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Interplanetary Spacecraft Failure Study: Analyzing Trends and Patterns

Kritik*

UG Research Scholar, Gautam Buddha University, Greater Noida, Uttar Pradesh – 201312.
ORCID - 0009-0006-6813-3565

Abstract: Interplanetary unmanned missions have yielded crucial insights about the solar system through landers and flybys. However, some missions have encountered catastrophic outcomes due to minor technical errors and faults. This paper analyzes these failures in order to compile a comprehensive list of mission failures, covering attempted maneuvers towards comets and planets throughout interplanetary exploration history. The paper provides a concise overview of instances where anomalies occurred and offers explanations for these failures. While certain original failure reports remain undisclosed by space organizations, this research relies on information from official websites and publications. By analyzing the available data, the report aims to enhance understanding of the causes and consequences of these failures, thereby contributing to a safer and more informed approach to interplanetary exploration.

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1. Introduction

This research paper investigates interplanetary spacecraft failures in order to understand patterns and trends in these failures over the years. By analyzing failed missions and plotting changes in failure rates, common factors contributing to failures can be identified, providing insights into the risks of interplanetary exploration. The paper examines a number of missions that have failed, including the Mars Observer, Kosmos, and Mariner [1-2]. The reasons behind these failures are analyzed, including technological, operational, and environmental challenges. By mapping failure occurrences over time, discernible patterns or trends can be identified, shedding light on the evolving risks associated with interplanetary missions. The paper also aims to extract valuable lessons from these failures to guide future interplanetary spacecraft design, planning, and execution. Identifying common hazards and areas for improvement enables risk mitigation, enhances mission success rates, and ensures safer and more efficient exploration of celestial bodies. Ultimately, the paper's findings contribute to advancing space exploration technology, improving mission reliability, and maximizing scientific missions.

2. Research Methodology

The methodology employed in this study involved the comprehensive analysis of unmanned space missions through online resources and published reports. Failed missions were specifically examined to understand the reasons behind their complete shutdown or degraded performance. Notable examples of mission failures were carefully investigated, including the spacecraft types involved, to highlight specific failure types and operational characteristics. Additionally, a graphical representation was created to compare the upward trend of successful

*UG Research Scholar, Gautam Buddha University, Greater Noida, Uttar Pradesh – 201312. **Contact**: kritik3553@gmail.com.
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unmanned space missions over the years with that of unsuccessful expeditions, illustrating the significant differences in mission safety. This methodology enabled a detailed examination of mission failures and provided insights into the overall landscape of unmanned space exploration.

3. Spacecraft Classification

Spacecraft equipped with robotic applications are sent to deep space and planets to carry out scientific studies and other operations. These spacecraft provide insights into the unfavorable environments of these celestial bodies. The robotic applications on these spacecraft allow them to perform a variety of tasks, such as collecting samples, conducting experiments, and mapping terrain. They also allow the spacecraft to operate autonomously, which is essential for long-duration missions in deep space. The insights provided by these spacecraft have been invaluable to our understanding of the solar system. They have helped us to learn more about the formation and evolution of planets, the presence of water on other worlds, and the potential for life beyond Earth. Some of the spacecraft classification are as follows **[1-5]**:

- ***Flybys:*** In a flyby mission, a spacecraft follows a close path around a planet without entering it. This is sometimes done to save fuel, as the spacecraft can use the planet's gravity to slingshot itself around and on to its next destination. Flyby missions are also used to collect data about planets and other celestial bodies without having to land on them.
- ***Landers:*** A lander spacecraft is a vehicle designed to touch down on the surface of a celestial body, such as the Moon or Mars. It carries scientific instruments to study the environment and collects data, contributing to our understanding of other worlds. Lander spacecraft are typically equipped with a variety of scientific instruments, such as cameras, spectrometers, and chromatographs. These instruments allow the lander to study the composition of the surface, the atmosphere, and the soil. Landers also typically carry a variety of sensors, such as temperature sensors, pressure sensors, and radiation sensors. These sensors allow the lander to monitor the environment and to collect data about the conditions on the surface.
- ***Orbiters:*** An orbiter spacecraft is a vehicle that remains in orbit around a celestial body, such as a planet or moon. It is equipped with instruments to study the target from a distance, collecting data on its atmosphere, surface features, and other characteristics.
- ***Atmospheric Spacecraft:*** An atmospheric spacecraft is a specialized vehicle designed to study the composition, dynamics, and properties of a planet's or moon's atmosphere. It collects data on temperature, pressure, gases, and other atmospheric parameters.
- ***Rovers:*** A rover spacecraft is a robotic vehicle designed to explore the surface of a celestial body, typically a planet or moon. It is equipped with scientific instruments to analyze rocks, soil, and the environment, aiding in scientific research.

