Day of Remembrance

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Introduction

Every year in late January, NASA holds a Day of Remembrance, honoring the astronauts lost in three major space flight accidents: Apollo 1, *Challenger* and *Columbia*. In an odd tragic coincidence, all three of the accidents happened in late January or early February, although many years apart: Apollo 1 on January 27, 1967; *Challenger* on January 28, 1986; and *Columbia* on February 1, 2003. While the day is a solemn one to commemorate the astronauts who lost their lives, it is also a day to reflect on the errors that led to the accidents and to remind all NASA workers and managers to be ever vigilant so that preventable accidents don't happen again.

"Fire in the cockpit!"

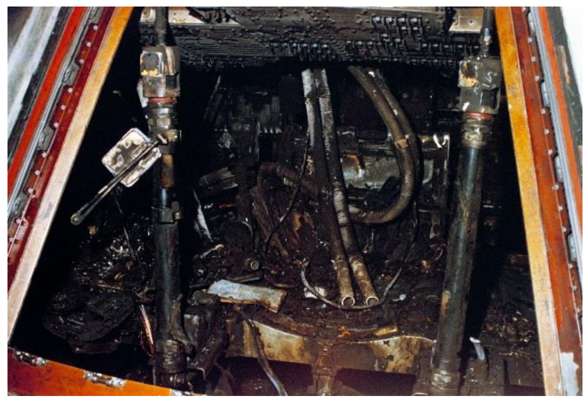
On January 27, 1967, one month before the planned inaugural flight of the Apollo spacecraft in Earth orbit, astronauts Gus Grissom, Ed White and Roger Chaffee strapped themselves into their capsule for a full up dress rehearsal of the countdown at Cape Kennedy in Florida. It was meant to be as realistic a simulation as possible, with the crew wearing full pressure suits and the cabin sealed as if for flight and pressurized to 16.7 psi (slightly higher than sea level pressure) with pure oxygen. During the long hours in the cabin, the crew dealt with numerous problems, among them poor communications with mission controllers. In the midst of the test, technicians heard a crewmember say "fire in the cockpit."

A small fire under Grissom's seat spread incredibly fast in the pure oxygen environment and the enclosed space of the capsule. The space suits they were wearing protected the crew from major burns, but the fire rapidly used up the oxygen and the various flammable items in the capsule gave off thick smoke. Within minutes all three men died of asphyxiation. The crew had valiantly tried to save themselves by trying to open the hatch, but the three-hatch design proved too much to overcome: the innermost hatch opened inward, and with the increased pressure caused by the fire the crew physically could not open it.

Immediately, NASA set up an investigation board to determine the cause of the accident. The exact source of ignition for the fire was not determined conclusively, but it was likely an electrical short that set some combustible material aflame. The pure oxygen atmosphere at high pressure and extensive use of flammable materials was an ideal environment for the fire to spread. Although in retrospect these conditions seem obviously hazardous, it was common practice in American aerospace and therefore accepted as safe because there had never before been an accident. Unknown to everyone in the US until decades later, a Soviet cosmonaut had died tragically in 1961 under similar circumstances during a ground test in an altitude chamber filled with pure oxygen, an accident the Soviets kept secret for decades. We can only speculate, but had the Americans known about this incident, perhaps they wouldn't have used pure oxygen in the Apollo spacecraft.

On the management side, NASA knew of many quality and safety issues related to North American Aviation, the prime contractor responsible for building the Apollo spacecraft. In fact many instances of poor workmanship and lack of safety oversight had been documented in an official report less than a year before the fire, yet no real corrections had been implemented.

In response to the review, the contractor implemented many modifications to the spacecraft, including redesign of the wiring, a quick opening hatch, eliminating the use of a pure oxygen atmosphere during ground tests, and removal of many flammable materials. NASA improved its management and safety organizations with the establishment of an independent safety review organization. No American flew in space for 21 months until October 1968, when NASA deemed the Apollo system was again safe to carry crewmembers.



Apollo 1 crew of (l. to r.) Gus Grissom, Ed White and Roger Chaffee (left); charred remains of the Apollo 1 capsule (right). Images courtesy of NASA.

