Historian Corner

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Titan History Roundtable Summary

On October 15 2020, MARS held a virtual roundtable discussion on Zoom featuring seven panelists and approximately 40 MARS Associates members. The roundtable honored the 15th anniversary of the end of the Titan program (October 19, 2005). Participating on the roundtable were former Titan program personnel including Fred Luhman, Larry Perkins, Samuel Lukens, Dave Giere, Dennis Brown and Jack Kimpton. I acted as another Roundtable member (25 years on Titan) and as the moderator, with Steve Sande administering the Zoom meeting. Two launch videos (TIVB-26 – the last Titan, and TIVB-33 – the Cassini launch) were highlighted and the discussions lasted nearly two hours.

Here is the link for the MARS Associates video on YouTube:
https://www.youtube.com/watch?v=KYPCTWJc1zw&feature=youtu.be

The discussions centered on the best and worst memories of each panelist and the programmatic challenges they faced. After the panel discussion, the audience was asked to contribute and many participants had interesting stories to share. I would like to thank the group for participating in this unique forum and hope to schedule more in the future (hopefully in person). I encourage all members to view the video!

Program Profile

This issue is part 2 of the profile of the third planned lunar landing Apollo mission: Apollo 13. A minor clarification is in order- the wording was incorrect in the first paragraph of the Program Profile article in the previous MARS STAR. Apollo 13 was obviously not the third Apollo mission, but was the third planned lunar landing and the seventh manned Apollo mission overall.

Part 2 of the Apollo 13 Profile focuses on the aftermath and the failure investigation.

Apollo 13 Mission Overview

Launched: 04/11/1970 19:13:00 UTC LC-39A
Splashdown: 04/17/1970 18:07:41 UTC, Southern Pacific, USS Iwo Jima recovery ship
Saturn V AS-508 Launch Vehicle
Hybrid/Free Lunar Trajectory Fly-by
CSM (Command/Service Module) Call Sign: *Odyssey* (CSM-109)
LM (Lunar Module) Call Sign: *Aquarius* (LM-7)
Crew: Commander Jim Lovell, LM Pilot Fred Haise, CM Pilot Jack Swigert (a last-minute substitution for Ken Mattingly)
Intended landing site: Fra Mauro Crater and Highlands
Connection to Lockheed Martin/ULA: The contributions of our heritage companies to the Apollo program were listed in the MARS STAR article about Apollo 11.

Establishing the Apollo 13 Review Board

After the worldwide sigh of relief that the Apollo 13 crew had returned home safely on April 17, 1970, the investigation began almost immediately. In fact, a letter was released by Thomas O. Paine, NASA Administrator, and George Low, Assistant NASA Administrator, on the very day of splashdown directing the establishment of the Apollo 13 Review Board. A follow-up letter on April 21, 1970, further defined the Board membership with the following participants:

Edgar M. Cortright, Chairman (Director, Langley Research Center)
Robert F. Allnutt (Assistant to the Administrator, NASA Headquarters)
Neil Armstrong (Astronaut, Manned Spacecraft Center)
Dr. John F. Clark (Director, Goddard Space Flight Center)
Brigadier General Walter R. Hedrick, Jr. (Director of Space, DCS/R&D, USAF Headquarters)
Vincent L. Johnson (Deputy Associate Administrator – Engineering, Office of Space Science and Applications)
Milton Klein (Manager, AEC-NASA Space Nuclear Propulsion Office)
Dr. Hans M. Mark (Director, Ames Research Center)

These board members were supported by legal counsel (George Malley, Langley), technical support (Charles Mathews, Office of Manned Space Flight), observers (William Anders, former Astronaut; Dr. Charles D. Harrington, NASA Aerospace Safety Panel; I. I. Pinkel, Lewis Research Center), a Congressional liaison (Gerald Mossinghoff), and a Public Affairs liaison (Brian Duff). Obviously, there was a marching army of support teams and groups brought in to do parts of the investigation.

The purposes of the Review Board were to:

1) Review the circumstances surrounding the accident during the flight of Apollo 13 and the subsequent flight and ground actions taken to recover, in order to establish the probable cause

or causes and assess effectiveness of recovery actions.

