

Space Shuttle Challenger disaster

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Space Shuttle *Challenger*'s smoke plume after its in-flight breakup, resulting in its destruction and the deaths of all seven crew members.

Date	January 28, 1986
Time	11:39:13 EST (16:39:13 UTC)
Location	Atlantic Ocean, off the coast of central Florida
Outcome	Grounding of the Space Shuttle fleet for nearly three years during which various safety measures, solid rocket booster redesign, and a new policy on management decision-making for future launches were implemented.
Casualties	
<ul style="list-style-type: none"> • Francis R. Scobee, Commander • Michael J. Smith, Pilot • Ronald McNair, Mission Specialist • Ellison Onizuka, Mission Specialist • Judith Resnik, Mission Specialist • Greg Jarvis, Payload Specialist • Christa McAuliffe, Payload Specialist 	
Inquiries	Rogers Commission

The **Space Shuttle *Challenger* disaster** occurred on January 28, 1986, when Space Shuttle *Challenger* (mission STS-51-L) broke apart 73 seconds into its flight, leading to the deaths of its seven crew members. The spacecraft disintegrated over the Atlantic Ocean, off the coast of Cape Canaveral, Florida at 11:38 EST (16:38 UTC). Disintegration of the vehicle began after an O-ring seal in its right solid rocket booster (SRB) failed at liftoff. The O-ring failure caused a breach in the SRB joint it sealed, allowing pressurized hot gas from within the solid rocket motor to reach the outside and impinge upon the adjacent SRB attachment hardware and external fuel tank. This led to the separation of the right-hand SRB's aft attachment and the structural failure of the external tank. Aerodynamic forces broke up the orbiter.

The crew compartment and many other vehicle fragments were eventually recovered from the ocean floor after a lengthy search and recovery operation. The exact timing of the death of the crew is unknown; several crew members are known to have survived the initial breakup of the spacecraft. The shuttle had no escape system, and the impact of the crew compartment with the ocean surface was too violent to be survivable.



STS-51-L crew: (front row) Michael J. Smith, Dick Scobee, Ronald McNair; (back row) Ellison Onizuka, Christa McAuliffe, Gregory Jarvis, Judith Resnik.

The disaster resulted in a 32-month hiatus in the shuttle program and the formation of the Rogers Commission, a special commission appointed by United States President Ronald Reagan to investigate the accident. The Rogers Commission found NASA's organizational culture and decision-making processes had been key contributing factors to the accident. NASA managers had known contractor Morton Thiokol's design of the SRBs contained a potentially catastrophic flaw in the O-rings since 1977, but failed to address it properly. They also disregarded warnings (an example of "go fever") from engineers about the dangers of launching posed by the low temperatures of that morning and failed to adequately report these technical concerns to their superiors.

What Rogers did not highlight was that the vehicle was never certified to operate in temperatures that low. The O-rings, as well as many other critical components, had no test data to support any expectation of a successful launch in such conditions. Bob Ebeling from Thiokol delivered a biting analysis: "[W]e're only qualified to 40 degrees ...what business does anyone even have thinking about 18 degrees, we're in no man's land."

As a result of the disaster, the Air Force decided to cancel its plans to use the Shuttle for classified military satellite launches from Vandenberg Air Force Base in California, deciding to use the Titan IV instead.

Approximately 17 percent of Americans witnessed the launch live because of the presence of crew member Christa McAuliffe, the first member of the Teacher in Space Project, who would have been the first teacher in space. Media coverage of the accident was extensive: one study reported that 85 percent of Americans surveyed had heard the news within an hour of the accident. The *Challenger* disaster has been used as a case study in many discussions of engineering safety and workplace ethics.

O-ring concerns

Each of the two Space Shuttle Solid Rocket Boosters (SRBs) that comprised part of the Space Transportation System was constructed of seven sections, six of which were permanently joined in pairs at the factory. For each flight, the four resulting segments were then assembled in the Vehicle Assembly Building at Kennedy Space Center (KSC), with three field joints. The factory joints were sealed with asbestos-silica insulation applied over the joint, while each field joint was sealed with two rubber O-rings. (After the destruction of *Challenger*, the number of O-rings per field joint was increased to three.) The seals of all of the SRB joints were required to contain the hot high-pressure gases produced by the burning solid propellant inside, forcing it out of the nozzle at the aft end of each rocket.

During the Space Shuttle design process, a McDonnell Douglas report in September 1971 discussed the safety record of solid rockets. While a safe abort was possible after most types of failures, one was especially dangerous: a burnthrough by hot gases of the rocket's casing. The report stated that "if burnthrough occurs adjacent to [liquid hydrogen/oxygen] tank or orbiter, timely sensing may not be feasible and abort not possible", accurately foreshadowing the *Challenger* accident. Morton Thiokol was the contractor responsible for the construction and maintenance of the shuttle's SRBs. As originally designed by Thiokol, the O-ring joints in the SRBs were supposed to close more tightly due to forces generated at ignition, but a 1977 test showed that when pressurized water was used to simulate the effects of booster combustion, the metal parts bent away from each other, opening a gap through which gases could leak. This phenomenon, known as "joint rotation," caused a momentary drop in air pressure. This made it possible for combustion gases to erode the O-rings. In the event of widespread erosion, a flame path could develop, causing the joint to burst—which would have destroyed the booster and the shuttle.^[1]

Engineers at the Marshall Space Flight Center wrote to the manager of the Solid Rocket Booster project, George Hardy, on several occasions suggesting that Thiokol's field joint design was unacceptable. For example, one engineer suggested that joint rotation would render the secondary O-ring useless, but Hardy did not forward these memos to Thiokol, and the field joints were accepted for flight in 1980.

Evidence of serious O-ring erosion was present as early as the second space shuttle mission, STS-2, which was flown by *Columbia*. Contrary to NASA regulations, the Marshall Center did not report this problem to senior management at NASA, but opted to keep the problem within their reporting channels with Thiokol. Even after the O-rings were redesignated as "Criticality 1"—meaning that their failure would result in the destruction of the

Orbiter—no one at Marshall suggested that the shuttles be grounded until the flaw could be fixed. During the investigation Sally Ride told Dr. Richard Feynman that the O-rings were not tested under 50 °F (10 °C).

By 1985, Marshall and Thiokol realized that they had a potentially catastrophic problem on their hands. They began the process of redesigning the joint with three inches (76 mm) of additional steel around the tang. This tang would grip the inner face of the joint and prevent it from rotating. They did not call for a halt to shuttle flights until the joints could be redesigned, but rather treated the problem as an acceptable flight risk. For example, Lawrence Mulloy, Marshall's manager for the SRB project since 1982, issued and waived launch constraints for six consecutive flights. Thiokol even went as far as to persuade NASA to declare the O-ring problem "closed". Donald Kutyna, a member of the Rogers Commission, later likened this situation to an airline permitting one of its planes to continue to fly despite evidence that one of its wings was about to fall off.

Pre-launch conditions

Delays

Challenger was originally set to launch from KSC in Florida at 14:42 Eastern Standard Time (EST) on January 22. Delays in the previous mission, STS-61-C, caused the launch date to be moved to January 23 and then to January 24. Launch was then rescheduled to January 25 due to bad weather at the Transoceanic Abort Landing (TAL) site in Dakar, Senegal. NASA decided to use Casablanca as the TAL site, but because it was not equipped for night landings, the launch had to be moved to the morning (Florida time). Predictions of unacceptable weather at KSC on January 26, caused the launch to be rescheduled for 09:37 EST on January 27.