4. Flyby Missions

4.1. Mariner 1

Mariner 1 was NASA's first attempt and an interplanetary flyby mission to Venus in 1962. Its main objective was to gather data on Venus' atmosphere, magnetic field, charged particle environment, and mass. However, approximately 291 seconds after launch, an unexpected deviation occurred, prompting the command to destroy the vehicle. Investigation revealed that the ground-based guidance system, responsible for obtaining rate data, malfunctioned for a brief period, resulting in a loss of signal **[1-3]**. Additionally, a coding error in a data-editing program led to the incorrect sweep frequency being used, causing errors in the computer command. Despite the failure of Mariner 1, the mission's goals were eventually achieved by Mariner 2 a few months later. Mariner 2 successfully flew by Venus and returned a wealth of data about the planet, including its surface temperature, atmosphere, and magnetic field. The failure of Mariner 1 was a setback for NASA, but it also provided valuable lessons that were applied to future missions **[6]**. The experience gained from Mariner 1 helped to ensure the success of subsequent interplanetary missions, including Mariner 2 and the many other missions that have followed.

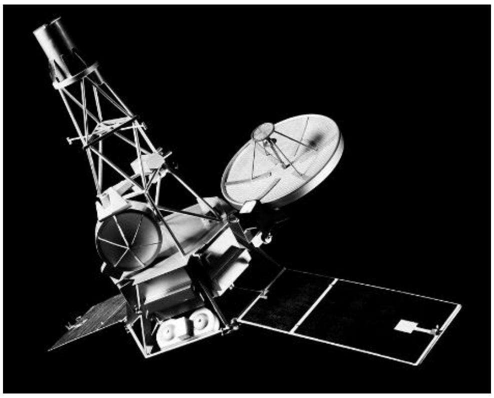

Figure 1 Mariner 1 [Courtesy: NASA]

4.2. Deep Impact

NASA's Deep Impact was a 2005 flyby mission to study comet 9P/Tempel 1. The mission comprised a flyby spacecraft and an impactor, which deliberately crashed into the comet on July 4, 2005. The impact revealed the comet's inner structure and composition, which was found to be richer in dust than ice. The flyby spacecraft carried a variety of instruments, including the Impactor Targeting Sensor (ITS), the High-Resolution Instrument (HRI), and the Medium-Resolution Instrument (MRI). The ITS provided close-range images of the comet, while the HRI and MRI captured the resulting crater **[1-2]**.

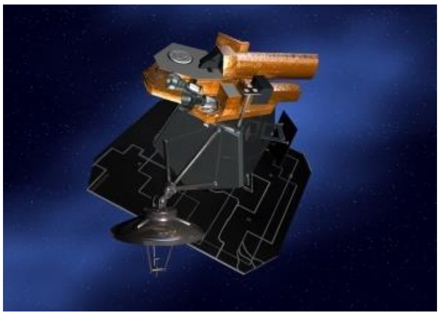

Figure 2 Deep Impact [Courtesy: NASA]

The Deep Impact mission was a success, and it provided valuable insights into the composition and structure of comets. The mission was also extended as EPOXI, which explored comets Boethin, Hartley 2, and Garradd. However, in 2013, communication with the spacecraft was lost due to unknown antenna orientation and computer reboots. The Deep Impact mission was a significant milestone in the history of space exploration, and it paved the way for future missions to study comets and other celestial bodies **[7]**.