2) Review all factors relating to the accident and recovery actions the Board determines to be significant and relevant, including actions undertaken by program offices, field centers, and contractors.
3) Direct further specific investigations as may be necessary.
4) Report as soon as possible the Board's findings relating to cause or causes of the accident and effectiveness of recovery actions.
5) Develop recommendations for corrective or other actions, based on findings.
6) Document findings, determinations and recommendations and submit a final report.

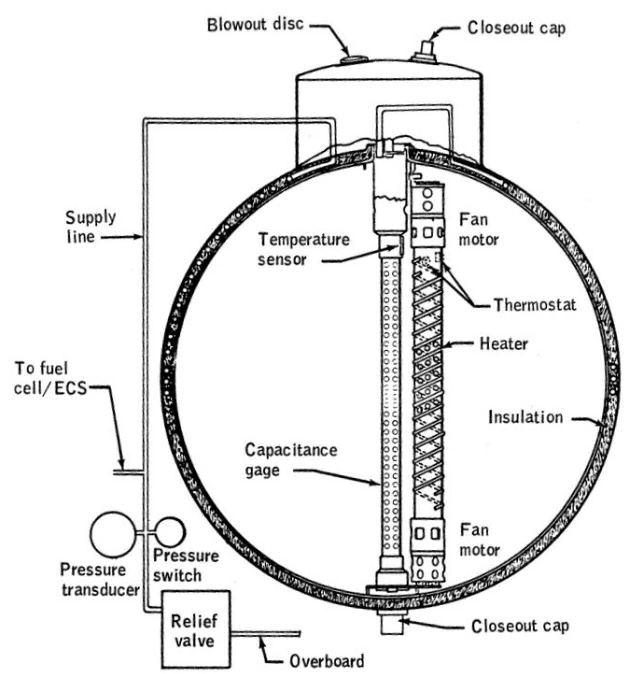
This sounds so familiar to anyone who was on the Titan program for any length of time or on other programs that had failures. We would lock down the data immediately, kick off an investigation board with an oversight panel, and start the painful and tedious process of determining what went wrong, with "all hands on deck". Obviously, in this case, NASA wanted the investigation and actions taken to be accomplished as rapidly as possible to support the remaining Apollo missions (14 through 17).

The Board convened on April 21, 1970, at the Manned Spacecraft Center in Houston. At the same time, another investigation team led by Astronaut and USAF Colonel James A. McDivitt was conducting its own analysis of the accident. The two investigation teams coordinated their efforts and findings. The Apollo 13 Review Board organization had major subgroups evaluating the accident - Mission Events, Manufacturing & Test, Design, and Project Management. The chronology of the mission was divided into pre-incident events, incident events, and post-incident events. A daily log in the Board report identifies the activities that took place almost every day from April 21 until June 7, 1970. The Board reconvened in Washington on June 15 to present its report.

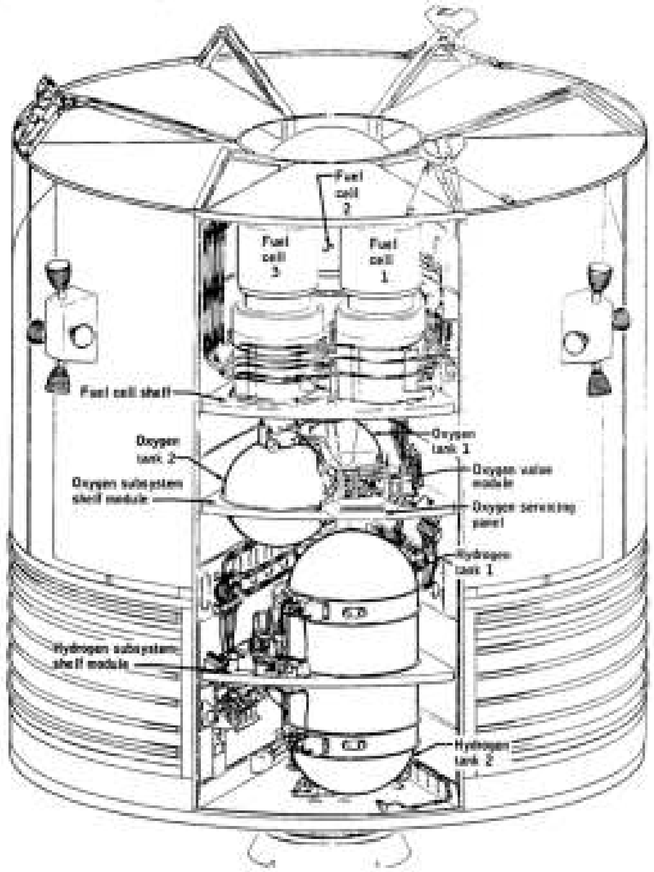
Oxygen Tank No. 2 Build & Assembly History

