# Space Mishaps

## Apollo 1, Apollo 13, Challenger, and Columbia

# Safety and Reliability Engineers

Provide the check and balance between Design Engineering and Systems Engineering to prevent catastrophic loss by identifying the single-failure points in systems.

- They support Systems, Design, Processing, Quality, Manufacturing, and Operations Engineers by
  - Anticipating failures by performing various analyses and making recommendations during the system's design phase.
  - Authoring new and revising existing safety requirements and standards.
  - Performing mishap investigations and/or failure analyses.
  - Supporting launch activities.
  - Documenting lessons learned.

KSC SAFETY & MISSION ASSURANCE

NASA JOHN F. KENNEDY SPACE CENTER

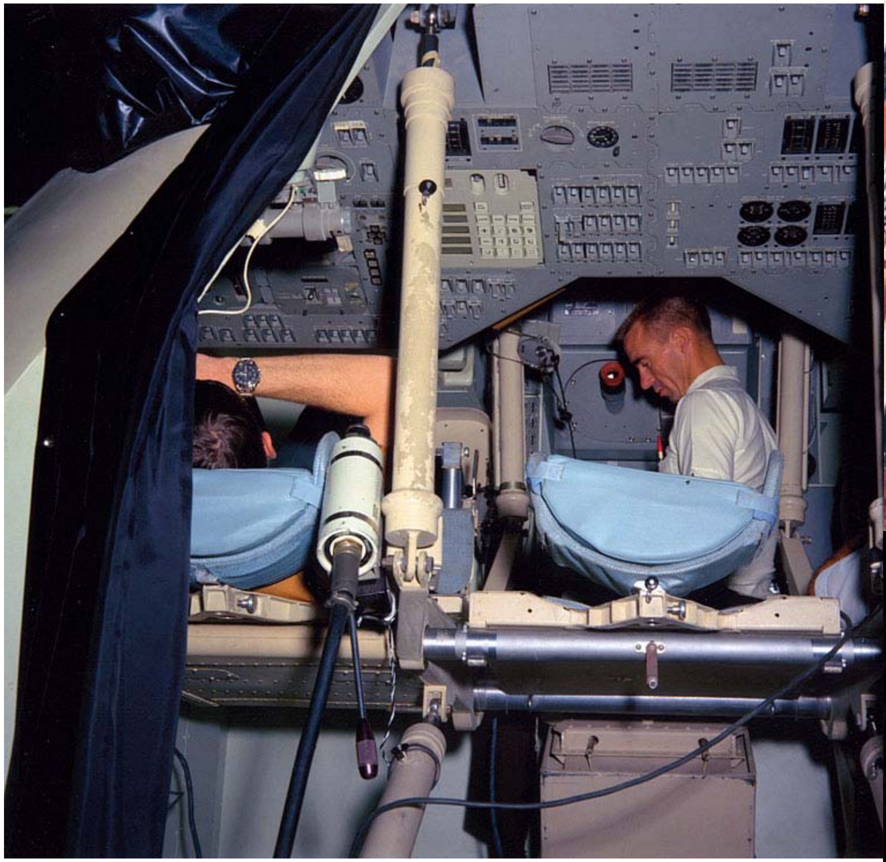
# Apollo 1

On January 27, 1967, tragedy struck the Apollo program when a flash fire occurred in command module 012 during a launch pad test of the Apollo/Saturn space vehicle being prepared for the first piloted flight, the AS-204 mission.

- Three astronauts died in this tragic accident.
  - Lt. Col. Virgil I. Grissom,
  - Lt. Col. Edward H. White, and
  - Roger B. Chaffee.

Source: NASA

# Apollo 1



# Apollo 1

## Contributing Factors and Root Cause

- The test cabin pressure was over 16 psi, almost 2 psi above the ambient sea level pressure and near the upper limits of measuring devices in the spacecraft. Following a worldwide survey of artificial oxygen-rich environments, it was found that rarely if ever had a 100% oxygen environment been created and maintained at such a high pressure. Note: A bar of aluminum can burn like wood in this environment.
- 34 square feet (3.2 $m^2$) of Velcro was installed throughout the spacecraft and Velcro was later found to be explosive in a high-pressure, 100% oxygen environment.
- Up to 70 lbs of other non-metallic, flammable materials had also been incorporated into the design.
- Substandard wiring and plumbing was found along with a misplaced socket wrench.
  - Sloppy workmanship, poor inspection, and inadequate safety design led to the accident.
    - A silver-plated copper wire was running through an environmental control unit near the Command Module pilot's couch which had become stripped of its Teflon insulation and abraded by repeated opening and closing of a small access door. This weak point in the wiring also ran near a junction in an ethylene glycol/water cooling line which was known to be prone to leaks. The electrolysis of ethylene glycol solution with the silver anode was a notable hazard which could cause a violent exothermic reaction, igniting the ethylene glycol mixture in the CM's corrosive test atmosphere of pure, high-pressure oxygen.
- In 1968, MIT physicists performed a static discharge test in the CM-103 command module of Apollo 8. With an electroscope, they measured the approximate energy of static discharges caused by a test crew dressed in nylon flight pressure suits and reclining on the nylon flight seats. The MIT investigators found sufficient energy for ignition discharged repeatedly when crewmembers shifted in their seats and then touched the spacecraft's aluminum panels. However, the ignition source for the Apollo 1 fire was never officially determined.

Source: Wiki Summary

# Apollo 1

## Design and Workmanship Changes made after Apollo 1

- At launch, the cabin atmosphere would be at sea-level pressure and consist of 60% oxygen and 40% nitrogen, lowering to 5 psi during ascent, and gradually changing over to 100% oxygen at about 2 psi during the first 24 hours of the trans-lunar coast.
- An explosive hatch would open outward in less than ten seconds. The redesigned hatch used a cartridge of pressurized nitrogen to drive the release mechanism in an emergency, as opposed to the pyrotechnic bolts used on Mercury.
- Flammable materials in the cabin were replaced with self-extinguishing versions.
- Plumbing and wiring were covered with protective insulation. 1,407 wiring problems were corrected.
- Nylon suits were replaced with suits made of early Beta cloth, a non-flammable, highly melt-resistant fabric woven from silica and coated with glass.
- Thorough protocols were implemented for documenting spacecraft construction and maintenance.

Source: Wiki Summary

# Apollo XIII

En route to the Moon, Mission Control had asked the crew to stir the hydrogen and oxygen tanks, destratifying the contents and increasing the accuracy of their quantity readings.

- The number two oxygen tank, one of two in the Service Module (SM), exploded.
- The resulting fire rapidly increased pressure beyond its nominal 1,000 PSI (7 MPa) limit and either the tank or the tank dome failed.
- All three astronauts survived.
  - James A. Lovell, Jr.
  - John L. Swigert, Jr.
  - Fred W. Haise, Jr.

