JSC Safety and Mission Assurance Space Shuttle Program Legacy Report

A legacy is something from the past that is passed on to a beneficiary. It is the hope of the S&MA community that the graphics in this report will provide instant visibility for lessons learned, which can be quickly assimilated and applied to future human spaceflight programs.

PURPOSE

❑ Share lessons learned on Space Shuttle Safety and Mission Assurance (S&MA) culture, processes, and products that can guide future enterprises to improve mission success and minimize the risk of catastrophic failures.

❑ Present the chronology of the Johnson Space Center (JSC) S&MA organization over the 40-year history of the Space Shuttle Program (SSP) and identify key factors and environments which contributed to positive and negative performance:

  ➢ Staffing skills/qualifications
  ➢ Budget
  ➢ Paradigms
  ➢ Requirements
  ➢ Program interfaces and expectations
  ➢ Communications
  ➢ Proactive/reactive processes
  ➢ Lessons learned

APPROACH

❑ Capture the findings of the formally-chartered boards that reviewed the Space Shuttle Program following the *Challenger* and *Columbia* incidents.

❑ Interview S&MA and program workers and managers from the past and present.

❑ Focus on culture, processes, and products.

   ➢ Evaluate the S&MA culture, processes and products that existed at times of successes and failures.

   ➢ Review the evolution of S&MA processes and products.

   ➢ Identify actions that ultimately transformed the JSC S&MA organization into an effective contributor to the shuttle program team.

❑ Use graphics to provide instant visibility of lessons learned and significant incidents during the Space Shuttle Program, so lessons learned can be quickly assimilated and applied to future human spaceflight programs.

KEY FACTORS

❑ Culture
- ➢ History of significant S&MA funding fluctuations, driven by accidents and periods of mission success.
- ➢ An organizational shift to a program support structure (SSP, ISS, CxP, etc.) versus a discipline structure (Safety, Reliability, Quality Assurance) improved S&MA relationships with the program offices and increased overall S&MA effectiveness.
- ➢ Established Program S&MA office – Integrated S&MA across centers

❑ Processes
- ➢ Risk analysis processes evolved over time and were eventually utilized in SSP decision-making forums.
- ➢ The establishment of the S&MA Technical Authority (STA) in 2004 resulted in a more focused role for the safety community in SSP risk decisions.

❑ Products
- ➢ Maturing of probabilistic risk assessment (PRA) and other analysis techniques improved the quality of risk assessments and overall effectiveness of S&MA.
- ➢ Risk assessment and risk trade skills improved over time and were better utilized near the end of the program.

CONCLUSIONS

❑ An effective S&MA organization identifies and recommends risk-based solutions to problems and is not merely a compliance organization ("yes if" vs. "no because).

❑ In order to be relevant, a safety organization must produce and deliver high quality risk analysis products (both quantitative and qualitative) to be utilized by both S&MA and program management in the decision making process.

❑ The establishment of the S&MA Technical Authority was effective in addressing a number of deficiencies within the S&MA community.
  ➤ Improved the appeal path for dissenting opinions.
  ➤ Led to a more technically competent S&MA organization due to improved relationships and interface with the engineering community.
  ➤ Addressed limited S&MA career path by providing high-profile technical leadership positions within the S&MA organization.

CONCLUSIONS (cont.)

❑ The integration of program S&MA functions across all participating centers has increased organizational effectiveness.

➢ Better coordination and sharing of technical data resulted in improved timeliness and quality of S&MA risk assessments.

➢ Early coordination and resolution of technical issues resulted in better S&MA support to the SSP and Office of Safety & Mission Assurance.

❑ A process is needed to periodically assess the health of the S&MA organization, taking into consideration:

➢ Budget trends/staffing levels

➢ Personnel turnover

➢ Anomaly trends/close calls

➢ Use of dissenting opinion process

➢ Review of S&MA products

GRAPHICS

S&MA Space Shuttle Program Legacy Graphic

❑ Depicts the chronology of the S&MA function from the early SR&QA organization to the current S&MA configuration.

