



Failure is not an option!





Failure is not an option!



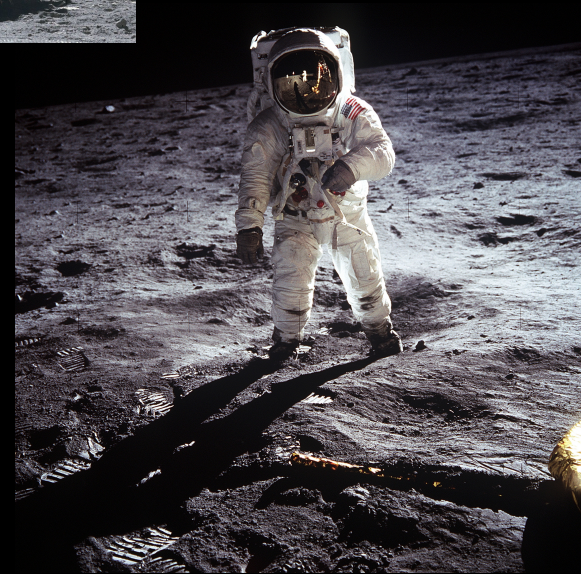
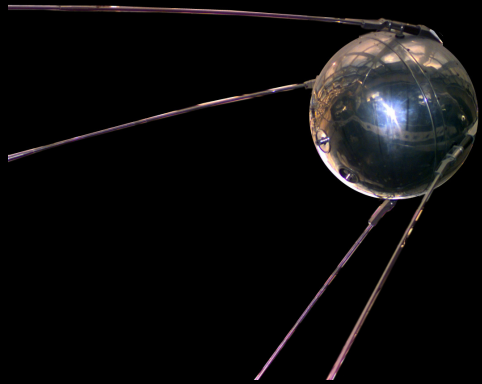
Robert Barron,
AIOps lead,
IBM Garage

brobert@il.ibm.com



SRE lessons 50 years after Apollo 13

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A perfect record of success leading up to Apollo 13



- Apollo 7 – First flight of Apollo
- Apollo 8 – First flight to orbit the Moon
- Apollo 9 – First flight with the full stack
- Apollo 10 – Dress rehearsal of the landing
- Apollo 11 – FIRST ON THE MOON
- Apollo 12 – Pinpoint landing on the Moon



- Apollo 13 – First flight to be oriented towards scientific discovery



The *Odyssey* to the Moon



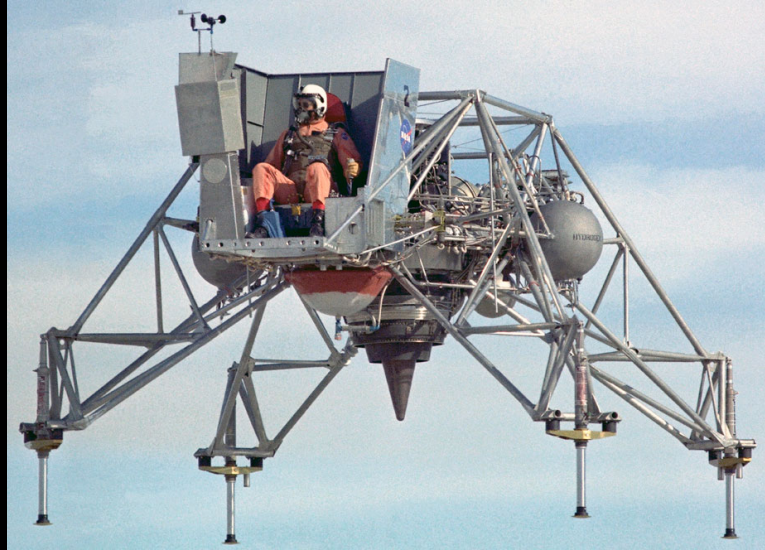


Getting ready for launch





Lesson I – Train for failures and responses.



Training for success... and failure... in any shape or form.
Experiments and risks in training mean less risk during flights.



Lesson I – Train for failures and responses.



ChatOps



Chaos Engineering



Lesson I – Train for failures and responses.



ChatOps

Chaos Engineering

Mission Control Channels

PHOTOGRAPHY MISSION CONTROL AUDIO ASTROMATERIAL SAMPLES

FOD MSN DIR FLIGHT FLIGHT-L FLIGHT-R CAPCOM CAPCOM-R BOOSTER BOOSTER-C BOOSTER-R RETRO FIDO GUIDO GUIDO-R SURGEON SURGEON-R EECOM GNC TELCOM CONTROL INCO OPS & PRO FAO ASST FD NETWORK COMM TECH COMM CTRL TRACK TRACK-R RECOVERY RCVY ASST RCVY STUS

102:38:33

CAPCOM [L]: Spacecraft Communicator – or Capsule Communicator - An astronaut who provided all the voice communications between the ground and the spacecraft. (left seat)

The screenshot displays the Mission Control interface for Apollo 13. At the top, there are three tabs: PHOTOGRAPHY, MISSION CONTROL AUDIO (which is selected), and ASTROMATERIAL SAMPLES. Below the tabs is a large window showing a CAPCOM audio waveform in cyan, with a red vertical line indicating a specific time point at 102:38:33. To the left of the waveform is a list of Mission Control Channels, including FOD, MSN DIR, FLIGHT, FLIGHT-L, FLIGHT-R, CAPCOM, CAPCOM-R, BOOSTER, BOOSTER-C, BOOSTER-R, RETRO, FIDO, GUIDO, GUIDO-R, SURGEON, SURGEON-R, EECOM, GNC, TELCOM, CONTROL, INCO, OPS & PRO, FAO, ASST FD, NETWORK, COMM TECH, COMM CTRL, TRACK, TRACK-R, RECOVERY, RCVY ASST, and RCVY STUS. Below the waveform is a 3D diagram of the Mission Control room seats, with various seats labeled with letters (A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T, U, V, W, X, Y, Z). The CAPCOM seat is highlighted in cyan. At the bottom of the interface, there is a text box that reads: "CAPCOM [L]: Spacecraft Communicator – or Capsule Communicator - An astronaut who provided all the voice communications between the ground and the spacecraft. (left seat)".