[Source: Wiki Summary]

# Apollo XIII

## Contributing Factors and Root Cause

After an intensive investigation, the Apollo 13 Accident Review Board identified the cause of the explosion:

- In 1965, the CM had undergone many improvements, which included raising the permissible voltage to the heaters in the oxygen tanks from 28 to 65 volts DC. The thermostatic switches on the heaters weren't modified.
- During one final test on the launch pad, the heaters were on for a long period of time. "This subjected the wiring in the vicinity of the heaters to very high temperatures (1000 F), which have been subsequently shown to severely degrade teflon insulation. The thermostatic switches started to open while powered by 65 volts DC and were probably welded shut."
- Other warning signs during testing went unheeded and the tank, damaged from 8 hours of overheating, was a potential bomb the next time it was filled with oxygen.
  - That bomb exploded on April 13, 1970 -- 200,000 miles from Earth.

Source: NASA

# Apollo XIII

## Contributing Factors and Root Cause

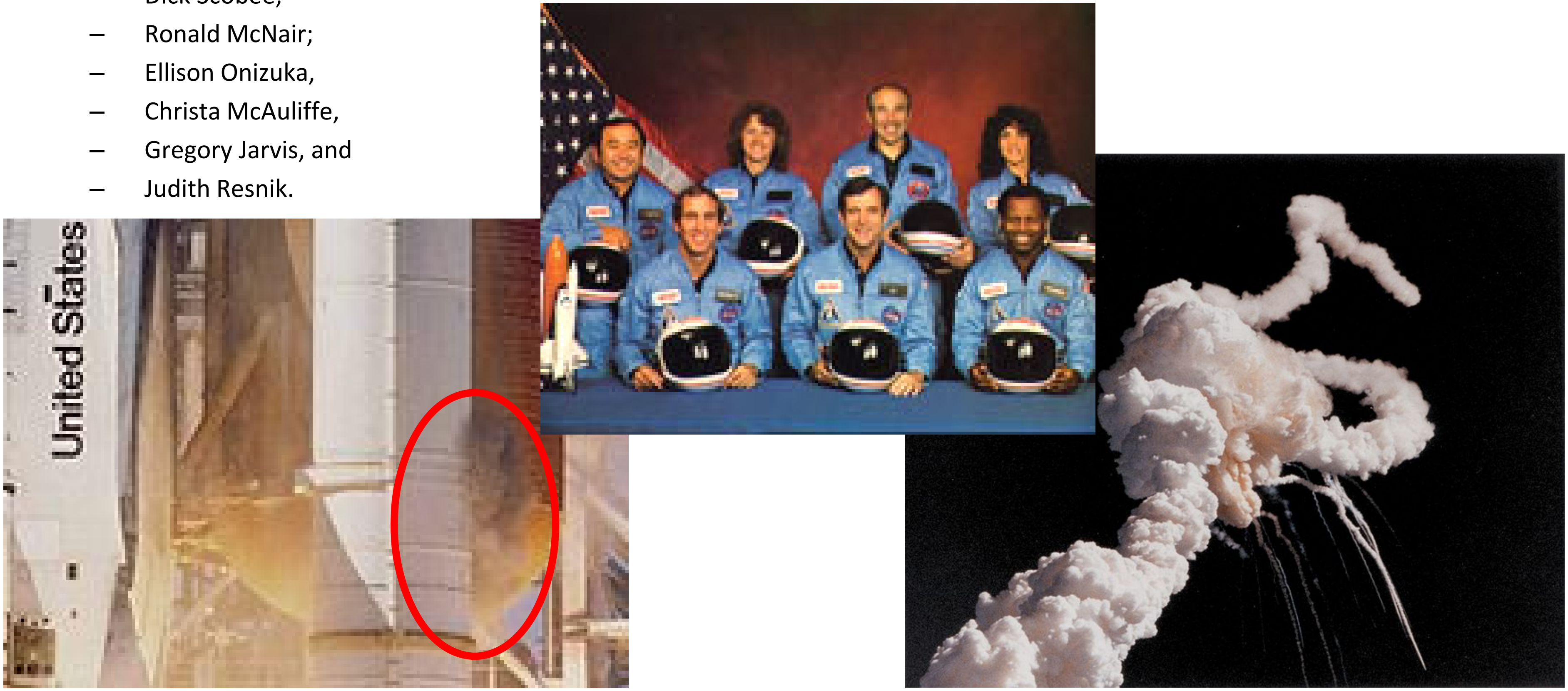
- Tank components relevant to the accident: a quantity sensor; a fan to stir the tank contents for more accurate quantity measurements; a heater to vaporize liquid oxygen as needed; a thermostat to protect the heater; a temperature sensor; and fill and drain valves and piping.
- The heater and protection thermostat were originally designed for the command module's 28-volt DC bus. However, their specifications were changed to allow a 65-volt ground supply to pressurize the tanks more rapidly. The thermostat was never upgraded to handle the higher voltage.
- The temperature sensor could not read above the highest operational temperature of the heater, about 100 °F (38 °C). Ordinarily, this was not a problem because the thermostat was designed to open at 80 °F (27 °C).
- The oxygen shelf carrying the oxygen tanks was originally installed in the Apollo 10 service module. It was removed to fix a potential electromagnetic interference problem. During removal, the shelf was accidentally dropped about 2 inches (5.1 cm) because a retaining bolt had not been removed. The tank appeared undamaged but a loosely fitting filling tube was apparently damaged, and photographs suggested that the close-out cap on the top of the tank may have hit the fuel cell shelf. The report of the Apollo 13 review board considers the probability of tank damage during this incident to be "rather low".
- After the tank was filled for ground testing, it could not be emptied through the normal drain line. To avoid delaying the mission to replace the tank, the heater was connected to 65V ground power to boil off the oxygen. Lovell signed off on this procedure. It should have taken a few days at the thermostatic opening temperature of 80 °F (27 °C). However, when the thermostat opened, the 65-volt supply fused its contacts closed and the heater remained powered. This raised the temperature of the heater to an estimated 1,000 °F (538 °C).
- A chart recorder on the heater current showed that the heater was not cycling on and off, as it should have been if the thermostat was functioning correctly, but no one noticed it at the time.
- Because the temperature sensor could not read higher than 100 °F (38 °C), the monitoring equipment did not register the true temperature inside the tank. The gas evaporated in hours rather than days.
- The sustained high temperatures melted the Teflon insulation on the fan power supply wires and left them exposed. Damaged insulation on the Teflon wires to the stirrer motor in oxygen tank 2 allowed them to short and ignite the insulation.
- When the tank was refilled with oxygen, it became a bomb waiting to go off. During the "cryo stir" procedure, fan power passed through the bare wires that had shorted, producing sparks and igniting the Teflon. This in turn boiled liquid oxygen faster than the tank vent could remove it.
- The other oxygen tank or its piping, located near the failed tank, was damaged allowing it to leak as well. Design changes included moving the tanks farther apart, adding a third tank, and an emergency battery to another sector in the service module.