5. Lander Missions

5.1. Kosmos 167

Kosmos 167 was a lander-type spacecraft designed by the Soviets in 1967 for Venus exploration. It had a similar design to Venera 4 and was part of the Venera program. However, the spacecraft's fourth-stage engine was unable to ignite during launch due to a problem with the turbopump's cooling system. As a result, the spacecraft never left low-Earth orbit and was destroyed upon re-entering the atmosphere. Kosmos 167 entered a low-Earth orbit with a perigee of 187 kilometers and an apogee of 262 kilometers. The spacecraft's inclination to the equator was 52 degrees. The failure of Kosmos 167 was a setback for the Venera program, However, it also bestowed invaluable teachings that were implemented in forthcoming expeditions, including Venera 9 and Venera 10 **[8-9]**.

Figure 3 Kosmos 167 [Courtesy: ROSCOSMOS]

5.2. Mars Polar Lander

The Mars Polar Lander (MPL) was a NASA mission designed to study Mars' polar region. It included two microprobes, Deep Space 2, and a lander with a robotic arm to search for water ice. However, the MPL crash-landed on Mars after its software misinterpreted anomalous signals during descent, prematurely shutting off the braking engine. The failure of the MPL was a major setback for NASA, and it led to a number of changes in the way that the agency plans and executes space missions. In particular, NASA has placed a greater emphasis on rigorous testing and preparation in the wake of the MPL disaster. There are a number of factors that contributed to the failure of the MPL. First, the lander's software was not adequately tested to handle the harsh conditions of the Martian atmosphere. Second, the lander's components were not strong enough to withstand the high g-forces of the Martian landing. Third, the microprobes were not adequately tested before launch. The failure of the MPL was a significant setback for NASA. Nevertheless, it also imparted crucial insights that were put into practice in subsequent missions, paving the way for their success. The experience gained from the MPL disaster has helped to ensure the success of subsequent Mars missions, such as the Phoenix lander and the Curiosity rover **[10-12]**.

Figure 4 Mars Polar Lander [Courtesy: NASA]

6. Orbiter Missions

6.1. Mars Climate Orbiter

The Mars Climate Orbiter (MCO) was part of NASA's Mars Surveyor program, intended to establish a communication link with the Polar Lander and Deep Space 2 while conducting studies of the Martian surface from orbit. However, the mission encountered a major setback shortly after its launch. A conversion error occurred when the software controlling the orbiter's flight system was programmed to receive thrust instructions in metric units (Newtons), while ground control provided instructions in Imperial units (pounds-force). This discrepancy caused confusion when determining the atmospheric entry altitude. As a result, the orbiter missed its intended orbit range of 140 to 50 kilometers and instead entered the Martian atmosphere at approximately 57 kilometers, succumbing to the atmospheric pressure and ultimately ending the mission [13-15]. The failure of the MCO was a major setback for NASA, and it led to a number of changes in the way that the agency plans and executes space missions. In particular, NASA has placed a greater emphasis on rigorous testing and preparation in the wake of the MCO disaster. The MCO failure was a significant loss for NASA. Nonetheless, it yielded significant lessons that were incorporated into subsequent missions.

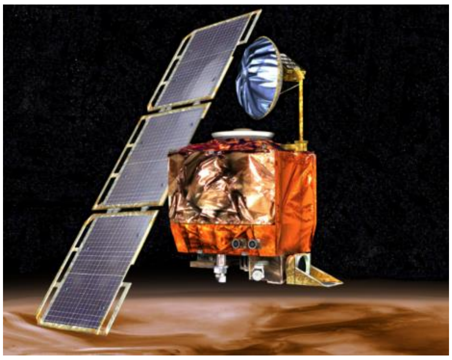

Figure 5 Mars Climate Orbiter [Courtesy: NASA]

6.2. Mangalyaan

The Mars Orbiter Mission (MOM), also known as Mangalyaan, was ISRO's first interplanetary venture. The mission's primary objective was to explore Mars' atmosphere and test interplanetary technology. However, communication with the orbiter was lost after encountering a series of eclipses. The MOM's battery was reliant on solar panels generating 800 watts of power. However, an eclipse lasting six hours exceeded the battery's one-hour eclipse duration capacity. As a result, the battery could not recharge, and the orbiter was unable to maintain its orbit [16-17]. Another possibility is that the satellite performed a spin-move motion to escape the eclipse, causing its antenna to lose alignment with Earth. This would have prevented the orbiter from communicating with ground control, resulting in the loss of the mission. Despite this, it offered invaluable experiences that were utilized in future endeavors, securing their favorable outcomes such as Chandrayaan 2 and ongoing Chandryaan 3. It may help ISRO's upcoming mission Mangalyaan 2 (Mars Orbiter Mission) [18-19].

