

Missions To and Around the Moon

How Historical Failures Provide Context for Present Decisions

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Scope

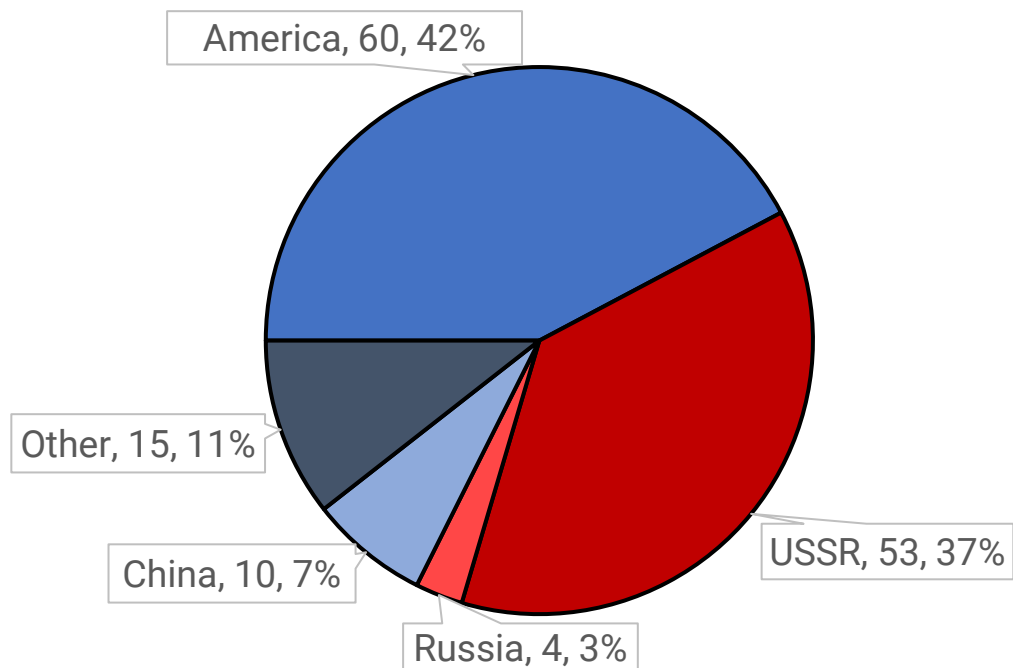
- All missions to or around the moon from Pioneer 0 in Aug 1958 to Lunar Trailblazer in Feb 2025 (142 over 66.5 years).
 - Who – Which countries and companies built and operated these missions?
 - What – What was the mass of the spacecraft and what came before?
 - Where – Where was the mission intended to go?
 - When – When did the mission launch, reach orbit, land, collect samples, return, end and/or fail?
 - Why – What was the mission objective? What was the failure mode?
 - How – Did they succeed or fail?