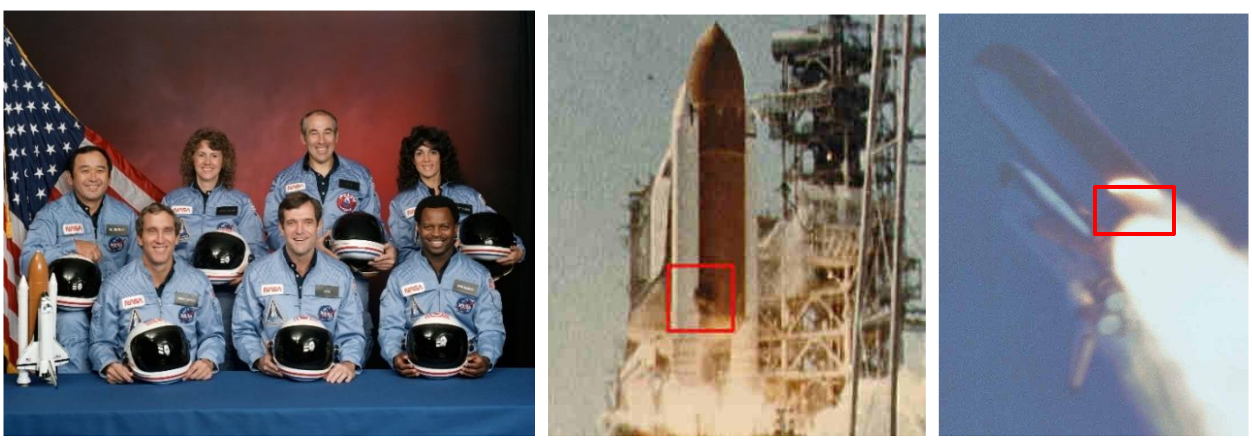
"*Challenger*, go at throttle up"

The morning of January 28, 1986, was exceptionally cold by Florida standards – the overnight temperature at the Kennedy Space Center had dipped to 18^{o}F. Icicles covered the launch pad on which the Space Shuttle *Challenger* was poised for flight. As the morning wore on and launch time approached, the temperature warmed to 28^{o}F, still far colder than the previous coldest launch (54^{o}F). Some engineers expressed serious concerns that O-rings in the joints between Solid Rocket Motor (SRM) segments inside the Solid Rocket Boosters (SRB's) would not work as predicted under such cold conditions and could let superheated gases escape and damage the boosters, a phenomenon observed on previous launches but never to catastrophic levels. These engineers urged a postponement, but the launch had already been scrubbed several times and managers wanted to fly that day, so they gave the "Go" to launch.

Unbeknownst to the crew and all watching the launch either in person or on TV, trouble started mere moments after liftoff. During the investigation, a puff of black smoke could be seen on video of the launch less than a second after liftoff, coming from the side of the right-hand SRB. This was the first sign that the O-rings were failing and hot gases were escaping. Within less than a minute, this had grown to a plume of flame that then burned through the strut connecting the SRB to the large hydrogen tank, causing the rocket to pivot into the tank, which at 73 seconds and an altitude of 48,000 feet exploded into a fireball. As the Shuttle disintegrated, the crew compartment was blown clear of the explosion. There's evidence at least some of the crew survived the explosion, only to be killed when the cabin hit the water at about 200 miles per hour. There was no escape system.

The independent Rogers Commission was empaneled to determine the cause of the accident and to make recommendations so the program could resume flying safely. The focus immediately turned to the O-rings in the joints of the SRM's. There had been issues with O-rings since the second flight in the program in 1981, but none had caused any real damage, and so the problem had become accepted as normal. But no data existed about how the O-ring material would behave at the low temperatures in which *Challenger* launched, although some engineers predicted it would become brittle and fail. In a simple test during the investigation, this was indeed proven to be true. What was more disturbing is that engineers had raised the issue of the O-rings before *Challenger*'s launch and had recommended a delay, but management that had normalized the problem with O-rings and didn't fully appreciate the risk had overruled them.

The Commission made several recommendations, both to the Shuttle system and to NASA management. On the Shuttle side, the addition of an escape system would allow crewmembers to exit the vehicle during stable flight (but wouldn't have saved the *Challenger* crew), the use of full pressure suits was mandated, and the O-rings and SRM's were redesigned to prevent a repeat of the *Challenger* accident. More importantly, NASA changed its decision making process to allow for more open discussions of dissenting opinions and created a new independent safety organization. The modifications required 32 months to complete before the next Shuttle flew in September 1988.



Crew of the Space Shuttle Challenger *(left): (l. to r.) Ellison Onizuka, Mike Smith, Christa McAuliffe, Dick Scobee, Greg Jarvis, Ron McNair and Judy Resnik. The puff of black smoke from the right SRB moments after launch (center) and the growing plume of flame at about 1 minute (right). Images courtesy of NASA.*