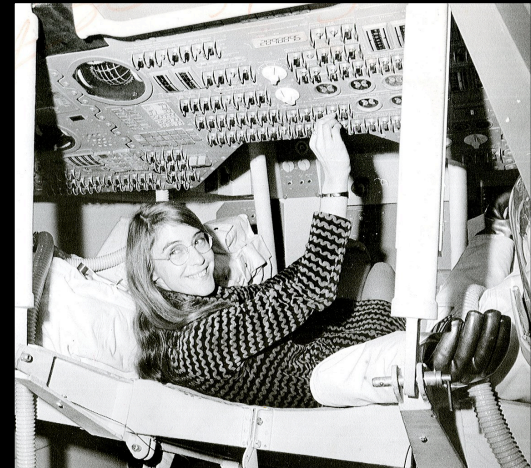
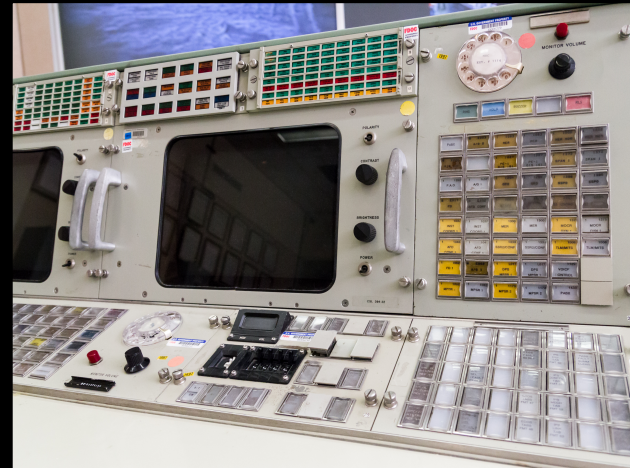


Lesson II – Build/code for failure.



Software Engineering

Observability



Telemetry and Metrics

Alerts and Alarms



Lesson III – Failure has many shapes and forms.



James Lovell
Commander

Fred Haise
Lunar Module (LM) Pilot

Jack Swigert
Command Module Pilot



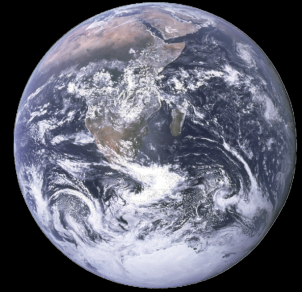
Ken Mattingly
Command/Service Module (CSM) Pilot



- August 1969 – Crew announced
- April 1970 – Launch planned
- Three days before launch – Mattingly exposed to German Measles and removed from flight
- He is replaced by backup Jack Swigert

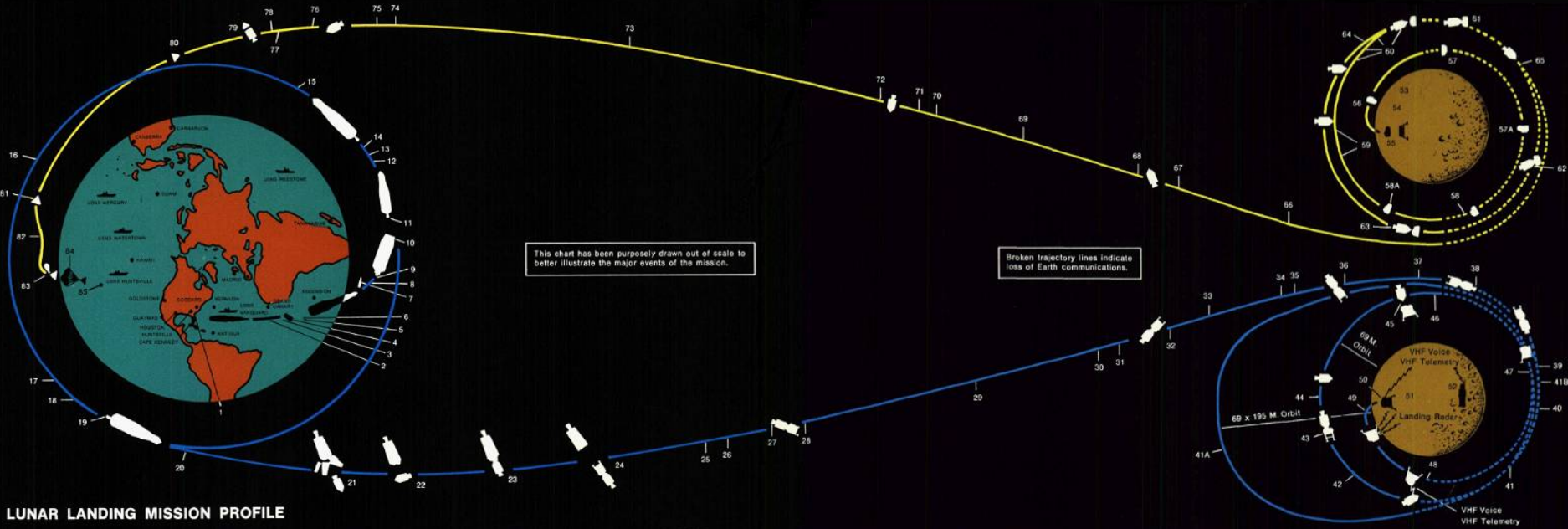


Failure is not an option!





The long journey to the Moon



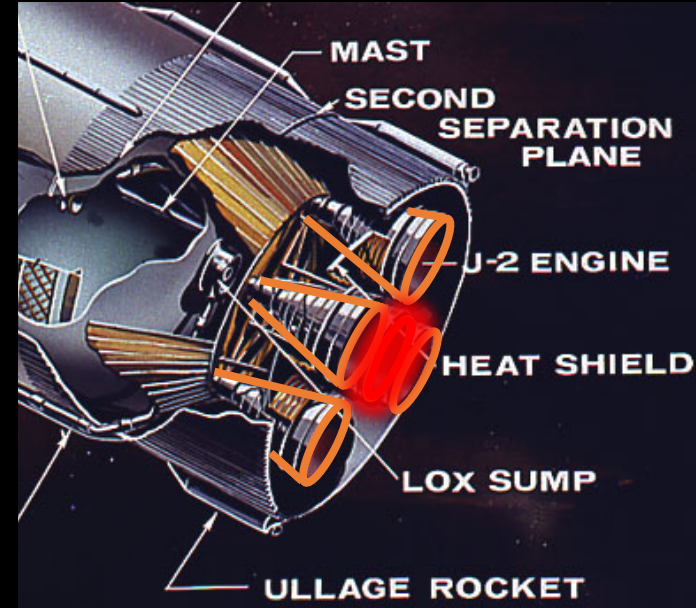


Lesson IV – Self-healing deflects failure.