The launch was delayed the next day, due to problems with the exterior access hatch. First, one of the micro-switch indicators used to verify that the hatch was safely locked malfunctioned.^[2] Then, a stripped bolt prevented the closeout crew from removing a closing fixture from the orbiter's hatch.^[3] By the time repair personnel had sawed the fixture off, crosswinds at the Shuttle Landing Facility exceeded the limits for a Return to Launch Site (RTLS) abort. While the crew waited for winds to die down, the launch window expired, forcing yet another scrub.

Thiokol-NASA conference call

Forecasts for January 28 predicted an unusually cold morning, with temperatures close to 31 °F (-1 °C), the minimum temperature permitted for launch. The low temperatures had prompted concerns from Thiokol engineers. At a teleconference on the evening of January 27, Thiokol engineers and managers discussed the weather conditions with NASA managers from Kennedy Space Center and Marshall Space Flight Center. Several engineers (most notably Roger Boisjoly) re-expressed their concerns about the effect of low temperatures on the resilience of the rubber O-rings that sealed the joints of the SRBs, and recommended a launch postponement. They argued that they did not have enough data to determine whether the joints would properly seal if the O-rings were colder than 53 °F (12 °C). This was an important consideration, since the SRB O-rings had been designated as a "Criticality 1" component, meaning that there was no backup if both the primary and secondary O-rings failed, and their failure would destroy the Orbiter and its crew.

Thiokol management initially supported its engineers' recommendation to postpone the launch, but NASA staff opposed a delay. During the conference call, Hardy told Thiokol, "I am appalled. I am appalled by your recommendation." Mulloy said, "My God, Thiokol, when do you want me to launch — next April?" One argument by NASA personnel contesting Thiokol's concerns was that if the primary O-ring failed, the secondary O-ring would still seal. This was unproven, and was in any case an argument that did not apply to a "Criticality 1" component. As astronaut Sally Ride stated when questioning NASA managers before the Rogers Commission, it is forbidden to rely on a backup for a "Criticality 1" component. The backup is there solely to provide redundancy in case of unforeseen failure, not to replace the primary component.

NASA did not know of Thiokol's earlier concerns about the effects of the cold on the O-rings, and did not understand that Rockwell International, the shuttle's prime contractor, viewed the large amount of ice present on the pad as a constraint to launch. Due to NASA's opposition, Thiokol management reversed itself and recommended that the launch proceed as scheduled.

Ice

The Thiokol engineers had also argued that the low overnight temperatures (18 °F or -8 °C the evening prior to launch) would almost certainly result in SRB temperatures below their redline of 40 °F (4 °C). Ice had accumulated all over the launch pad, raising concerns that ice could damage the shuttle upon lift-off. The Kennedy Ice Team inadvertently pointed an infrared camera at the aft field joint of the right SRB and found the temperature to be only 8 °F (-13 °C). This was believed to be the result of supercooled air blowing on the joint from the liquid oxygen tank vent. It was much lower than the air temperature and far below the design specifications for the O-rings. However, the 8 °F (-13 °C) reading was later determined to be erroneous, the error caused by not following the temperature probe manufacturer's instructions. Tests and adjusted calculations later confirmed that the temperature of the joint was not substantially different from the ambient temperature.



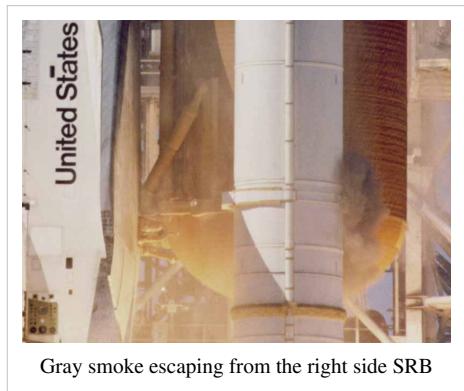
Ice on the launch tower hours before
Challenger launch

The temperature on the day of the launch was far lower than had been the case with previous launches: below freezing at 28 to 29 °F (-2.2 to -1.7 °C); previously, the coldest launch had been at 53 °F (12 °C). Although the Ice Team had worked through the night removing ice, engineers at Rockwell still expressed concern. Rockwell engineers watching the pad from their headquarters in Downey, California, were horrified when they saw the amount of ice. They feared that during launch, ice might be shaken loose and strike the shuttle's thermal protection tiles, possibly due to the aspiration induced by the jet of exhaust gas from the SRBs. Rocco Petrone, the head of Rockwell's space transportation division, and his colleagues viewed this situation as a launch constraint, and told Rockwell's managers at the Cape that Rockwell could not support a launch. However, Rockwell's managers at the Cape voiced their concerns in a manner that led Houston-based mission manager Arnold Aldrich to go ahead with the launch. Aldrich decided to postpone the shuttle launch by an hour to give the Ice Team time to perform another inspection. After that last inspection, during which the ice appeared to be melting, *Challenger* was finally cleared to launch at 11:38 am EST.

January 28 launch and failure

Further information: STS-51-L Mission timeline

Liftoff and initial ascent



Gray smoke escaping from the right side SRB

The following account of the accident is derived from real time telemetry data and photographic analysis, as well as from transcripts of air-to-ground and mission control voice communications.^[4] All times are given in seconds after launch and correspond to the telemetry time-codes from the closest instrumented event to each described event.

Until liftoff actually occurs, the Space Shuttle main engines (SSMEs) can be safely shut down and the launch aborted if necessary. At liftoff time (T=0, which was at 11:38:00.010 EST), the three SSMEs were at 100% of their original rated performance, and began throttling up to

104% under computer control. At this moment, the two SRBs were ignited and hold-down bolts were released with explosives, freeing the vehicle from the pad. With the first vertical motion of the vehicle, the gaseous hydrogen vent arm retracted from the External Tank (ET) but failed to latch back. Review of film shot by pad cameras showed that the arm did not re-contact the vehicle, and thus it was ruled out as a contributing factor in the accident. The post-launch inspection of the pad also revealed that kick springs on four of the hold-down bolts were missing, but they were similarly ruled out as a possible cause.

Later review of launch film showed that at T+0.678, strong puffs of dark gray smoke were emitted from the right-hand SRB near the aft strut that attaches the booster to the ET. The last smoke puff occurred at about T+2.733. The last view of smoke around the strut was at T+3.375. It was later determined that these smoke puffs were caused by the opening and closing of the aft field joint of the right-hand SRB. The booster's casing had ballooned under the stress of ignition. As a result of this ballooning, the metal parts of the casing bent away from each other, opening a gap through which hot gases—above 5,000 °F (2,760 °C)—leaked. This had occurred in previous launches, but each time the primary O-ring had shifted out of its groove and formed a seal. Although the SRB was not designed to function this way, it appeared to work well enough, and Morton-Thiokol changed the design specs to accommodate this process, known as extrusion.

