

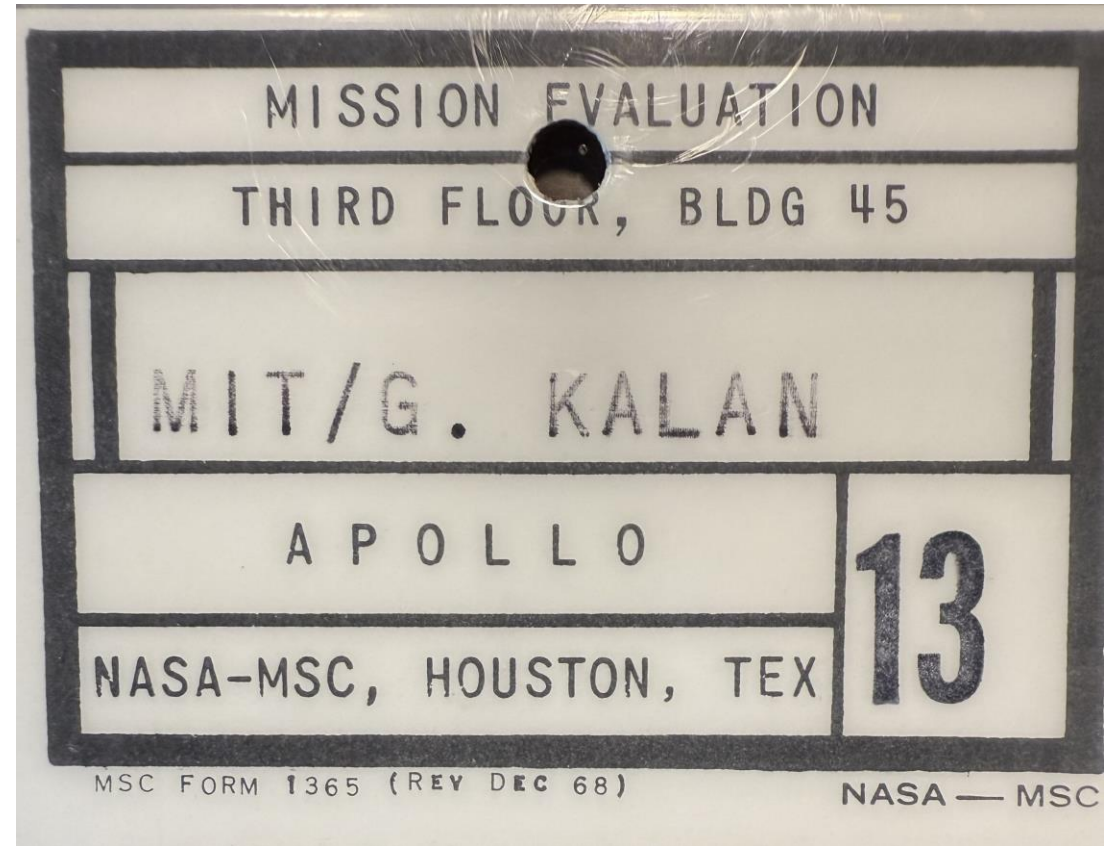
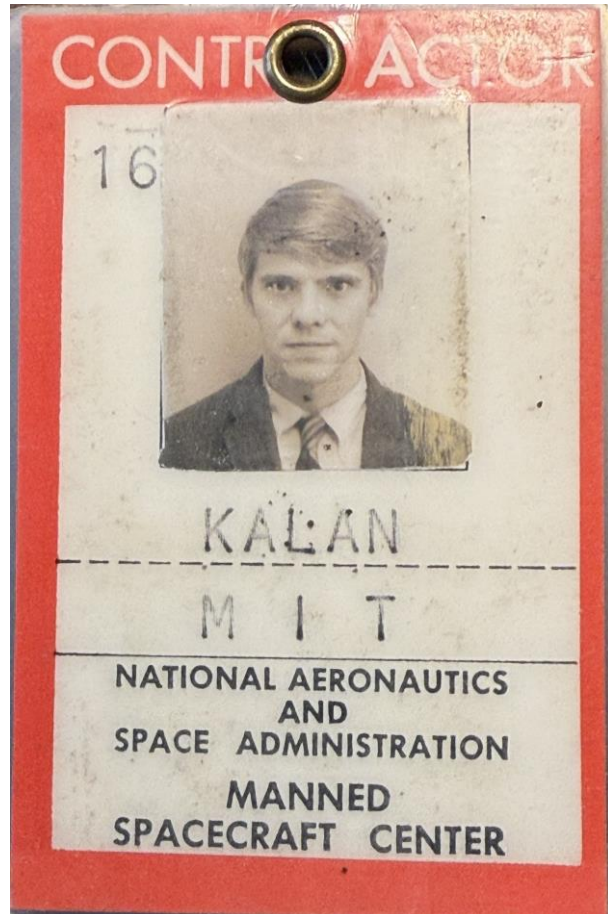


Inside the Apollo 13 Rescue

George Kalan
11/20/25

Houston Manned Spacecraft Center (MSC)

Monday, April 13, 1970 9:07 PM CST



“Houston, We’ve Had A Problem”