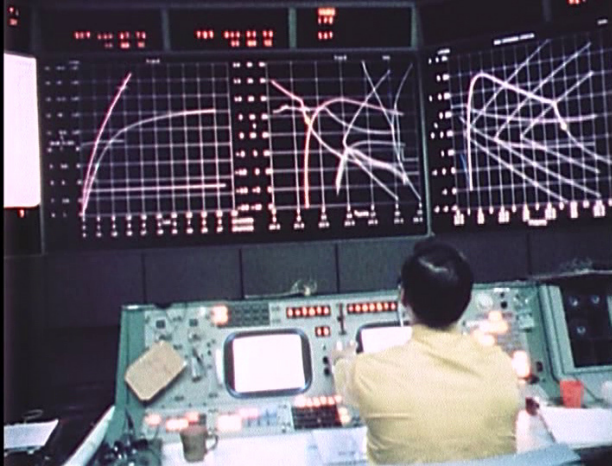
Apollo 13

launched April 11th, 1970 at 13:13 CST





Lesson IV – Self-healing deflects failure.



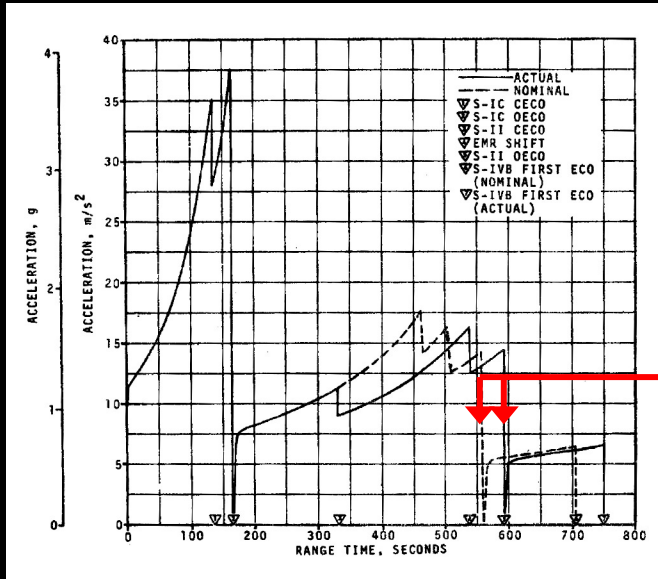
Trajectory displays filmed during the launch at Mission Control.
NASA 16mm capture. Via JSC.



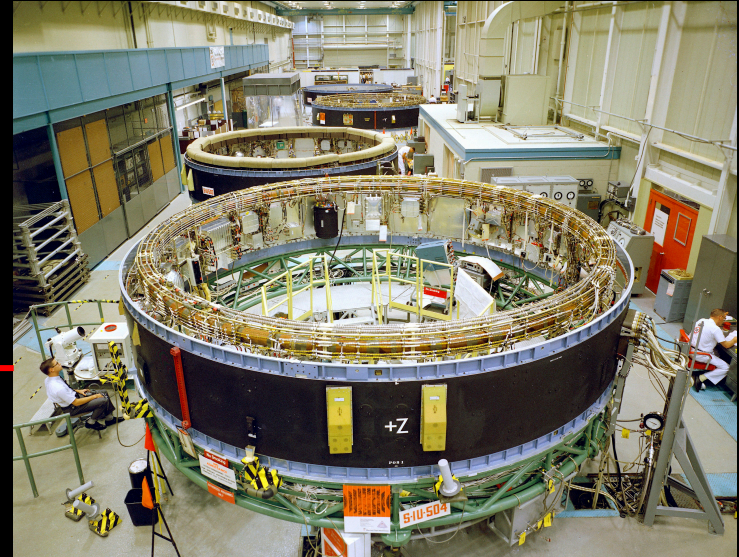
Engine lights in the Apollo Command Module dashboards



Lesson IV – Self-healing deflects failure.



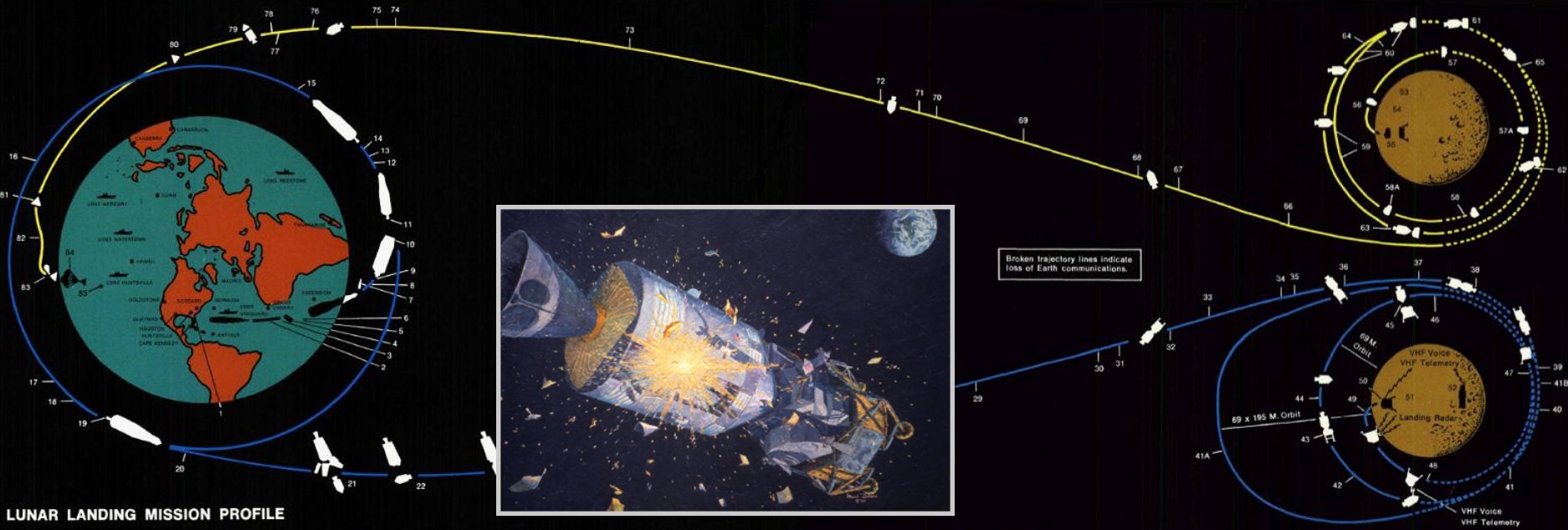
~60 second difference



The “Brain” of the Saturn V:
IBM’s Instrument Unit



After the reliability issue of the mission, all systems go!