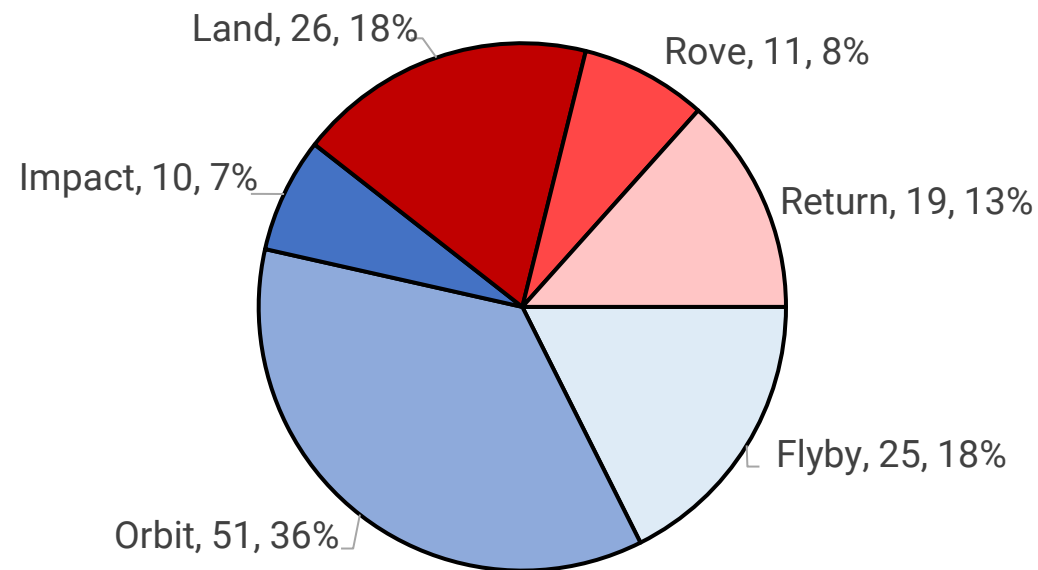
Attempts

142 Total Missions. 9 Crewed = 6% (Apollo)

Missions by Country



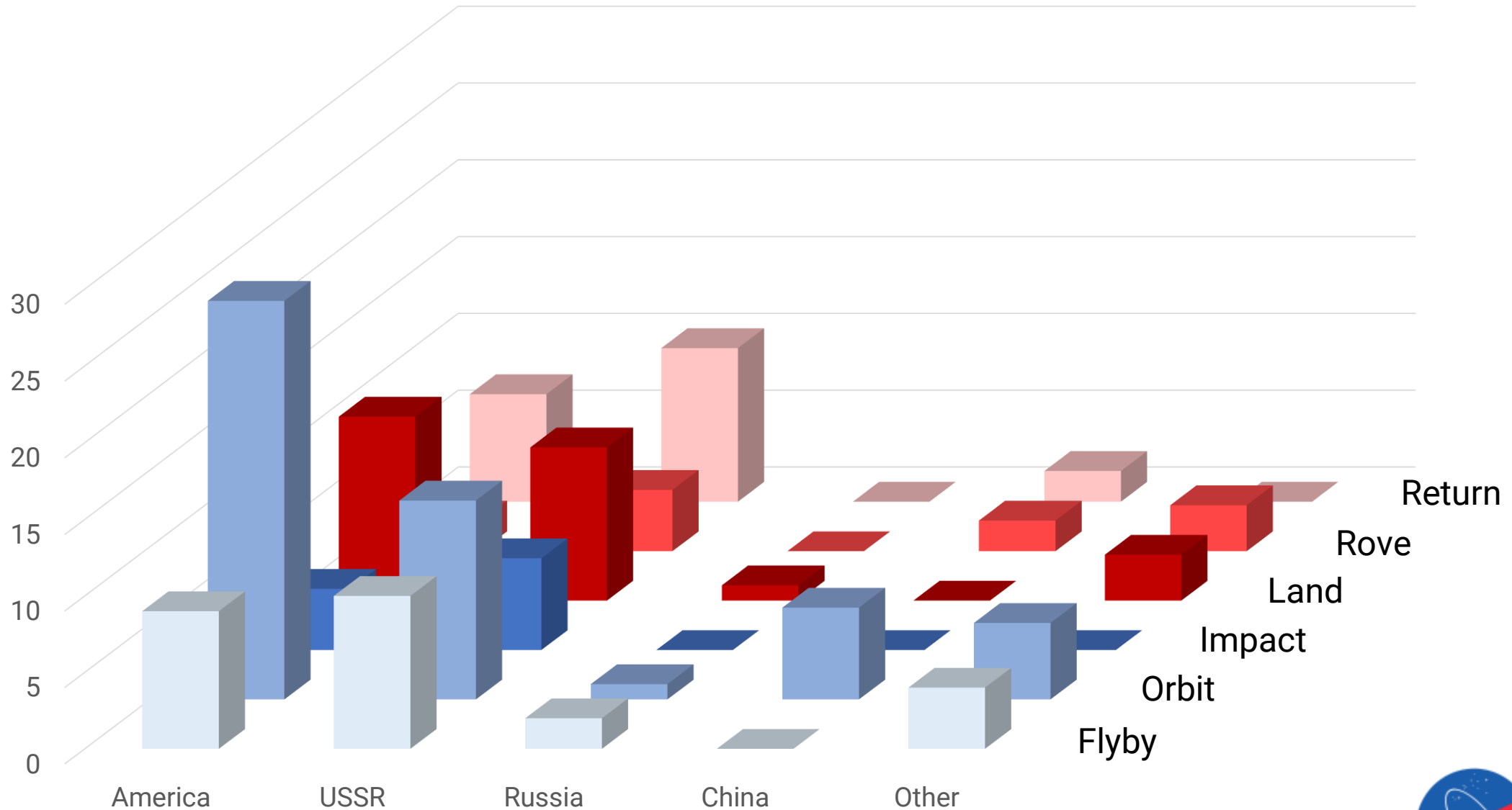
Missions by Ambition

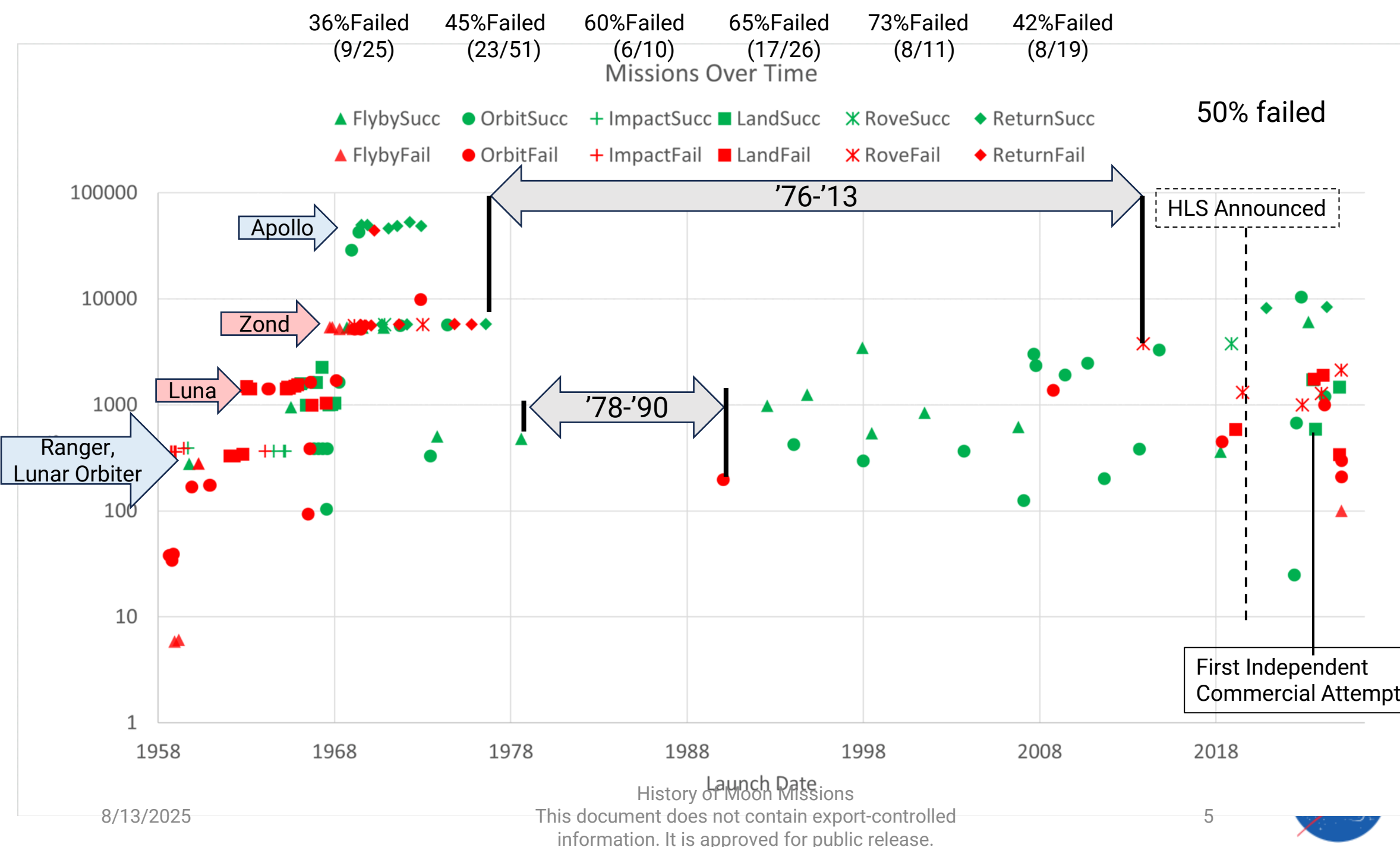


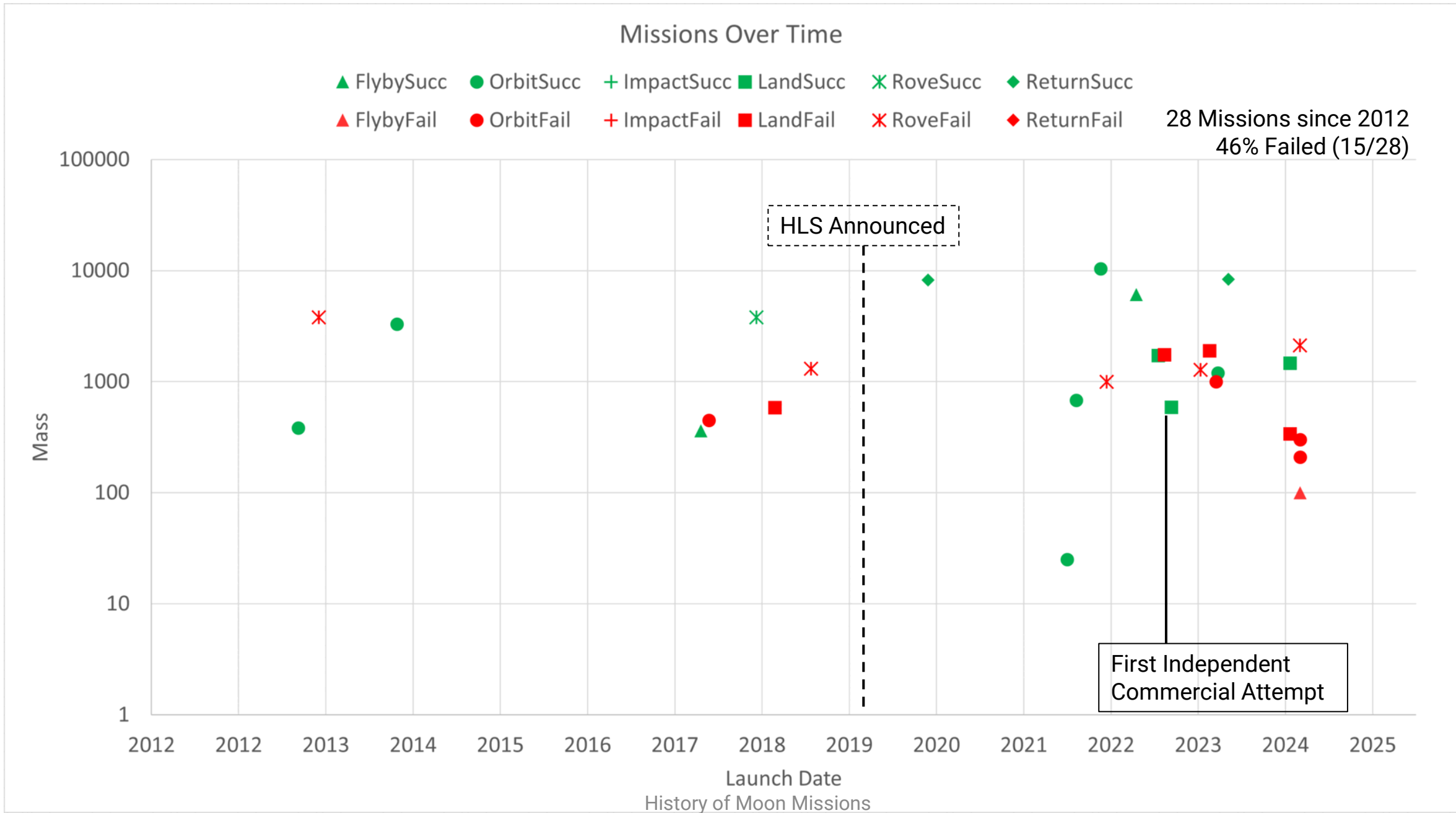
Missions were categorized by their furthest objective. It is assumed that the farther a mission goes, the more complicated it is. More complicated missions are assumed to encompass the objectives of less complicated missions. (e.g. To land, a mission must reach lunar orbit, and to reach lunar orbit, the spacecraft must fly near the moon.)