❑ Graphic is centered around a notional depiction of S&MA effectiveness over time.

❑ Annotations have been added to the timeline to explain variations and provide summaries of formal investigation committee reports.

❑ Information sources include interviews with current and past shuttle and S&MA employees, formal reports, and organizational/budget records.

Space Shuttle Program Significant Incidents Graphic

This graphic is extracted from the *Significant Incidents and Close Calls in Human Spaceflight* graphic to reflect only the Space Shuttle Program incidents. It is presented to characterize and better define the situational environment during the shuttle era from a risk awareness perspective.

NASA/JSC SAFETY AND MISSION ASSURANCE

Limited career path prestige and potential within Safety
Space Shuttle Program (SSP) controlled Safety funding
Safety products were not used to drive operations products (flight rules, crew procedures, etc.)
"Silent Safety" era
Rote compliance – "No, because …"

Brief period of Engineering Technical Base funding
S&MA products integrated into operations products.
S&MA

NASA HQ Office of Safety & Mission Assurance (OSMA) era

◊ 1986 Roger's Commission Report
Final report of the Space Transportation System Safety Risk Assessment Ad Hoc Committee, 1987
◊ Augustine Report, 1990
◊ Pate-Cornell Report, 1990

Culture
Limited career path potential within the Safety organization made it difficult to attract and retain skilled people. Safety organization must have similar career potential and support from human resources, including recruitment emphasis, to ensure a functional capability base.

Culture
Funding source impacts on Safety. A lack of independent funding can lead to Safety being compromised – "Don't bite the hand that feeds you." At the very least, safety needs to have independent funding for an independent assessment function to ensure that areas dependant on funding from the program are not being unduly influenced or compromised.

Products
Comprehensive safety requirements need to be developed and adopted at program inception. A comprehensive set of safety requirements are key to the success of a program. With the exception of a good set of reliability and quality requirements, such a set was lacking at the start of the shuttle program. Use of hazard analysis methodologies was also lacking. This resulted in the failure to identify and adequately control hazards early in the program.

Culture
Safety became a rote compliance organization. Rote compliance to requirements without regard for sound engineering judgment and risk trades gave SR&QA a bad reputation. This reputation has been very hard to overcome once established and hindered effectiveness and recruitment – "no one wants to be a traffic cop."

Culture
Office of Safety and Mission Assurance formed at NASA Headquarters.

Culture
Engineering Technical Base Funding

Products
Strong design requirements were in place and enforced:
- NHB 5300.4(1D-2)
- JSCM-8080
- NSTS 07700
- NHB 1700.7A

Process
Minimal communications within and between Safety organizations reduced integration and organizational effectiveness. Prior to the Challenger accident there was not a strong Level II SR&QA integration function.

Notional Strength/ Effectiveness of NASA S&MA for the Space Shuttle Program

Shuttle Program inherited a weak safety organization from Apollo. Years of mission success, budget pressure, and attrition had taken a toll.

Culture
"Silent Safety"

Loss of Challenger, STS-51L

Report of the Presidential Commission on the Space Shuttle Challenger Accident
"… faults include a lack of problem reporting requirements, inadequate trend analysis, misrepresentation of criticality and lack of involvement in critical discussions. A properly staffed, supported, and robust safety organization might well have avoided these faults and thus eliminated the communication failures."

Culture
Quality and Reliability disciplines were strong, proactive, and effective.

Process
Maintenance, logistics, and supportability analysis must start early and account for the impacts of ground processing cycles on time/life/cycle limits. Such analysis was not performed early in the program, which resulted in hardware life being used up on the ground.

Process
S&MA staffing levels and funding decreasing as flight rates rapidly increase.

Process
Safety not watching trend data such as time-cycle data.

Process
S&MA assigned a position in the MER to review and sign-off on CHITs.

Process
Unique and effective electrical, electronic, and electromechanical parts program.

Process
Certification by similarity can result in unforeseen problems. Be very cautious about certifying hardware by similarity, especially when safety is weak. Variations in design, materials, manufacture, operations, and operational environments may invalidate similarity assumptions.