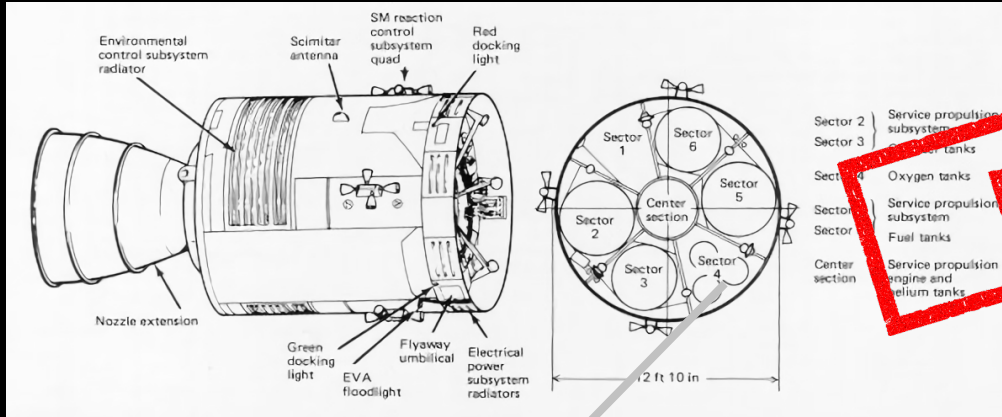


LUNAR LANDING MISSION PROFILE

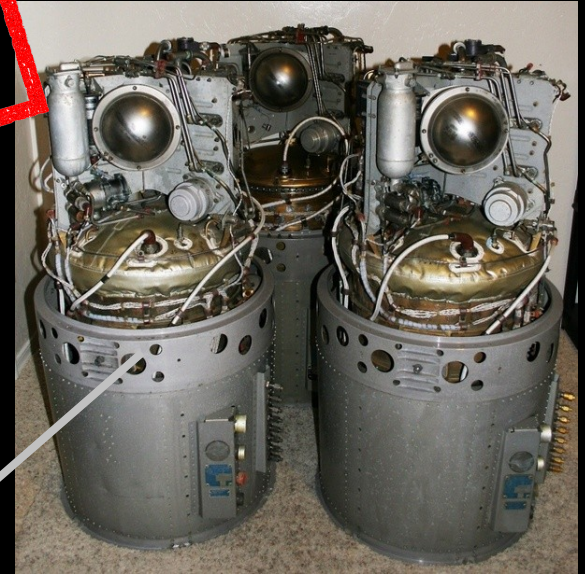
Broken trajectory lines indicate loss of Earth communications.



Lesson V – Avoid failure through robustness & resilience.



FAIL

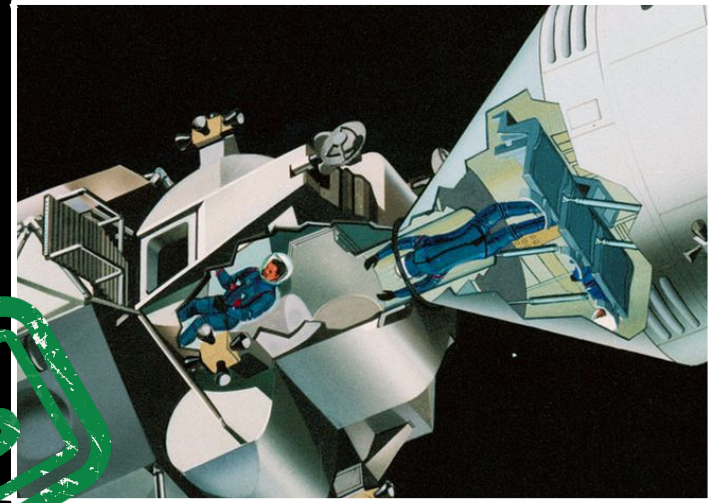
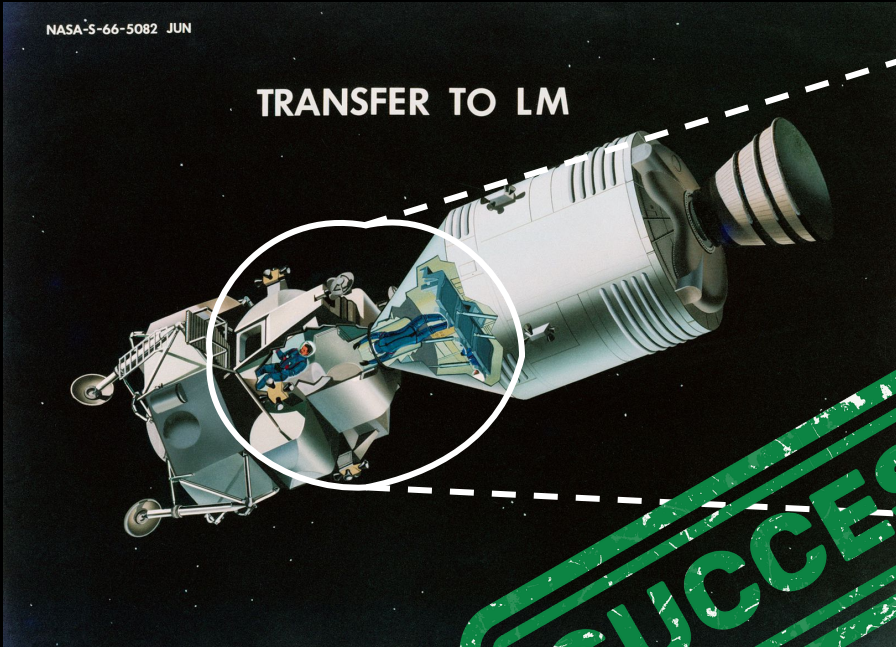


Oxygen tanks are robust – they are redundant.
But they are adjacent so when the one ruptured, the other was damaged and all the oxygen was lost

Multiple redundant fuel cells generate electricity, fed by the redundant oxygen tanks – but when both tanks were empty, no power was generated



Lesson V – Avoid failure through robustness & resilience.