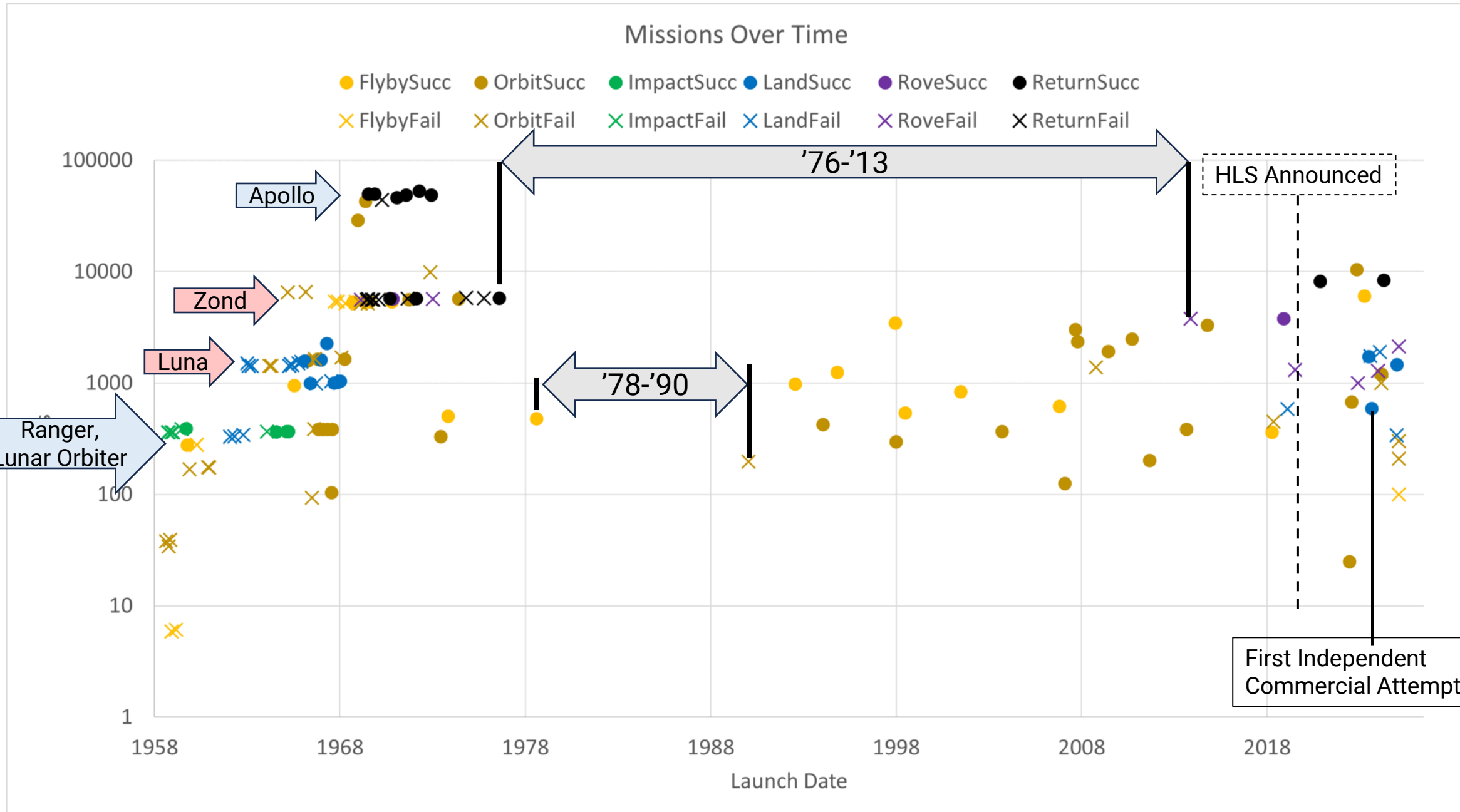


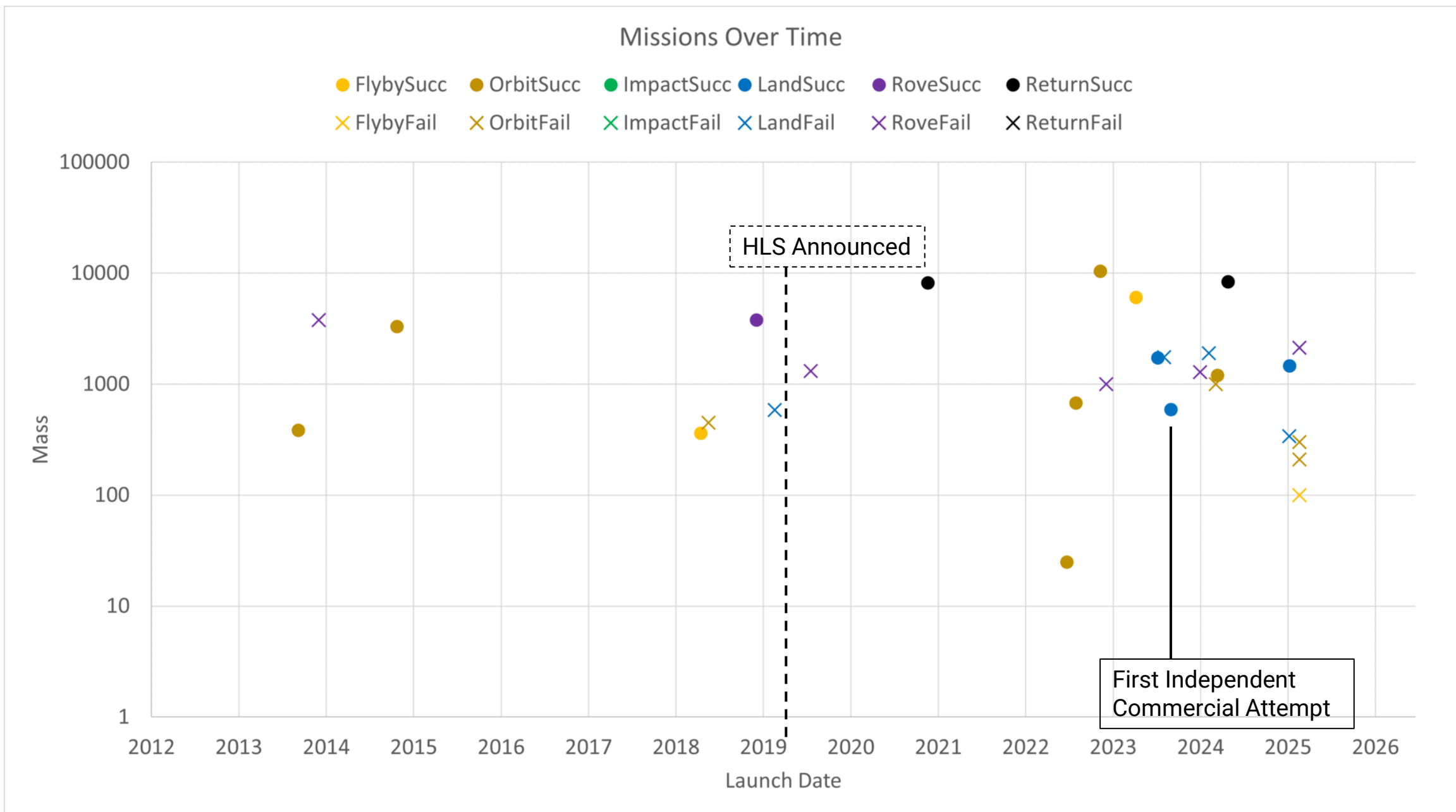
Mission Type Attempts by Country

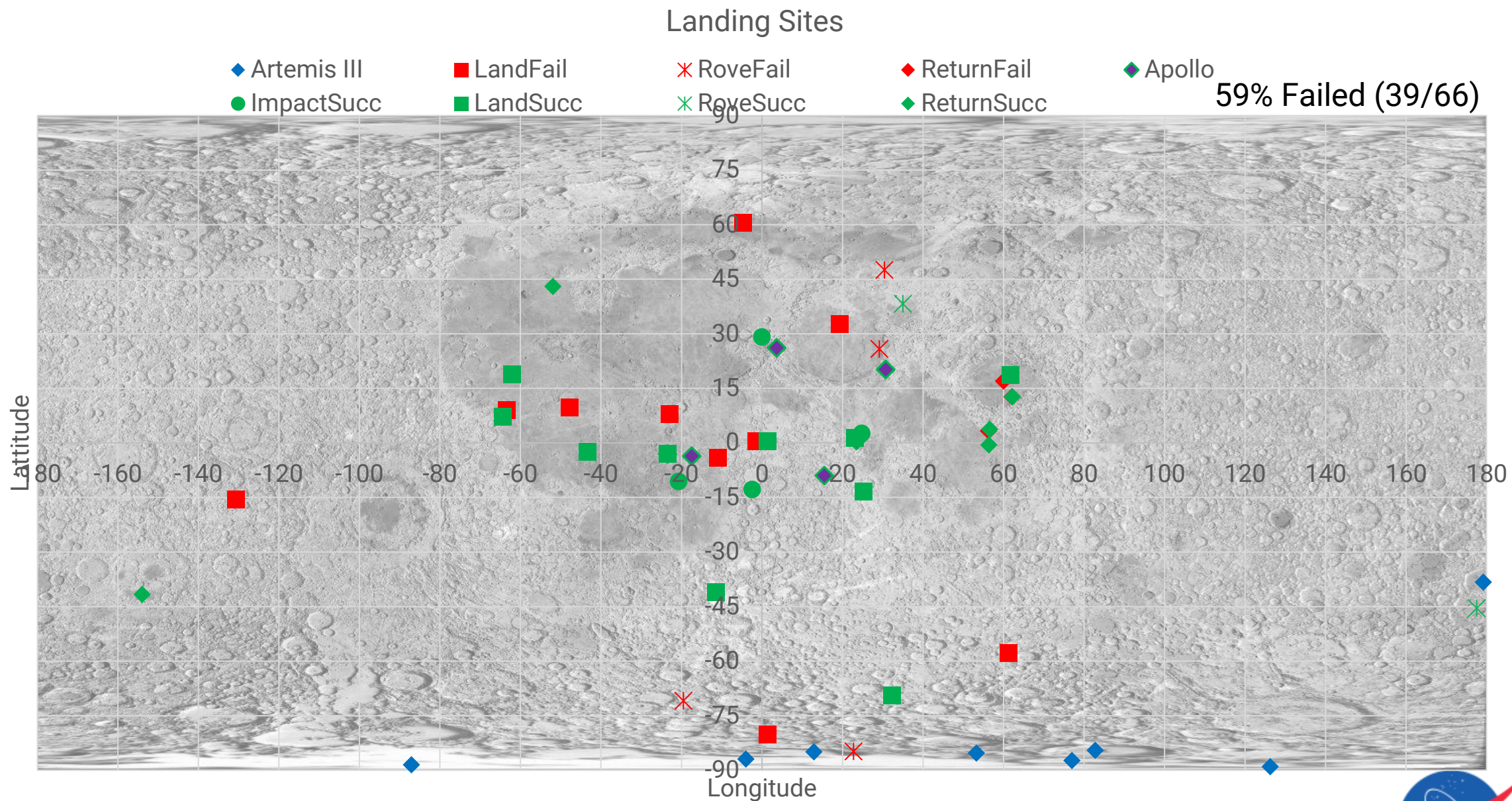