Figure 6 Mangalyaan [Courtesy: Kevin M.Gill]

7. Graphical Briefing

The graphical representation here (figure 7) demonstrates the total number of unmanned space missions each year from 1960 to 1970. The surge in unmanned space missions began around the 1960s, with a significant increase in the number of missions launched in the 1970s. This difference of 10 years can be attributed to a number of factors, including:

- The development of new technologies, such as the miniaturization of electronics and the improvement of rocket engines, which made it possible to launch smaller and more affordable unmanned missions.
- The increasing interest in space exploration, which led to the launch of a number of ambitious missions, such as the Apollo program.
- The lessons learned from the failures of early manned missions, which led to a shift towards unmanned missions as a safer and more cost-effective way to explore space.

- The rise of unmanned space missions has had a profound impact on our understanding of the universe. Unmanned missions have been used to study the Moon, Mars, Venus, and other planets, as well as comets and asteroids. They have also been used to conduct experiments in space and to develop new technologies that have been used in manned missions.

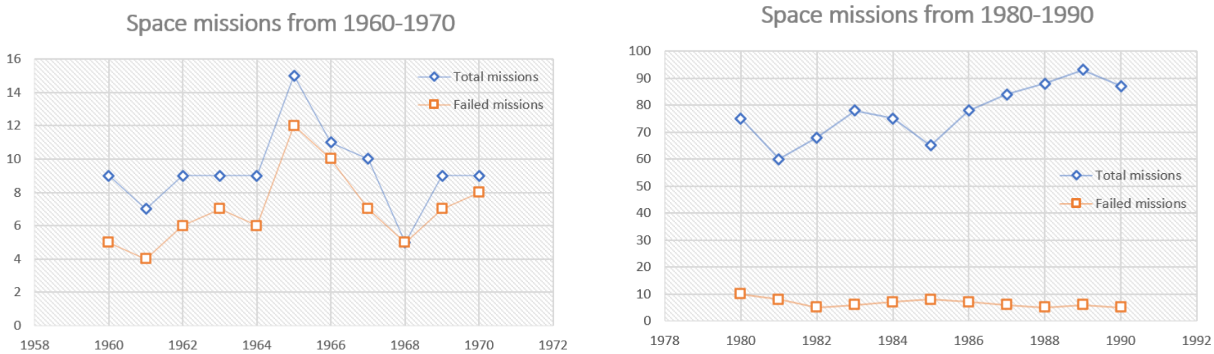

Figure 7 Graphical Briefing of Total versus and Failed Missions

The continued growth of unmanned space missions is essential for our future exploration of space. Unmanned missions are less risky and more cost-effective than manned missions, and they can be used to conduct missions that would be too dangerous or too difficult for humans. As we continue to explore space, unmanned missions will play an increasingly important role in our efforts to understand the universe and our place in it.

Figure 8 shows the root cause classification analysis of unsuccessful unmanned space missions. The majority of failures (40%) were attributed to technical/electrical malfunctions within the spacecraft's internal components. Mechanical issues accounted for 30% of failures, while software errors accounted for 20%. The remaining 10% of failures were due to unidentified causes or undisclosed reports.

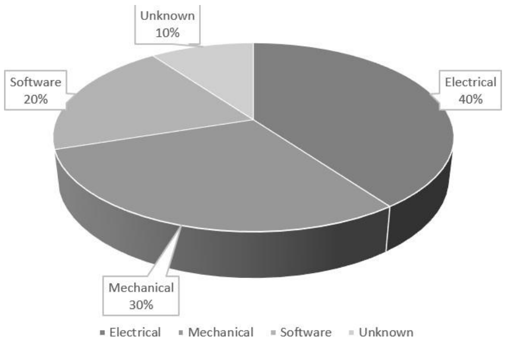

Figure 8 Spacecraft Failure Type*

[*The data sources utilized for generating these graphs may exhibit discrepancies with the precise count of unmanned space missions, owing to certain missions being classified or undisclosed by their respective agencies]

Figure 8 displays the distribution of unmanned space missions based on their outcomes. The data reveals that a significant portion (86%) of missions failed. These failures were caused by a variety of factors, including technical malfunctions, operational errors, and communication breakdowns. The remaining 14% of missions were classified as partially complete, indicating that they encountered challenges or obstacles but managed to achieve some degree of success.