Products
Safety products lagged the development process and were not considered to be in the critical path. Rather than being used to drive the design and operations, Safety products, such as hazard reports and FMEAs, were being used to document and justify the design and operation.

Products
Safety products must be available early if they are to influence design and operations. The hazard reports and FMEA/CILs for the shuttle program were always lagging behind the design process and therefore were ineffective in influencing the design and operation during the DDT&E phase of the program. Prior to the loss of STS-51L the flight rules and crew procedures were developed without them and did not even reference them.

Products
Extensive re-evaluation and update of existing FMEAs and CILs.

Culture
First flights (glide and powered) were crewed flights. Prior programs had always used non-crewed flights to validate design prior to risking crew.

Launch Rate by Year
Retrospective Risk | 1:10 1:10 1:10 1:10 1:10 1:10 1:18 → 1:34 1:35 1:35
Calendar Year | 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 **1986** 1987 1988 1989 1990

	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Major Spaceflight Programs		Apollo			Shuttle																	Space Station	
		Skylab		ASTP	↑ ASTP crew critically injured.																		

Vehicles
- OV99 Challenger — STA → Challenger — Crew and vehicle lost during launch of STS-51L (January 28, 1986)
- OV101 Enterprise — Congress approves Space Shuttle Program (April 1972) → Design & Construction / Approach and Landing Tests / Launch Site Interface Testing / On Display at Smithsonian Institute
- OV102 Columbia — Design & Construction / Launch Prep / Operational
- OV103 Discovery — Design & Construction / Launch Prep / Operational
- OV104 Atlantis — Design & Construction / Operational
- OV105 Endeavour — Design & Construction

Key Personnel
- NASA Administrator: Paine | Paine | Low | Fletcher | Frosch | Lovelace | Beggs | Graham | Fletcher | Truly
- AA Safety: OSMA did not exist at this time | Rodney
- JSC Center Director: Gilruth | Kraft | Griffin | Moore | Cohen
- Shuttle Program Manager: Thompson | Lunney | Aldrich | Kohrs | Nicholson
- Orbiter Project Manager: Cohen | Aldrich | Colonna | Germany
- Shuttle Safety Manager: Menear (NA) | McCarty (LA/NA) | Merrell (GA3/NA2)
- JSC S&MA Director: Raines | Harlan

Political Factors
- President: Nixon | Ford | Carter | Reagan | Bush
- Senate Majority: Democratic majority | Republican majority | Democratic majority
- House Majority: Democratic majority

Limited career path potential within Safety

Improving career path potential within Safety (Safety Technical Authority, Training, Rotations, etc.)

Brief period of Engineering Technical Base funding

Space Shuttle Program (SSP) controlled Safety funding

Safety products integrated into operations products.

Return to "Silent Safety"

Participatory S&MA

Rote compliance – "No, because …"

Changed to "risk-based" management of safety. "Yes, if …"

NASA HQ Office of Safety & Mission Assurance (OSMA) era

For a lesson learned to be beneficial, it must be captured and implemented in future programs in the form of requirements, organizational structures, and/or policies.

◊ Aldrich Report, 1992
◊ Agreement between the United States of America and the Russian Federation Concerning Cooperation in the Exploration and Use of Outer Space for Peaceful Purposes, 1992
◊ GAO: NASA Infrastructure, 1996
◊ GAO: NASA Workforce Reductions, 1996
◊ SSIAT, 1999
◊ NIAT, 2000
◊ Super Light Weight Tank Independent Assessment, 1997

April 2004 – Shuttle S&MA Office established (code MX w/ matrix support from NA/NC) – Integrated S&MA across centers
Sept 2004 – Governance model – established S&MA Tech Authorities (included previous IA org role – no more separate IA org)
S&MA Problem Investigation Team – Era of proactive support to the Mission Management Team

RAND
► A strong independent safety organization is critical to maintaining and/or improving safety.
► Establish an Independent Safety Assurance Office.
► Establish a "Three-Key CoFR" process in which NASA, the ISAO, and the operational contractor share.