Source: Wiki

# STS-51L - Challenger

On January 28, 1986, Space Shuttle Challenger broke apart 73 seconds into flight due to a poor joint seal in the Right Solid Rocket Booster.

- All seven of Challenger’s crew members perished in the accident.
  - Michael J. Smith,
  - Dick Scobee,
  - Ronald McNair;
  - Ellison Onizuka,
  - Christa McAuliffe,
  - Gregory Jarvis, and
  - Judith Resnik.



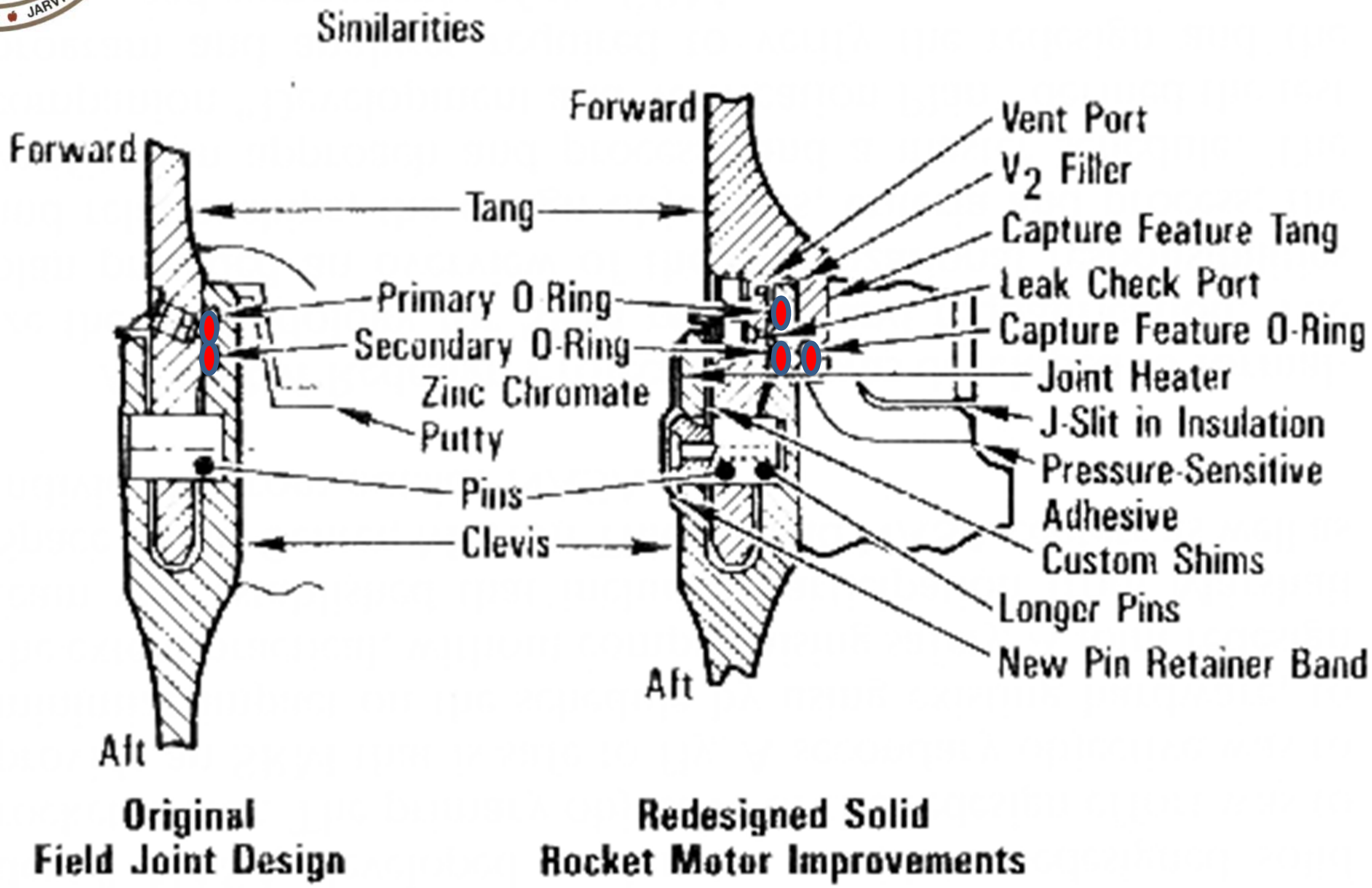
# STS-51L - Challenger

## Contributing Factors and Root Cause

- In the STS-51L design, the application of actuating pressure to the upstream face of the O-ring was essential for proper joint sealing performance because large sealing gaps were created by pressure-induced deflections, compounded by significantly reduced O-ring sealing performance at low temperature.
  - The major change in the motor case is the new tang capture feature to provide a positive metal-to-metal interference fit around the circumference of the tang and clevis ends of the mating segments.
  - The interference fit limits the deflection between the tang and clevis O-ring sealing surfaces caused by motor pressure and structural loads. The joints are designed so that the seals will not leak under twice the expected structural deflection and rate.