MIT Campus



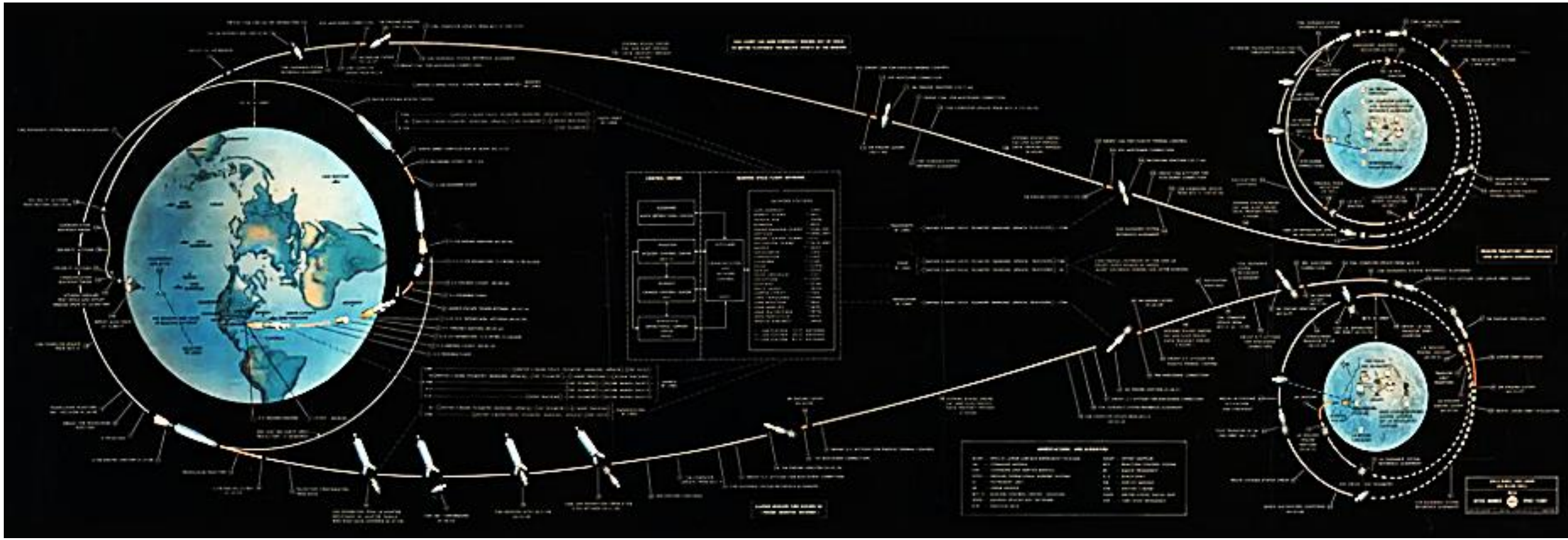
The Rocket: Saturn V



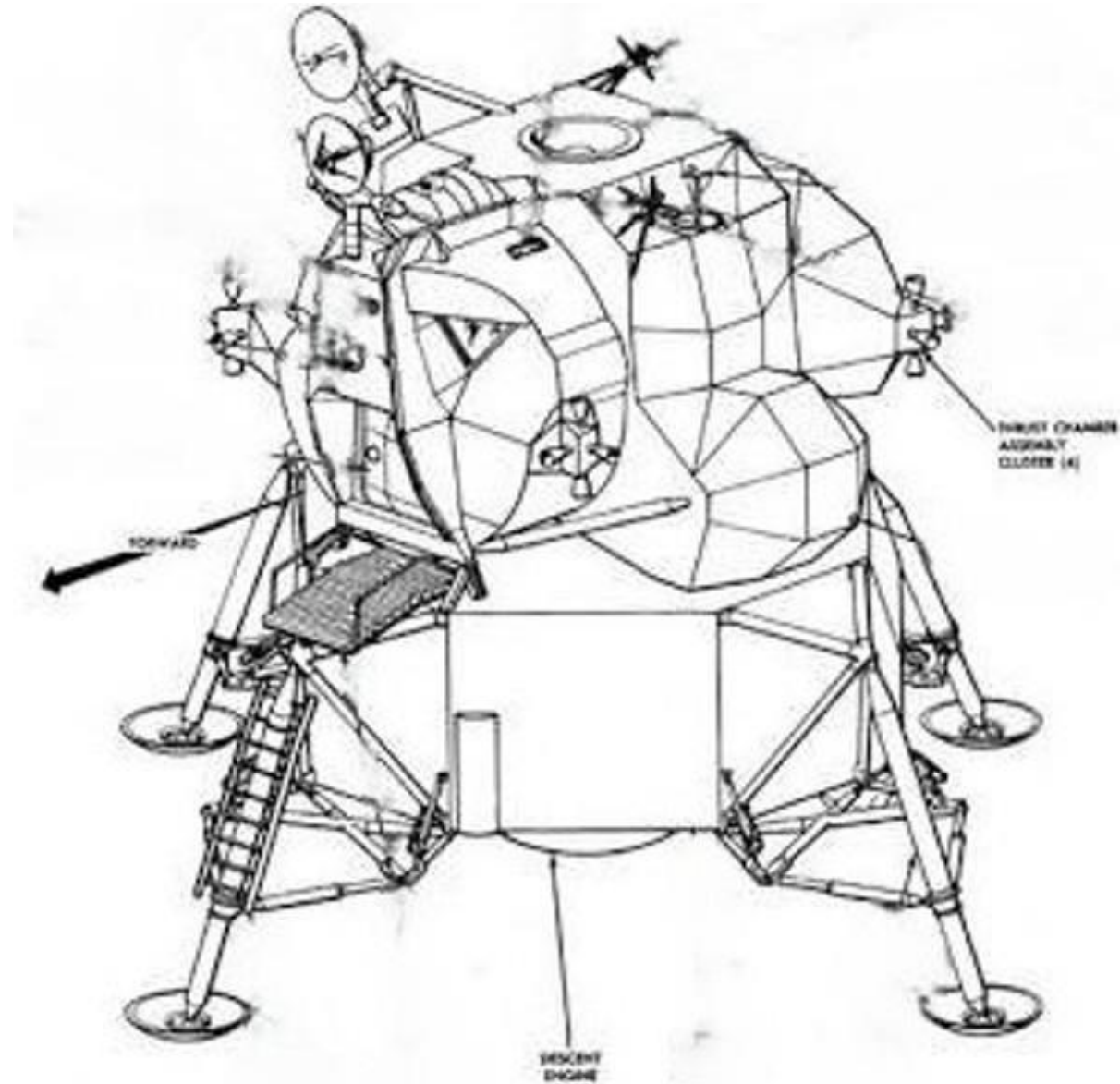
The Spacecraft



