The Human Interface: Human Factors and Redundancy on Apollo 10 and Skylab 4

Steve Lilley

10/18/2016

Human Factors and Redundancy

- While major Apollo and Skylab Program events — such as the Apollo 1 fire, the Apollo 13 oxygen tank explosion, and the Skylab 1 micrometeoroid shield loss — continue to serve as lessons and reminders, multiple lesser known crises were averted during the 21 missions that utilized the Apollo spacecraft.
- During Apollo 10 and Skylab 4, crews suffered from human factors related incidents that were remedied by engineered redundancies and excellent operational knowledge of the spacecraft.

Apollo 10

- May 18, 1969: Apollo 10 launched as the dress rehearsal mission for the Apollo 11 lunar landing.
- The crew of Apollo 10 completed translunar injection and the transposition, docking and extraction maneuver. Three days after launch, the Commander (CDR) and Lunar Module Pilot (LMP) entered the LM, fired the descent engine and executed the descent orbit insertion maneuver.
- Apollo 10 surveyed the Apollo 11 landing site in the Sea of Tranquility.

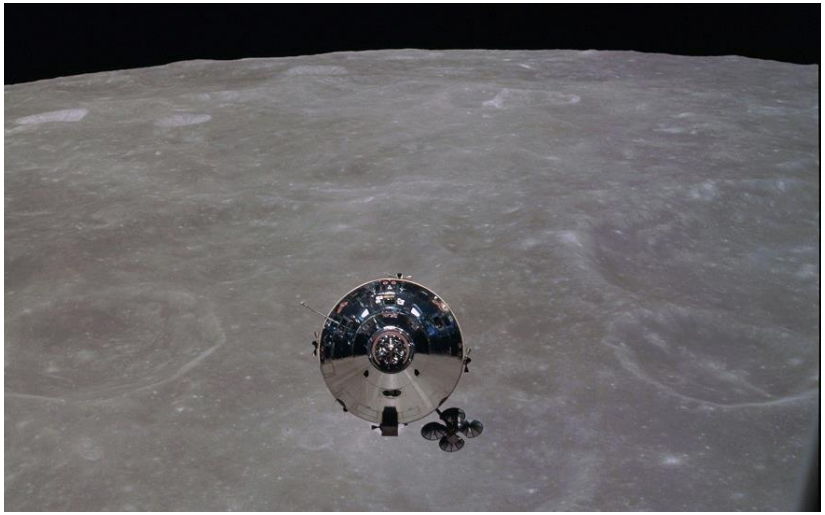

Figure 1. The Apollo 10 CM above the lunar surface. Source. NASA

excellence • teamwork • safety • integrity • knowledge

Apollo 10: Control Loss at Staging

- During the last LM pass the crew donned helmets and gloves for the “staging” maneuver — when the crew would jettison the LM decent engine.
- At 28 seconds to staging, the LM attitude indicator showed a slight yaw rate from the commanded attitude. Telemetry suggested an electrical anomaly, so the CDR began to troubleshoot the problem.
- It was difficult to reach the right switch with helmet and gloves on and the CDR inadvertently cycled the Abort Guidance System (AGS) mode control switch from the “ATT HOLD” (attitude hold) position to “AGS AUTO.”
- The LM immediately entered a rapid end-over-end roll as the AGS searched for the CSM seconds before staging. As danger of losing the inertial platform rose, the CDR grabbed the hand controller, switched to manual flight, jettisoned the descent stage and stabilized the ascent stage.
- The LM attitude indicator “GIMBAL LOCK” light came on. The inertial guidance platform was in danger of losing reference data which would cause the loss attitude indication; however, the inertial platform was still stable and the primary guidance system was still usable.