While extrusion was taking place, hot gases leaked past (a process called "blow-by"), damaging the O-rings until a seal was made. Investigations by Morton-Thiokol engineers determined that the amount of damage to the O-rings was directly related to the time it took for extrusion to occur, and that cold weather, by causing the O-rings to harden, lengthened the time of extrusion. (The redesigned SRB field joint used subsequent to the *Challenger* accident used an additional interlocking mortise and tang with a third O-ring, mitigating blow-by.)

On the morning of the disaster, the primary O-ring had become so hard due to the cold that it could not seal in time. The secondary O-ring was not in its seated position due to the metal bending. There was now no barrier to the gases, and both O-rings were vaporized across 70 degrees of arc. However, aluminum oxides from the burned solid propellant sealed the damaged joint, temporarily replacing the O-ring seal before actual flame rushed through the joint.

As the vehicle cleared the tower, the SSMEs were operating at 104% of their rated maximum thrust, and control switched from the Launch Control Center (LCC) at Kennedy to the Mission Control Center (MCC) at Johnson Space Center in Houston, Texas. To prevent aerodynamic forces from structurally overloading the orbiter, at T+28 the SSMEs began throttling down to limit the velocity of the shuttle in the dense lower atmosphere, as per normal operating procedure. At T+35.379, the SSMEs throttled back further to the planned 65%. Five seconds later, at about 5,800 metres (19,000 ft), *Challenger* passed through Mach 1. At T+51.860, the SSMEs began throttling back up to

104% as the vehicle passed beyond Max Q, the period of maximum aerodynamic pressure on the vehicle.

Plume

Beginning at about T+37 and for 27 seconds, the shuttle experienced a series of wind shear events that were stronger than on any previous flight.

At T+58.788, a tracking film camera captured the beginnings of a plume near the aft attach strut on the right SRB. Unknown to those on *Challenger* or in Houston, hot gas had begun to leak through a growing hole in one of the right-hand SRBs joints. The force of the wind shear shattered the temporary oxide seal that had taken the place of the damaged O-rings, removing the last barrier to flame rushing through the joint. Had it not been for the wind shear, the fortuitous oxide seal might have held through booster burnout.

Within a second, the plume became well defined and intense. Internal pressure in the right SRB began to drop because of the rapidly enlarging hole in the failed joint, and at T+60.238 there was visual evidence of flame burning through the joint and impinging on the external tank.



Plume on right SRB at T+ 58.778 seconds

At T+64.660, the plume suddenly changed shape, indicating that a leak had begun in the liquid hydrogen tank, located in the aft portion of the external tank. The nozzles of the main engines pivoted under computer control to compensate for the unbalanced thrust produced by the booster burn-through. The pressure in the shuttle's external liquid hydrogen tank began to drop at T+66.764, indicating the effect of the leak.

At this stage the situation still seemed normal both to the astronauts and to flight controllers. At T+68, the CAPCOM Richard O. Covey informed the crew that they were "go at throttle up", and Commander Dick Scobee confirmed the call. His response, "Roger, go at throttle up," was the last communication from *Challenger* on the air-to-ground loop.

Vehicle breakup

At T+72.284, the right SRB pulled away from the aft strut attaching it to the external tank. Later analysis of telemetry data showed a sudden lateral acceleration to the right at T+72.525, which may have been felt by the crew. The last statement captured by the crew cabin recorder came just half a second after this acceleration, when Pilot Michael J. Smith said "Uh oh." Smith may also have been responding to onboard indications of main engine performance, or to falling pressures in the external fuel tank.

At T+73.124, the aft dome of the liquid hydrogen tank failed, producing a propulsive force that pushed the hydrogen tank into the liquid oxygen tank in the forward part of the ET. At the same time, the right SRB rotated about the forward attach strut, and struck the intertank structure. This resulted in the spontaneous conflagration of the fuel which exploded the external tank, creating a massive plume of water vapor exhaust that enveloped the entire stack.



Challenger begins to disintegrate.

The breakup of the vehicle began at T+73.162 seconds and at an altitude of 48,000 feet (15 km). With the external tank disintegrating (and with the semi-detached right SRB contributing its thrust on an anomalous vector), *Challenger* veered from its correct attitude with respect to the local airflow, resulting in a load factor of up to 20 (or 20 g), well over its design limit of 5 g and was quickly torn apart by abnormal aerodynamic forces (the orbiter itself did not explode). The two SRBs, which could withstand greater aerodynamic loads, separated from the ET and

continued in uncontrolled powered flight. The SRB casings were made of half-inch (12.7 mm) thick steel and were much stronger than the orbiter and ET; thus, both SRBs survived the breakup of the space shuttle stack, even though the right SRB was still suffering the effects of the joint burn-through that had set the destruction of *Challenger* in motion.

The more robustly constructed crew cabin also survived the breakup of the launch vehicle; while the SRBs were subsequently destroyed remotely by the Range Safety Officer, the detached cabin continued along a ballistic trajectory and was observed exiting the cloud of gases at T+75.237. Twenty-five seconds after the breakup of the vehicle, the altitude of the crew compartment peaked at a height of 65,000 feet (20 km).

The Thiokol engineers who had opposed the decision to launch were watching the events on television. They had believed that any O-ring failure would have occurred at liftoff, and thus were happy to see the shuttle successfully leave the launch pad. At about one minute after liftoff, a friend of Boisjoly said to him "Oh God. We made it. We made it!" Boisjoly recalled that when the shuttle exploded a few seconds later, "we all knew exactly what happened."

Post-breakup flight controller dialog



Jay Greene at his console after the breakup of *Challenger*

In Mission Control, there was a burst of static on the air-to-ground loop as *Challenger* disintegrated. Television screens showed a cloud of smoke and water vapor (the product of hydrogen combustion) where *Challenger* had been, with pieces of debris falling toward the ocean. At about T+89, flight director Jay Greene prompted his flight dynamics officer (FIDO) for information. FIDO responded that "...the (radar) filter has discrediting sources", a further indication that *Challenger* had broken into multiple pieces. A minute later, the ground controller reported "negative contact (and) loss of downlink" of radio and telemetry data from *Challenger*. Greene ordered his team to "watch your data carefully" and look for any sign that the Orbiter had escaped.

At T+110.250, the Range Safety Officer (RSO) at the Cape Canaveral Air Force Station sent radio signals that activated the range safety system's "destruct" packages on board both solid rocket boosters. This was a normal contingency procedure, undertaken because the RSO judged the free-flying SRBs a possible threat to land or sea. The same destruct signal would have destroyed the External Tank had it not already disintegrated.

Public affairs officer Steve Nesbitt reported: "Flight controllers here looking very carefully at the situation. Obviously a major malfunction. We have no downlink."

On the Mission Control loop, Greene ordered that contingency procedures be put into effect; these procedures included locking the doors of the control center, shutting down telephone communications with the outside world, and following checklists that ensured that the relevant data were correctly recorded and preserved. [Wikipedia:Citation needed](#)

Nesbitt relayed this information to the public: "We have a report from the Flight Dynamics Officer that the vehicle has exploded. The flight director confirms that. We are looking at checking with recovery forces to see what can be done at this point."

Cause and time of death



The intact crew cabin was seen exiting the cloud by a tracking camera after its trajectory carried it across an adjacent contrail.



Enlarged detail of the previous picture, the arrow indicating the crew cabin. The nose cone containing the RCS thrusters is missing.