During the investigation, it became clear that the accident started in the Service Module cryogenic oxygen tank no. 2. Two oxygen tanks essentially identical to this tank on Apollo 13, and two hydrogen tanks of similar designs operated satisfactorily on several unmanned Apollo flights and on the Apollo 7, 8, 9, 10, 11 and 12 manned missions. The review emphasized differences in design, manufacturing, assembly and test for this particular tank.

On February 26, 1966, North American Aviation company and primary contractor for the Apollo Command Module (CM)/Service Module (SM) systems (later becoming North American Rockwell) awarded a subcontract to Beech Aircraft Corporation (located in north Boulder, Colorado) to build the Block II cryogenic gas storage subsystem for the service module. The simplified drawing below shows the design of the oxygen tank, with an inner and outer shell arranged to provide a vacuum space to reduce heat leak, and a dome enclosing the path into the tank for transmission of fluids and electrical power and signals. Insulation fills the spaces between the shells and in the dome. Two tubular assemblies are mounted in the tank: the heater tube contains two thermostatically protected heater coils and two small fans (1800 rpm) to stir the tank contents and the quantity probe has a capacitance gage to measure electrically the quantity of fluid in the tank. The inner cylinder of this second probe serves as a fill and drain tube and as one plate of the capacitance gage. A temperature sensor is mounted on the outside of the quantity probe near the head. The supply line from the tank leads from the head of the quantity probe to the dome, exiting through the dome to supply oxygen to the fuel cells in the SM and the Environmental Control System in the CM; the line also connects to a relief valve. Under normal conditions pressure in the tank is measured by a gage in the supply line and a switch near the gage turns on heaters in the tank if the pressure drops below a specified value.



The oxygen tank is designed for a capacity of 320 pounds of super-critical oxygen (oxygen maintained at temperatures and pressures that ensure it is a homogenous, single-phase fluid) at pressures from 865 to 935 psia, operating at temperatures from -340 degrees F to +80 degrees F. Burst pressures are at 2200 psi at -150 degrees F.



S/N 10024XTA0008 Oxygen Tank Number 2 (Apollo 13 tank) was manufactured in 1966 and was the eighth block II tank built; 28 block I tanks had previously been built by Beech. The assembly process results in a substantial amount of wire movement inside tank, where possible wire insulation damage can occur and not be detected before the tank is capped off and welded closed. Some tank rework was required due to welding flaws and a faulty fan motor. Acceptance testing of the tank included dielectric, insulation, and functional tests of heaters, fans, and vac-ion pumps. The tank itself was leak tested at 500 psi and proof tested at 1335 psi with helium. After the proof test, the tank was filled with liquid oxygen and pressurized to a proof pressure of 1335 psi by use of the tank heaters powered by 65 V (AC). Heat-leak tests were run over 25-30 hours over a range of conditions and outflow rates. The tank was then emptied by forcing the LOX out through the fill line. The rate of heat leak into the tank was higher than permitted by specifications and was accepted with a waiver of this condition (this apparently did not factor into the failure modes). The tank was shipped to North American Rockwell (NAR) on May 3, 1967.