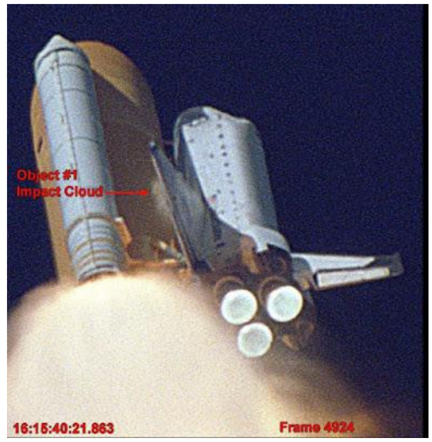
16 minutes from home

On February 1, 2003, the crew of the Space Shuttle *Columbia* was wrapping up a highly successful 16-day research mission. They had all donned their orange launch and entry suits, had their helmets on and most were already strapped in their seats for reentry. They fired the Shuttle's engines to drop them out of orbit and turned the ship around so it was flying nose first, ready to face the upper layers of the atmosphere at 400,000 feet, signaling their reentry. As the craft descended lower, the densifying atmosphere interacted with the vehicle as it traveled at supersonic speeds, heating the leading edges to up to 3,000^{o}F. Unknown to the crew, observers on the ground watching the reentry noted abnormalities in the usually smooth streak of light, as if the Shuttle were shedding pieces. Around this time, Mission Control noted some very odd telemetry data coming from *Columbia* that they simply couldn't explain. It's likely that the crew onboard also began noticing strange things happening, but all communications were suddenly cut off. Mission Control tried in vain to hail the crew, but there was no response. In the skies over Texas, observers noted the single trail of *Columbia* breaking into multiple trails as the vehicle disintegrated. The debris field extended over a long swath of east Texas and into western Louisiana. *Columbia* and her crew were 16 minutes from landing in Florida.

The *Columbia* Accident Investigation Board (CAIB) determined the proximate cause of the accident, and once again noted that there were management cultural issues that were significant contributing factors. NASA knew that 82 seconds after liftoff, a suitcase-size chunk of insulating foam (probably mixed with ice) had come loose from the Shuttle's large orange External Tank and struck the Shuttle's left wing. Imagery of the Shuttle during the flight using powerful ground-based telescopes didn't show any apparent damage, but the resolution was not optimal and some parts of the vehicle couldn't be properly observed. Concerned engineers repeatedly requested the use of other "national assets" to photograph *Columbia* at higher resolution but ultimately management rejected the requests. Based on the available data, therefore, management deemed the situation to be of no real concern, and provided this assessment to the crew. As it turns out, that chunk of foam had punched a hole in *Columbia*'s left wing leading edge. The hole didn't cause any issues until the reentry 16 days later, when super-hot gases intruded into the wing's structure, melting the aluminum frame, eventually causing the wing to detach and the entire vehicle to then disintegrate at 200,000 feet and traveling at about 14,000 mph. The crew cabin rapidly depressurized, causing the crew to lose consciousness within seconds and expire shortly thereafter.

Although there was a requirement from the very beginning of the program that the External Tank not shed any foam during launch, the phenomenon had been observed on many Shuttle flights going back to the early days of the program. Many times these strikes did no harm, but on several flights, larger pieces of foam had damaged the delicate heat shield tiles that lined the bottom of the vehicle and were critical for a safe reentry. But since none of these incidents was considered serious enough, the shedding became accepted as normal, a postflight maintenance issue rather than an inflight safety issue, contributing to the overall assessment that the foam impact on *Columbia* was not a cause for concern.

The CAIB made several recommendations, and as after the *Challenger* accident, these focused on improving the safety and reliability of the Shuttle itself as well as making organizational and cultural changes to how NASA makes its decisions. Among the former, NASA instituted changes to how the insulating foam was applied and improved monitoring of any foam shedding, and mandated orbital inspection of the Shuttle thermal protection system as the vehicle approached the International Space Station (ISS). Engineers also evaluated methods for in-flight repair of any damage. As far as the latter, the commission again reiterated the need for more open discussions during decision-making meetings and more acceptance of dissenting opinions. No Shuttle flew again for nearly 30 months, until July 2005, but the fate of the program was already sealed. Flights could resume with all the mandated safeguards in order to complete the assembly of the ISS, but once that was accomplished, the Shuttle would be retired. The last Shuttle mission flew in 2011.



Crew of the Space Shuttle Columbia (left): (l. to r.) Mark Brown, Rick Husband, Laurel Clark, Kalpana Chawla, Mike Anderson, Willie McCool, and Ilan Ramon. Foam debris at moment of impact during launch of Columbia (right). Images courtesy of NASA.

Epilogue

Space is indeed the final frontier. And as such, space flight is inherently dangerous and risky and anything but routine. The accidents reviewed here, and others less catastrophic, only serve to highlight those risks and dangers. And yet, it's also very clear that all of these accidents were preventable. The proximate cause in each was some mechanical failure, but the root causes involved organizational failure of management to properly address known safety issues, and in some cases putting schedule before safety. The accidents resulted in significant redesigns of spacecraft and management structures to make subsequent space flights safer. Perhaps in this way, the deaths of the brave astronauts were not in vain.

Patch to commemorate the three US space accidents (left). Memorial left on the Moon during Apollo 15 to commemorate known fallen astronauts and cosmonauts (right). Images courtesy of NASA.