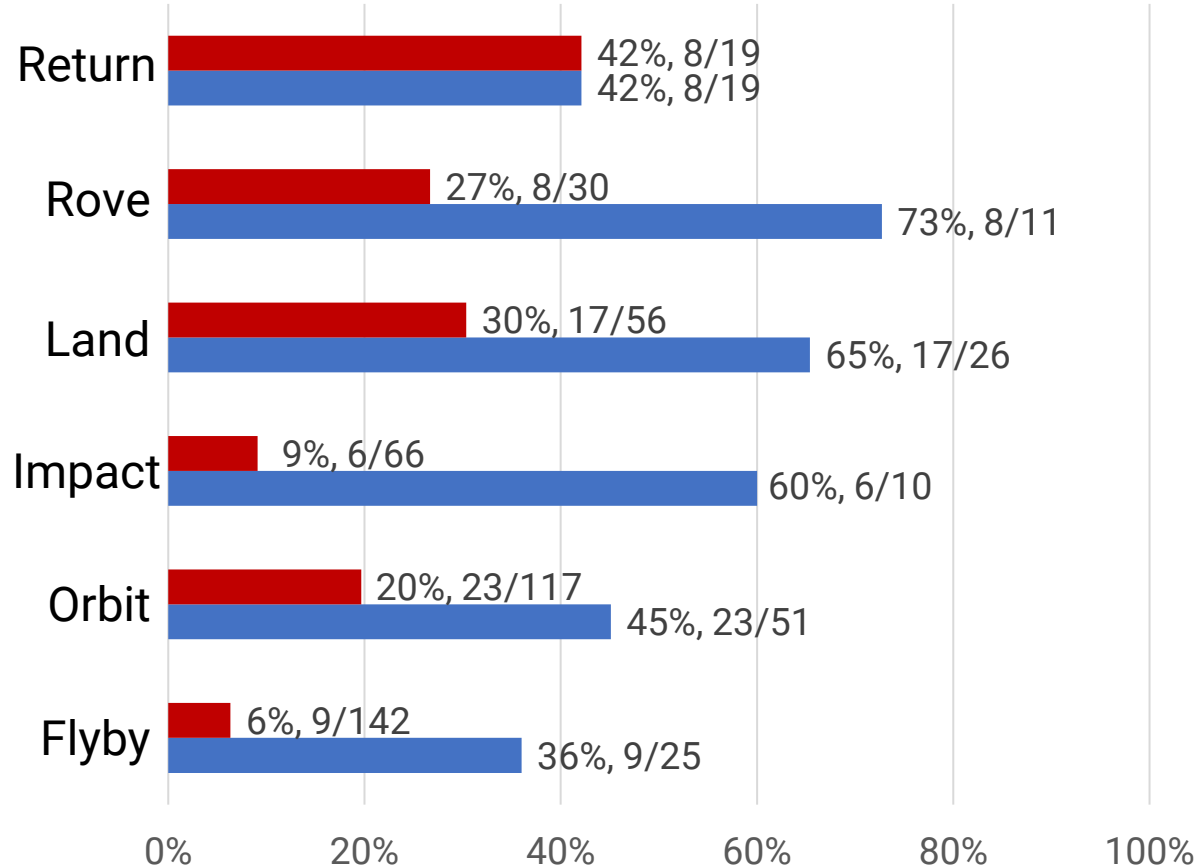




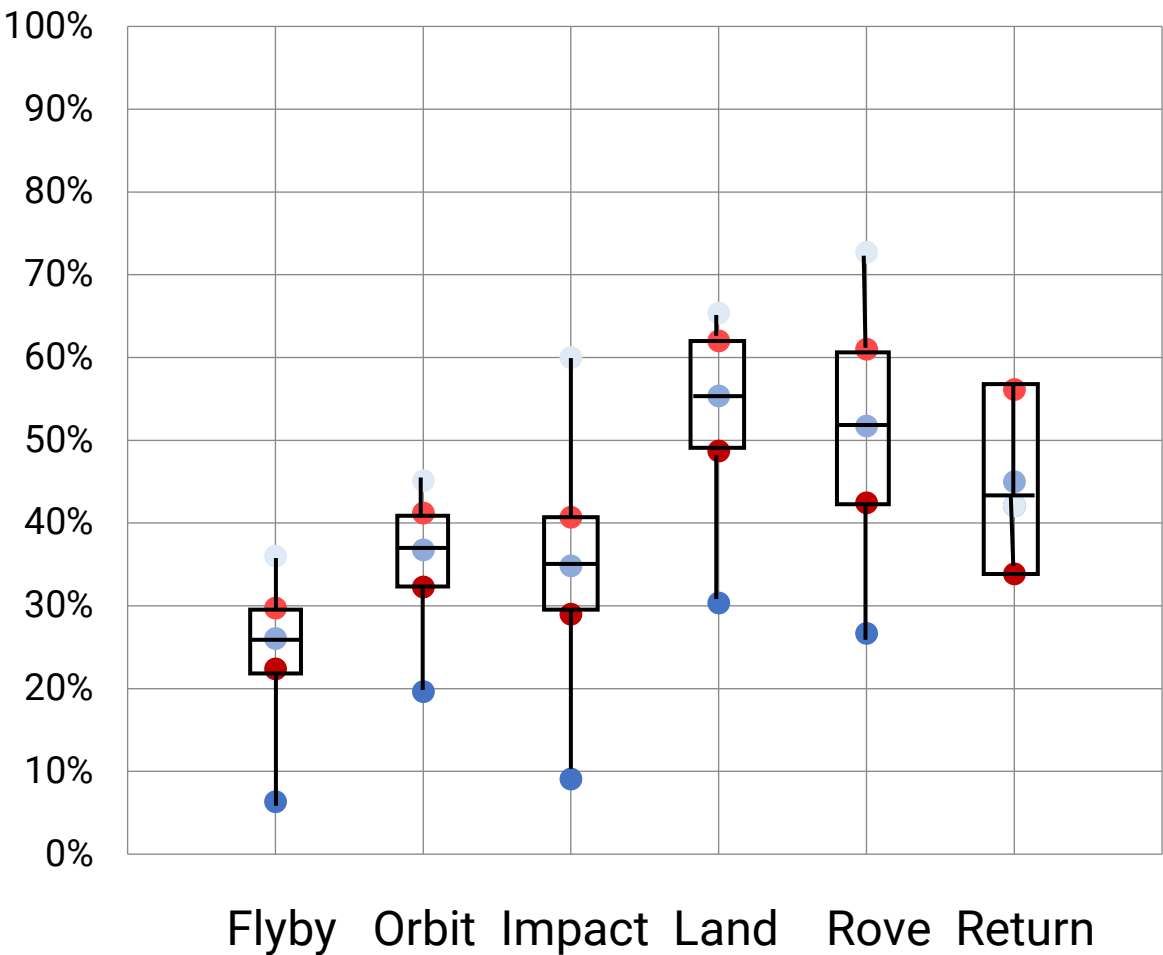
These are conservative extrapolations, only based on demonstrated capability. They do not account for Reliability Growth.