NIAT
► Develop a Risk Management Plan.
► Develop tools to access, analyze, manage, and mitigate risk.
► Define "allowable risk" as a function of the program/project.
► The S&MA role should include: mandatory participation on prevention/resolution teams and in problem categorization, investigation of escapes and diving catches, and dissemination of lessons learned.
► Management needs to foster an environment where problems are raised without fear of reprisal.
► Develop methods of quantitative risk assessment.
► Quantitative methods of risk assessment and safety need to be integrated.
► Maintain and communicate a database of lessons learned.

Columbia Accident Investigation Board (CAIB) Report, 2003
◊ Government Mandatory Inspection Points (GMIPS): Independent Assessment Final Report, 2004
◊ NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond, 2005

Columbia Crew Survival Investigation Report, 2008

Culture
"… tendency to accept risk solely because of prior success." -SSIAT

Culture
~40% budget reduction over 10 years. -CAIB

Process
Various efforts to improve effectiveness of S&MA.

CAIB Report
► NASA is not functioning as a learning organization.
► NASA's safety culture has become reactive, complacent, and dominated by unjustified optimism.
► Careers in safety have lost organizational prestige.
► An Independent Safety Assurance function should be created that would hold one of "three keys" in the CoFR process … effectively giving this function the ability to stop any launch.
► Safety is largely dependent upon the SSP for funding.
► Detrimental organizational and cultural traits were allowed to form.
► Establish an independent technical engineering authority.
► NASA HQ OS&MA should have direct line authority over the entire SSP safety organization and should be independently funded.

Culture
• Established MX office – Integrated S&MA across centers.
• S&MA included in Chief Engineer's Council events.
• Changed to "risk-based" management of safety.
• SMSR process improvements – focus on risks (3x4 matrix), participation of Engineering.
• Utilized analytical tools for risk characterization and trade studies.
• Fostered a "Yes, if …" mindset rather than the old "No, because …" Offered alternative technical solutions if a disapproval or non-concur was submitted.
• Considered rationale and applicability of requirements rather than blind applicability – no longer just a "traffic cop" with iron checklist.

Culture
► Cooperation and Coordination within and between organizations is needed to increase organizational effectiveness - avoid "sandboxing."
Benefits: (1) Better coordination and sharing of technical data resulted in improved timeliness and quality of S&MA risk assessments.
(2) Earlier coordination and resolution of technical issues resulted in better S&MA support to the SSP and OSMA.
► Safety must be more than a rote compliance organization. (Rote compliance to requirements without regard for sound engineering risk trades reduced SR&QA's credibility.)
Benefits: Improved working relationship with other organizations and added real value to program mission support.

Culture
"Cultural traits and organizational practices detrimental to safety were allowed to develop…"

Culture
"… NASA is not functioning as a learning organization."

Culture
"… echoes of *Challenger* ..."

Loss of Columbia, STS-107

Process
• Risks were highlighted in a real-time manner.
• Developed the capability for rapid S&MA team response to significant events or anomalies.
• Set the expectation that all of the Safety Directorate was accessible to support real-time operations.

Process
► Safety must be involved early to be effective and must be committed to "near real-time/real-time" support for flight operations.
Benefits: Provided MMT with information needed for risk-based decision making.

Culture
ISS Phase 1 Manager asked for EVA operations safety reviews. Start of greater S&MA involvement in operational safety.

SSIAT
► The S&MA role should include: mandatory participation on prevention/resolution teams and in problem categorization, investigation of escapes and diving catches and dissemination of lessons learned.
► One causal factor is success-engendered safety optimism. The SSP must rigorously guard against the tendency to accept risk solely because of prior success.
► Risk Management process erosion created by the desire to reduce costs
► NASA S&MA should be restored to the process in its previous role of an independent oversight body, and not be simply a "safety auditor."
► SSP should systematically evaluate and eliminate all potential human single point failures.

Columbia Crew Survival Investigation Report
► During the design of the space shuttle, NASA focused on preventing an accident through high reliability and redundancy. As a result, traditional crew survival principles were not part of the SSP.
► Crew survival should be an integral part of all human spaceflight programs. Safety should extend beyond just preventing the accident and include provisions for minimizing the consequences of the accident.