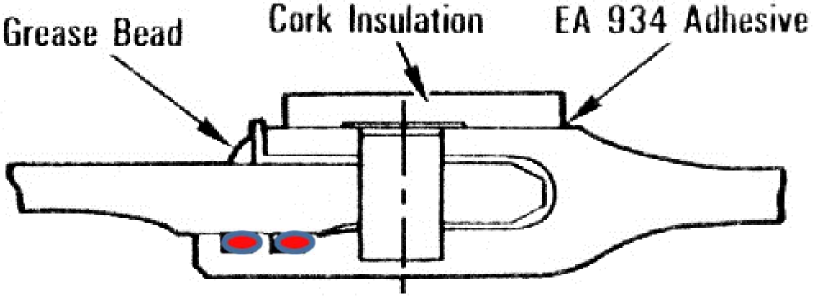
Source: NASA

# STS-51L - Challenger

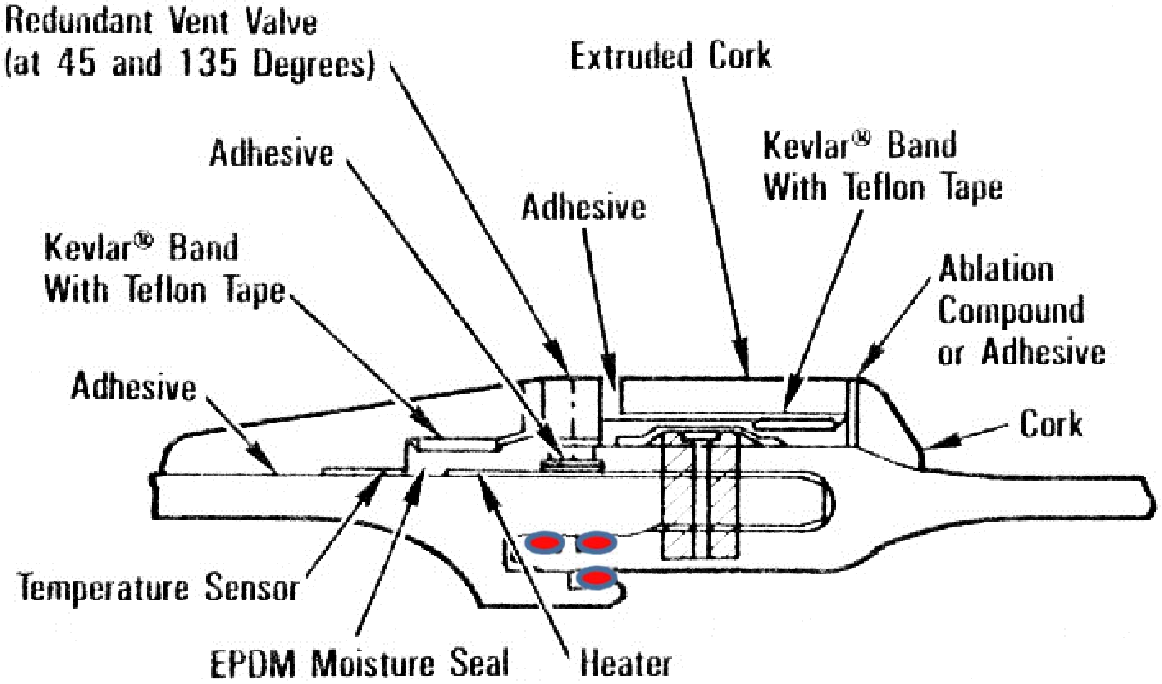


*Field Joint Comparison*

# STS-51L - Challenger



**Original Field Joint Design**



**Redesigned Solid Rocket Motor Field Joint**

*Field Joint Protection System*

# STS-51L - Challenger

## Solid Rocket Booster Design Changes

- The new design, with the tang capture feature, the interference fit, and the use of custom shims between the outer surface of the tang and inner surface of the outer clevis leg, controls the O-ring sealing gap dimension. The sealing gap and the O-ring seals are designed so that a positive compression (squeeze) is always on the O-rings. The minimum and maximum squeeze requirements include the effects of temperature, O-ring resiliency and compression set, and pressure. The clevis O-ring groove dimension has been increased so that the O-ring never fills more than 90 % of the O-ring groove and pressure actuation is enhanced.
- The new field joint design also includes a new O-ring in the capture feature and an additional leak check port to ensure that the primary O-ring is positioned in the proper sealing direction at ignition. This new, or third, O-ring also serves as a thermal barrier in case the sealed insulation is breached.
- The field joint internal case insulation was modified to be sealed with a pressure-actuated flap called a J-seal, rather than with putty as in the STS-51L configuration.
- Longer field-joint-case mating pins, with a reconfigured retainer band, were added to improve the shear strength of the pins and increase the metal parts' joint margin of safety. The joint safety margins, both thermal and structural, are being demonstrated over the full ranges of ambient temperature, storage compression, grease effect, assembly stresses and other environments. External heaters with integral weather seals were incorporated to maintain the joint and O-ring temperature at a minimum of 75 deg F. The weather seal also prevents water intrusion into the joint.
- The SRM case-to nozzle joint, which experienced several instances of O-ring erosion in flight, has been redesigned to satisfy the same requirements imposed upon the case field joint. Similar to the field joint, cast-to-nozzle joint modifications have been made in the metal parts, internal insulation and O-rings. Radial bolts with Stato-O-Seals were added to minimize the joint sealing gap opening. The internal insulation was modified to be sealed adhesively, and third O-ring was included. The third O-ring serves as a dam or wiper in front of the primary O-ring to prevent the polysulfide adhesive from being extruded into the primary O-ring groove. It also serves as a thermal barrier in case the polysulfide adhesive is breached. The polysulfide adhesive replaces the putty used in the STS-51L joint. Also, an additional leak check port was added to reduce the amount of trapped air in the joint during the nozzle installation process and to aid in the leak check procedure.

# STS-51L - Challenger

## Additional Design Changes Made to SRB Components

- **NOZZLE -** The internal joints of the nozzle metal parts have been redesigned to incorporate redundant and verifiable O-rings at each joint. The nozzle steel fixed housing part has been redesigned to permit the incorporation of the 100 radial bolts that attach the fixed housing to the case's aft dome. Improved bonding techniques are being used for the nozzle nose inlet, cowl/boot and aft exit cone assemblies. The distortion of the nose inlet assembly's metal-part-to-ablative-parts bond line has been eliminated by increasing the thickness of the aluminum nose inlet housing and improving the bonding process. The tape-wrap angle of the carbon cloth fabric in the areas of the nose inlet and throat assembly parts was changed to improve the ablative insulation erosion tolerance. Some of these ply-angle changes were in progress prior to STS-51L. The cowl and outer boot ring has additional structural support with increased thickness and contour changes to increase their margins of safety. Additionally, the outer boot ring ply configuration was altered.
- **FACTORY JOINT -** Minor modifications were made in the case factory joints by increasing the insulation thickness and lay-up to increase the margin of safety on the internal insulation. Longer pins were also added, along with a reconfigured retainer band and new weather seal to improve factory joint performance and increase the margin of safety. Additionally, the O-ring and O-ring groove size was changed to be consistent with the field joint.
- **PROPELLANT -** The motor propellant forward transition region was recontoured to reduce the stress fields between the star and cylindrical portions of the propellant grain.
- **IGNITION SYSTEM -** Several minor modifications were incorporated into the ignition system. The aft end of the igniter steel case, which contains the igniter nozzle insert, was thickened to eliminate a localized weakness. The igniter internal case insulation was tapered to improve the manufacturing process. Finally, although vacuum putty is still being used at the joint of the igniter and case forward dome, it was changed to eliminate asbestos as one of its constituents.
- **GROUND SUPPORT EQUIPMENT -** The ground support equipment has been redesigned to (1) minimize the case distortion during handling at the launch site; (2) improve the segment tang and clevis joint measurement system for more accurate reading of case diameters to facilitate stacking; (3) minimize the risk of O-ring damage during joint mating; and (4) improve leak testing of the igniter, case and nozzle field joints. A Ground Support Equipment (GSE) assembly aid guides the segment tang into the clevis and rounds the two parts with each other. Other GSE modifications include transportation monitoring equipment and lifting beam.
- **DESIGN ANALYSIS SUMMARY -** Improved, state-of-the-art, analyses related to structural strength, loads, stress, dynamics, fracture mechanics, gas and thermal dynamics, and material characterization and behavior were performed to aid the field joint, nozzle-to-case joint and other designs. Continuing these analyses will ensure that the design integrity and system compatibility adhere to design requirements and operational use. These analyses will be verified by tests, whose results will be correlated with pretest predictions.
- **VERIFICATION/CERTIFICATION TEST -** The verification program demonstrates that the RSRM meets all design and performance requirements, and that failure modes and hazards have been eliminated or controlled. The verification program encompasses the following program phases: development, certification, acceptance, preflight checkout, flight, and post-flight.
- Redesigned SRM certification is based on formally documented results of development motor tests; qualification motor tests and other tests and analyses. The certification tests are conducted under strict control of environments, including thermal and structural loads; assembly, inspection and test procedures; and safety, reliability, maintainability and quality assurance surveillance to verify that flight hardware meets the specified performance and design requirements. The "Development and Verification Plan" stipulates the test program, which follows a rigorous sequence wherein successive tests build on the results of previous tests leading to formal certification.