Astronauts from a later Shuttle flight (STS-34) stand next to their PEAPs

The crew cabin, made of reinforced aluminum, was a particularly robust section of the shuttle. During vehicle breakup, it detached in one piece and slowly tumbled into a ballistic arc. NASA estimated the load factor at separation to be between 12 and 20 g; within two seconds it had already dropped to below 4 g and within ten seconds the cabin was in free fall. The forces involved at this stage were likely insufficient to cause major injury.

At least some of the astronauts were likely alive and at least briefly conscious after the breakup, as three of the four recovered Personal Egress Air Packs (PEAPs) on the flight deck were found to have been activated. Investigators found their remaining unused air supply roughly consistent with the expected consumption during the 2 minute 45 second post-breakup trajectory.

While analyzing the wreckage, investigators discovered that several electrical system switches on Pilot Mike Smith's right-hand panel had been moved from their usual launch positions. Fellow Astronaut Richard Mullane wrote, "These switches were protected with lever locks that required them to be pulled outward against a spring force before they could be moved to a new position." Later tests established that neither force of the explosion nor the impact with the ocean could have moved them, indicating that Smith made the switch changes, presumably in a

futile attempt to restore electrical power to the cockpit after the crew cabin detached from the rest of the orbiter.

Whether the astronauts remained conscious long after the breakup is unknown, and largely depends on whether the detached crew cabin maintained pressure integrity. If it did not, the time of useful consciousness at that altitude is just a few seconds; the PEAPs supplied only unpressurized air, and hence would not have helped the crew to retain consciousness. If, on the other hand, the cabin was not depressurized or only slowly depressurizing, the astronauts may have been conscious for the entire fall until impact.

NASA routinely trained shuttle astronauts for splashdown events, but the cabin hit the ocean surface at roughly 207 mph (333 km/h), with an estimated deceleration at impact of well over 200 g, far beyond the structural limits of the crew compartment or crew survivability levels.

On July 28, 1986, Rear Admiral Richard H. Truly, NASA's Associate Administrator for Space Flight and a former astronaut, released a report from Joseph P. Kerwin, biomedical specialist from the Johnson Space Center in Houston, relating to the deaths of the astronauts in the accident. Kerwin, a veteran of the Skylab 2 mission, had been commissioned to undertake the study soon after the accident. According to the Kerwin Report:

The findings are inconclusive. The impact of the crew compartment with the ocean surface was so violent that evidence of damage occurring in the seconds which followed the disintegration was masked.

Our final conclusions are:

- the cause of death of the *Challenger* astronauts cannot be positively determined;
- the forces to which the crew were exposed during Orbiter breakup were probably not sufficient to cause death or serious injury; and
- the crew possibly, but not certainly, lost consciousness in the seconds following Orbiter breakup due to in-flight loss of crew module pressure.

Some experts believe most if not all of the crew were alive and possibly conscious during the entire descent until impact with the ocean. Astronaut and NASA lead accident investigator Robert Overmyer said "Scob fought for any and every edge to survive. He flew that ship without wings all the way down... they were alive."

Prospect of crew escape

Further information: Shuttle ejection escape systems, Post-*Challenger* abort enhancements

During powered flight of the space shuttle, crew escape was not possible. Launch escape systems were considered several times during shuttle development, but NASA's conclusion was that the shuttle's expected high reliability would preclude the need for one. Modified SR-71 Blackbird ejection seats and full pressure suits were used on the first four shuttle orbital missions, which were considered test flights, but they were removed for the "operational" missions that followed. (The Columbia Accident Investigation Board later declared, after the 2003 *Columbia* re-entry disaster, that the space shuttle system should never have been declared operational because it is experimental by nature due to the limited number of flights as compared to certified commercial aircraft.) Providing a launch escape system for larger crews was considered undesirable due to "limited utility, technical complexity and excessive cost in dollars, weight or schedule delays."

After the loss of *Challenger*, the question was re-opened, and NASA considered several different options, including ejector seats, tractor rockets and bailing out through the bottom of the orbiter. However, NASA once again concluded that all of the launch escape systems considered would be impractical due to the sweeping vehicle modifications that would have been necessary and the resultant limitations on crew size. A system was designed to give the crew the option to leave the shuttle during gliding flight; however, this system would not have been usable in the *Challenger* situation.

Aftermath



U.S. President Ronald Reagan addresses the nation after the shuttle disaster.

Tributes

On the night of the disaster, President Ronald Reagan had been scheduled to give his annual State of the Union address. He initially announced that the address would go on as scheduled, but then postponed the State of the Union address for a week and instead gave a national address on the *Challenger* disaster from the Oval Office of the White House. It was written by Peggy Noonan, and was listed as one of the most significant speeches of the 20th century in a survey of 137 communication scholars.^{[5][6]} It finished with the following statement, which quoted from the poem "High Flight" by John Gillespie Magee, Jr.:

We will never forget them, nor the last time we saw them, this morning, as they prepared for their journey and waved goodbye and 'slipped the surly bonds of Earth' to 'touch the face of God'.^[7]

Three days later, Reagan and his wife Nancy traveled to the Johnson Space Center to speak at a memorial service honoring the astronauts where he stated:

Sometimes, when we reach for the stars, we fall short. But we must pick ourselves up again and press on despite the pain.^[8]

It was attended by 6,000 NASA employees and 4,000 guests,^[9] as well as by the families of the crew.^[10] During the ceremony, an Air Force band led the singing of "God Bless America" as NASA T-38 Talon jets flew directly over the scene, in the traditional missing-man formation. All activities were broadcast live by the national television networks.

President Reagan would further mention the *Challenger* astronauts at the beginning of his State of the Union address on February 4.



Memorial service on January 31, 1986, at Houston, Texas, attended by Ronald Reagan and First Lady Nancy Reagan (left).

Recovery of debris



Recovered right solid rocket booster showing the hole caused by the plume.

In the first minutes after the accident, recovery efforts were begun by NASA's Launch Recovery Director, who ordered the ships normally used by NASA for recovery of the solid rocket boosters to be sent to the location of the water impact. Search and rescue aircraft were also dispatched. At this stage, however, debris was still falling, and the Range Safety Officer (RSO) held both aircraft and ships out of the impact area until it was considered safe for them to enter. It was about an hour until the RSO allowed the recovery forces to begin their work.

The search and rescue operations that took place in the first week after the *Challenger* accident were managed by the Department of Defense on behalf of NASA, with assistance from the United States Coast Guard, and mostly involved surface searches. According to the Coast

Guard, "the operation was the largest surface search in which they had participated." This phase of operations lasted until February 7. Thereafter, recovery efforts were managed by a Search, Recovery, and Reconstruction team; its aim was to salvage debris that would help in determining the cause of the accident. Sonar, divers, remotely operated submersibles and manned submersibles were all used during the search, which covered an area of 480 nautical miles (890 km), and took place at depths of up to 370 meters (1,210 ft). On March 7, divers from the USS *Preserver* identified what might be the crew compartment on the ocean floor. The finding, along with discovery of the remains of all seven crew members, was confirmed the next day and on March 9, NASA announced the finding to the press. While recovering the remains of the crew, Gregory Jarvis's body floated out of the shattered crew compartment and was lost to the diving team. A day later, his body was seen floating on the ocean's surface. It sank as a team prepared to pull him from the water. His body was recovered on a later dive. His body had settled 101.2 feet below the water on the surface of the ocean, some 0.7 nautical miles from the final resting place of the crew compartment. He was recovered and brought to the surface before being processed with the other astronauts and then prepared for release to his family.