Products
• Developed detailed Shuttle PRA model.
• Developed expertise and capability to quickly generate quantitative and qualitative risk assessments for significant technical issues and anomalies.
• Improved utility of traditional/heritage risk management tools (Hazards, CILs, etc).
• Broad implementation of risk analysis techniques (7 Elements of Flight Rationale)

Products
► Improve risk assessment capability through use of quantitative and qualitative risk assessment tools.
Benefits: Helped frame risk discussions and characterized Safety risks for program and agency management.

Products
Maturing of PRA and other S&MA risks tools increase contributions and effectiveness of SR&QA.

Culture
"… success-engendered safety optimism." -SSIAT

Culture
"Faster, Better, Cheaper"

Process
S&MA staffing shifts toward a better skills balance with training programs to increase effectiveness.

Process
Safety needs a balance between systems specialist and systems engineers to facilitate affective risk-based decision making.

Culture
Continuing budget reductions and workforce attrition.

Launch Rate by Year
Retrospective Risk

Effective August 31, 2011, the Space Shuttle Program becomes the Space Shuttle Transition and Retirement Office.

Shuttle
Space Station
Phase 2: 1st element launch
ISS
Phase 1: Shuttle-Mir
Constellation Program
Cancelled
Contingency Shuttle Crew Support era

On Display at Smithsonian Institute
† Crew and vehicle lost during entry of STS-107

Operational	OV99 Challenger
Operational	OV101 Enterprise
Operational	OV102 Columbia
Operational	OV103 Discovery
Launch Prep / Operational	OV104 Atlantis
	OV105 Endeavour
Truly	Goldin	O'Keefe	Griffin	NASA Administrator
Rodney	Gregory	O'Connor	AA Safety
Cohen	Huntoon	Abbey	Estess	Howell	Coats	JSC Center Director
Nicholson	Shaw	Holloway	Dittemore	Parsons	Hale	Shannon	Shuttle Program Manager
Germany	Greene	Dittemore	Roe	Poulos	McArthur	Stich	Orbiter Project Manager
Merrell (GA3/NA2)	Emminger (MA3/NA2)	Harris (MA)	Currie (MX)	Wilcutt (MX)	McArthur (MX)	Doremus (MX)	Shuttle Safety Manager
Harlan	Casper	Marshall	Wilcutt	JSC S&MA Director
Bush	Clinton	Bush	Obama	President
Democratic majority	Republican majority	Democratic majority	Republican majority	Democratic majority	Senate Majority
Democratic majority	Republican majority	Democratic majority	House Majority

Safety and Mission Assurance
Space Shuttle Program
Legacy Report

JSC Flight Safety Office

Significant Incidents and Close Calls in Human Spaceflight:
Space Shuttle Program

Challenger

Columbia

Legend box:

Mission — Date of Mission or Incident/Close Call (month/day/year or month/year)

STS-107   2/1/2003
TPS damage from ascent debris strike resulted in loss of crew and vehicle on entry.
Crew: 7   Loss of Crew

Summary

Red border with yellow shading – Loss of crew
Orange shading – Crew injury and/or loss of vehicle/mission
Blue Shading – Recurring event
Black text – No injury or loss of crew or vehicle

Crew Size

Significant Result

Earth Orbit

Ascent

Entry

Descent

Integration, Assembly, and Processing

Landing and Postlanding

TPS Entry Events (1981-2003):

STS-107   2/1/2003
TPS damage from ascent debris strike resulted in loss of crew and vehicle on entry.
Crew: 7   Loss of Crew

STS-51D   4/19/1985
TPS burn-through on left outboard elevon.
Crew: 7

STS-1   4/14/1981
Right-hand main landing gear door warped due to entry heating.
Crew: 2

Other significant STS TPS anomalies:
STS-6, 41B, 51G, 27*, 28, 40, 42, 45
* Most severe tile damage to date.