Source: NASA

# STS-107 - Columbia

On February 1, 2003, the Space Shuttle *Columbia* disintegrated over Texas during re-entry into the Earth's atmosphere due to a hole in the left wing’s RCC that allowed hot gasses to enter the structure and melt it.

- All seven astronauts perished in the accident
  - Rick D. Husband,
  - William C. McCool,
  - Michael P. Anderson,
  - Ilan Ramon,
  - Kalpana Chawla,
  - David M. Brown,
  - Laurel Clark.

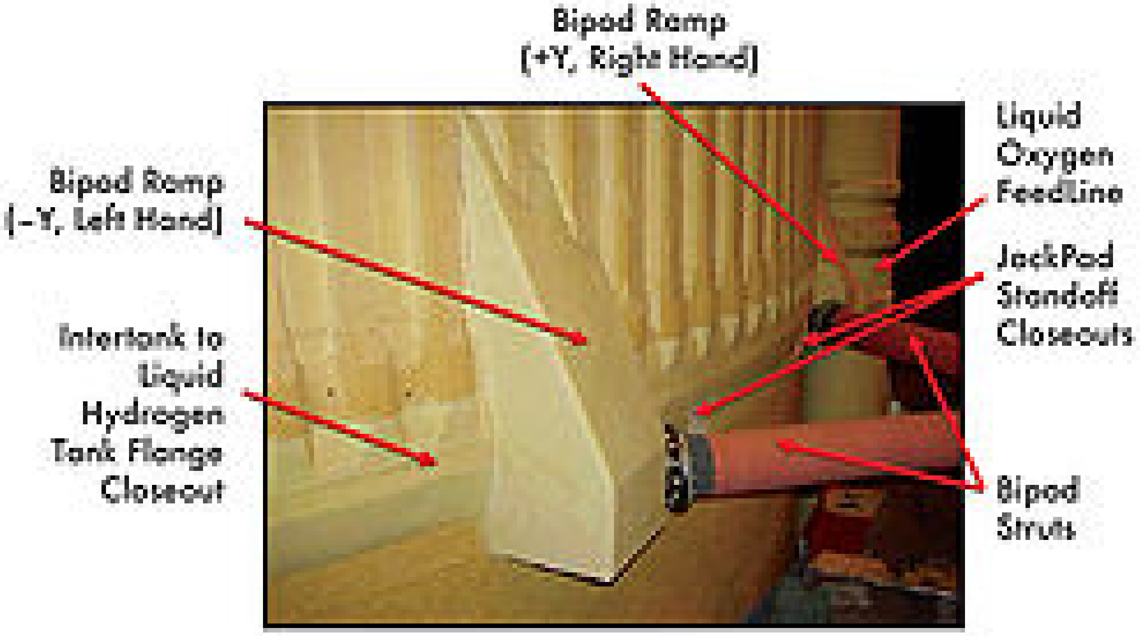
Source: Wiki Summary

# STS-107 - Columbia

"In four simple words, the foam did it."
- Scott Hubbard, Deputy Director for Research at NASA Ames Research Center

Photo Source: SPACE.com

# STS-107 - Columbia



# STS-107 - Columbia

## Contributing Factors and Root Cause

The investigation focused on the foam strike from the very beginning.

- Incidents of debris strikes from ice and foam causing damage during take-off were already well known, and had actually damaged orbiters, most noticeably during STS-45, STS-27, and STS-87.
  - Normally, engineers notice a phenomenon known as "popcorning" on the intertank foam, in which "you have small air bubbles in that area and in the heating of ascent they'll expand and pop off," John Shannon said. "Usually, that's in the two-and-a-half to three-minute timeframe on the flight.“ – CNET
- “The root cause of TPS foam debris shedding has been attributed to internal defects (voids) within the foam structure. Entrapped gas or liquid nitrogen/liquid air within the defect (void) expands during ascent due to the reduced ambient pressure and aerodynamic heating. Depending on the size, depth and geometry of the defect, the resultant pressure differential may cause failure of the surrounding foam. This type of failure mode has been identified as “cohesive” failure and results in chunks of foam being shed from the tank.” – NASA ESC