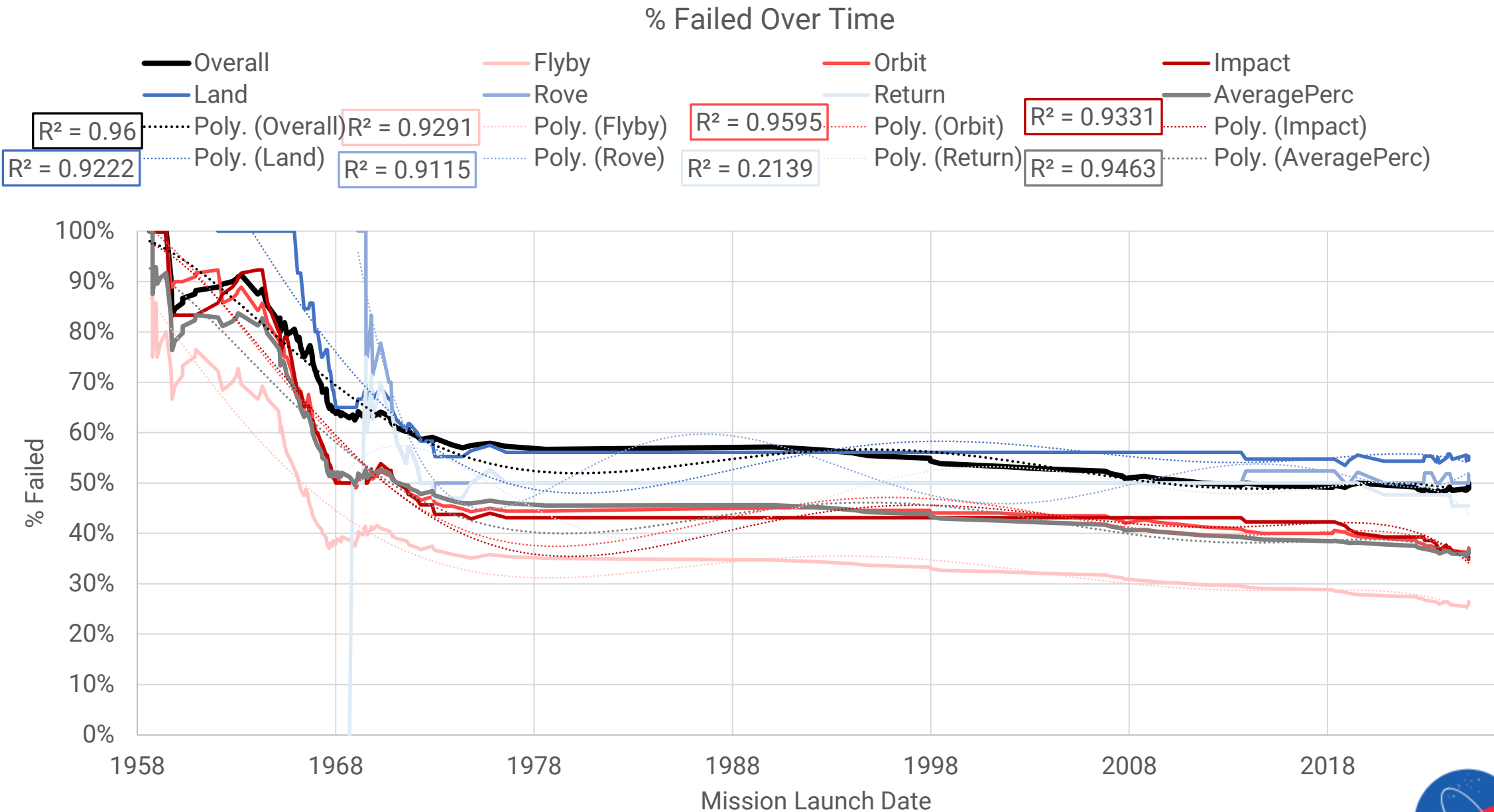
% Failed by Ambition

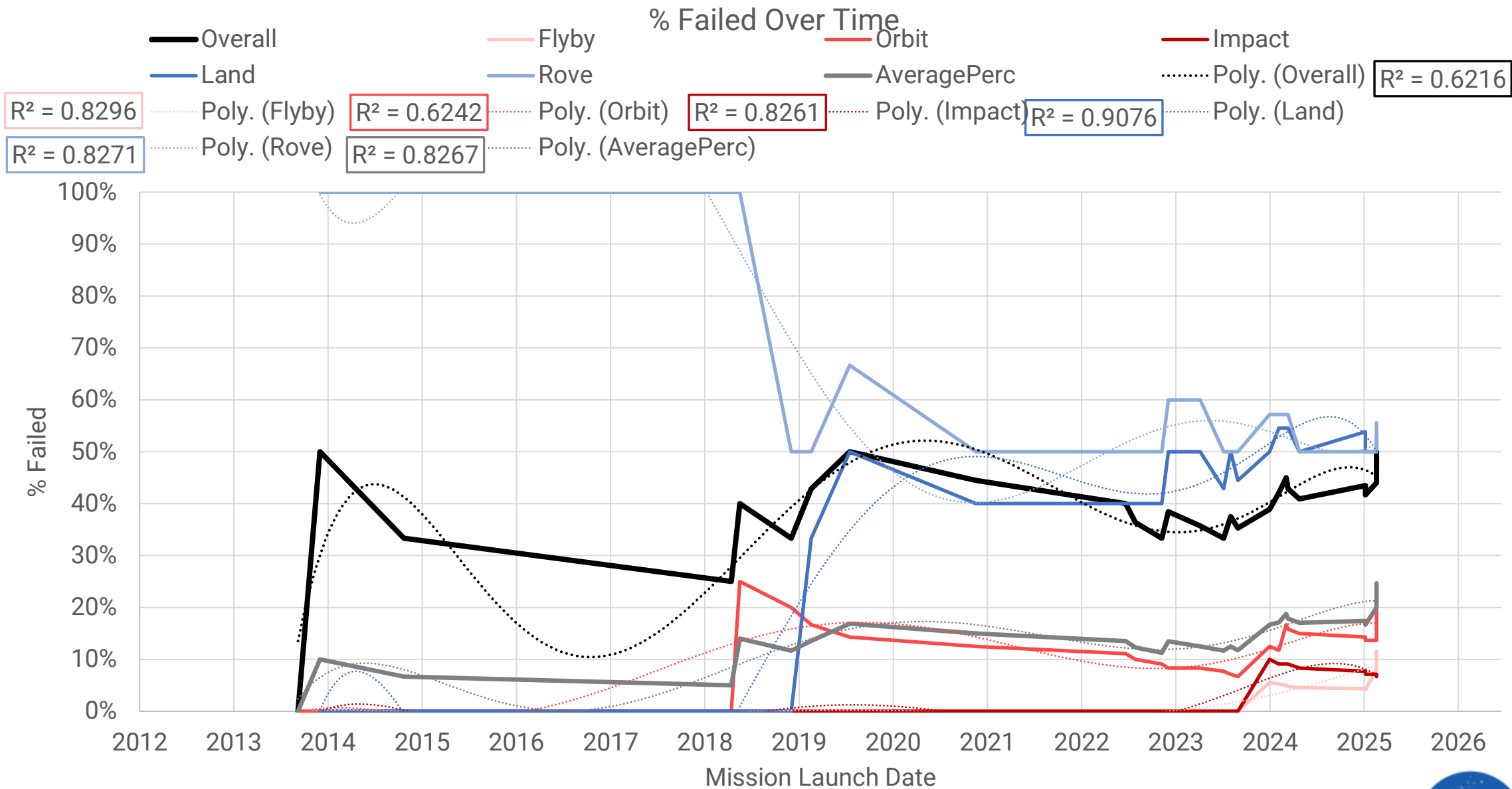
■ Cumulative ■ Independent



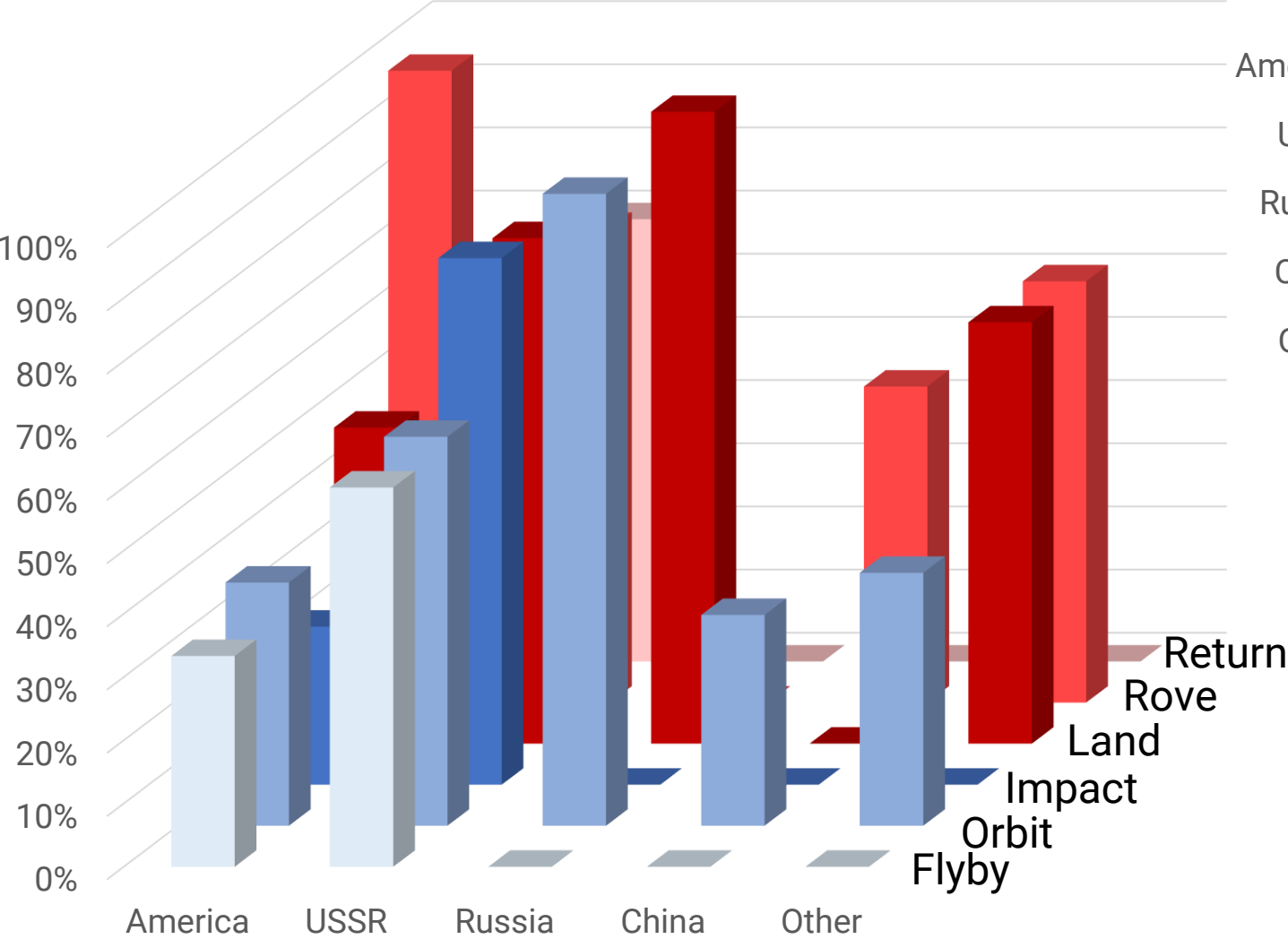
Failure Rate Estimate by Mission Ambition