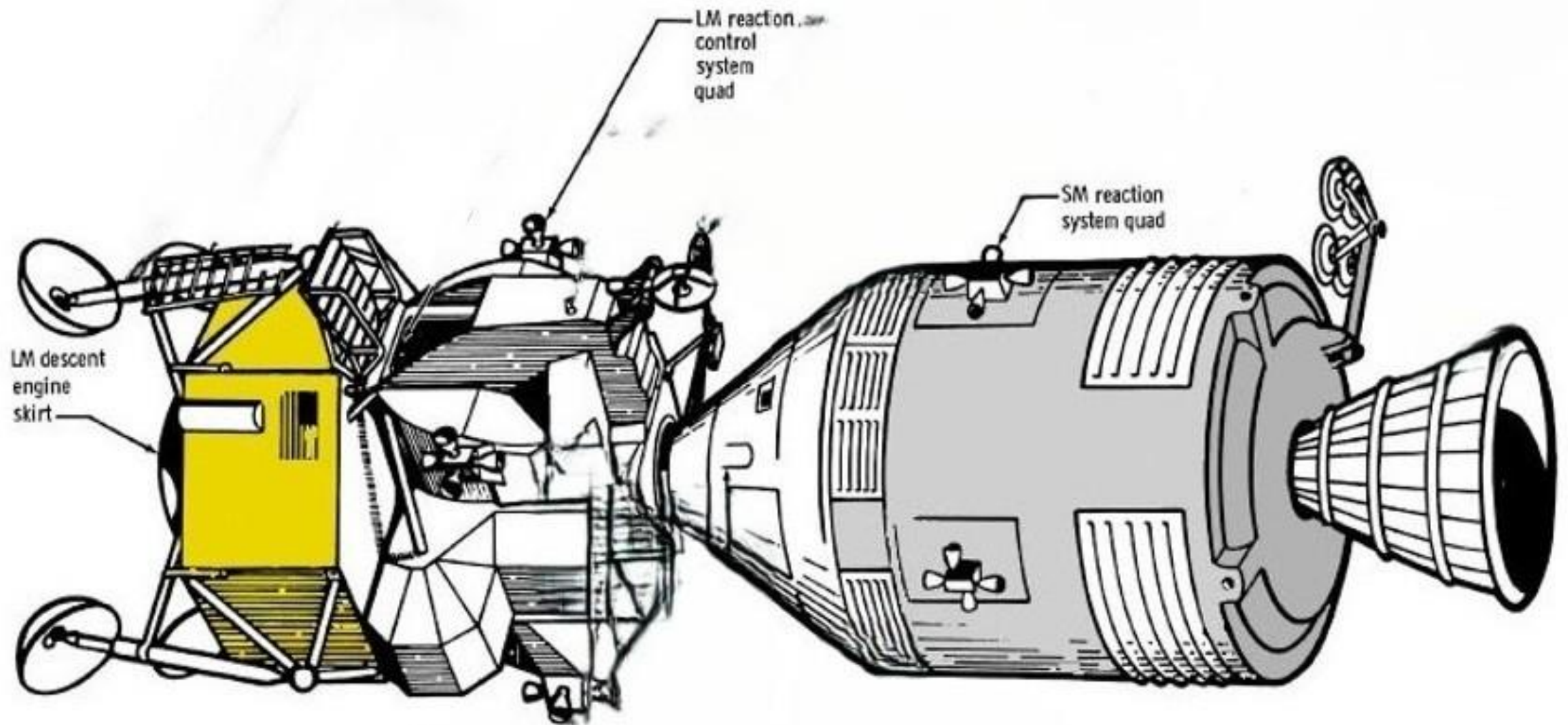
The Mission



LM Digital Autopilot Control System



The CSM-LM Docked Digital Autopilot (The “Backup Autopilot”)