Source: Wiki Summary CNET, and NASA ESC

# STS-107 - Columbia

## Culture and Cognitive Bias as Contributing Factors

- Similar to the *Challenger* disaster, NASA management failed to recognize the relevance of engineering concerns for safety. Two examples were failure to honor engineer requests for imaging to inspect possible damage, and failure to respond to engineers’ requests about the status of astronaut inspection of the left wing.
  - Engineering made three separate requests for Department of Defense (DOD) imaging of the orbiter to more precisely determine damage. While the images were not guaranteed to show the damage, the capability existed for imaging of sufficient resolution to provide meaningful examination. In fact, the CAIB recommended subsequent missions be imaged while in orbit using ground-based or space-based Department of Defense assets. NASA management did not honor the requests and in some cases intervened to stop the DOD from assisting.
  - NASA's chief thermal protection system (TPS) engineer was concerned about left wing TPS damage and asked NASA management whether an astronaut would visually inspect it. NASA managers never responded.
- Throughout the risk assessment process, senior NASA managers were influenced by their belief that nothing could be done even if damage was detected; hence, this affected their stance on investigation urgency, thoroughness, and possible contingency actions. They decided to conduct a parametric "what-if" scenario study more suited to determine risk probabilities of future events, instead of inspecting and assessing the actual damage.
  - Much of the risk assessment hinged on damage predictions to the thermal protection system. These fall into two categories: damage to the silica tile on the wing lower surface, and damage to the reinforced carbon-carbon (RCC) leading-edge panels.
- Damage-prediction software was used to evaluate possible tile and RCC damage. The tool for predicting tile damage was known as "Crater", described by several NASA representatives in press briefings as not actually a software program but rather a statistical spreadsheet of observed past flight events and effects. The "Crater" tool predicted severe penetration of multiple tiles by the impact if it struck the TPS tile area, but NASA engineers downplayed this. The engineers believed that results showing that the model overstated damage from small projectiles meant that the same would be true of larger Spray-On Foam Insulation (SOFI) impacts. The program used to predict RCC damage was based on small ice impacts the size of cigarette butts, not larger SOFI impacts, as the ice impacts were the only recognized threats to RCC panels up to that point. Under 1 of 15 predicted SOFI impact paths, the software predicted an ice impact would completely penetrate the RCC panel. Engineers downplayed this, too, believing that impacts of the less dense SOFI material would result in less damage than ice impacts. In an e-mail exchange, NASA managers questioned whether the density of the SOFI could be used as justification for reducing predicted damage. Despite engineering concerns about the energy imparted by the SOFI material, NASA managers ultimately accepted the rationale to reduce predicted damage of the RCC panels from possible complete penetration to slight damage to the panel's thin coating.
- Ultimately, the NASA Mission Management Team felt there was insufficient evidence to indicate that the strike was an unsafe situation; therefore, they declared the debris strike a "turnaround" issue (not of highest importance) and denied the requests for the Department of Defense images.

Source: Wiki Summary

# STS-107 - Columbia

## Dozens of changes were made

- The ET bi-pod is susceptible to icing due to the ultra-cold fuel. Until the Columbia accident, the ET bi-pod was protected from ice buildup using thick sheets of foam. The improved bi-pod design now relies on electric heaters versus foam to keep the area clear of ice.
- NASA added a heater to the LOX Feedline bellows and installing a foam "drip-lip" that prevents condensation from building up and freezing as the liquid oxygen (LOX) feedline expand sand contract as it carries fuel from the External Tank to the Orbiter.
- NASA upgraded the short-, medium-, and long-range tracking camera system around the Center's launch pads 39A and 39B, along with those lining the nearby Atlantic coastline. The addition of nine camera sites provides unprecedented views of launch, allowing engineers to clearly observe the flight high into the sky.
- The orbiters also received new imaging equipment with the installation of a digital External Tank camera.
- On-orbit, the R-Bar Pitch Maneuver (RPM) is performed to allow the ISS crew to visually inspect and photograph the belly of the orbiter for damage.
- The Canadian-built Orbiter Boom Sensor System boom extension houses a camera and laser-powered measuring device that astronauts use to scan the orbiter's exterior. The boom attaches to the end of the existing robotic arm and doubles its length to 100 feet, allowing the arm to reach around the spacecraft for the best possible views.
- Each of Discovery's leading wing edges are outfitted with temperature sensors to measure how heat is distributed across their spans and accelerometers to detect impacts and gauge their strength and location. The sensors are highly sensitive and take 20,000 readings per second.
- On Earth, flash thermography is used to examine the Reinforced Carbon-Carbon panels that make up the wing's leading edges. The technique starts by applying an intensely hot and bright burst of light to the panels. Technicians then survey the panels with a heat-sensitive infrared camera to see if any flaws appear under stress from the extreme heat.
- “NASA has redesigned the way foam is applied to the tank to minimize "shedding" and to prevent large pieces from breaking away. “ – CNET
- The Columbia Crew Survival Investigation Report made further recommendations to improve a crew's survival chances on future space vehicles. These include improvements in crew restraints, finding ways to deal more effectively with catastrophic cabin depressurization, more "graceful degradation" of vehicles during a disaster to provide crews with a better chance at survival, and automated parachute systems.

