Beresheet Probe Crash Report

Based on: https://davidson.weizmann.ac.il/en/online/sciencepanorama/what-happened-beresheet

Introduction

In 2019, Israel attempted their first landing on the moon via a probe called "Beresheet". Israel has indeed made history by landing the Probe on the moon, but unfortunately, it crash landed, destroying the craft in the process.

Crash Chain of Events (Chronological Order)

0. PRE-LAUNCH/ EARTH SURFACE

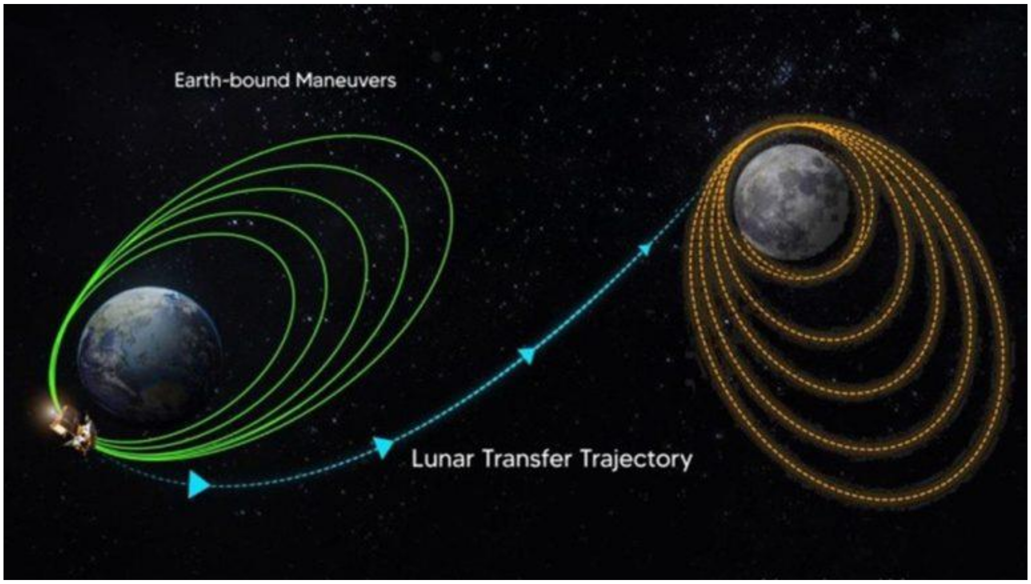
Very close to launch, the Beresheet team discovered a malfunction in the engine component: in order to restart the engine, it must receive voltage from two sources. Since they had insufficient time to fix this issue, they decided to proceed with the mission as planned.

1. DURING SEPERATION PHASE / EARTH ORBIT

Ground control detected a malfunction in the Spacecraft's star trackers (two digital cameras), which could have been caused by dust particles landing on the shields meant to protected the cameras from Sunlight. The particles may have reflected the sunlight, causing the cameras to be blinded and rendered them unusable. The implication is that the Spacecraft would not be able to determine it's orientation via the star trackers and would need to depend on the onboard IMU2 gyroscopes for correct orientation.

2. EARTH-BOUND ORBITING MANEUVERS / EARTH ORBIT

While making its way to the moon, the single onboard computer kept unexpectedly rebooting itself and attempting to cancel planned orbital maneuvers:



Clearly, these maneuvers are critical to the mission and missing even one maneuver could cost the mission. This may have been caused by damage to the craft's electrical box by radiation exposure or other external factors. It has also been revealed that the electrical box has not been tested for space.

3. DURING LANDING PHASE / MOON ORBIT

The spacecraft was equipped with two IMUs (Inertial Measurement Unit) to determine it's orientation in space; without knowing the orientation, the spacecraft cannot descend safely since the spacecrafts needs to point the engines in the right direction to ultimately slow its speed. Recall that the onboard star trackers were rendered unusable and therefore the spacecraft relied on these 2 components to know its orientation.

During the descent, one IMU unexpectedly shut down. The spacecraft could still continue with the mission with a single IMU, but it were to fail as well, the craft would crash.

Ground control had to make a quick call to either continue the mission with a single IMU or restart the IMU that had shut down. They opted for restarting the IMU.

Due to the spacecraft's design, by restarting one IMU briefly blocks communication with the functioning IMU. From the computer's perspective, it did not receive orientation data for a split second, declaring a malfunction deciding to reboot as designed.

After the reboot, the computer was missing critical software add-ons which were supposed to be loaded on-the-fly. Only after ~5 reboots, all of the addons were successfully loaded.

These series of reboots caused the main engine to shut down, which was supposed to be running since this was a critical stage where the spacecraft had to slow its descent to the lunar surface.

Unfortunately, this is where the pre-launch engine issue came into play; the main engine did not turn on, and the spacecraft crashed into the lunar surface at a speed of 3000km/h, which is approximately Mach 2.43. To put this into perspective, the terminal velocity of the US Airforce's high-altitude reconnaissance aircraft "SR-71 Blackbird" is approximately Mach 3 - faster than a generic bullet on Earth. Clearly, Beresheet instantly evaporated on impact with the lunar surface.

The following are a summary of the most critical issues we found, possibly resulting in the crash of the spacecraft:

- The engine restart issue requiring dual voltage sources should have been addressed before proceeding with the mission, as it introduced a single point of failure.
- Single onboard computer introduced another single point of failure.
- Star trackers could have incorporated better shielding.
- Spacecraft had minimal radiation protection due to budget, which caused issues with the single onboard computer.
- The design flaw where resetting one IMU interrupted data flow from the other should have been avoided; the system should have been designed so that resets on one redundant component do not trigger failure modes in the monitoring system or affect other components.
- The computer's decision to reboot due to a momentary loss of IMU data during a deliberate reset procedure was overly sensitive; the software logic should have been more sophisticated to differentiate between transient data loss during known procedures and genuine, persistent failures, especially during critical phases like landing.
- The onboard electronic box was never tested in space. It should have been tested and certified for space condition.

While the Beresheet team achieved remarkable milestones on a limited budget, the mission ultimately faced a low probability of success due to numerous single points of failure and many components untested for space. With all these in mind, we believe that the feat of even orbiting the moon was a huge success for a small country like Israel.