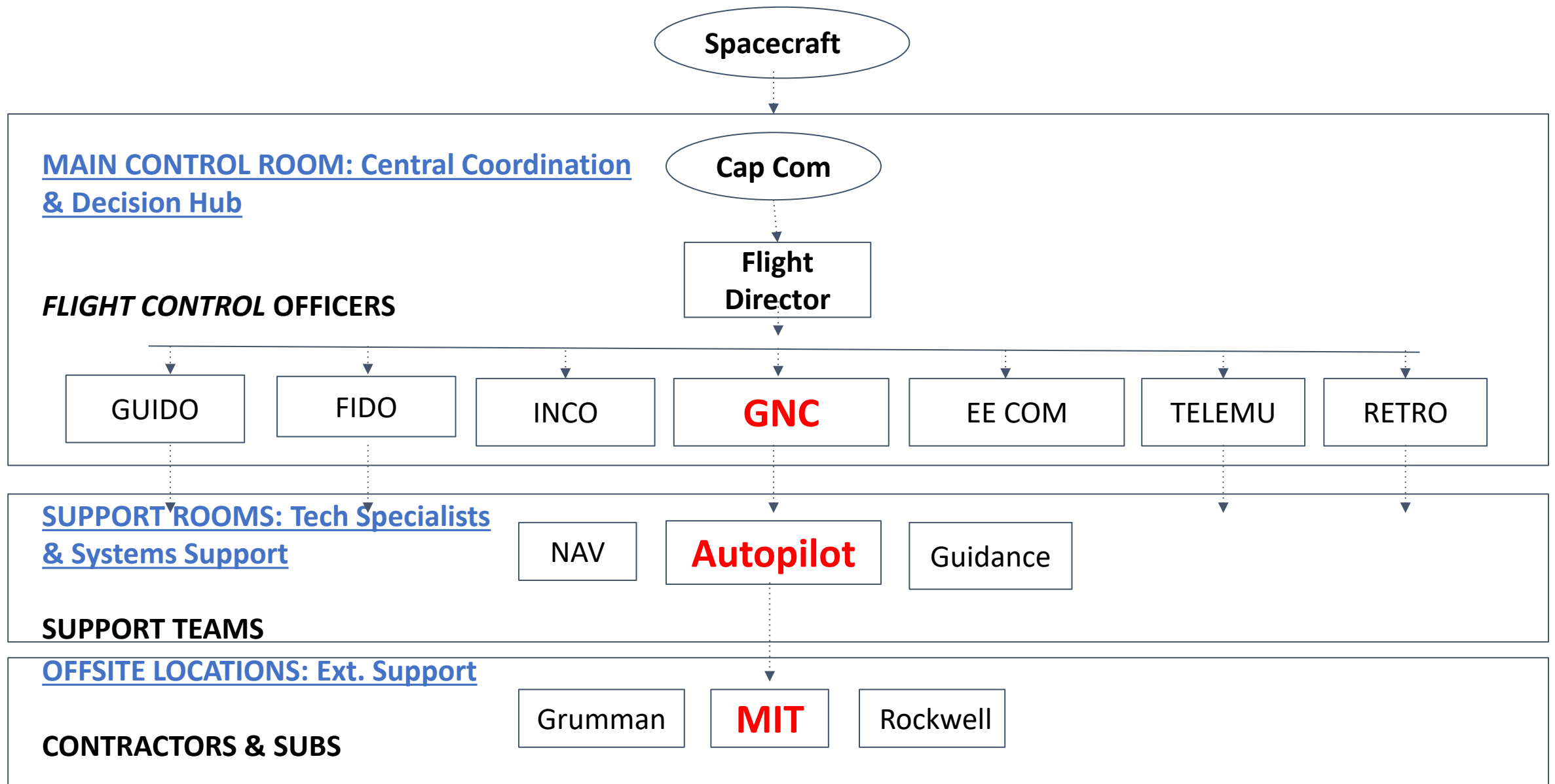
Change of Direction

- **Change in Role-Spring 1969:**
 - Lead Engineer left group
 - Promoted as replacement
 - PhD plans put on hold
- **Managed LM Digital Autopilot group and served as NASA interface, with responsibility for extensive LM Autopilot improvements from Apollo 12 through Apollo 15**

Main Control Room-Mission Control



Mission Control Organization



“Houston, We’ve Had A Problem”

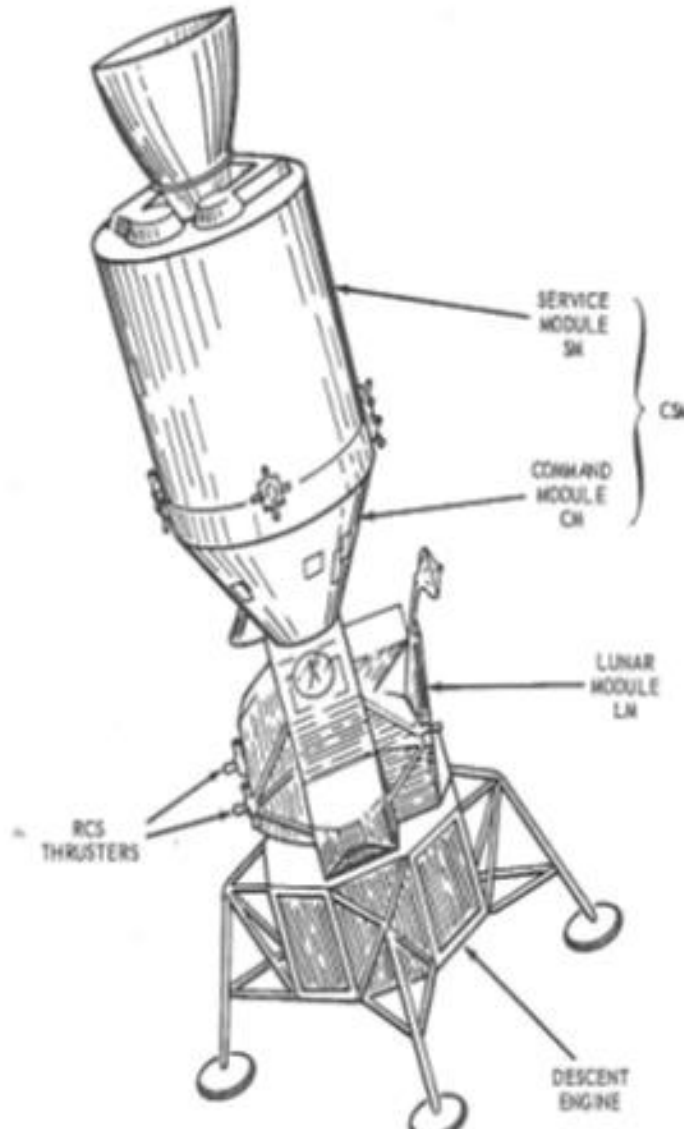
Avalanche of Bad News

- **Critical alarm conditions pouring into Flight Control Officers and Flight Director from support rooms throughout Mission Control**
- **Low point of entire rescue mission**