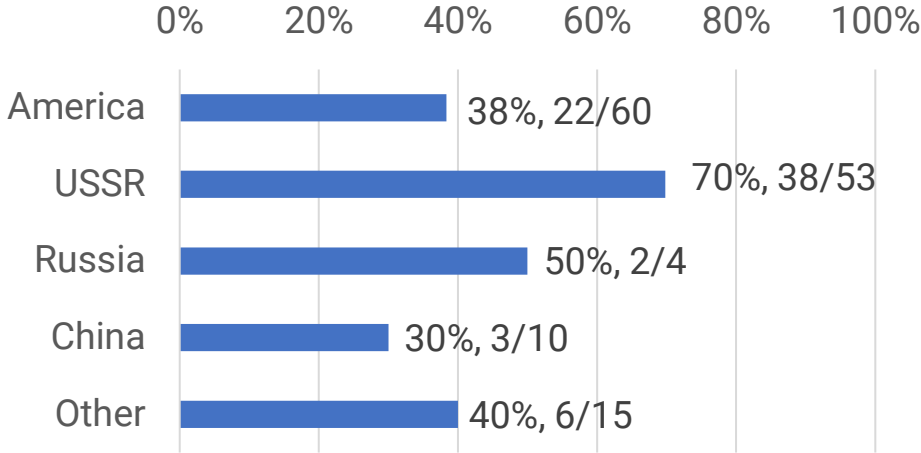




% Failed by Type and Country



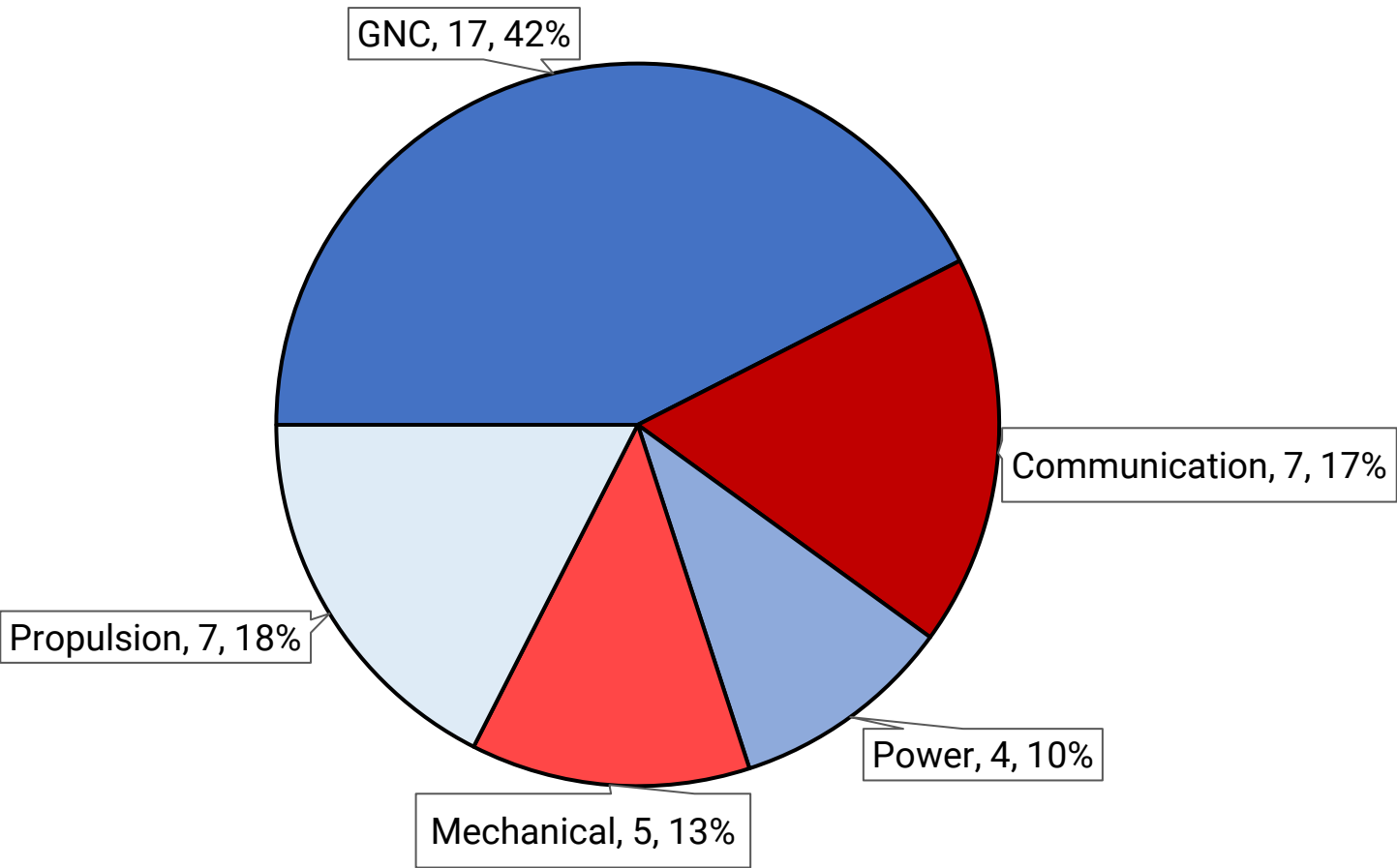
% Failed by Country



What Went Wrong?