This histogram highlights the predominance of unsuccessful outcomes in unmanned space missions. This underscores the need for further analysis and improvements in mission planning, technology, and operational procedures to enhance overall mission success rates. The data presented in Figures 7 and 8 is based on a comprehensive analysis of unmanned space missions that have been launched since the 1960s. The analysis includes missions from a variety of countries, including the United States, the Soviet Union, Europe, and Japan.

The data reveals that there are a number of factors that contribute to the failure of unmanned space missions. These factors include:

- Technical malfunctions: These can be caused by a variety of factors, such as faulty components, software errors, or environmental conditions.
- Operational errors: These can be caused by human error, such as a mistake in the launch sequence or a failure to follow procedures.
- Communication breakdowns: These can be caused by problems with the spacecraft's communication systems or with the ground control network.

The analysis also reveals that there are a number of steps that can be taken to improve the success rate of unmanned space missions. These steps include:

- Improving the reliability of spacecraft components: This can be done by using more robust components and by conducting more rigorous testing.
- Improving the quality of software: This can be done by using more rigorous software development processes and by conducting more extensive testing.
- Improving communication systems: This can be done by using more robust communication systems and by developing more reliable ground control networks.

The data presented in Figures 7 and 8 provides valuable insights into the factors that contribute to the failure of unmanned space missions. This information can be used to improve the success rate of future missions and to ensure that the risks associated with space exploration are minimized.

The research on interplanetary spacecraft failures has provided valuable insights into the root causes behind mission failures. By identifying common factors such as technical malfunctions, operational errors, and communication challenges, this research has facilitated a better understanding of the risks associated with interplanetary exploration.

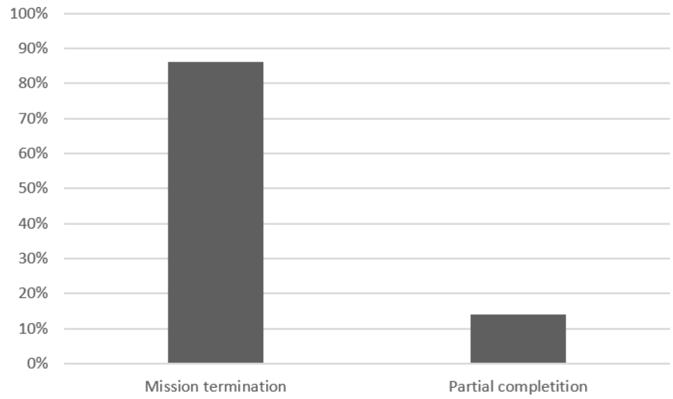

Figure 9 Influence on Mission Goal

8. Conclusion

The findings of this research have led to significant changes in space missions, including:

- Improvements in spacecraft design
- Enhanced operational procedures
- Increased focus on risk mitigation

As a result, future interplanetary missions are better equipped to address the challenges identified through this research, increasing the likelihood of mission success. This research has also highlighted the importance of continuous improvement in the design, development, and operation of interplanetary spacecraft. As our understanding of the risks associated with space exploration grows, so too must our efforts to mitigate those risks. By continuing to invest in research and development, we can ensure that future interplanetary missions are even more successful than those that have come before.

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10. Biography

Kritik, a passionate individual with a deep interest in astrophysics and particle physics. Hailing from Bangalore, Karnataka, India, Kritik has displayed a remarkable commitment to his field of study. His recent achievement includes the successful completion of an internship at Acceleron Aerospace, where he conducted groundbreaking research on “Interplanetary Spacecraft Failure Study: Analyzing Trends and Patterns.” Kritik’s dedication, analytical skills, and attention to detail were evident in his research article. His work promises to contribute significantly to the field of space exploration and serves as a testament to his intellectual curiosity and potential for future breakthroughs.

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12. Conflict of Interest

The author have no conflict of interest to report.

13. Funding

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