excellence • teamwork • safety • integrity • knowledge
NSC NASA SAFETY CENTER

Close Calls: Human Factors and Redundancy on Apollo 10 and Skylab 4

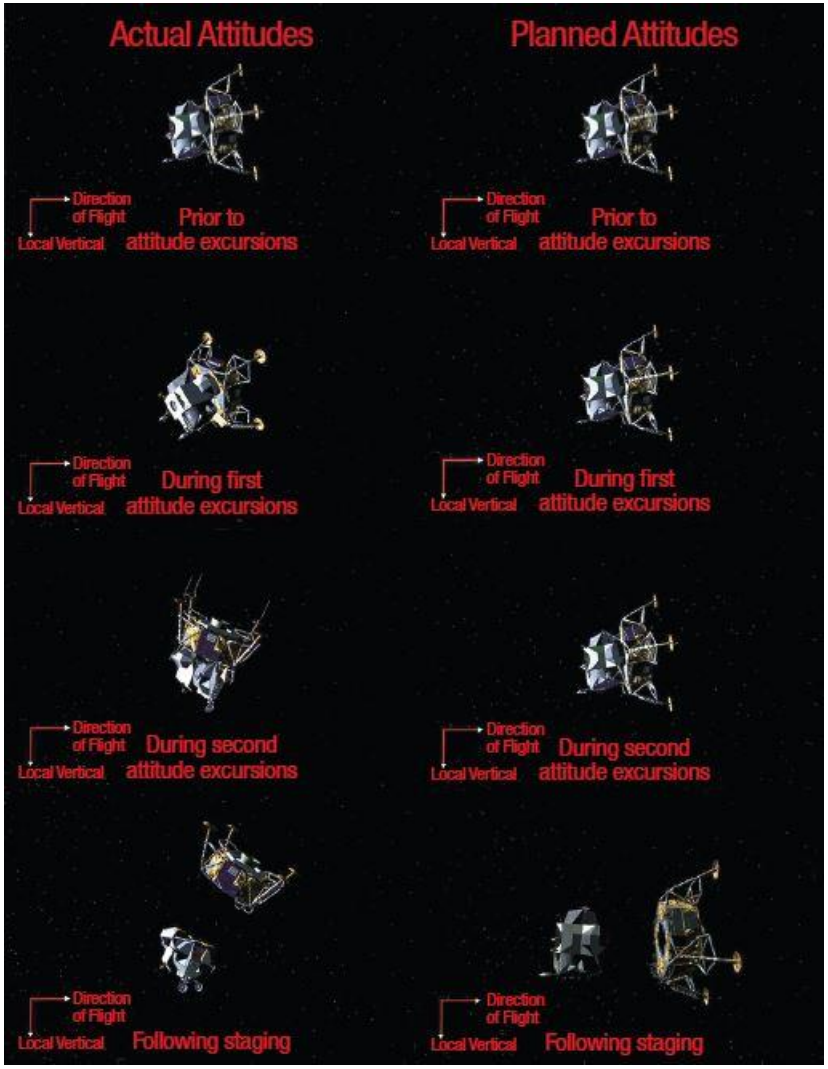

Figure 2. Comparison of actual (left) and planned (right) LM attitudes leading up to and following the staging sequence. Source: NASA

excellence • teamwork • safety • integrity • knowledge

INFORM YOURSELF nsc.nasa.gov

Apollo 10: Fuel Cell Pump Failure

- The LM crew docked with the CSM and jettisoned the LM. While the CSM was still in lunar orbit a Caution & Warning (C&W) alarm sounded.
- Fuel Cell 1 AC circuit breaker had tripped, due to a short in the hydrogen pump, which caused a loss of Fuel Cell 1. The crew followed procedures to minimize non-essential electrical loads on the two remaining fuel cells.
- The Command Module Pilot (CMP) joked, “I bet when we get our next loss of signal another fuel cell’s going to fail.”
- The Fuel Cell 2 Caution Light proceeded to come on, followed by a Warning Light: the fuel cell’s condenser exhaust temperature was cycling between its high and low limits.
- The crew immediately shut off automatic fuel cell heat to reduce electric load. Fuel Cell 2 continued to provide power while the crew manually controlled the heaters and monitored fuel cell skin temperature.

excellence • teamwork • safety • integrity • knowledge

Apollo 10: Underlying Issues

- During the control loss at staging, the CDR's attention was focused on reacting to an LM electrical anomaly while involved in procedures for LM ascent/descent separation.
- Additionally, the crew had limited reach, dexterity, and visibility while fully suited, with helmet and gloves on.

Apollo 10: Aftermath

- Apollo 10 was a successful "dress rehearsal" for the Apollo 11 lunar landing.
- The mission also set records:
  - Highest speed attained by a manned vehicle during return to Earth (24,791 miles per hour)
  - Furthest humans have travelled from home in Houston (254,109 miles) when on orbit on the far side of the moon while Houston was the farthest on Earth's rotation.

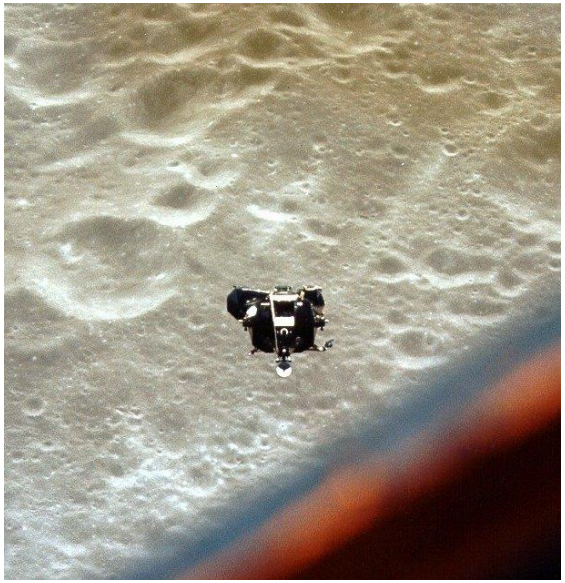

Figure 3. The Apollo LM, nicknamed "Snoopy," on approach to the CSM "Charlie Brown," following the staging sequence. Source: NASA

excellence • teamwork • safety • integrity • knowledge
NSC NASA SAFETY CENTER

Skylab 4

- November 16, 1973, Skylab 4 launched. The mission completed 1,214 Earth orbits, had four Extravehicular Activities (EVAs) totaling more than 22 hours, and lasted 84 days.
- Although the crew set a record for length of time in orbit, Skylab 4 was the first mission for each of the three crewmembers.
- The rookie Skylab 4 crew experienced issues while attempting to accomplish the ambitious workload initially outlined by ground control.
- The crew was troubleshooting an issue with the Command Module (CM) Reaction Control System (RCS) System Ring 2 while involved in procedures for CM/SM separation.
- Prior to SM separation, procedures dictated that the crew pull four Service Propulsion System (SPS) circuit breakers (CBs) to “deadface” or de-mate the power connection to the unnecessary SPS pitch and yaw gimbal motors.