The crew transfer took place on April 29, 1986, three months and one day after the accident. Seven hearses carried the astronauts remains from the Life Sciences Facility on Cape Canaveral, to a waiting MAC C-141 aircraft. Their caskets were each draped with an American flag and carried past an honor guard and followed by an astronaut escort. The astronaut escorts for the *Challenger* crew were: Dan Brandenstein, Jim Buckley, Norm Thagard, Charles Bolden, Tammy Jernigan, Dick Richards, and Loren Shriver. Once the astronauts' remains were aboard the jet, they were flown to Dover Air Force Base in Delaware to be processed and then released to their loved ones.

By May 1, enough of the right solid rocket booster had been recovered to determine the original cause of the accident, and the major salvage operations were concluded. While some shallow-water recovery efforts continued, this was unconnected with the accident investigation; it aimed to recover debris for use in NASA's studies of the properties of materials used in spacecraft and launch vehicles. The recovery operation was able to pull 15 short tons (14 t) of debris from the ocean; 55% of *Challenger*, 5% of the crew cabin and 65% of the satellite cargo is still missing. Some of the missing debris continued to wash up on Florida shores for some years, such as on December 17, 1996, nearly 11 years after the incident, when two large pieces of the shuttle were found at Cocoa Beach.^[11] Under 18 U.S.C. § 641^[12] it is against the law to be in possession of *Challenger* debris, and any newly discovered pieces must be turned in to NASA.

On board *Challenger* was an American flag, dubbed the Challenger flag, that was sponsored by Boy Scout Troop 514 of Monument, Colorado. It was recovered intact, still sealed in its plastic container.

All recovered non-organic debris from *Challenger* was ultimately buried in a former missile silo at Cape Canaveral Air Force Station Launch Complex 31.

Funeral ceremonies



The remains of the *Challenger* crew are transferred to a C-141 at the NASA KSC Shuttle Landing Facility, bound for Dover Air Force Base, Delaware.

The remains of the crew that were identifiable were returned to their families on April 29, 1986. Three of the crew members, Judith Resnik, Dick Scobee, and Capt. Michael J. Smith, were buried by their families at Arlington National Cemetery at individual grave sites. Mission Specialist Lt Col Ellison Onizuka was buried at the National Memorial Cemetery of the Pacific in Honolulu, Hawaii. Unidentified crew remains were buried communally at the Space Shuttle *Challenger* Memorial in Arlington on May 20, 1986.

NASA crisis



The launch attempt of the Delta 3914 carrying the GOES-G, ends in failure 71 seconds later, May 3, 1986

Several National Reconnaissance Office (NRO) satellites that only the shuttle could launch were grounded because of the accident, a dilemma NRO had feared since the 1970s when the shuttle was designated as the United States' primary launch system for all government and commercial payloads.^{[13][14]} NASA had difficulties with its own Titan rocket and Delta rocket programs, due to other unexpected rocket failures occurring before and after the *Challenger* disaster. On August 28, 1985, a Titan 34D carrying a KH-11 KENNAN satellite exploded after liftoff over Vandenberg Air Force Base, when the first stage propellant motor failed. It was the first failure of a Titan missile since 1978. On April 18, 1986, another Titan 34D-9 carrying a classified payload, said to be a Big Bird spy satellite, exploded at about 830 feet above the pad after liftoff over Vandenberg AFB, when a burnthrough occurred on one of the rocket boosters. On May 3, 1986, a Delta 3914 carrying the GOES-G weather satellite exploded 71 seconds after liftoff over Cape Canaveral Air Force Station due to an electrical malfunction on the Delta's first stage, which prompted the range safety officer on the ground to decide to destroy the rocket, just as a few of the rocket's boosters were jettisoned. As a result of these three failures, NASA decided to cancel all Titan and Delta launches from Cape Canaveral and Vandenberg for four months, until the problem in the rockets' designs were solved.

Due to the shuttle fleet being grounded, excess ammonium perchlorate that was manufactured as rocket fuel was kept on site at the Pacific Engineering and Production Company of Nevada (PEPCON) plant in Henderson, Nevada. This excess ammonium perchlorate later caught fire and the resulting explosion destroyed the PEPCON facility and the neighboring Kidd & Co marshmallow factory.^[15]

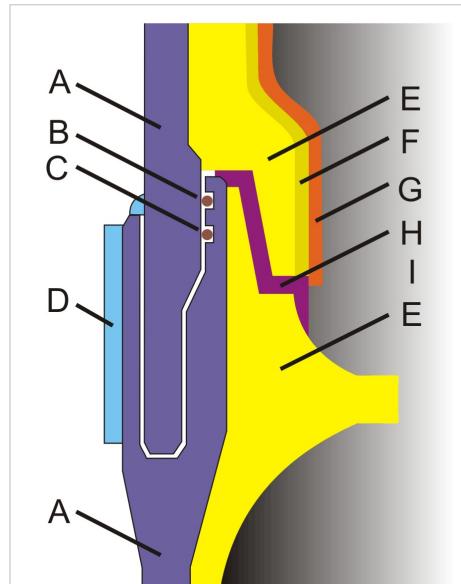
Investigation

In the aftermath of the accident, NASA was criticized for its lack of openness with the press. *The New York Times* noted on the day after the accident that "neither Jay Greene, flight director for the ascent, nor any other person in the control room, was made available to the press by the space agency". In the absence of reliable sources, the press turned to speculation; both *The New York Times* and United Press International ran stories suggesting that a fault with the space shuttle external tank had caused the accident, despite the fact that NASA's internal investigation had quickly focused in on the solid rocket boosters.^{[16][17]} "The space agency," wrote space reporter William Harwood, "stuck to its policy of strict secrecy about the details of the investigation, an uncharacteristic stance for an agency that long prided itself on openness."

Rogers Commission

Main article: Rogers Commission Report

The **Presidential Commission on the Space Shuttle *Challenger* Accident**, also known as the Rogers Commission (after its chairman), was formed to investigate the disaster. The commission members were Chairman William P. Rogers, Vice Chairman Neil Armstrong, David Acheson, Eugene Covert, Richard Feynman, Robert Hotz, Donald Kutyna, Sally Ride, Robert Rummel, Joseph Sutter, Arthur Walker, Albert Wheelon, and Chuck Yeager. The commission worked for several months and published a report of its findings. It found that the *Challenger* accident was caused by a failure in the O-rings sealing a joint on the right solid rocket booster, which allowed pressurized hot gases and eventually flame to "blow by" the O-ring and make contact with the adjacent external tank, causing structural failure. The failure of the O-rings was attributed to a faulty design, whose performance could be too easily compromised by factors including the low temperature on the day of launch.



Simplified cross section of the joints between rocket segments SRB. Legend:

- A - steel wall thickness 12.7 mm,
- B - base O-ring gasket,
- C - backup O-ring gasket,
- D - Strengthening-Cover band,
- E - insulation,
- F - insulation,
- G - carpeting,
- H - sealing paste,
- I - fixed propellant



Members of the Rogers Commission arrive at Kennedy Space Center.