This tank, and the companion oxygen tank no. 1, were combined into the assembly known as the oxygen shelf at NAR in March, 1968 and designated for SM 106 for Apollo 10. The diagram above shows the installation in the SM. An unrelated problem with electromagnetic interference with the vac-ion pumps on the tank domes required a modification to the oxygen shelf. This shelf was removed from SM 106 for the modification and was planned to be installed on a later spacecraft. During the initial attempt to remove the shelf and extract it, one bolt was mistakenly left in place; as a consequence, when the shelf was raised about two inches, the fixture broke, allowing the shelf (with both tanks) to drop back into place. The closeout cap on the dome on oxygen tank no. 2 likely struck the underside of the shelf during this incident. The shelf assembly was retested, including proof-pressure tests, leak tests, and functional tests of transducers, switches, and vac-ion pumps. No cryogenic testing was conducted at that time. These tests would not disclose any fill line leakage within oxygen tank no. 2. The discrepancy was considered low risk for any significant damage.

Oxygen Tank No. 2 Test History at KSC

The shelf assembly was installed in SM 109 assigned to Apollo 13 in November, 1968 and shipped to KSC in June, 1969 for further testing, assembly on the vehicle stack, and launch. Now we get into a very interesting testing scenario at KSC that likely created the conditions leading to the failure during the Apollo 13 mission while in its trans-lunar trajectory. The Countdown Demonstration Test (CDDT) began on March 16, 1970. Previous subsystem and shelf assembly testing at KSC was nominal. During the CDDT the oxygen tanks were evacuated to 5mm Hg (Mercury), followed by a pressurization to 80 psi. Cryogenic oxygen was loaded and pressures increased to 331 psi without anomalies. During the CDDT, the oxygen tanks are normally partially emptied to about 50% of capacity. Tank no. 1 behaved normally, but tank no. 2 only went down to 92% of its capacity. The accepted procedure during CDDT is to reduce the quantity in the tank by applying gaseous oxygen at 80 psi through the vent line and to open the fill line. This procedure failed and the decision was made to document the anomaly in an Interim Discrepancy Report and complete the CDDT, then return to the detanking problem.

Detanking operations were resumed on March 27, 1970, after discussions with KSC, MSC (Manned Spacecraft Center), NAR and Beech personnel. The first step was to vent oxygen tank no. 2 through its vent line (it had self-pressurized to 178 psi and was 83% full). This decreased the quantity to 65%. The troubleshooting team considered a possible leak in the path between the fill line and the quantity probe due to a loose fit in the sleeves and tube -- a manufacturing artifact that was encountered on many builds, but the condition might have also occurred because of the drop incident. Another discrepancy report was written and a "normal" detanking procedure was conducted on both tanks, pressurizing through the vent line and opening the drain lines. Tank no. 1 emptied in a few minutes; tank no. 2 did not. A decision was made to try and "boil off" the remaining oxygen in tank no. 2 by using the tank heaters. The heaters were energized with 65 Vdc from the GSE (Ground Support Equipment) power supply, and 90 minutes later the fans were turned on to add more heat and mixing. After six hours of heater operation, the tank quantity had only decreased to 35 percent, so pressure cycling was tried, pressurizing the tank to 300 psi and venting through the fill line. Five pressure/vent cycles were required and the tank was finally emptied after 8 hours of heater operation.

The team suspected the loosely fitting fill line as the problem and determined that if they could fill the tank without problems, the leak in the fuel line would not be a issue in flight, as they speculated an electrical short between the capacitance plates of the quantity gage would result in low levels of energy that would not be problematic. Replacement of the tank itself on the oxygen shelf was considered too risky to the schedule and could cause collateral damage to other tank assemblies (sound familiar?). Flow tests on the tanks were performed again on March 30; both tanks filled without difficulty, but tank no. 2 again required numerous pressure cycles with the heaters turned on. The team did not consider the drop incident during any of their discussions and they were also under the impression that the detanking process at Beech was different, so it was not relevant to the problem at KSC. That impression was false, as the successful detanking process at the supplier was very similar.

The team focused on the potential for a loose fill tube and did not pay attention to possible concerns for the extended operation of the heaters and fans and its effects on the tank due to excessive heat. The heaters are protected with thermostatic switches, which are intended to open the heater circuit when the switch senses a temperature of 80 degrees F. The switches failed to open at KSC when the heaters were powered from a 65V dc supply as the switches were rated for 28V dc spacecraft power; no testing had ever been done to assess the capability of these switches to open while under full current conditions. Because the switches did not function, the temperature in the tank likely exceeded 1000 degrees F during detanking, resulting in serious damage to Teflon wiring insulation. This catastrophic condition was not known prior to flight and the team accepted the tank and the mission processing continued. In retrospect, the tank damage was a significant hazard during tank fill and operations before launch, as well as during flight operations up to the point of the actual failure.