Gene Kranz- Lead Apollo 13 Flight Director



To the LM Lifeboat!

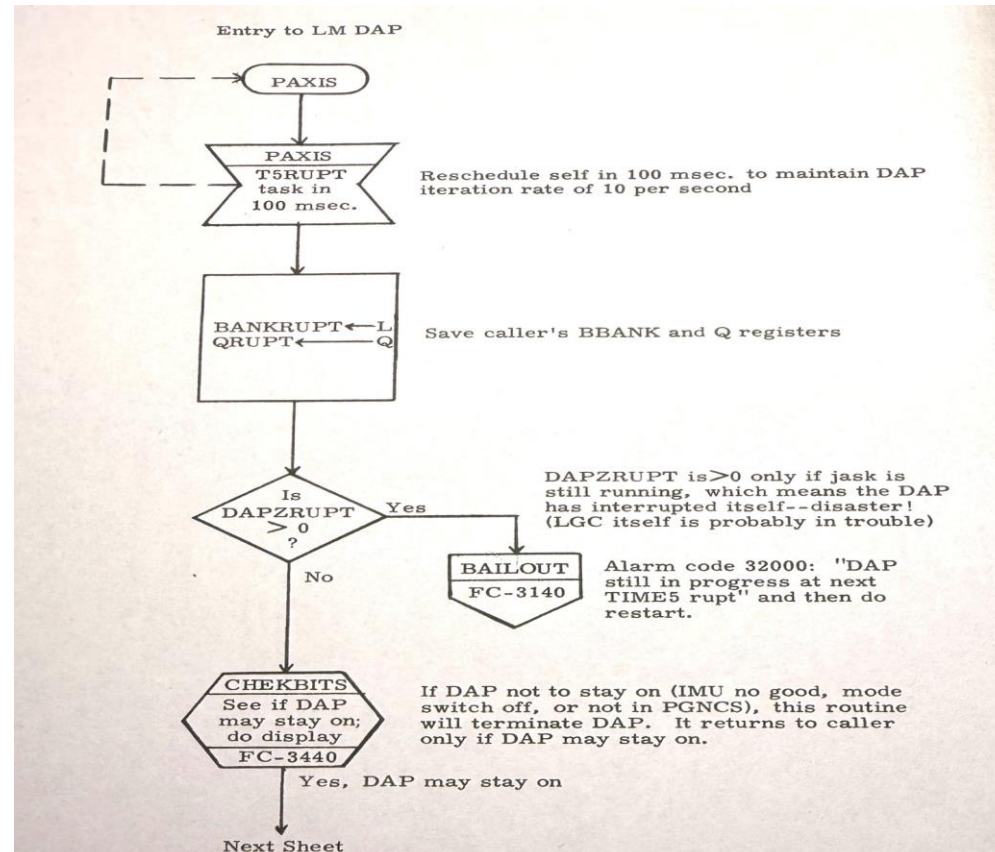


- Problems traced to loss of O₂
- Life support systems in death spiral
- Decision to use LM as lifeboat
- CSM powerdown/LM powerup
- Backup Autopilot stabilized spacecraft attitude
- **Crew transferred to LM 1 hr 43 min after first alarm**

Free Return Burn Challenge

- **Backup Autopilot needed to power urgent Free Return Burn**
- **Concerns:**
 - LM-powered flight of CSM-LM never modelled or tested on simulators
 - Never flight tested at all under power
 - Less than 4 hours before scheduled burn

Analyze Flowchart Logic



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>L. Duncan</i>		LM RCS DAP	
PRGMR	<i>3/16/69</i>	LUMINARY 1D	DOCUMENT NO.
ANALST <i>James R. Kelen</i>	<i>3/25/69</i>		FC-3470
DOCMR <i>Robert M. Sutton</i>	<i>3/25/69</i>	REV 1	SHEET 2 OF 11
APPR'D <i>Robert M. Sutton</i>	<i>3/25/69</i>		

Prepare Crew Procedures and Verify on Hybrid Simulators

MIT LM Hybrid Simulator



MSC LM Hybrid Simulator



Verify Performance on Digital Simulators



Coasting Flight Challenges

- **Disable half the RCS jets to conserve propellant**
- **Widen the band of allowed attitude swings to conserve additional propellant**
- **Initiate Passive Thermal Control roll (Bar BQ Roll) to ensure uniform solar heating**

Consumables Challenges

- **LM designed to support 2 astronauts for 2 days, but return would take 4 days with 3 astronauts**
- **Radical actions being explored to reduce power and water consumption still not sufficient to make it home**
- **Conclusion: Speed-Up Burn required for crew to survive**

Consumables Challenges (2)

Three Speed-Up Burn options under consideration:

- **Superfast Return:** Jettison SM; 100% throttle, Burn all fuel
- **Fast Return:** Jettison SM; Less time at 100% throttle;
Conserve some fuel
- **Slower Return:** Keep SM; Even less time at 100% throttle;
Conserve more fuel

Speed-Up Burn Challenges

- **Control of CM-LM Alone Configuration with LM**
- **Concerns:**
 - Configuration never envisioned by mission planners
 - Never simulated or flight tested
- **Long burn at 100% thrust**
- **Concerns:**
 - Flight tests never done under power
 - Free Return Burn only lasted 30 seconds at 40% thrust

Last Challenge Before LM Powerdown

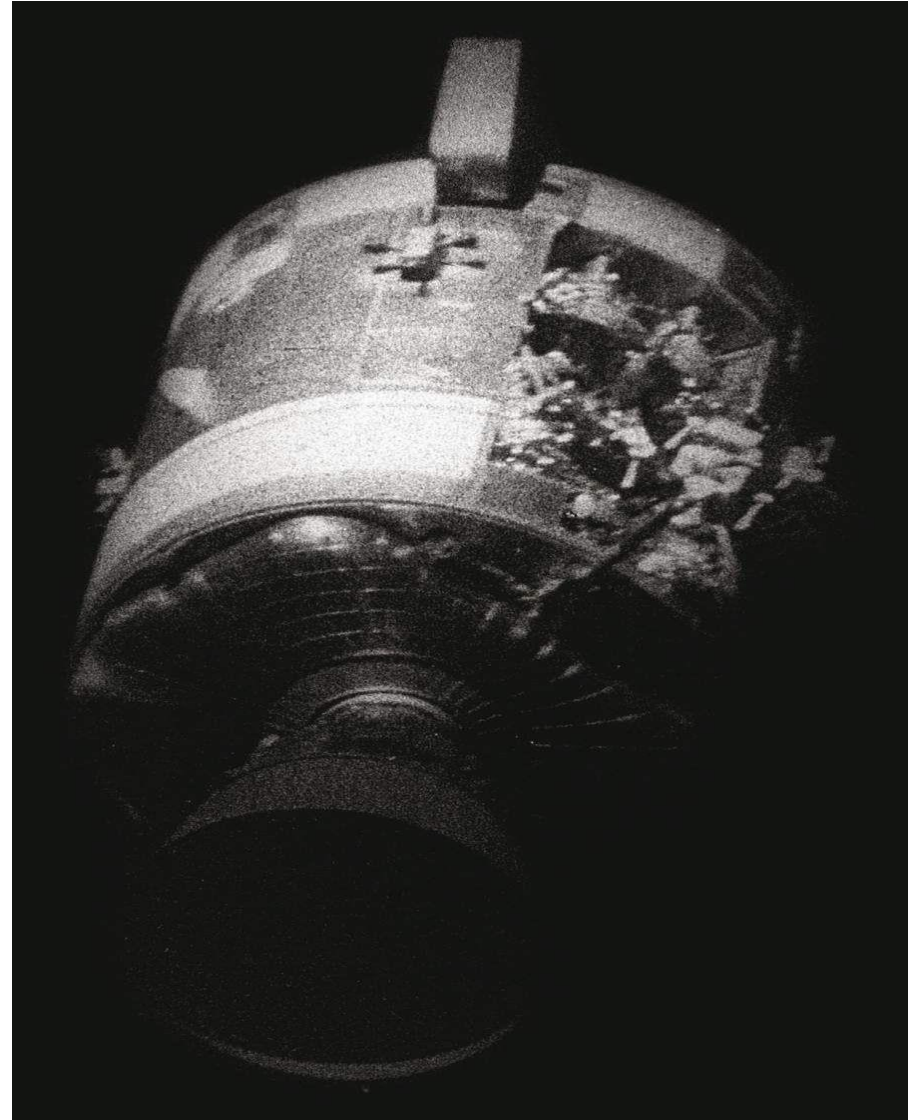
- **Angles to orient spacecraft for Bar BQ roll needed ASAP before proceeding with powerdown**
- **Intense pressure to complete calculation with entire space center and crew waiting for results**