Source: NASA and CNET

# STS-107 - Columbia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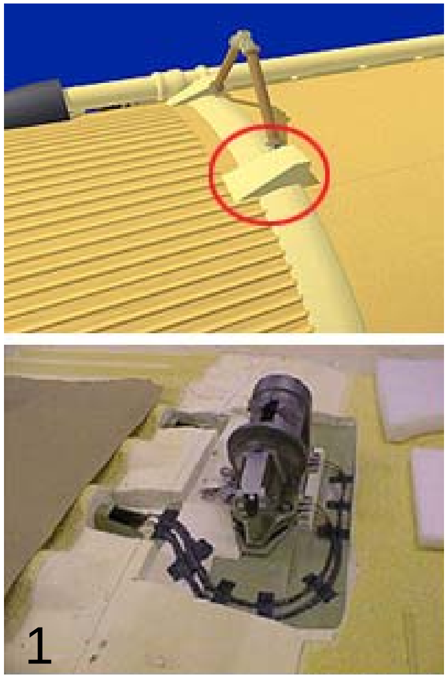
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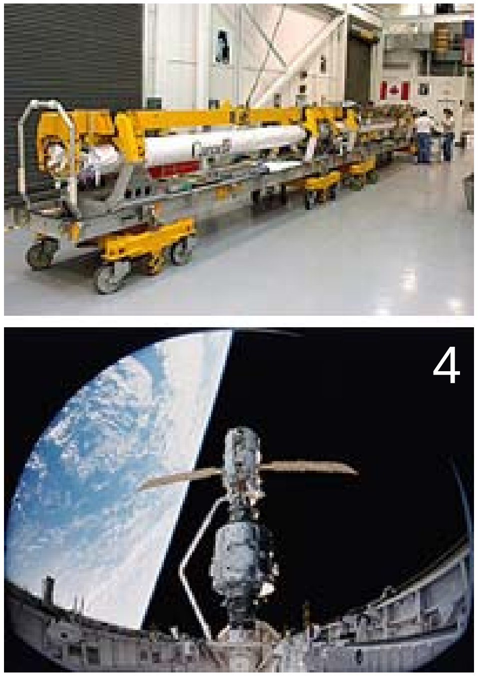
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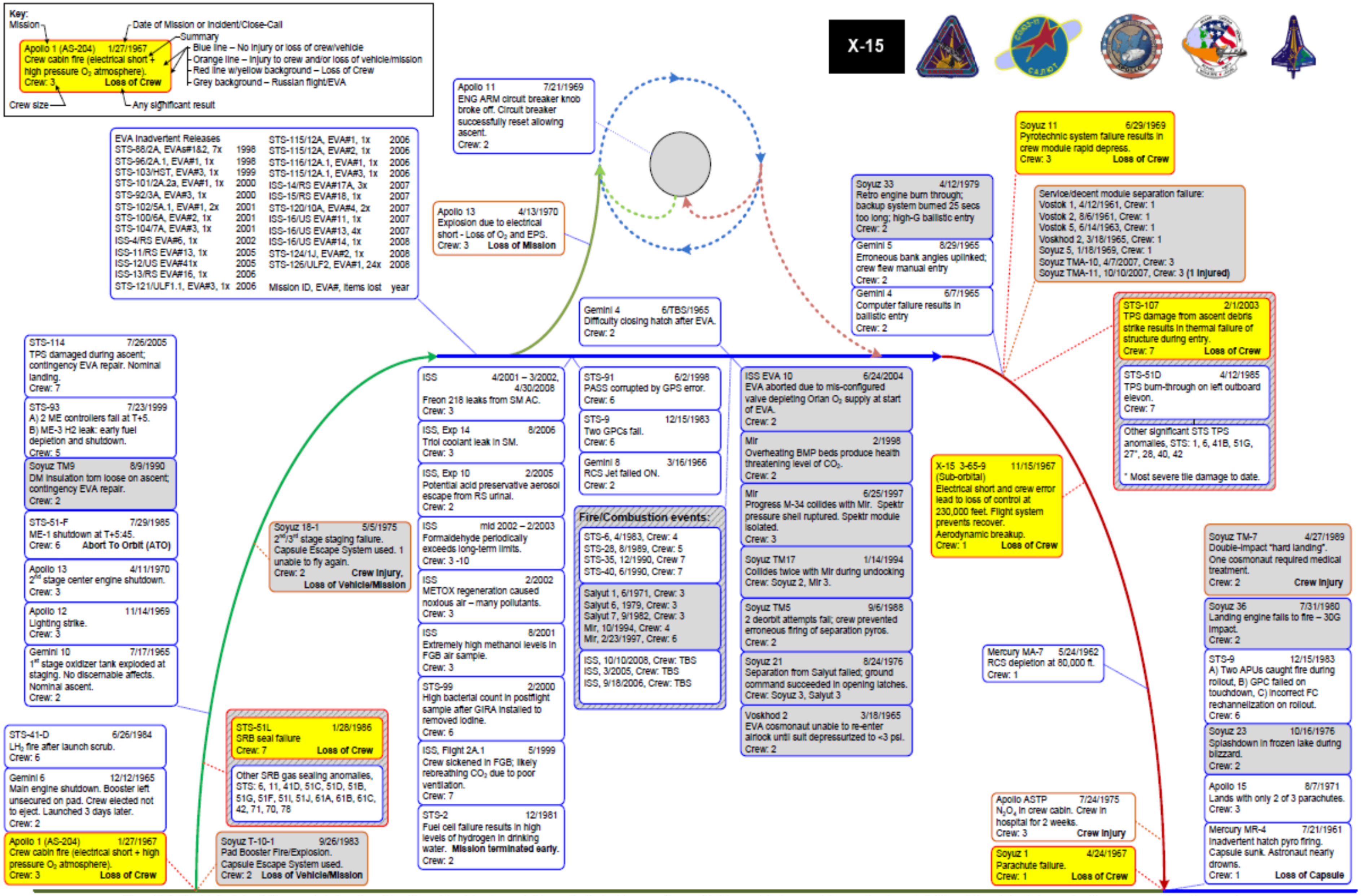
1. ET Bi-Pod; 2. Ground Cameras; 3. RPM; 4. RMS Extension Boom; 5. Wing Leading Edge Sensors

# Mishaps Summary



**Key:**
Mission
Date of Mission or Incident/Close-Call
Summary
Apollo 1 (AS-204) 1/27/1967
Crew cabin fire (electrical short + high pressure $O_2$ atmosphere).
Crew: 3 **Loss of Crew**
Blue line – No injury or loss of crew/vehicle
Orange line – Injury to crew and/or loss of vehicle/mission
Red line w/yellow background – Loss of Crew
Grey background – Russian flight/EVA
Crew size
Any significant result

X-15

EVA Inadvertent Releases

| | | | |
|---|---|---|---|
| STS-88/2A, EVAs#1&2, 7x | 1998 | STS-115/12A, EVA#1, 1x | 2006 |
| STS-96/2A.1, EVA#1, 1x | 1998 | STS-115/12A, EVA#2, 1x | 2006 |
| STS-103/HST, EVA#3, 1x | 1999 | STS-116/12A.1, EVA#1, 1x | 2006 |
| STS-101/2A.2a, EVA#1, 1x | 2000 | STS-115/12A.1, EVA#3, 1x | 2006 |
| STS-92/3A, EVA#3, 1x | 2000 | ISS-14/RS EVA#17A, 3x | 2007 |
| STS-102/5A.1, EVA#1, 2x | 2001 | ISS-15/RS EVA#18, 1x | 2007 |
| STS-100/6A, EVA#2, 1x | 2001 | STS-120/10A, EVA#4, 2x | 2007 |
| STS-104/7A, EVA#3, 1x | 2001 | ISS-16/US EVA#11, 1x | 2007 |
| ISS-4/RS EVA#6, 1x | 2002 | ISS-16/US EVA#13, 4x | 2007 |
| ISS-11/RS EVA#13, 1x | 2005 | ISS-16/US EVA#14, 1x | 2008 |
| ISS-12/US EVA#41x | 2005 | STS-124/1J, EVA#2, 1x | 2008 |
| ISS-13/RS EVA#16, 1x | 2006 | STS-126/ULF2, EVA#1, 24x | 2008 |
| STS-121/ULF1.1, EVA#3, 1x | 2006 | Mission ID, EVA#, Items lost | year |

Apollo 11 7/21/1969
ENG ARM circuit breaker knob broke off. Circuit breaker successfully reset allowing ascent.
Crew: 2

Apollo 13 4/13/1970
Explosion due to electrical short - Loss of $O_2$ and EPS.
Crew: 3 **Loss of Mission**

Gemini 4 6/TBS/1965
Difficulty closing hatch after EVA.
Crew: 2

Soyuz 11 6/29/1969
Pyrotechnic system failure results in crew module rapid depress.
Crew: 3 **Loss of Crew**

Soyuz 33 4/12/1979
Retro engine burn through; backup system burned 25 secs too long; high-G ballistic entry
Crew: 2

Gemini 5 8/29/1965
Erroneous bank angles uplinked; crew flew manual entry
Crew: 2

Gemini 4 6/7/1965
Computer failure results in ballistic entry
Crew: 2

Service/decent module separation failure:
Vostok 1, 4/12/1961, Crew: 1
Vostok 2, 8/6/1961, Crew: 1
Vostok 5, 6/14/1963, Crew: 1
Voskhod 2, 3/18/1965, Crew: 1
Soyuz 5, 1/18/1969, Crew: 1
Soyuz TMA-10, 4/7/2007, Crew: 3
Soyuz TMA-11, 10/10/2007, Crew: 3 **(1 Injured)**

STS-107 2/1/2003
TPS damage from ascent debris strike results in thermal failure of structure during entry.
Crew: 7 **Loss of Crew**

STS-51D 4/12/1985
TPS burn-through on left outboard elevon.
Crew: 7

Other significant STS TPS anomalies, STS: 1, 6, 41B, 51G, 27*, 28, 40, 42

* Most severe tile damage to date.