Part 1 of this program profile (in the last MARS STAR) has details of the anomaly as it occurred during the Apollo 13 mission and the actions that were required to bring the crew home safely. The Review Board analyzed telemetry data and determined that combustion in oxygen tank no. 2 lead to failure of that tank, damage to oxygen tank no. 1 or its lines and valves, explosive removal of the bay 4 panel, and the loss of all three fuel cells, leading to the mission abort. The extended heater operation at KSC damaged the insulation on wiring in the tank, making it susceptible to a short circuit condition that occurred immediately upon command to stir the tanks. This combined with the super-critical oxygen in the tank, ignited the damaged tank insulation, resulting in an explosive condition.

Review Board Findings

Many key findings were documented in the Review Board report, which can be obtained by accessing the Apollo Flight Journal documents (see link at the end of the article). Here are some of the more critical findings, many of which were confirmed in testing during the investigation:

1) Oxygen tank no. 2 contained materials, including Teflon and aluminum, that would burn if ignited in supercritical oxygen.
2) The tank contains potential ignition sources, including electrical wiring, unsealed electric motors, and rotating aluminum fans.
3) During the difficulties with detanking of oxygen tank no. 2 at KSC following the CDDT, the thermostatic switches on the heaters were required to open while powered by 65 Vdc to protect the heaters from overheating. The switches were rated at 30 Vdc and would weld closed at the higher voltage. This subjected the wiring around the heaters to very high temperatures.
4) The cause (failure mechanism) of the failure of oxygen tank no. 2 was combustion within the tank, most likely due to the ignition of Teflon wire

insulation on the fan motor wires due to electrical arcs in the wiring.

5) Failure of the oxygen tank no. 2 caused a rapid local pressurization of bay 4 of the SM by the high-pressure oxygen escaping from the tank.
6) From a design standpoint, the need to stir the oxygen tank contents and the use of materials that are potential ignition sources constitute an undue hazard. The pure oxygen hazards and deficiencies associated with this design were not recognized during the recovery from the Apollo 204 fatal fire.
7) The thermostatic switches were rated at 7 amps at 30 Vdc. While the switches could carry this current at 65 Vdc in a closed position, they would fail if they started to open to interrupt this load. These switches had never been qualified or acceptance tested at 65 Vdc nor had they been operated in flight or on the ground under load because the heaters had only been used with a relatively full tank, which kept the switches cool and closed.
8) The unique conditions during the detanking operations following CDDT at KSC welded the switches shut and disguised the effects of the off-scale high temperatures (1000 degrees F) in the tank during the special detanking. There were ammeters on the tank heater control panels at KSC that would have indicated the lack of switch operation, but that information was not reviewed.
9) The fan motors were unsealed and immersed in the supercritical oxygen, which is a questionable practice.
10) The tank design is “blind” to inspections after completion of assembly, which can result in damage to electrical wiring. Loose fill tube parts are also a likely artifact of the manufacturing process. For the tank on Apollo 13, the potential damage that occurred during the shelf disassembly might have exacerbated the fill tube displacement concerns. This anomaly was not discussed at KSC during the detanking problems.
11) Launch operations personnel were not aware of the thermostatic switch limitations at 65Vdc and assumed the tank was protected from overheating by those same switches.
12) The Block II design specifications from NAR required the tank heater assembly to operate with 65 Vdc GSE power only during tank pressurization. Beech Aircraft did not require their Block I thermostatic switch supplier to make a change in the switch to operate at the higher voltage. This incompatibility between design and specification was not detected during product reviews and testing.
13) In flight at the critical time of the incident (55:53 hours elapsed time) , oxygen tank no. 2 pressure rose from 887 to 954 psia and again to 1008 psia, likely due to combustion occurring within the tank. Due to inhibition of the master alarm in the CM (occurred due to an unrelated low hydrogen pressure), neither the crew nor Mission Control was alerted to the ox pressurization rise. The master caution and warning system on board could allow a problem to go unnoticed because of the presence of a previous out-of-tolerance condition in the same subsystem. This would not have stopped the failure from occurring, however, as the combustion was already underway in the tank.