Re-Entry Challenges

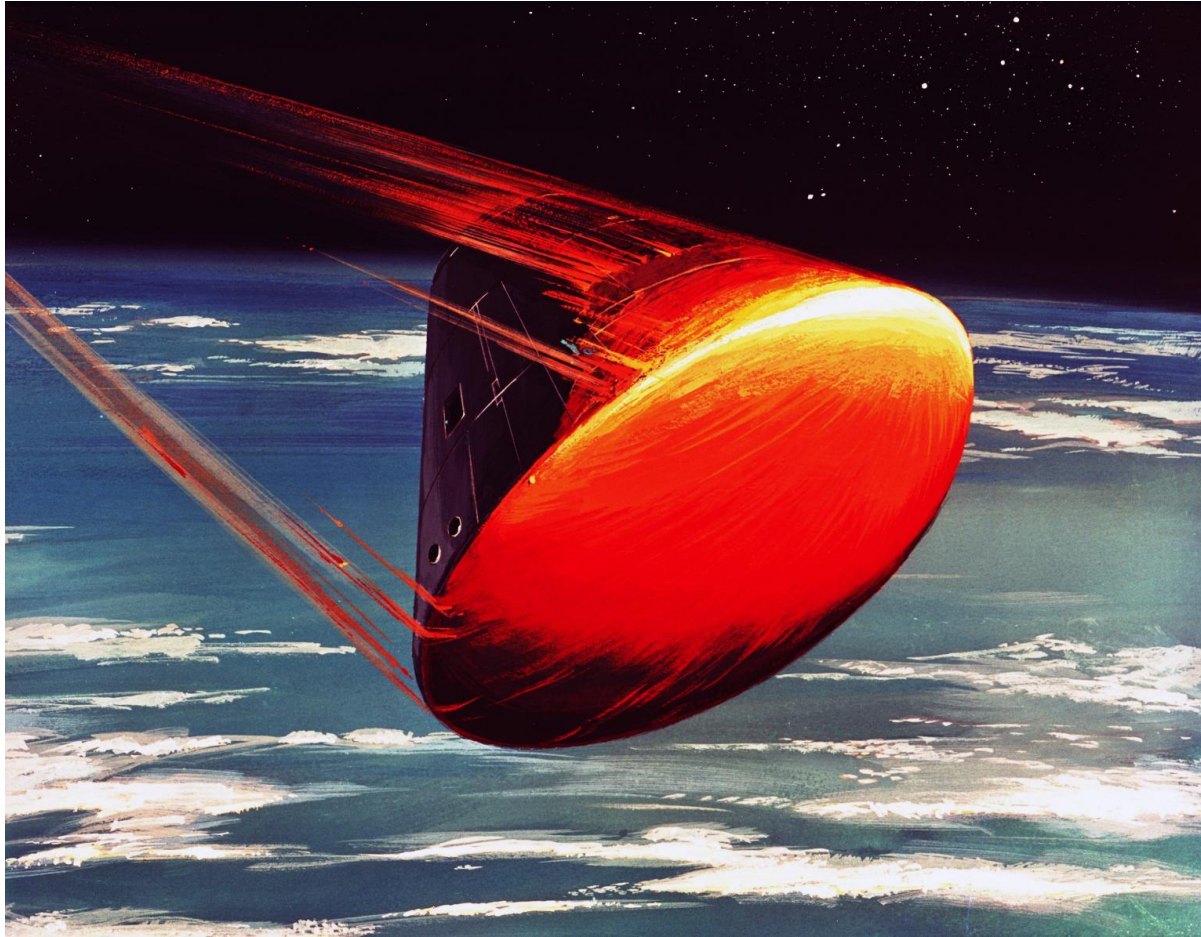
- **Separation of SM before Re-Entry**
- **Control of CM-LM Alone after separation of SM**
- **Spin-stabilization of CM-LM Alone if CM Computer failed to powerup or LM didn't separate from CM**
- **Pilotless LM control after CM separation**

Damage to Service Module

- **Primary Concerns:**
 - **Any damage to CM heat shield from explosion or overexposure to cold?**
 - **Would it fail during the 3,000°F Re-Entry and incinerate the crew?**

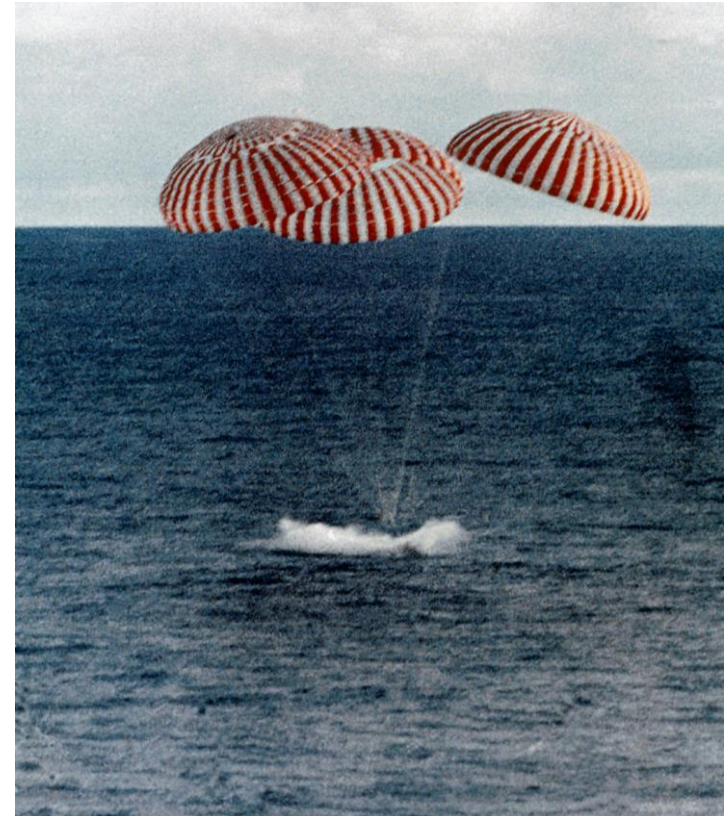


Final Re-Entry Drama



- **Drifting out of narrow approach angle band**
- **3-4 minute communications blackout on prior flights**
- **Crew contact attempts:**
 - **4 minutes-no response**
 - **15 seconds later- nothing**
 - **Another 30 seconds-still no response; Hopes fading**

Back Alive Against All Odds!



Thank You!