Total Non-Launch Failures: 40, 57% of 70 Total Failures

Failure Modes

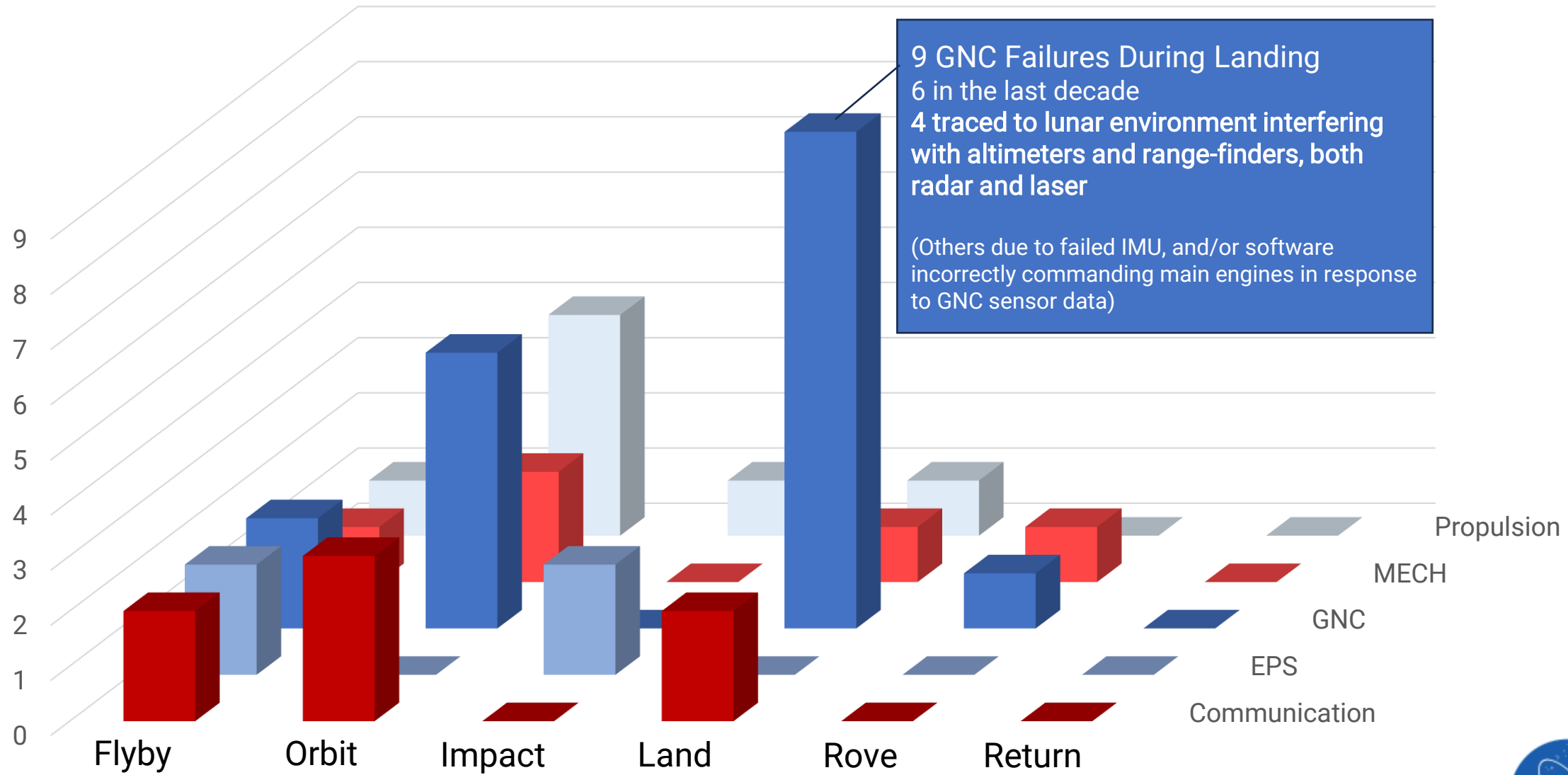


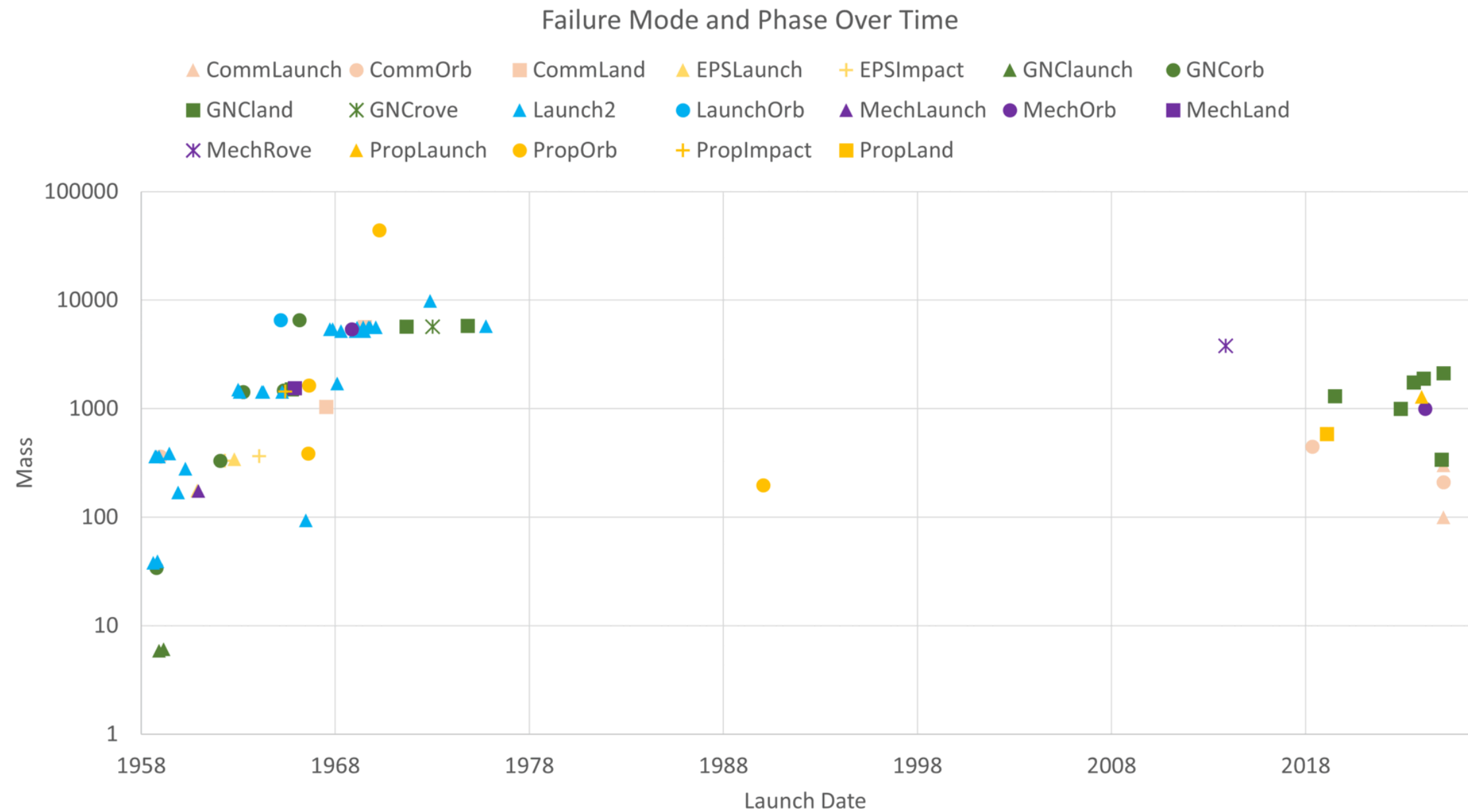
Launch, EPS, and GNC failures are more likely to end a mission earlier.

Mechanical, propulsion, and communication failures are more likely to end a mission at a later stage.