The board came up with many more observations and findings from the actions that were required to bring the crew home; these were turned into recommendations for corrective actions that should be taken before the next Apollo flight. The key corrective actions are noted below:

1) Remove from contact with the oxygen all wiring and unsealed motors, which can potentially short circuit and ignite adjacent materials
2) Minimize the use of Teflon, aluminum and other combustible materials.
3) The modified cryogenic oxygen storage system should be subjected to a rigorous requalification program.
4) The warning system on board the Apollo spacecraft and in Mission Control should be modified to increase the differential between master alarm trip levels to avoid unnecessary alarms; revise the logic to prevent an out-of-limits alarm from blocking another alarm; establish a second level of limit sensing to ensure alarms are not overlooked; and provide talkback indicators for each of the fuel cell reactant valves.
5) Improve the lifeboat compatibilities between the LM and CM (see the first profile for an example of the incompatible Lithium Hydroxide canisters).
6) Whenever significant anomalies occur in critical subsystems during final preparation for launch, revise the standard procedures to require a presentation of all prior anomalies on that particular piece of equipment, using expert testimony. Ironically, NASA completely forgot this lesson during the run-ups to the Challenger failure (O-ring temperature deformation, which was a known issue) and Columbia failure (debris damage during ascent, another known issue).

7) Reviews should be conducted of all hazardous subsystems (particularly for those containing oxygen or oxidizers). These reviews should include materials compatibility.
8) Reassess all Apollo spacecraft subsystems and ensure adequate understanding of the controls of engineering and manufacturing details at the subcontractor and vendor level.

Apollo 14 was being processed at this time and actions were taken to redesign the oxygen tanks for the SM and ensure the hazardous designs were likely eliminated and the heaters were protected by the thermostatic switches at the proper voltages. Other actions from the issues identified in the non-standard flight of Apollo 13 were obviously assessed for the upcoming missions. Confirmation of incorporation of those changes is not easily found looking at the documentation available from NASA but the remaining four missions were successful in accomplishing their goals of multi-day lunar exploration.

A few personal observations: I spent most of my career in Mission Success and became a subject matter expert in system failures, having evaluated many failures for lessons learned, conference papers, and intra-company and conference tutorials. The Apollo 13 anomaly had the potential of destroying the spacecraft, killing the crew and ending the Apollo missions. NASA is quite fortunate that the failure occurred on the way to the moon, that they had an amazing technical staff in Mission Control and could rely on a veteran commander on board the mission (Lovell was on his fourth spaceflight). This failure had the following systemic attributes that I observed:

1) A major contractor (NAR) was not fully cognizant of the test processes and change management deficiencies at a sub-tier supplier. This included not understanding the tanking test process at Beech and not realizing that the requirements for the Block II thermostatic switch upgrades to 65Vdc operation were not incorporated. A rigorous compatibility analysis review would have likely discovered the non-incorporation of the design change for the switches.
2) That same major contractor had undergone significant system design changes after the fatal Apollo 1 fire to alleviate concerns for pure oxygen environment hazards, but the design of the cryogenic tanks for the SM was overlooked during this process. These tanks were designed with hazardous materials and assembled with the potential for damage within the tank that could not be detected by in-line testing.
3) Personnel running the CDDT at KSC were not aware of the operating voltage design limitations with the thermostatic switches and were also not aware of the dropped tank anomaly that occurred during modification work on the Ox tank shelf at NAR. The detanking process led to major damage within ox tank no. 2 and this damage could have manifested itself anytime as an explosive condition during the processing and launch phase of the mission. The potential for damage from the drop was never properly discussed in light of the difficulties that occurred during detanking.
4) The warning system on board the Apollo spacecraft would mask additional concerns that might crop up in a subsystem if the master alarm was inhibited due to an unrelated previous issue.
5) During system reviews, all anomalous conditions down to the sub-tier supplier need to be reviewed and discussed, including concerns from previous missions that were still being evaluated or closed out. Anomalies that occur during rework and modification efforts need special attention. The tendency to normalize deviations in critical systems is a recurring problem in our industry and other industries. In the Apollo 13 case, loose ox tank fill tube discrepancies were considered "acceptable".
6) In this unforgiving business, we seem to learn the same lessons over and over again. Some aspects of this mission remind me of the decisions that were made with the extensively repaired SRM segment that was moved around and finally flown on TIVA-11 in what was assumed to be a more favorable structural position at VAFB in August 1993; that segment burned through to the case during flight, resulting in the loss of that mission. Another mission failure, TIVA-20 in August 1998, was attributed to wire harness damage that caused shorting to structure (the harness was unprotected and was likely stepped on during a – you guessed it – unrelated and late special inspection).