Appendix

Multiple Mistakes Led to Explosion

- O₂ tank contained heater, stirring fan, thermostat and venting ports
- **Mistake #1:** Voltage changed from 28v to 65v, but tank subcontractor forgot to change thermostat
- **Mistake #2:** Tank dropped during removal from Apollo 10 for upgrades, and rescheduled for use in Apollo 13
- **Mistake #3:** Inspection concluded no damage even though drop misaligned internal venting ports
- **Mistake #4:** Tank upgraded for Apollo 13, but 28v thermostat still not replaced

Multiple Mistakes...(2)

- **Mistake #5:** Tank wouldn't vent after countdown demo test and heater turned on to boil off liquid remaining O₂. NASA decided not to replace tank to avoid delaying launch.
- **Mistake #6:** Gages in test stand maxed out at 80°F. When 65v from test stand were used to turn on heater, 28v thermostat fused shut and never opened again. Tank temperature increased to 1000°F, burning off wire insulation and leaving bare heater, fan and thermostat wires exposed inside tank.
- **Result:** During Apollo 13, the third time Swigert switched on fan, bare wires sparked and ignited insulation fragments in pure O₂ environment, causing explosion.

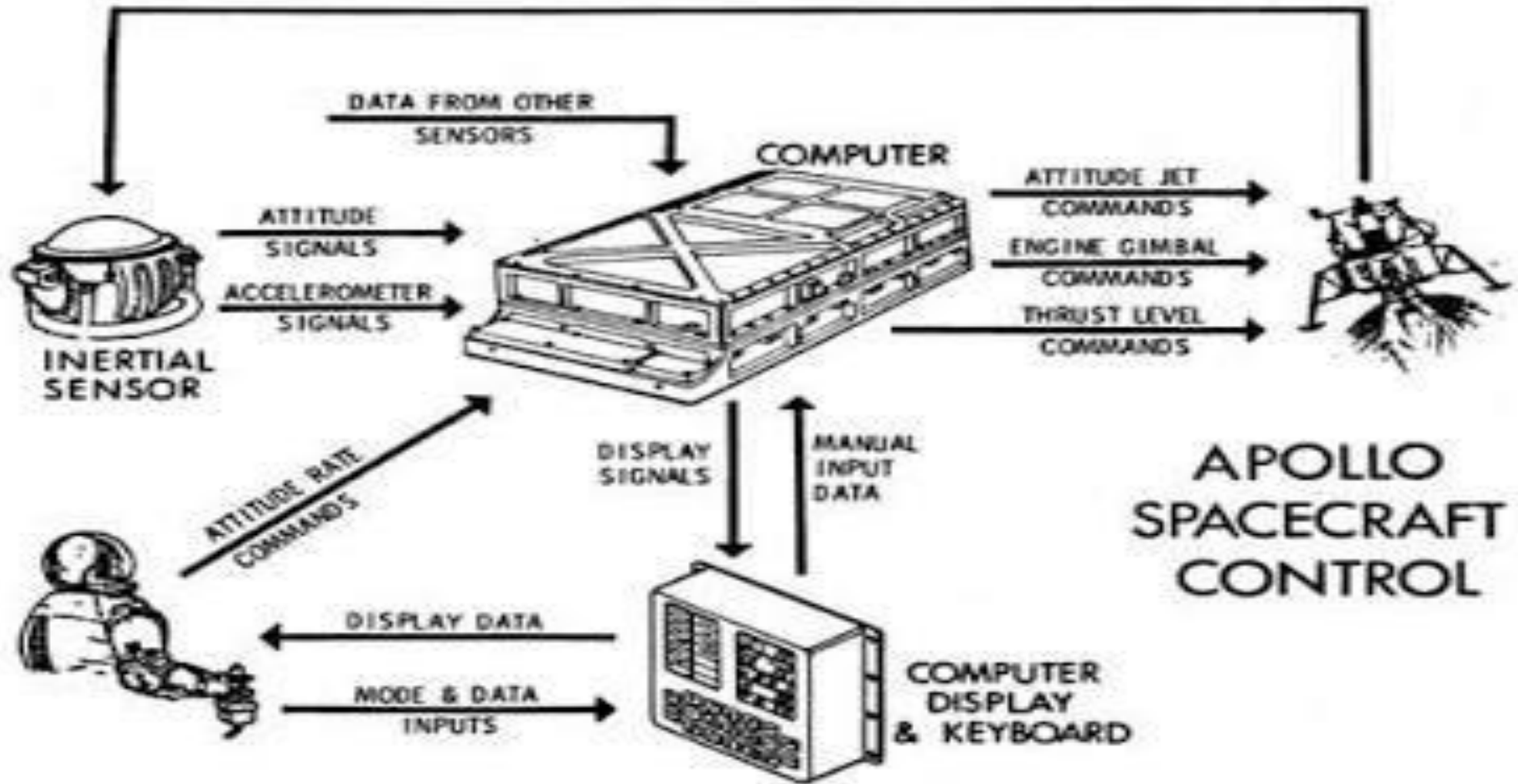
Explanation of Post-Explosion Events

- Loss of O₂ in first tank due to explosion of tank
- Power failure occurred when lack of O₂ caused fuel cells to stop generating electricity
- Leak of O₂ from second tank due to shared plumbing
- Unexplained switch from one antenna to another caused when active antenna was hit by panel blown out by explosion
- Uncontrollable wobbling and swaying occurred because shock of explosion caused several RCS jet propellant valves to slam shut permanently, unbalancing autopilot and manual attempts to stabilize spacecraft

Events while LM Computer was Off

- **CSM's square O₂ removal canisters adapted to replace LM's round ones**
- **Small manual navigation and midcourse correction maneuvers accomplished- with great difficulty-using only the original analog control system**
- **Explosion of LM battery, causing partial reduction of power, and rupture of Helium tank overpressure disk**
- **Fred Haise very sick and entire crew cold, sleep deprived and exhausted**

Apollo Lunar Module Control System



Apollo Guidance Computer and Display and Keyboard (DSKY)