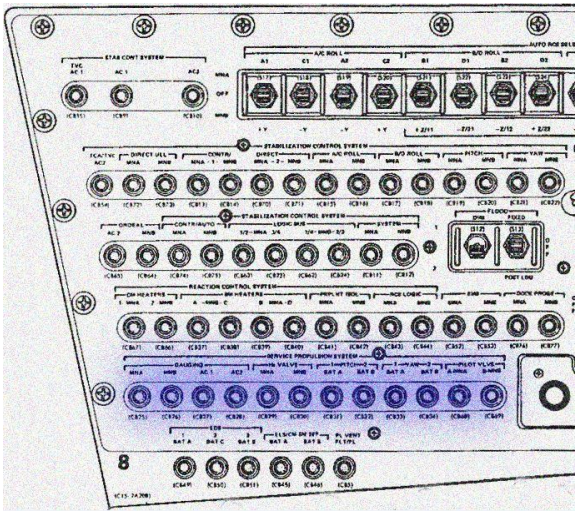

Figure 4. The SCS CBs that were incorrectly pulled are located two rows above the SPS CBs, which are highlighted. Source: NASA

excellence • teamwork • safety • integrity • knowledge
NASA SAFETY CENTER

Skylab 4: Underlying Issues

- Post flight, the crew stated that during the time critical preparation for SM separation, they inadvertently pulled SCS Pitch and Yaw CBs instead of the SPS pitch and yaw CBs.
- The two sets of CBs were located two rows apart from each other on the CB panel and were similarly labeled.

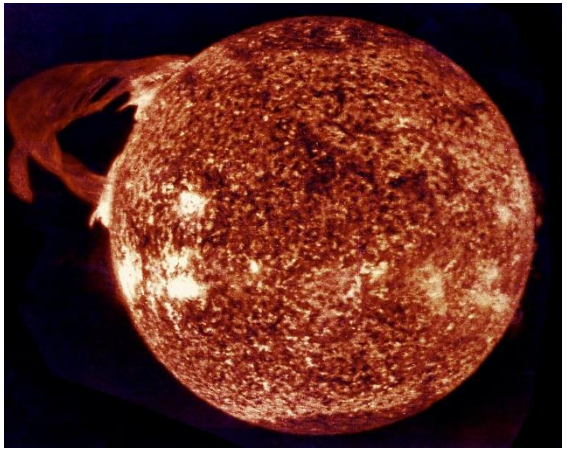

Figure 5. Color-enhanced ultraviolet exposure of a colossal solar eruption photographed during the Skylab 4 mission. Source: NASA

Skylab 4: Aftermath

- The successful splashdown of the Skylab 4 crew marked the end of Skylab missions.
- Although the Skylab missions were troubled early on with the loss of the station's micrometeorite shield and one of its primary solar arrays, Skylab logged approximately 2,000 hours of experiments and 173,000 film images that would have been impossible for unmanned systems to duplicate.
- Skylab also paved the way for NASA's research into long-term human space habitability.

excellence • teamwork • safety • integrity • knowledge
NASA SAFETY CENTER

Relevance to NASA

- During Apollo 10, the CDR saved the vehicle and crew by using a direct manual redundant backup to the automated LM RCS. Later in the mission, two-fault tolerant CSM Fuel Cells assured mission success, as the CSM could safely returned with one fuel cell powered down, and Apollo 10 with two fuel cells powered down.
- Similar to Apollo 10, during Skylab 4, the manual redundant backup to auto RCS control was direct which saved this vehicle and crew.
- Critical automatic functions should have a manual or unlike redundancy backup. Consumables, like electrical power required for crew safety, should have additional levels of redundancy.
- In both missions, the CDRs' intimate knowledge of system operations led to quick recoveries and assured the safety of the crew and spacecraft. Extensive crew knowledge of nominal and off-nominal systems operation is essential when immediate action is required and communications with Earth are delayed or blocked.
- The CDRs cognitive performance under high-stress conditions is a testament to NASA astronaut training during the Apollo-era. However, both short-term and long-term memory is subject to degradation. Training discussions can be done inflight to regain and maintain proficiency during long duration missions and refresher simulations can be conducted before time-critical operations.

excellence • teamwork • safety • integrity • knowledge
NSC NASA SAFETY CENTER