Lunar Module as a lifeboat instead of a lander

SUCCESS

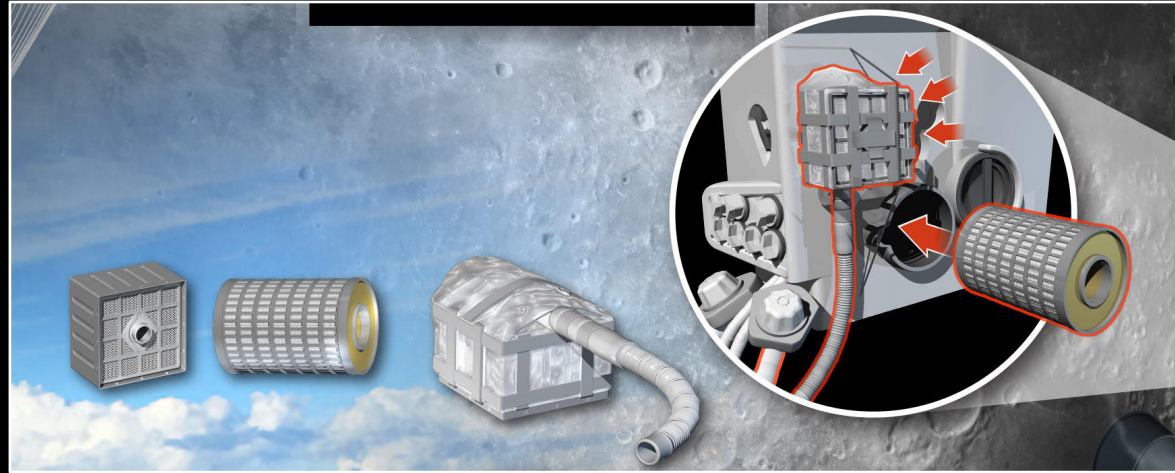
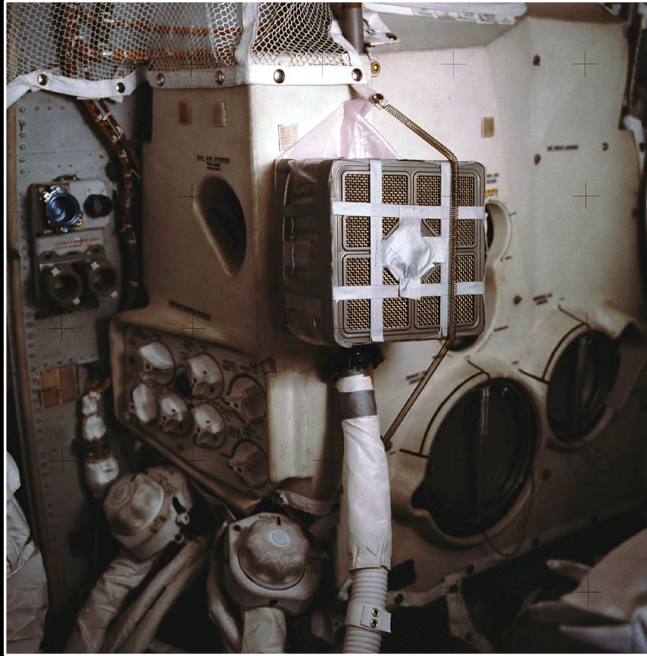


Lesson VI – Failure is not an option – deal with problems





Lesson VI – Failure is not an option – have a plan



Runbooks and Contingencies



Lesson VI – Failure is not an option – have a plan



Scenario	When tested
Lunar module as a lifeboat	Practised in Apollo 10
Navigating without the computer	Practised in Gemini
Maneuvering without the computer	Practised in Apollo 8
Fixing Carbon Dioxide "scrubbers"	Practised in Apollo 8
Last minute crewmember change before launch	Backups trained for all missions

It's not improvisation if you've prepared for it!



Lesson VI – Failure is not an option – have a plan

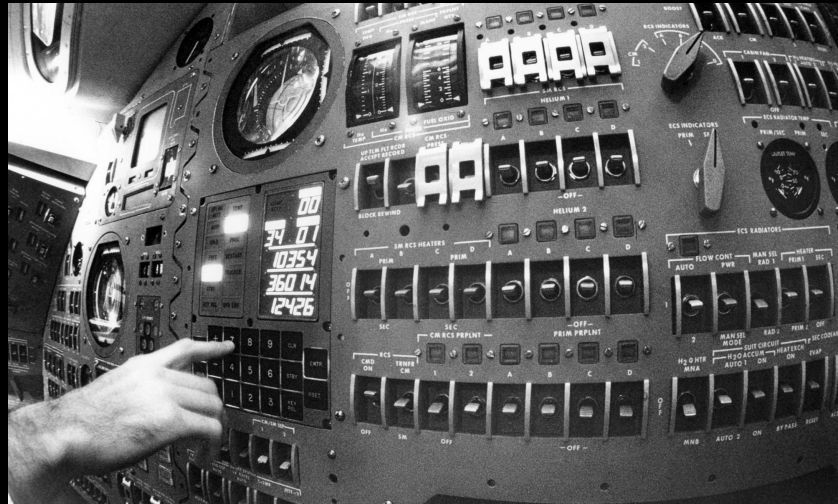


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Changing mission parameters	IBM computers constantly running "what if" scenarios before and during flights

It's not improvisation if you've prepared for it!



Lesson VI – Failure is not an option – have a plan



Scenario	When tested
Lunar module as a lifeboat	Practised in Apollo 10
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Fixing Carbon Dioxide "scrubbers"	Practised in Apollo 8
Last minute crewmember change before launch	Backups trained for all missions
Changing mission parameters	IBM computers constantly running "what if" scenarios before and during flights
Restart all Apollo Command Module systems midflight	Never before

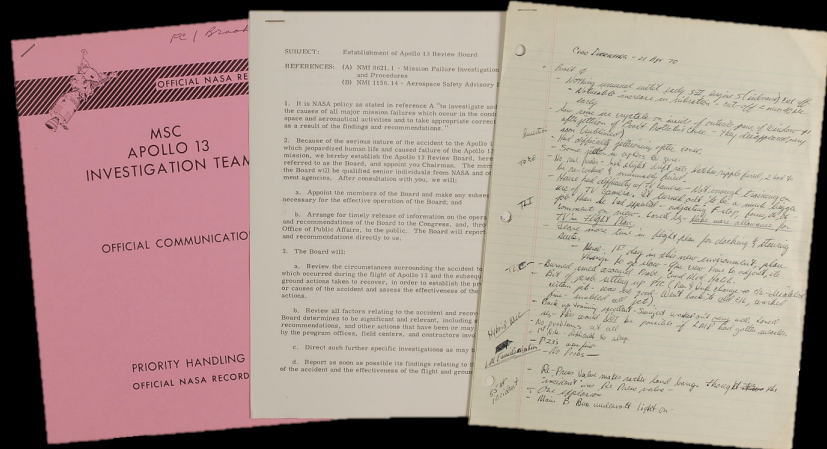


After all the problems, a safe landing!