I highly encourage anyone interested in more details to explore the Apollo Flight journals. They are an extremely valuable resource!

References for Apollo 13 article

Apollo Flight Journal: https://history.nasa.gov/afj/
Apollo 13 Failure Review Board Report: https://history.nasa.gov/afj/ap13fj/pdf/report-of-a13-review-board-19700615-19700076776.pdf

NASA Apollo Program:
https://www.nasa.gov/mission_pages/apollo/missions/apollo13.html

On This Date in History

This section lists milestones retrieved from publicly available information for LM, ULA and heritage programs from 10 to 60 years ago (2010, 2000, 1990, 1980, 1970, and 1960). Delta launches prior to the formation of ULA, unless it included an LM or heritage company payload or upper stage, are not listed. No classified programs are identified, even if the program is now considered unclassified, with the exception of the Discoverer program (Corona). The events reflect milestone activity in the quarter previous to the release of the MARS STAR -- where appropriate, key press releases are also included; significant milestones are in bold. There will be gaps if no events occurred in that decadal year for that month. The list is not intended to be all-inclusive due to historical record inaccuracies.

Events in October (10 to 60 years ago)

- 10/28/2010: LM BSAT-3b (for Japan) launched on Ariane 5 ECA, ELA-3, Kourou, French Guiana
- 10/11/2000: STS-92 (Discovery) launched, LC-39A, KSC; seven crewmembers, 100th shuttle launch
- 10/20/2000: DSCS III B-11 launched by LM Atlas IIA, SLC-36A, CCAFS
- 10/06/1990: STS-41 (Discovery) launched, LC-39B, KSC; five crew, deployed Ulysses spacecraft
- 10/31/1980: FLTSATCOM4 launched by GD Atlas SLV-3D/Centaur, LC-36A, CCAFS
- NO EVENTS IN OCTOBER, 1970
- 10/05/1960: Lockheed UGM-27 Polaris A1 launched, LC-25A, CCAFS
- 10/07/1960: MM HGM-30A Titan I launched, LC-20, CCAFS
- 10/10/1960: Lockheed UGM-27 Polaris A1 launched, LC-25A, CCAFS
- 10/11/1960: GD SM-65E Atlas launched, LC-25A, CCAFS; **FAILURE**, maiden launch of Atlas E
- 10/11/1960: SAMOS-1 launched by GD Atlas LV-3A/Lockheed Agena-A, Point Arguello LC-1-1; **FAILURE**, Upper stage
- 10/13/1960: GD SM-65D Atlas launched, LC-576B-3, VAFB; **FAILURE**
- 10/13/1960: GD SM-65D Atlas launched, LC-11, CCAFS
- 10/15/1960: Lockheed UGM-27 Polaris A1 launched, USS Patrick Henry, ETR
- 10/16/1960: Lockheed UGM-27 Polaris A1 launched, USS Patrick Henry, ETR
- 10/18/1960: Lockheed UGM-27 Polaris A1 launched, USS Patrick Henry, ETR
- 10/22/1960: GD SM-54D Atlas launched, LC-14, CCAFS
- 10/24/1960: MM HGM-30A Titan I launched, LC-19, CCAFS
- 10/26/1960: Discoverer 16 launched by Thor DM-21/Lockheed Agena-B, LC-75-4-5, VAFB; Maiden flight of Thor-Agena B. **FAILURE** (stage separation)

