parts Per Million
PR	Problem Report
PRCB	Program Requirements Control Board
PRSD	Power Reactant Storage and Distribution
psi	Pounds Per Square Inch
psi/hr	Pounds Per Square Inch/Hour
psia	Pounds Per Square Inch Absolute
psid	Pounds Per Square Inch Differential
psig	Pounds Per Square Inch Gage
QC	Quality Control
QD	Quick Disconnect

APPENDIX A

LIST OF ACRONYMS - CONTINUED

RCS	Reaction Control System
RF	Radio Frequency
RGA	Rate Gyro Assembly
RH	Right-Hand
RI	Rockwell International
RM	Redundancy Management
RME	Radiation Monitoring Equipment
RMS	Remote Manipulator System
RSRM	Redesigned Solid Rocket Motor
RSS	Range Safety System
RSU	Rate Sensor Unit
RTLS	Return-to-Launch Site
S/N	Serial Number
SA	Solar Array
sccm	Standard Cubic Centimeters Per Minute
scfm	Standard Cubic Feet Per Minute
SE	Student Experiment
sec	Second
SI	Scientific Instrument
SOV	Shutoff Valve
SR&QA	Safety, Reliability, and Quality Assurance
SRB	Solid Rocket Booster
SRM	Solid Rocket Motor
SSM	Support System Module
SSME	Space Shuttle Main Engine
SSRP	System Safety Review Panel
SSV	Space Shuttle Vehicle
TAL	Transatlantic Abort Landing
TEM	Test and Evaluation Motor
TPMS	Tire Pressure Measurement System
TPS	Thermal Protection System
TPTA	Transient Pressure Test Article
TSM	Tail Service Mast
TWX	Teletype Wire Transmission
U/N	Unit Number
UPS	Uninterruptable Power Supply
USBI	United Space Boosters, Inc.

APPENDIX A

LIST OF ACRONYMS - CONTINUED

V/m	Volts/Meters
VAB	Vehicle Assembly Building
VAC	Volts Alternating Current
WCS	Waste Collection System
WF/PC	Wide Field/Planetary Camera
WPAFB	Wright Patterson Air Force Base
WSB	Water Spray Boiler
WWMS	Waste Water Management System