Left column (Ascent / early):

STS-134   5/6/2011
Small cylindrical object liberated from vehicle during ascent.
Crew: 6

STS-95   10/29/1998
Drag chute door separated during launch and impacted main engine bell.
Crew: 7

STS-91   6/2/1998
Main engine pressure chamber sensor failed. If it occurred later, logic error may have triggered an RTLS.
Crew: 6†/7↓

SRB Seal Events (1981-1996):

STS-51L   1/28/1986
SRB seal failure.
Crew: 7   Loss of Crew

Other SRB gas sealing anomalies: STS-2, 6, 11, 41D, 51C, 51D, 51B, 51G, 51F, 51I, 51J, 61A, 61B, 61C, 42, 71, 70, 78

STS-51F   7/29/1985
Temperature sensor problems resulted in Main Engine (ME-1) shutdown at T+ 5:45.
Crew: 7   Abort To Orbit

STS-112   10/7/2002
T-0 umbilical issues resulted in none of the 8 SRB Hold Down Post "A" pyrotechnic charges firing.
Crew: 6

STS-41D   6/26/1984
LH₂ fire after launch scrub. Evacuation by slidewire baskets considered but not used due to lack of confidence in a system that had not been tested with human subjects.
Crew: 6

STS-1   4/12/1981
SRB ignition pressure wave caused TPS and structural damage.
Crew: 2

STS-2 N₂O₄ Spill   9/22/1981
Ground half coupling failed due to iron nitrate buildup, resulting in release of 15-20 gallons of N₂O₄ onto vehicle, which damaged adhesive bond on 370 tiles.

STS-1 Anoxia   3/19/1981
Workers entered orbiter aft compartment unaware it was filled with nitrogen.
                    Loss of Life (3)
                    Injury (2)

Second column:

STS-114   7/26/2005
A) Bird-strike on External Tank.
B) Loss of foam from External Tank PAL ramp.
C) TPS gap fillers protruding. Removed during third mission EVA.
Crew: 7

STS-93   7/23/1999
A) At T+ 5 a short on AC1 Phase A resulted in loss of SSME 1 Controller A and SSME 3 Controller B.
B) ME-3 H₂ leak: early LOX depletion and shutdown.
Crew: 5

STS-133   2/26/2011
Experienced significant misalignment between orbiter and ISS during post-capture free drift due to gravity-gradient-induced motion.
Crew: 6

STS-130   2/10/2010
Experienced significant misalignment between orbiter and ISS during post-capture free drift due to gravity-gradient-induced motion.
Crew: 6

OPF2 Fire Deluge Soaks Orbiter   9/24/1989
While replacing a leaking valve, technicians inadvertently activated the OPF2 fire deluge system due to isolation valve handles not complying with industry convention.

Post-STS-6 FRCS MMH Spill   4/18/1983
Liquid MMH spilled onto technician when thruster ferry plug was removed. Low temperatures during ferry flight resulted in leaking valves.
                    Injury (1)

STS-2 OMS Pod MMH Fire   Fall 1981
MMH spilled onto MLI blanket containing gold foil. Gold foil catalyzed the MMH, resulting in fire.

N₂H₄ Spill after APU Hotfire   11/1979
Leak of approximately 2 gallons of N₂H₄ after hotfire in OPF1 due to incompatible material in gage saver fittings on servicing cart.

Third column:

STS-104   7/2001
EMU battery leaked hazardous KOH. Discovered during EMU checkout.
Crew: 5

STS-98   2/10/2001
EVA crew member sprayed with ammonia requiring decontamination procedures.
Crew: 5 (2 EVA)

STS-99   2/2000
High bacterial count in postflight sample after GIRA installed to removed iodine.
Crew: 6

ISS, Flight 2A.1   5/1999
Crew sickened in FGB; likely a result of high localized CO₂ levels due to poor ventilation.
Crew: 7

STS-95   10/29/1998
Preflight sterilization process chemically altered the Low Iodine Residual System resulting in contaminated drinking water.
Crew: 7

STS-91   6/2/1998
PASS corrupted by GPS error.
Crew: 6

STS-87   11/21/1997
Spartan satellite deployed without proper activation. Recapture with RMS failed. Later captured by EVA crew.
Crew: 6