After the flight – Post-Mortems



https://www.hq.nasa.gov/alsj/a13/A13_MissionReport.pdf

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Significant Incidents & Close Calls in Human Spaceflight



Significant Incidents & Close Calls in Human Spaceflight

A product of the JSC SMA Flight Safety Office

FILTERS LESSONS LEARNED PROGRAMS HUMAN ERROR THE STORY THE TEAM ACRONYMS OTHER INTERACTIVE FSO TOOLS HELP

Loss of Crew Crew Injury/Illness and/or Loss of Vehicle or Mission Related/Recurring event



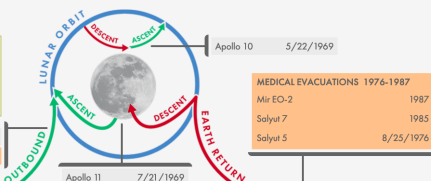
STS-108, 109, 110	12/5/01 - 4/8/02
STS-91	6/2/1998
Soyuz TM-9	2/11/1990
SRB SEAL EVENTS	1981-96
STS-51L (Challenge)	1/28/1986
Other SRB gas seal anomalies: STS-2, 6, 418, 41C, 41D, 31C, 31D, 31B, 31G, 51F, 51I, 51J, 61A, 61B, 61C, 42, 71, 70, 78	
STS-51F	7/29/1985
Soyuz 18-1 (Isla)	4/5/1975
POGO EVENTS	1962-70
Apollo 13	4/11/1970
Other significant pogo events: Apollo 4, 6, early Titan II	
Apollo 12	11/14/1969
Gemini 10	7/18/1966

STS-112	10/7/2002
STS-61C	1/6/1986
ON-PAD ABORT EVENTS	1984-93
STS-41D	6/26/1984
Soyuz T-10-1 (T-10a)	9/26/1983
Other on-pad abort events: STS-51F, 55, 51, 68	
STS-1	4/10/1981
Skylab 2	5/25/1973
Apollo 1 (AS-204)	1/27/1967
Gemini 6	12/12/1965

Soyuz MS-10	10/11/2018
ISS CARGO MISSION FAILURES 2011-2016	
Progress M-12M (44P) 8/24/2011	
Other ISS cargo mission failures: Progress M-27M & MS-04, Cygnus CRS Orb-3, Dragon CRS SpX-7	
STS-117	6/8/2007
STS-114	5/26/2005
STS-93	7/23/1999
ASCENT DEBRIS	
STS-124	5/31/2008
STS-95	10/29/1998
Other debris events have occurred on: STS-116 and STS-125 Late Release Orbiter Tyvek Covers	
STS-114, 115, 118, 119, 124, 126	

EVA INCIDENTS SUMMARY	1965-2016
12 EVAs resulted in crew injury: Gemini 10, Apollo 17, Salyut 7 PE-1, Salyut 7 YE-3, STS-61-B EVAs 1A2, STS-37, Mir PE-9, STS-63, STS-97/4A, STS-100/6A EVAs 1A2, STS-134/1J16	

Apollo 14	1/31/1971
Apollo 13	4/13/1970



MEDICAL EVACUATIONS	1976-1987
Mir EO-2	1987
Salyut 7	1985
Salyut 5	8/25/1976

ISS, Increment 5B	2/1/2019	STS-95	10/29/1998
Soyuz MS-09	8/30/2018	STS-87	11/21/1997
ISS, Increment 38	12/11/2013	Mir	7/17/1997
Soyuz TMA-18 (22S)	9/23/2010	STS-83	4/6/1997
ISS, Increment 17	4/30/2008	STS-51	9/12/1993
ISS, Increment 15	6/10/18/2007	STS-44	11/24/1991
ISS, Increment 13	8/2006	STS-32	1/9/1990
ISS, Increment 10	2/2005	STS-9	12/8/1983
ISS, Increment 5&6 mid 2002-2/03		STS-2	11/21/1988
ISS, Increment 2-4	4/01-3/02	Soyuz 33	4/12/1979
ISS, Increment 4	2/2002	Soyuz 23	10/16/1976
ISS, Increment 2	8/2001	Soyuz 21	8/24/1976
STS-104	7/2001	Soyuz 6	10/19/69
ISS, Increment 2	4/24/2001	Soyuz 1	4/23/1967
STS-99	2/2000	Gemini 8	3/16/17/1966
ISS, Flight 2A.1	5/1999	Mercury MA-9	5/16/1963
DOCKING ANOMALIES			
STS-133	2/26/2011	ISS	10/10/2008
STS-130	2/10/2010	ISS*	9/18/2006
Soyuz T-8	4/22/1983	ISS	3/2005
Skylab 2	5/26/1973	Mir*	2/28/1998
Soyuz 10	4/23/1971	Mir*	2/24/1997
Soyuz 15	8/28/1974	Mir	10/1994
STS-40*	6/1991	STS-35*	12/1990
STS-28*	8/1989	STS-52*	4/1983
Salyut 7	9/1982	Salyut 7	9/1982
Salyut 6	1979	Salyut 6	6/1971
Mir	1/14/1994	Salyut 1	6/1971
* toxic byproducts released			
MIR COLLISION EVENTS 1994-1997			
M21-D21	7/30/1966	Soyuz MS-02	4/10/2017
SR-71	1/25/1966	Soyuz TM-25	8/17/1997
		Apollo ASTP	7/24/1975
		Mercury MA-7	2/20/1962
		Mercury MA-6	2/20/1962
SpaceShipOne, 10P			
SpaceShipOne, 14P			
Soviet Altitude Chamber O2 Fire			
3/23/1961			
Navy Chamber			
11/17/1972			
SpaceShipTwo, PFO4			
10/31/2014			
SpaceShipTwo			
Flight 11P			
12/17/2003			

Soyuz TM-5	9/6/1988
Soyuz T-11	10/2/1984
Soyuz 33	4/12/1979
Skylab 4	2/8/1974
Soyuz 11	6/30/1971
Apollo 11	7/24/1969
Apollo AS-201 Test	2/26/1966
Gemini 5	8/29/1965
Gemini 4	6/7/1965
Voskhod 2	3/19/1965
Mercury MA-7	2/20/1962
Mercury MA-6	2/20/1962

SERVICE/DESCENT MODULE SEPARATION FAILURES 1961-2008	
Soyuz TMA-11 (15S)	4/9/2008
Soyuz TMA-10 (14S)	10/21/2007
Soyuz 5	1/18/1969
Voskhod 2	3/19/1965
Vostok 5	6/19/1963
Vostok 2	8/7/1961
Vostok 1	4/12/1961
TPS ENTRY EVENTS	
STS-107 (Columbia)	2/1/2003
STS-51D	4/19/1985
STS-1	4/14/1981
Other significant STS TPS anomalies: STS-6, 418, 51G, 27*, 28, 40, 42, 45 * Most severe tile damage to date	