More broadly, the report also considered the contributing causes of the accident. Most salient was the failure of both NASA and Morton Thiokol to respond adequately to the danger posed by the deficient joint design. Rather than redesigning the joint, they came to define the problem as an acceptable flight risk. The report found that managers at Marshall had known about the flawed design since 1977, but never discussed the problem outside their reporting channels with Thiokol—a flagrant violation of NASA regulations. Even when it became more apparent how serious the flaw was, no one at Marshall considered grounding the shuttles until a fix could be implemented. On the contrary, Marshall managers went as far as to issue and waive six launch constraints related to the O-rings. The report also strongly

criticized the decision-making process that led to the launch of *Challenger*, saying that it was seriously flawed.

...failures in communication... resulted in a decision to launch 51-L based on incomplete and sometimes misleading information, a conflict between engineering data and management judgments, and a NASA management structure that permitted internal flight safety problems to bypass key Shuttle managers.

—Richard Feynman,

One of the commission's best-known members was theoretical physicist Richard Feynman. During a televised hearing, he famously demonstrated how the O-rings became less resilient and subject to seal failures at ice-cold temperatures by immersing a sample of the material in a glass of ice water. He was so critical of flaws in NASA's "safety culture" that he threatened to remove his name from the report unless it included his personal observations on the reliability of the shuttle, which appeared as Appendix F. In the appendix, he argued that the estimates of reliability offered by NASA management were wildly unrealistic, differing as much as a thousandfold from the estimates of working engineers. "For a successful technology," he concluded, "reality must take precedence over public relations, for nature cannot be fooled."^[18]

Richard Feynman wrote that while other members of the Commission met with NASA and supplier top management he sought out the engineers and technicians. That is how he became aware of the O-ring problem. He also noted that one of the Commission's main worries concerned the type of leather binding in which to present the report to the President.

U.S. House Committee hearings

The U.S. House Committee on Science and Technology also conducted hearings, and on October 29, 1986, released its own report on the *Challenger* accident. The committee reviewed the findings of the Rogers Commission as part of its investigation, and agreed with the Rogers Commission as to the technical causes of the accident. However, it differed from the committee in its assessment of the accident's contributing causes:

...the Committee feels that the underlying problem which led to the Challenger accident was not poor communication or underlying procedures as implied by the Rogers Commission conclusion. Rather, the fundamental problem was poor technical decision-making over a period of several years by top NASA and contractor personnel, who failed to act decisively to solve the increasingly serious anomalies in the Solid Rocket Booster joints.

NASA and Air Force response

After the *Challenger* accident, further shuttle flights were suspended, pending the results of the Rogers Commission investigation. Whereas NASA had held an internal inquiry into the Apollo 1 fire in 1967, its actions after *Challenger* were more constrained by the judgment of outside bodies. The Rogers Commission offered nine recommendations on improving safety in the space shuttle program, and NASA was directed by President Reagan to report back within thirty days as to how it planned to implement those recommendations.

When the disaster occurred, the Air Force had performed extensive modifications of its Space Launch Complex 6 (SLC-6, pronounced as "Slick Six") at Vandenberg Air Force Base in California, for launch and landing operations of classified Shuttle launches of satellites in polar orbit, and was planning its first polar flight for October 15, 1986. Originally built for the Manned Orbital Laboratory project cancelled in 1969, the modifications were proving problematic and expensive, costing over \$4 billion. The Challenger loss motivated the Air Force to set in motion a chain of events that finally led to the May 13, 1988 decision to cancel its Vandenberg Shuttle launch plans, in favor of the Titan IV unmanned launch vehicle.

In response to the commission's recommendation, NASA initiated a total redesign of the space shuttle's solid rocket boosters, which was watched over by an independent oversight group as stipulated by the commission. NASA's contract with Morton Thiokol, the contractor responsible for the solid rocket boosters, included a clause stating that in the event of a failure leading to "loss of life or mission," Thiokol would forfeit \$10 million of its incentive fee and formally accept legal liability for the failure. After the *Challenger* accident, Thiokol agreed to "voluntarily accept" the monetary penalty in exchange for not being forced to accept liability.^[19]

NASA also created a new Office of Safety, Reliability and Quality Assurance, headed as the commission had specified by a NASA associate administrator who reported directly to the NASA administrator. George Martin, formerly of Martin Marietta, was appointed to this position. Former *Challenger* flight director Jay Greene became chief of the Safety Division of the directorate.

The unrealistically optimistic launch schedule pursued by NASA had been criticized by the Rogers Commission as a possible contributing cause to the accident. After the accident, NASA attempted to aim at a more realistic shuttle flight rate: it added another orbiter, *Endeavour*, to the space shuttle fleet to replace *Challenger*, and it worked with the Department of Defense to put more satellites in orbit using expendable launch vehicles rather than the shuttle. In August 1986, President Reagan also announced that the shuttle would no longer carry commercial satellite payloads. After a 32-month hiatus, the next shuttle mission, STS-26, was launched on September 29, 1988.

Although changes were made by NASA after the *Challenger* accident, many commentators have argued that the changes in its management structure and organizational culture were neither deep nor long-lasting.

After the Space Shuttle Columbia disaster in 2003, attention once again focused on the attitude of NASA management towards safety issues. The Columbia Accident Investigation Board (CAIB) concluded that NASA had failed to learn many of the lessons of *Challenger*. In particular, the agency had not set up a truly independent office for safety oversight; the CAIB felt that in this area, "NASA's response to the Rogers Commission did not meet the Commission's intent". The CAIB believed that "the causes of the institutional failure responsible for *Challenger* have not been fixed," saying that the same "flawed decision making process" that had resulted in the *Challenger* accident was responsible for *Columbia*'s destruction seventeen years later.



Astronaut Charles F. Bolden reads a passage from the Bible during memorial services for the seven crew members of 51-L who lost their lives aboard the Space Shuttle Challenger in a Florida accident
(NASA)

Media coverage

While the presence of New Hampshire schoolteacher Christa McAuliffe on the *Challenger* crew had provoked some media interest, there was little live broadcast coverage of the launch. The only live national TV coverage available publicly was provided by CNN; although several radio networks were also live. Due to McAuliffe's presence on the mission, NASA arranged for many U.S. public schools to view the launch live on NASA TV. As a result, many who were schoolchildren in the US in 1986 did in fact have the opportunity to view the launch live. After the accident, however, 17% of respondents in one study reported that they had seen the shuttle launch, while 85% said that they had learned of the accident within an hour. As the authors of the paper reported, "only two studies have revealed more rapid dissemination [of news]." (One of those studies was of the spread of news in Dallas after President John F. Kennedy's assassination, while the other was the spread of news among students at Kent State regarding President Franklin D. Roosevelt's death.) Another study noted that "even those who were not watching television at the time of the disaster were almost certain to see the graphic pictures of the accident replayed as the television networks reported the story almost continuously for the rest of the day." Children were even more likely than adults to have seen the accident live, since many children — 48 percent of nine to thirteen-year-olds, according to a *New York Times* poll — watched the launch at school.

Following the day of the accident, press interest remained high. While only 535 reporters were accredited to cover the launch, three days later there were 1467 reporters at Kennedy Space Center and another 1040 at Johnson Space Center. The event made headlines in newspapers worldwide.