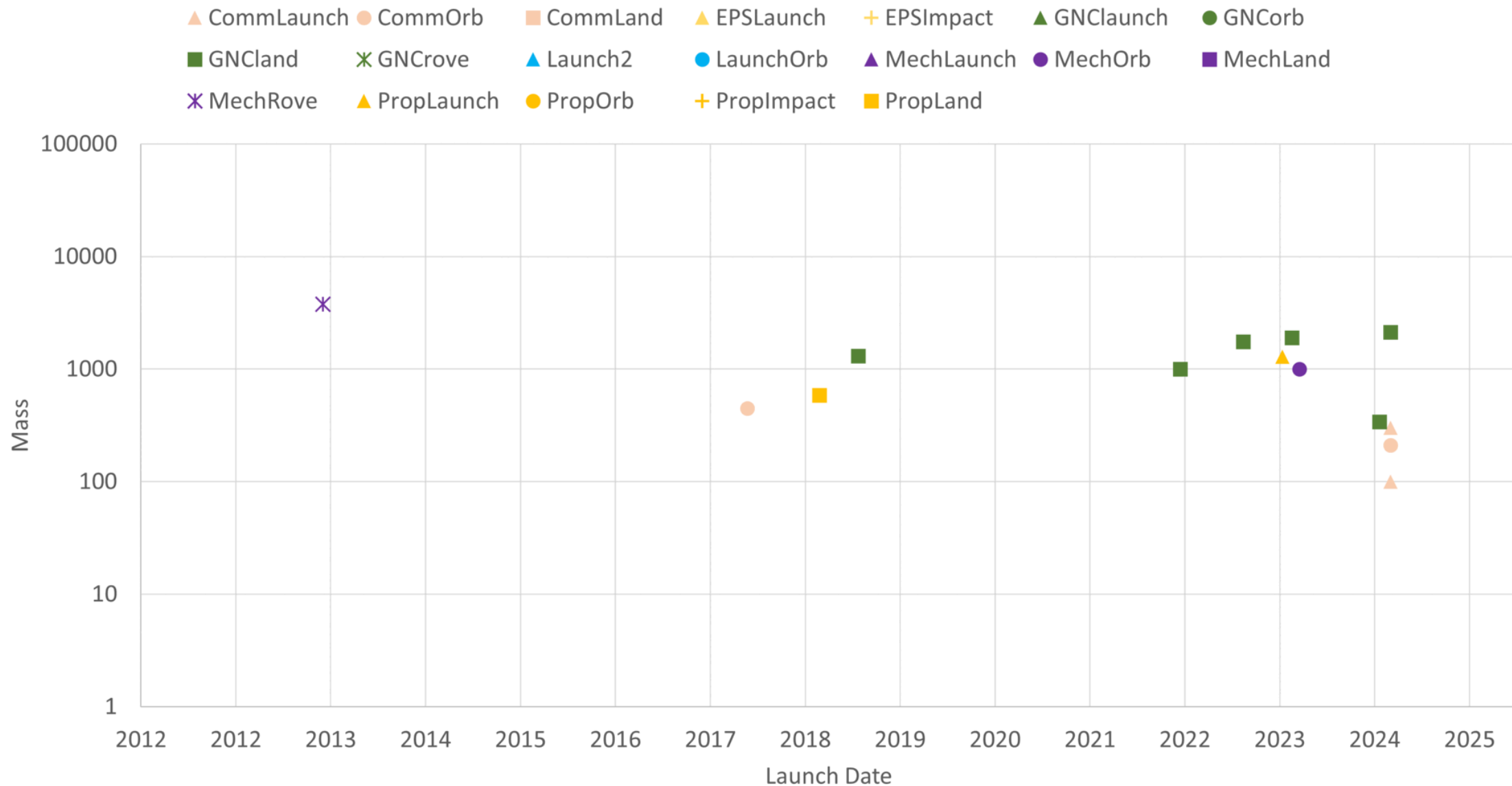


Failure Modes by Phase





Failure Mode and Phase Over Time



Notable Cases

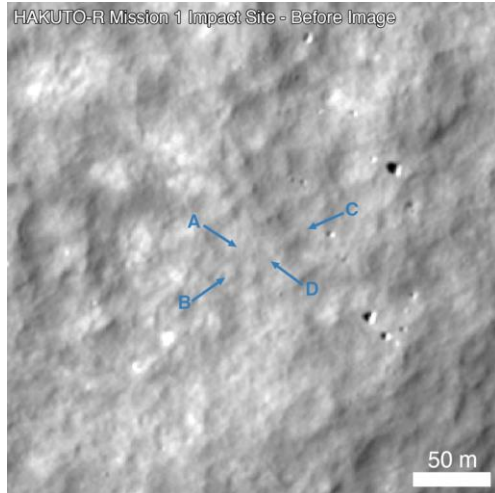
- Hakuto-R Mission 1: Communication lost during landing descent
- Beresheet: Gyroscopes failed, triggering main engine shut off and crash landing
- IM-2: Communication lost during landing, sideways when re-connected, thus power lost
- Apollo/Artemis Con-ops comparison



Hakuto-R Mission 1

Mission Objective: Rove

- Started as a Google Lunar-X Prize project
- Dec 22 Falcon 9 launch
- Slow long travel to conserve fuel



- Unreliable telemetry identified incorrect landing site
- Communication lost during descent
- Lander was hovering 5km above surface because the flight computer software assumed radar data was faulty
- Crashed when propellant ran out



Beresheet

Mission Objective: Land

- Google Lunar X Prize
- Feb 2019 Falcon 9 Launch
- Inspired/became Blue Ghost (Firefly)



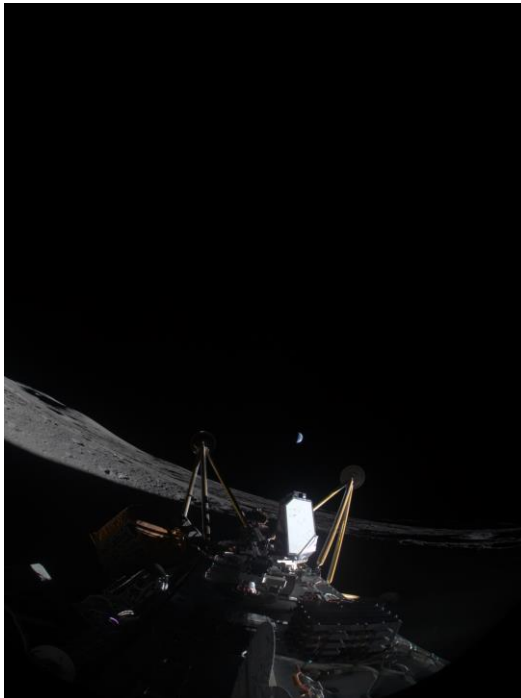
- During braking Gyroscopes failed leading to main engine shut off
- Sudden loss of communication meant that the ground team could not reset the component
- Comm regained too late to slow descent (500km/hr 150m above the surface)



IM-2

Mission Objective: Rove

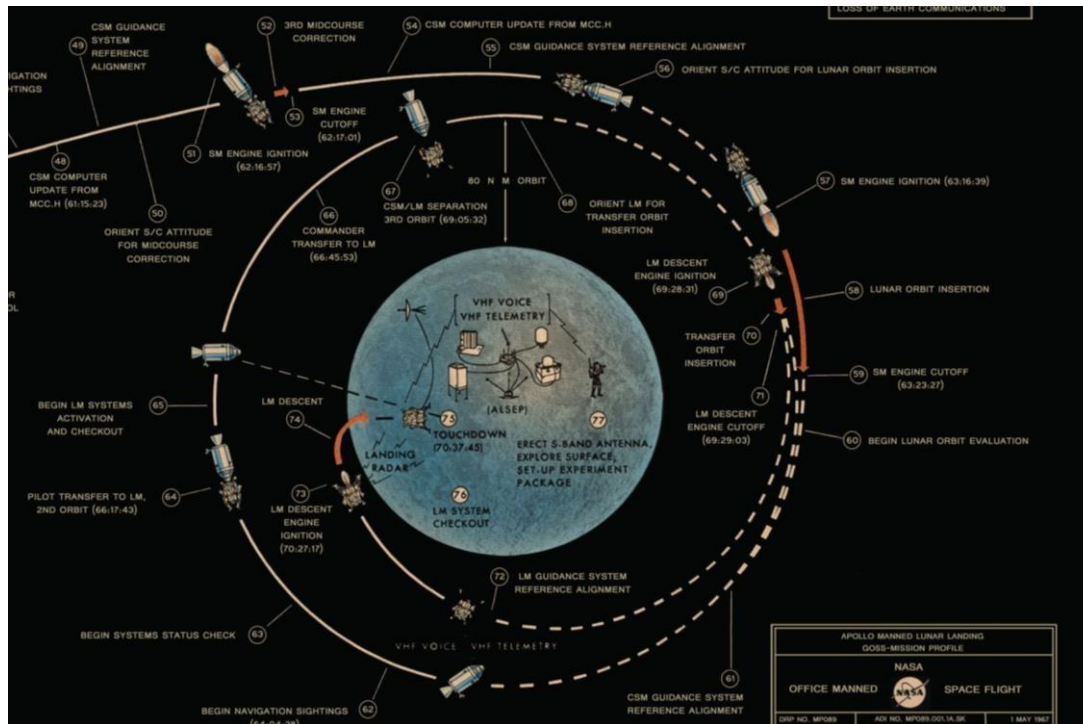
- CLPS Program
- Feb 25 Falcon 9 Launch



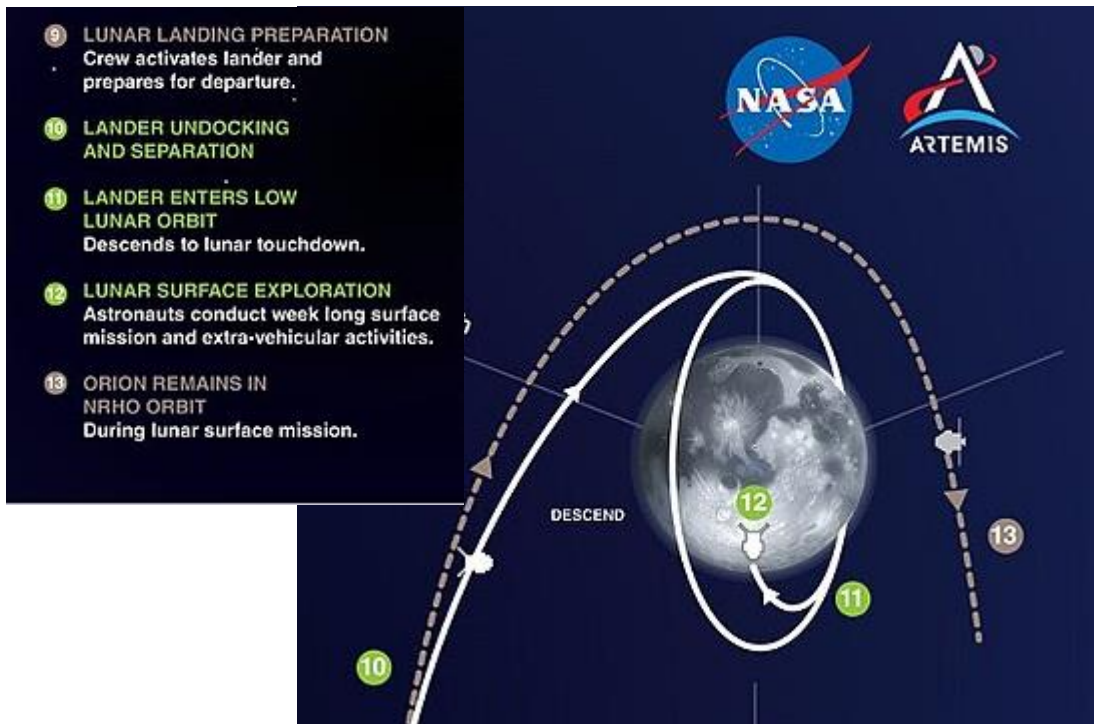
- During descent, dust obscured laser and range, and radio comm.
- After landing, low power and a broken antenna indicated it was on its side (imagery confirmed)
- Altimeter failing caused computer to steer into a plateau edge.
- Crash also coated solar panels in dust.

Apollo LEM vs Artemis HLS

Apollo Landings 1969-1972



Artemis III Con-ops



Summary

- Landing is a high-risk phase of moon missions
- Primarily due to plume interactions that interfere with telemetry and communications
- Loss of communication should be expected, creating increased reliance on sensor readings during landing
- American Industry is re-learning how to do this after decades-long break, leading to a gap in knowledge