Events in November (10 to 60 years ago)

- 11/06/2010: COSMOS-4 launched by ULA Delta II 7420-10, SLC-2W, VAFB; last launch of Delta II 7420
- 11/21/2010: USA-223 launched by ULA Delta IV Heavy, SLC-37B, CCAFS
- 11/10/2000: LM GPS IIR-6 launched by Delta II 7924-9.5, SLC-17A, CCAFS
- 11/13/1990: DSP-15 launched by MM Titan IVA/IUS, LC-41, CCAFS
- 11/15/1990: STS-38 (Atlantis) launched, LC-39A, KSC; 5 crewmembers, deployed USA-67 and Prowler
- 11/12/1980: *Voyager 1 flyby of Saturn system; launched on a MM Titan IIIE with GD Centaur upper stage*
- NO EVENTS IN NOVEMBER, 1970
- 11/07/1960: Lockheed UGM-27 Polaris A1 launched, LC-25A, CCAFS
- 11/10/1960: Lockheed UGM-27 Polaris A2 launched, LC-25A, CCAFS; maiden flight of Polaris A2
- 11/12/1960: Discoverer 17 launched by Thor DM-21/Lockheed Agena-B, LC-75-3-5, VAFB; **FAILURE** (spacecraft)
- 11/16/1960: MM MGM-31 Pershing I launched, LC-30A, CCAFS
- 11/17/1960: Lockheed UGM-27 Polaris A1 launched, LC-25A, CCAFS; **FAILURE**
- 11/23/1960: RCA TIROS-2 (B) launched by Thor DM-19 Delta, LC-17A, CCAFS
- 11/30/1960: GD SM-65E Atlas launched, LC-13, CCAFS; **FAILURE**

Events in December (10 to 60 years ago)

- **12/15/2010: Lockheed Martin Press Release: NASA's Mars Odyssey Orbiter Passes Longevity Record** (still functional as of November, 2020)
- 12/01/2000: STS-97 (Endeavour) launched, LC-39A, KSC; five crewmembers, ISS assemblies
- 12/06/2000: USA-155 launched by LM Atlas IIAS, LC-36A, CCAFS
- 12/01/1990: LM DMSP 5D2 F10 launched by GD Atlas-E/Star 37, SLC-3W, VAFB
- 12/02/1990: STS-35 (Columbia) launched, LC-39B, KSC; 7 crewmembers

- 12/09/1980: OPS 3255 launched by GD Atlas E/F-MSD, SLC-3W, VAFB – **FAILURE,** booster engine loss of control
- NO EVENTS IN DECEMBER, 1970
- 12/06/1960: Lockheed UGM-27 Polaris A2 launched, LC-25A, CCAFS
- 12/07/1960: Discoverer 18 launched by Thor DM-21/Lockheed Agena-B, LC-75-3-4, VAFB
- 12/12/1960: MM MGM-31 Pershing 1 launched LC-30A, CCAFS
- 12/15/1960: Pioneer P-31 launched by GD Atlas-Able, LC-12, CCAFS; **FAILURE** (launch vehicle), last Atlas-Able
- 12/16/1960: GD SM-65D Atlas launched, LC-576B-3, VAFB
- 12/20/1960: Discoverer 19 launched by Thor DM-21/Lockheed Agena-B, LC-75-3-5, VAFB
- 12/20/1960: MM HGM-30A Titan I launched, LC-20, CCAFS; **FAILURE**
- 12/22/1960: Lockheed UGM-27 Polaris A1 launched, USS Robert E. Lee, ETR

Reference websites:
https://nssdc.gsfc.nasa.gov/planetary/chronology.html#2014
https://en.wikipedia.org/wiki/Timeline_of_spaceflight
https://www.ulalaunch.com/missions
https://news.lockheedmartin.com/news-releases?year=2020
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http: www.astronautix.com

Next Edition

Check back in the next MARS STAR for the story of the Apollo 14 mission, which has its 50th anniversary in early 2021. The History on the Road stories are suspended at this time due to the difficulty in traveling and visiting museums.

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