STS-134	6/1/2011	SOYUZ LANDING EVENTS	
STS-108	12/7/2001	Soyuz TM-15	2/1/1993
STS-90	5/3/1998	Soyuz TM-14	8/10/1992
STS-37	4/11/1991	Soyuz TM-12	10/10/1991
STS-51D	4/19/1985	Soyuz TM-7	4/27/1989
STS-9	12/8/1983	Soyuz T-7	12/10/1982
STS-3	3/30/1982	Soyuz 36	7/31/1980
Soyuz 15	8/28/1974	Soyuz 23	10/16/1976
Apollo 15	8/7/1971	Soyuz 18-1 (Isla)	4/5/1975
Apollo 12	11/24/1969	Soyuz 5	1/18/1969
Mercury MR-4	7/21/1969	Soyuz 1	4/24/1967

LAUNCH/GROUND SUBORBITAL FLIGHTS RESEARCH FACILITY ATMOSPHERIC FLIGHTS LANDING & POSTLANDING

Site last updated: September 30, 2019

NASA Official: Nigel Packham Technical Questions/Infographic Editor: Faisal Ali



<https://sma.nasa.gov/SignificantIncidents/index.html>

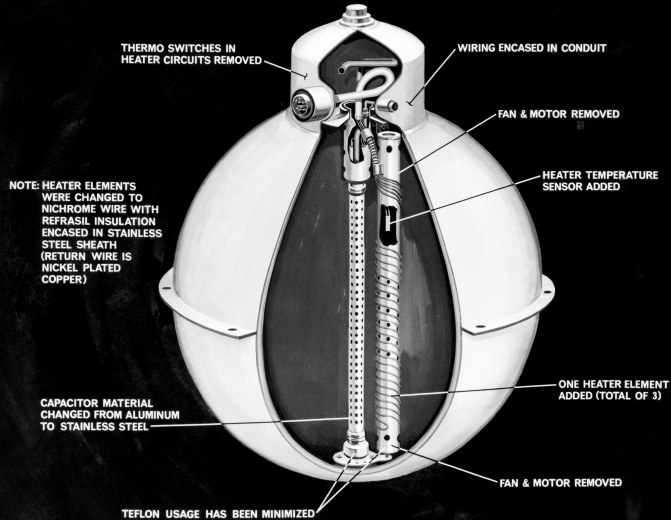
@flyingbarron



Lessons VII – Tools fail, validate your assumptions



APOLLO CSM OXYGEN TANK

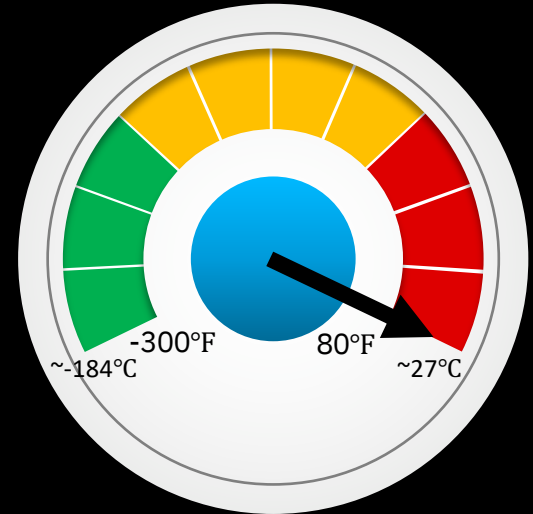


Tank passes all tests till pre-flight testing (April 1970)

After the last test, the tank is heated to “boil off” the liquid oxygen

Tank reaches 1,000°F! (~540°C)

Insulation of wires is burnt off, exposing them to the liquid oxygen in the tank...



The tank was dropped in early 1969 (a year before the flight)



Lesson VIII – Avoid future failure by reducing technical debt



Add reliability

Add observability

Add redundancy

The cryogenic oxygen tank design will be changed to eliminate the mechanisms which could initiate burning within the tank and ultimately lead to a structural failure of the tank or its components. All electrical wires will be stainless-steel sheathed and the quantity probe will be made from stainless steel instead of aluminum. The fill-line plumbing internal to the tank will be improved, and a means of warning the crew of an inadvertent closure of either the fuel cell hydrogen or oxygen valves will be provided. A third cryogenic oxygen tank will be added to the service module for subsequent Apollo missions. The fuel cell oxygen supply valve will be redesigned to isolate polytetrafluoroethylene-coated wires from the oxygen. Warning systems at the Mission Control Center will be modified to provide more immediate and visible warnings of anomalies in all systems.

A more thorough discussion of this anomaly is presented in reference 1.

This anomaly is closed.



Not improvisation – preplanning!

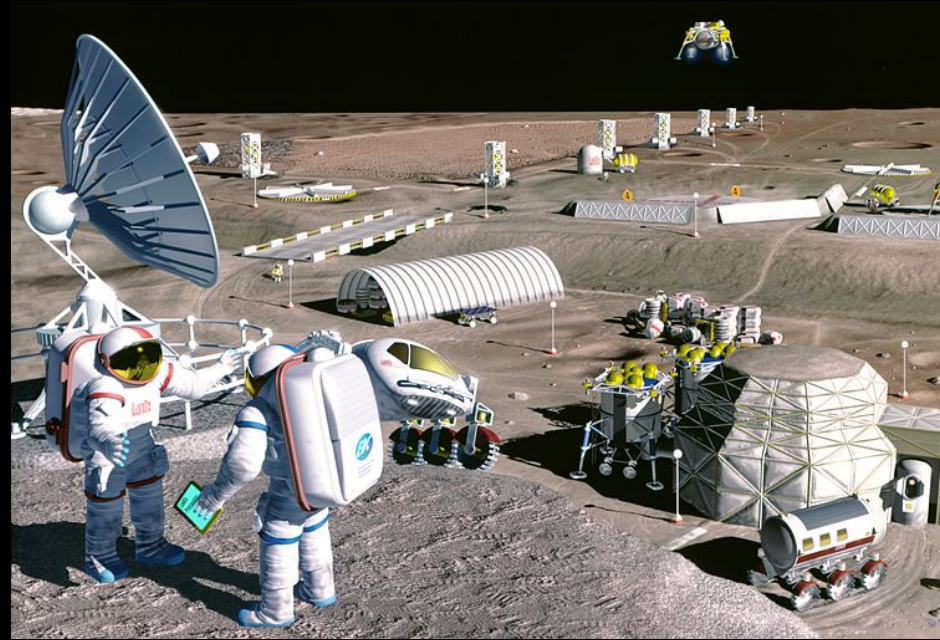
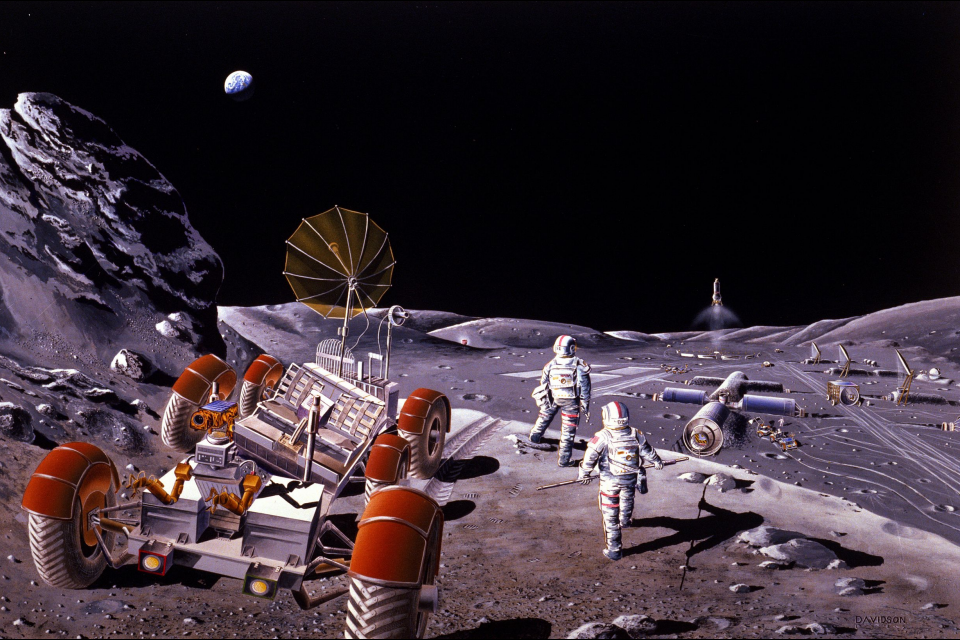