STS-114 7/26/2005
TPS damaged during ascent; contingency EVA repair. Nominal landing.
Crew: 7

STS-93 7/23/1999
A) 2 ME controllers fail at T+5.
B) ME-3 H2 leak: early fuel depletion and shutdown.
Crew: 5

Soyuz TM9 8/9/1990
DM insulation torn loose on ascent; contingency EVA repair.
Crew: 2

STS-51-F 7/29/1985
ME-1 shutdown at T+5:45.
Crew: 6 **Abort To Orbit (ATO)**

Apollo 13 4/11/1970
2nd stage center engine shutdown.
Crew: 3

Apollo 12 11/14/1969
Lighting strike.
Crew: 3

Gemini 10 7/17/1965
1st stage oxidizer tank exploded at staging. No discernable affects. Nominal ascent.
Crew: 2

STS-41-D 6/26/1984
$LH_2$ fire after launch scrub.
Crew: 6

Gemini 6 12/12/1965
Main engine shutdown. Booster left unsecured on pad. Crew elected not to eject. Launched 3 days later.
Crew: 2

Apollo 1 (AS-204) 1/27/1967
Crew cabin fire (electrical short + high pressure $O_2$ atmosphere).
Crew: 3 **Loss of Crew**

Soyuz 18-1 5/5/1975
2nd/3rd stage staging failure. Capsule Escape System used. 1 unable to fly again.
Crew: 2 **Crew Injury, Loss of Vehicle/Mission**

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

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

Soyuz T-10-1 9/26/1983
Pad Booster Fire/Explosion.
Capsule Escape System used.
Crew: 2 **Loss of Vehicle/Mission**

ISS 4/2001 – 3/2002, 4/30/2008
Freon 218 leaks from SM AC.
Crew: 3

ISS, Exp 14 8/2006
Triol coolant leak in SM.
Crew: 3

ISS, Exp 10 2/2005
Potential acid preservative aerosol escape from RS urinal.
Crew: 2

ISS mid 2002 – 2/2003
Formaldehyde periodically exceeds long-term limits.
Crew: 3 -10

ISS 2/2002
METOX regeneration caused noxious air – many pollutants.
Crew: 3

ISS 8/2001
Extremely high methanol levels in FGB air sample.
Crew: 3

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 rebreathing $CO_2$ due to poor ventilation.
Crew: 7

STS-2 12/1981
Fuel cell failure results in high levels of hydrogen in drinking water. **Mission terminated early.**
Crew: 2

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

STS-9 12/15/1983
Two GPCs fail.
Crew: 6

Gemini 8 3/16/1966
RCS Jet failed ON.
Crew: 2

**Fire/Combustion events:**
STS-6, 4/1983, Crew: 4
STS-28, 8/1989, Crew: 5
STS-35, 12/1990, Crew 7
STS-40, 6/1990, Crew: 7

Salyut 1, 6/1971, Crew: 3
Salyut 6, 1979, Crew: 3
Salyut 7, 9/1982, Crew: 3
Mir, 10/1994, Crew: 4
Mir, 2/23/1997, Crew: 6

ISS, 10/10/2008, Crew: TBS
ISS, 3/2005, Crew: TBS
ISS, 9/18/2006, Crew: TBS

ISS EVA 10 6/24/2004
EVA aborted due to mis-configured valve depleting Orlan $O_2$ supply at start of EVA.
Crew: 2

Mir 2/1998
Overheating BMP beds produce health threatening level of $CO_2$.
Crew: 2

Mir 6/25/1997
Progress M-34 collides with Mir. Spektr pressure shell ruptured. Spektr module isolated.
Crew: 3

Soyuz TM17 1/14/1994
Collides twice with Mir during undocking
Crew: Soyuz 2, Mir 3.

Soyuz TM5 9/6/1988
2 deorbit attempts fail; crew prevented erroneous firing of separation pyros.
Crew: 2

Soyuz 21 8/24/1976
Separation from Salyut failed; ground command succeeded in opening latches.
Crew: Soyuz 3, Salyut 3

Voskhod 2 3/18/1965
EVA cosmonaut unable to re-enter airlock until suit depressurized to <3 psi.
Crew: 2

X-15 3-65-9 11/15/1967
(Sub-orbital)
Electrical short and crew error lead to loss of control at 230,000 feet. Flight system prevents recover.
Aerodynamic breakup.
Crew: 1 **Loss of Crew**

Mercury MA-7 5/24/1962
RCS depletion at 80,000 ft.
Crew: 1

Apollo ASTP 7/24/1975
$N_2O_4$ in crew cabin. Crew in hospital for 2 weeks.
Crew: 3 **Crew Injury**

Soyuz 1 4/24/1967
Parachute failure.
Crew: 1 **Loss of Crew**

Soyuz TM-7 4/27/1989
Double-impact "hard landing". One cosmonaut required medical treatment.
Crew: 2 **Crew Injury**

Soyuz 36 7/31/1980
Landing engine fails to fire – 30G impact.
Crew: 2

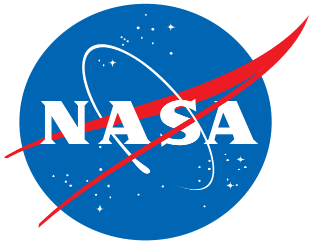
STS-9 12/15/1983
A) Two APUs caught fire during rollout, B) GPC failed on touchdown, C) incorrect FC rechannelization on rollout.
Crew: 6

Soyuz 23 10/16/1976
Splashdown in frozen lake during blizzard.
Crew: 2

Apollo 15 8/7/1971
Lands with only 2 of 3 parachutes.
Crew: 3

Mercury MR-4 7/21/1961
Inadvertent hatch pyro firing. Capsule sunk. Astronaut nearly drowns.
Crew: 1 **Loss of Capsule**

The JSC Flight Safety Office maintains the *Significant Incidents and Close Calls in Human Spaceflight* graphic to provide continuing visibility of the risks inherent with space exploration and provide engineers with a summary of past experience. It is hoped this information will be used to learn from the past and make present and future missions safer.



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