Use as case study

The *Challenger* accident has frequently been used as a case study in the study of subjects such as engineering safety, the ethics of whistle-blowing, communications, group decision-making, and the dangers of groupthink. It is part of the required readings for engineers seeking a professional license in Canada and other countries. Roger Boisjoly, the engineer who had warned about the effect of cold weather on the O-rings, left his job at Morton Thiokol and became a speaker on workplace ethics. He argues that the caucus called by Morton Thiokol managers, which resulted in a recommendation to launch, "constituted the unethical decision-making forum resulting from intense customer intimidation." For his honesty and integrity leading up to and directly following the shuttle disaster, Roger Boisjoly was awarded the Prize for Scientific Freedom and Responsibility from the American Association for the Advancement of Science. Many colleges and universities have also used the accident in classes on the ethics of engineering.

Information designer Edward Tufte has claimed that the *Challenger* accident is an example of the problems that can occur from the lack of clarity in the presentation of information. He argues that if Morton Thiokol engineers had more clearly presented the data that they had on the relationship between low temperatures and burn-through in the solid rocket booster joints, they might have succeeded in persuading NASA managers to cancel the launch. To demonstrate this, he took all of the data he claimed the engineers had presented during the briefing, and reformatted it onto a single graph of O-ring damage versus external launch temperature, showing the effects of cold on the degree of O-ring damage. Tufte then placed the proposed launch of *Challenger* on the graph according to its predicted temperature at launch. According to Tufte, the launch temperature of *Challenger* was so far beyond from the coldest launch with the worst damage ever seen to date, that even a casual observer could have determined that the risk of disaster was severe.^[20]

Tufte has also argued that poor presentation of information may have also affected NASA decisions during the last flight of the space shuttle *Columbia*.

However, Robison, a Rochester Institute of Technology professor, and Boisjoly vigorously repudiated Tufte's conclusions about the Morton Thiokol engineers' role in the loss of *Challenger*. First they say that the engineers didn't have the information available as Tufte claimed: "But they did not know the temperatures even though they did try to obtain that information. Tufte has not gotten the facts right even though the information was available to

him had he looked for it." They further argue that Tufte "misunderstands thoroughly the argument and evidence the engineers gave". They also criticized Tufte's diagram as "fatally flawed by Tufte's own criteria. The vertical axis tracks the wrong effect, and the horizontal axis cites temperatures not available to the engineers and, in addition, mixes O-ring temperatures and ambient air temperature as though the two were the same."

Continuation of the Shuttle Program

After the accident, NASA's Space Shuttle fleet was grounded for almost three years while the investigation, hearings, engineering redesign of the SRBs, and other behind-the-scenes technical and management reviews, changes, and preparations were taking place. At 11:37 on September 29, 1988, Space Shuttle *Discovery* lifted off with a crew of five from Kennedy Space Center pad 39-B. It carried a Tracking and Data Relay Satellite, TDRS-C (named TDRS-3 after deployment), which replaced TDRS-B, the satellite that was launched and lost on Challenger. The "Return to Flight" launch of Discovery also represented a test of the redesigned boosters, a shift to a more conservative stance on safety (e.g., it was the first time the crew had launched in pressure suits since STS-4, the last of the four initial Shuttle test flights), and a chance to restore national pride in the American space program, especially manned space flight. The mission, STS-26, was a success (with only two minor system failures, one of a cabin cooling system and one of a Ku-band antenna), and a regular schedule of STS flights followed, continuing without extended interruption until the 2003 *Columbia* disaster.

Barbara Morgan, the backup astronaut for McAuliffe who trained with her in the Teacher in Space program and was at KSC watching her launch on January 28, 1986, flew on STS-118 as a Mission Specialist in August 2007.

Legacy

The families of the *Challenger* crew organized the Challenger Center for Space Science Education as a permanent memorial to the crew. Fifty-two learning centers have been established by this non-profit organization.[Wikipedia:Citation needed](#)

Rendez-vous Houston is remembered for being the concert which celebrated the astronauts of the Challenger disaster, which had happened only two and a half months beforehand. It was a live performance by musician Jean Michel Jarre in Houston on the evening of April 5, 1986. Jarre and crew member Ron McNair were friends. McNair was supposed to play the saxophone from space during the track "Last Rendez-Vous". It was to have become the first musical piece played and recorded in space. His substitute for the concert was Houston native Kirk Whalum.



The Space Shuttle *Challenger* Memorial in Arlington National Cemetery, where some remains were buried



Squadron "Challenger" 17 logo

The Squadron "Challenger" 17 is an Air Force unit in the Texas A&M Corps of Cadets that emphasizes athletic and academic success in honor of the Challenger crew.^[21] The unit was established in 1992.^[22]

An elementary school in Nogales, Arizona, commemorates the accident in name, Challenger Elementary School, and their school motto, "Reach for the sky". The suburbs of Seattle, Washington are home to Challenger Elementary School in Issaquah, Washington and Christa McAuliffe Elementary School in Sammamish, Washington. In San Diego, California, the next-opened public middle school in the San Diego Unified School District was named Challenger Middle School. The City of Palmdale, the birthplace of the entire shuttle fleet, and its neighbor City of Lancaster, California, both renamed *10th Street East*, from Avenue M to Edwards Air Force Base, to *Challenger Way* in honor of the lost shuttle and its crew.Wikipedia:Citation needed This was the road that the *Challenger*, *Enterprise*, and *Columbia* all were towed along in their initial move from

U.S. Air Force Plant 42 to Edwards AFB after completion since Palmdale airport had not yet installed the shuttle crane for placement of an orbiter on the 747 Shuttle Carrier Aircraft.Wikipedia:Citation needed In addition, the City of Lancaster has built Challenger Middle School, and Challenger Memorial Hall at the former site of the Antelope Valley Fairgrounds, all in tribute to the *Challenger* shuttle and crew.Wikipedia:Citation needed Another school was opened in Chicago, IL as the Sharon Christa McAuliffe Elementary school. The public Peers Park in Palo Alto, California features a "Challenger Memorial Grove" that includes redwood trees grown from seeds carried aboard *Challenger* in 1985. In 1986 in Webster, Texas, the "Challenger Seven Memorial Park" was also dedicated in remembrance of the event.

In Cocoa, Brevard County, Florida (the county where Cape Canaveral and KSC are located), Challenger 7 Elementary School is named in memory of the seven astronauts who lost their lives. There is also a middle school in neighboring Rockledge, McNair Magnet School, named after astronaut Ronald McNair. A middle school (formerly high school) in Mohawk, New York is named after payload specialist Gregory Jarvis. Another middle school in Boynton Beach, Florida, is named after deceased teacher/astronaut, Christa McAuliffe. There are also schools in Saratoga, California, Lowell, Massachusetts, and Lenexa, Kansas, named in honor of Christa McAuliffe. The McAuliffe-Shepard Discovery Center, a science museum and planetarium in Concord, New Hampshire, is also partly named in her honor. There is also an elementary school in Germantown, Maryland, named after Christa McAuliffe as well as in Green Bay, Wisconsin and Hastings, Minnesota. The draw bridge over the barge canal on State Rd.3 on Merritt Island, Florida, is named the Christa McAuliffe Memorial Bridge.