Fourth column:

STS-83   4/6/1997
Failure of fuel cell number 2 resulted in minimum duration flight being declared. The 15-day mission was shortened to 3 days.
Crew: 7   Loss of Mission

STS-80   11/28/1996
Lose screw jammed airlock hatch preventing operation.
Crew: 5 (2 EVA)   EVA Terminated

STS-63   2/9/1995
EVA thermal system failed to protect hands of crew from extreme cold.
Crew: 2 EVA   EVA Terminated

STS-51   9/12/1993
Both port-side primary & secondary SUPER* ZIP explosive cords fired, resulting in containment tube failure and damage in the payload bay.
Crew: 5

STS-44   11/24/1991
Failure of IMU 2 caused minimum duration flight to be declared. 10-day mission shortened to 7 days.
Crew: 6   Minimum Duration Flight

STS-32   1/9/1990
Erroneous state vector up-linked to flight control system, causing immediate and unpredictable attitude control problems.
Crew: 5   Loss of Attitude Control

STS-9   12/8/1983
Two GPCs failed during reconfiguration for entry. One GPC could not be recovered.
Crew: 6

STS-2   11/12/1981
Fuel cell failure resulted in high levels of hydrogen in drinking water.
Crew: 2   Mission Terminated

EVA Inadvertent Releases:
Mission ID / EVA / # lost / year

STS-134/ULF6 / 2 / 4 / 2011
STS-133/ULF5 / 1 / 1 / 2011
STS-126/ULF2 / 1 / 24 / 2008
STS-124/1J / 2 / 1 / 2008
STS-120/10A / 4 / 2 / 2007
STS-116/12A.1 / 3 / 1 / 2006
STS-116/12A.1 / 1 / 1 / 2006
STS-115/12A / 2 / 1 / 2006
STS-115/12A / 1 / 1 / 2006
STS-121/ULF1.1 / 3 / 1 / 2006
STS-102/5A.1 / 1 / 2 / 2001
STS-104/7A / 3 / 1 / 2001
STS-100/6A / 2 / 1 / 2001
STS-92/3A / 3 / 1 / 2000
STS-101/2A.2a / 1 / 1 / 2000
STS-103/HST / 3 / 1 / 1999
STS-96/2A.1 / 1 / 1 / 1999
STS-88/2A / 2 / 3 / 1998
STS-88/2A / 1 / 4 / 1998
STS-I-I / 1 / 1 / 1985
STS-51-A / 2 / 2 / 1984
STS-41-G / 1 / 1 / 1984
STS-41-C / 2 / 1 / 1984

Fire/Overheating Events:
STS-40, 6/1991, Crew: 7 *
STS-35, 12/1990, Crew: 7 *
STS-28, 8/1989, Crew: 5 *
STS-6, 4/1983, Crew: 4 *
* toxic byproducts released

Right column (Descent / Landing):

STS-134   6/1/2011
Brief fire observed between the left main landing gear tires during runway rollout.
Crew: 7

STS-108   12/17/2001
Violation of minimum landing weather requirements.
Crew: 7

STS-90   5/3/1998
Hard, fast landing due to human factors and rogue wind gust. Hardest STS landing to date.
Crew: 7

STS-37   4/11/1991
Several factors contributed to a low-energy landing 623 feet prior to the threshold of the runway at the backup landing location.
Crew: 5   Low Energy Landing

STS-51D   4/19/1985
Right brake failed (locked-up) causing blowout of inboard tire and significant damage to outboard tire.
Crew: 7

STS-51D Fire   4/12/1984
Tire damage from spin-up wear and locked brake sufficient to pose explosion risk to ground crew.

STS-9 APU Fire   12/8/1983
APU hydrazine leak resulted in a fire in the aft compartment of the vehicle during landing and subsequent runway operations. The fire caused damage to and early shutdown of APUs 1 and 2.
Crew: 6

STS-3   3/30/1982
Pilot induced oscillation during derotation. Stronger than predicted winds contributed.
Crew: 2