There are several aspects of the mission which deserve special note although these do not appear in the narrative. First of all, the procedures used in recovering from the anomaly were, in a great many instances, fairly well thought out premission. For example: The LM jettison sequence and time, the LM operation at minimum cooling, the midcourse alignment technique, and the procedure to separate the LM and the Saturn S-IVB stage communication frequency to name a few. When new procedures were required or when existing procedures had to be reviewed, the core of the premission planning team was used. This resulted in well coordinated, quickly defined procedures.

Another important aspect is that premission work with LM systems and CSM systems in minimum power configurations contributed greatly to the ability to provide suitable systems configurations for the Apollo 13 case. This work also provided an additional capability that was available through minimum duty cycles. Fortunately this was not required, but the point should be made that there was a level of operations available that would have resulted in LM water and battery power usage rates well below the final stabilized rates obtained.



Lesson IX – Business failure despite technical success



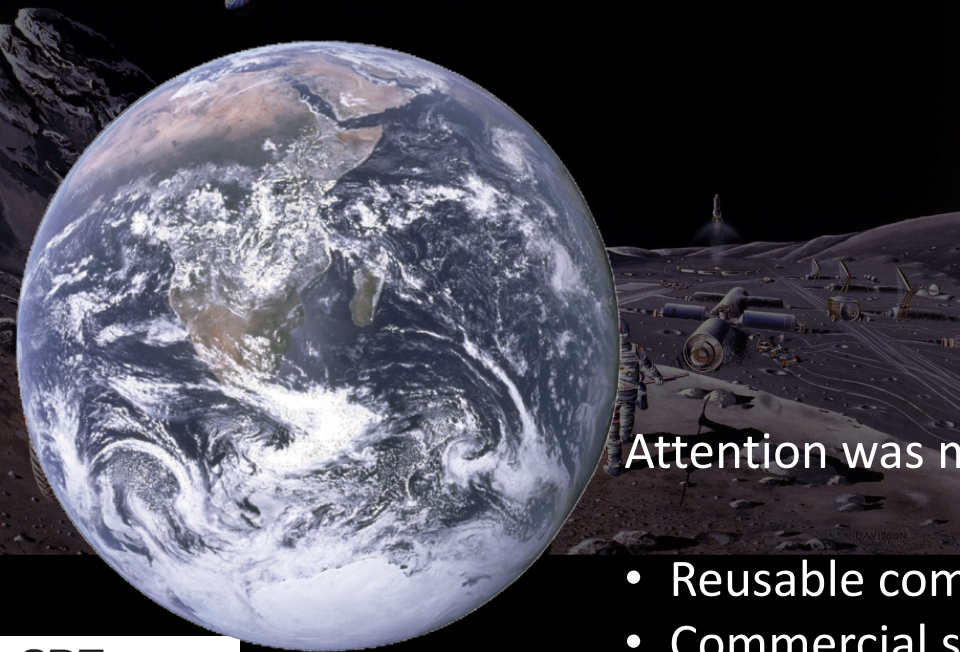


Lesson IX – Business failure despite technical success





Lesson IX – Business failure despite technical success



Attention was moved to

- Reusable components (saving money & other resources)
- Commercial satellites
- International cooperation in Space



Lessons



- Lesson I – Train for failures and responses.
- Lesson II – Build/code for failure.
- Lesson III – Failure has many shapes and forms.
- Lesson IV – Self-healing deflects failure.
- Lesson V – Avoid failure through robustness & resilience.
- Lesson VI – Failure is not an option – deal with the unexpected
- Lessons VII – Tools fail, validate your assumptions
- Lesson VIII – Avoid future failure by reducing technical debt
- Lesson IX – Business failure despite technical success

Prepare for failure

Adapt to failure

Reduce future failure



Build for reliability Learning Reserve Capacity
Culture Runbooks and Playbooks
Resilience
Performance Tuning
Leadership Simulations & Chaos Engineering Blameless Robust
Skills Automation
Change Management



Failure is not an option;

it's a certainty – be prepared for the things
you're not prepared for.



Resources used / Further information



- Apollo 13 in real time – <https://apolloinrealtime.org/13>
- BBC *13 minutes to the Moon* – <https://www.bbc.co.uk/programmes/p083wp70>
- NASA database of Significant Incidents & Close Calls in Human Spaceflight – <https://sma.nasa.gov/SignificantIncidents>
- Apollo Infographics – <http://www.tonybela.com/>
- Remastered video – <https://www.youtube.com/c/Dutchsteammachine>



Further information



- <https://ibm.biz/apollo-lessons> & <https://ibm.biz/apollo-lessons-first> & <https://medium.com/@flyingbarron>
- IBM and the Apollo missions – <https://newsroom.ibm.com/apollo> & <https://www.ibm.com/thought-leadership/the-apollo-missions>



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Thank you for watching

SRE lessons 50 years after Apollo 13