In 2004, President George W. Bush conferred posthumous Congressional Space Medals of Honor to all 14 astronauts lost in the *Challenger* and *Columbia* accidents.

In December 2013 the release by Beyoncé Knowles of song XO which begins with a sample of former NASA public affairs officer Steve Nesbitt, recorded moments after the disaster: "Flight controllers here looking very carefully at the situation. Obviously a major malfunction." raised controversy, with former NASA astronauts and families labelling Knowles' sample as "insensitive." Hardeep Phull of *New York Post* described the sample's presence as "tasteless," and Keith Cowing of NASA Watch suggested that the usage of the clip ranged from "negligence" to "repugnant." On December 31, 2013, NASA criticized the use of the sample, stating that "The *Challenger* accident is an important part of our history; a tragic reminder that space exploration is risky and should never be trivialized. NASA works everyday to honor the legacy of our fallen astronauts as we carry out our mission to reach for new heights and explore the universe." On December 30, 2013, Knowles issued a statement to ABC News, saying: "My heart goes out to the families of those lost in the *Challenger* disaster. The song 'XO' was recorded with the sincerest intention to help heal those who have lost loved ones and to remind us that unexpected things happen, so love and

appreciate every minute that you have with those who mean the most to you. The songwriters included the audio in tribute to the unselfish work of the *Challenger* crew with hope that they will never be forgotten."

Video documentation

The disaster is notable for the lack of video documentation of the event. Until 2010, the live broadcast of the launch and subsequent disaster by CNN was the only known on-location video footage from within range of the launch site. More recently, as of March 15, 2014, seven other motion picture recordings of the event have become publicly available:

- a video recording by Jack Moss from the front yard of his house in Winter Haven, Florida, 80 miles (130 km) from Cape Canaveral
- a video recording by Ishbel & Hugh Searle on a plane leaving from Orlando International Airport, 50 miles (80 km) from Cape Canaveral, was posted by their daughter Victoria Searle on January 30, 2011 along with an interview taken on January 28, 2011 by Ishbel & Hugh Searle
- a video recording by Bob Karman from Orlando International Airport, 50 miles (80 km) from Cape Canaveral
- a Super 8 mm film recorded by then-19-year-old Jeffrey Ault of Orange City, Florida, at the Kennedy Space Center, 10 miles (16 km) from the launch
- a video recording by Lawrence Hebert of Electric Sky Films, filmed at the Kennedy Space Center, 10 miles (16 km) from the launch, uncovered in March 2012
- a video recording by Steven Virostek uncovered in May 2012
- a video recording by Michael and Frances VanKulick of Melbourne, Florida was made public in 2014.

Film

A BBC docudrama titled *The Challenger* was broadcast on March 18, 2013, based on the last of Richard Feynman's autobiographical works, *What Do You Care What Other People Think?*. It stars William Hurt as Feynman. It includes the notion that NASA promised the US Air Force that it could launch military payloads on the Shuttle, in order to get funding that would have been earmarked for development of the Titan IV expendable launcher. Numerous delays on previous flights had already reduced NASA's credibility, and after the Challenger disaster, the Air Force developed the Titan IV instead of using the Shuttle. Wikipedia:Citation needed

Notes

- [1] McConnell, Malcolm. *Challenger: A Major Malfunction*, page 118.
- [2] McConnell, Malcolm. *Challenger: A Major Malfunction*, pages 150–153.
- [3] McConnell, Malcolm. *Challenger: A Major Malfunction*, page 154.
- [4] A major source for information about the *Challenger* accident is the STS 51-L Incident Integrated Events Timeline developed by the NASA Photo and TV Support Team as part of the Rogers Report. Numerous other timelines have been written based on this information. A detailed transcript of air-to-ground and mission control voice communications was put together by Rob Navias and William Harwood for CBS News, and integrates a timeline of events:
- [5] American Rhetoric: Top 100 Speeches of the 20th Century by Rank (<http://www.americanrhetoric.com/top100speechesall.html>)
- [6] <http://www.oup.com/us/catalog/he/subject/Communication/SpeechCommunication/PublicSpeaking/?&ci=9780195168051>
- [7] Ronald Reagan Presidential Library, Address to the nation on the *Challenger* disaster. (<http://www.reagan.utexas.edu/archives/speeches/1986/12886b.htm>) Retrieved July 4, 2006.
- [8] "Reagan's Eulogy for the Challenger Astronauts" (<http://www.eulogyspeech.net/famous-eulogies/Ronald-Reagan-Eulogy-for-the-Challenger-Astronauts.shtml>). Ronald Reagan. January 31, 1986.
- [9] "When a Community Weeps: Case Studies in Group Survivorship—Google Books Result" (page 29 of book), by Ellen Zinner, Mary Beth Williams, 1999, Psychology Press, p.29, webpage: Books-Google-ID-id=8DuhIv8U11oC&pg=PA29 ([http://books.google.com/books?id=8DuhIv8U11oC&pg=PA29&lpg=PA29&dq=challenger+1986+"missing+man+formation"+god+bless+america"&source=web&ots=L-aC6lrn5M&sig=XiS_yzne8-9VKbQU269tZIG0jTs](http://books.google.com/books?id=8DuhIv8U11oC&pg=PA29&lpg=PA29&dq=challenger+1986+)).
- [10] Jensen, Claus, *No Downlink*, p. 17.

- [11] CNN (1996), "Shuttle Challenger debris washes up on shore" (<http://www.cnn.com/TECH/9612/17/challenger.debris/index.html>). December 17, 1996. Retrieved July 4, 2006.
- [12] <http://www.law.cornell.edu/uscode/18/641.html>
- [13] Day, Dwayne A. "The spooks and the turkey (<http://www.thespacereview.com/article/748/1>)" *The Space Review*, 20 November 2006.
- [14] Day, Dwayne A. "Big Black and the new bird: the NRO and the early Space Shuttle (<http://www.thespacereview.com/article/1542/1>)" *The Space Review*, 11 January 2010.
- [15] American Pacific Corporation, Las Vegas, NV USA, 89169, parent company of the former PEPCON subsidiary and current parent to the WECCO division which manufactures perchlorate chemicals, including Human Resources, employees on site 5-4-88.
- [16] Archived by the Internet Archive on May 4, 2006.
- [17] See, for example, *New Orleans Times-Picayune*, January 29, 1986, p. 1.
- [18] Feynman, Richard P. (1986) Appendix F- Personal Observations on the reliability of the Shuttle. (<http://science.ksc.nasa.gov/shuttle/missions/51-l/docs/rogers-commission/Appendix-F.txt>)
- [19] Jensen, Claus. *No Downlink*, p. 355.
- [20] Edward Tufte. (1997) *Visual Explanations*, ISBN 0-9613921-2-6, Chapter 2.
- [21] <http://corps.tamu.edu/Outfit-Pages/squadron-17.html>
- [22] <http://www.corpsofcadets.org/outfit-genealogy-since-1876/>

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 - Part 4 (<http://donswaim.com/wcbs-challenger-4.mp3>) (mp3).

Coordinates: 28°38'24"N 80°16'48"W (http://tools.wmflabs.org/geohack/geohack.php?pagename=Space_Shuttle_Challenger_Disaster¶ms=28_38_24_N_80_16_48_W_region:US-FL_type:landmark_scale:1500000)

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