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# A comparative analysis of the Perseverance and Mangalyaan Mars Missions

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## Abstract

This paper presents a comparative analysis of NASA's Perseverance rover and ISRO's Mars Orbiter Mission (Mangalyaan), examining their technological innovations, mission objectives, and scientific contributions to Mars exploration. While Perseverance is designed to explore the astrobiological potential of Mars, collecting rock and soil samples for future return missions, Mangalyaan focuses on cost-effective orbital studies of Mars' atmosphere and surface. The study highlights significant differences in mission budgets, with NASA's high-cost Perseverance contrasted by ISRO's low-cost Mangalyaan. Despite these differences, both missions have expanded humanity's understanding of Mars, making notable contributions to planetary science and space technology.

**Keywords:** Perseverance; Mangalyaan; Mars exploration; Space technology; Planetary science

## 1. Introduction

The economic constraints of long-term Mars colonisation necessitate a shift towards cost-effective exploration strategies, positioning ISRO's Mangalyaan, with its demonstrated success in achieving significant scientific objectives under severe budgetary limitations due to its resourcefulness and creativity, as a potential leader in future colonisation efforts, outperforming the scientific advancements of missions like NASA's Perseverance in the coming century.

### 1.1. Overview of Mars Exploration

Mars exploration has become one of the most ambitious and technologically demanding undertakings in modern planetary science. NASA, with its long history of space exploration, has sent multiple missions to Mars, the latest being the Perseverance rover, which landed on the planet in 2021. This mission, designed to search for signs of past life and collect samples from Jezero Crater, is part of a broader plan to understand Mars' habitability and prepare for future human exploration. On the other hand, ISRO (Indian Space Research Organisation) made history in 2013 with the successful launch of Mangalyaan, also known as the Mars Orbiter Mission, which aimed to study Mars' surface morphology and atmosphere. This achievement not only marked India's first interplanetary mission but also showcased its capacity to execute deep space exploration on a remarkably low budget.

### 1.2. Mission Objectives and Scope

Both missions share the common goal of expanding our understanding of Mars, yet they differ vastly in scope, technology, and financial resources. NASA's Perseverance, with a budget exceeding $2 billion, represents the pinnacle of astrobiological research, focusing on collecting Martian samples that may offer clues to past microbial life. ISRO's Mangalyaan, in contrast, aimed to demonstrate low-cost space technology while investigating Mars' atmosphere and no surface. Despite operating on a fraction of NASA's budget, Mangalyaan successfully entered Mars's orbit and provided valuable scientific data.

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This paper seeks to compare NASA's Perseverance and ISRO's Mangalyaan missions, focusing on their technological advancements, scientific goals, and budgetary efficiency. By highlighting the achievements of both missions, the paper aims to assess their respective contributions to Mars exploration and consider the potential future of planetary science led by both organisations in consideration of the following question: with the coming of the second space race, which organisation is more likely to establish itself in the field of Mars Colonisation?

## 2. Material and methods

### 2.1. Purpose of a Literature Review

This section provides an in-depth examination of NASA's Perseverance rover and ISRO's Mars Orbiter Mission (Mangalyaan), with a focus on their technological innovations, mission objectives, and scientific contributions. An analysis of existing research highlights the significant technological advances of each mission, while also identifying gaps in comparative studies.

### 2.2. NASA's Perseverance Rover

#### *2.2.1. Mission Objectives and Technology Overview*

NASA's Perseverance rover, launched in July 2020 as part of the Mars 2020 mission, represents one of the most technologically sophisticated efforts in the history of Mars exploration. Its landing in Jezero Crater on February 18, 2021, marked a critical phase in NASA's broader strategy to investigate the planet's potential for past life. The primary objective of the mission is astrobiological, with the specific goal of identifying signs of ancient microbial life through the collection of Martian rock and soil samples. These samples will serve as the basis for a future Mars Sample Return mission, anticipated in the 2030s, which marks a significant advancement in planetary science. Moreover, Perseverance played a vital role in preparing for future human exploration by testing key technologies required for long-duration missions to Mars.

The Perseverance rover embodies the latest developments in space exploration technology, incorporating a suite of advanced scientific instruments designed to collect and analyse Martian geological data. Among its notable innovations is the SHERLOC (Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals), which employs a deep ultraviolet laser to detect organic compounds and minerals that could signal past microbial life. SHERLOC represents a major leap forward in planetary spectroscopy, providing unprecedented insights into the chemical composition of Martian rocks.

Additionally, the MOXIE (Mars Oxygen In-Situ Resource Utilisation Experiment) instrument is a pioneering technology that aims to convert Mars' carbon dioxide-rich atmosphere into oxygen. This experiment has profound implications for future manned missions, as it is the first demonstration of in-situ resource utilisation (ISRU) on another planet, thereby enabling the production of breathable air and fuel for rockets. MOXIE's success signals a critical shift in how future missions may be sustained independently of Earth-based resupply.

Perseverance is also equipped with PIXL (Planetary Instrument for X-ray Lithochemistry), a tool designed for high-resolution imaging and chemical analysis of surface materials. Together with RIMFAX (Radar Imager for Mars' Subsurface Experiment), which offers ground-penetrating radar to study subsurface geologic structures, these instruments enable a detailed investigation of Mars' geology, particularly the stratigraphy of Jezero Crater's ancient lakebed. The rover's mobility is further enhanced by the inclusion of Ingenuity, the first helicopter to achieve powered flight on another planet. Ingenuity has successfully conducted multiple test flights, providing valuable data on the challenges of operating aircraft in Mars' thin atmosphere.

#### *2.2.2. Scientific Contributions*

Geological Analysis

Perseverance's scientific output has already been considerable. Early analysis of the rover's samples indicates the presence of both igneous and sedimentary rocks, suggesting a complex geological history that includes both volcanic activity and the presence of ancient water bodies. Moreover, SHERLOC's detection of organic molecules in rock formations at Jezero Crater has reignited discussions about the possibility of past life on Mars. These discoveries align with broader astrobiological efforts to establish whether Mars could have supported life in its ancient past. Perseverance has also made substantial contributions to planetary geology, particularly in its investigation of Mars' Jezero Crater, a site chosen for its potential to reveal the planet's aqueous and volcanic history. Initial analyses from

Perseverance have revealed terrain shaped by both volcanic activity and water flow. The identification of rock formations with a history of interaction with water significantly enhances our understanding of Mars' ancient hydrological cycles and its potential to have sustained life in its distant past and the presence of both igneous and sedimentary rocks, indicating a complex geological history.

Detection of Organic Molecules

The rover's SHERLOC instrument (Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals), a sophisticated Raman spectrometer, has detected organic molecules embedded in Martian rock samples. These molecules are potential biosignatures, suggesting that Mars once had the chemical ingredients necessary for life. This is a critical finding in planetary science, as it builds upon earlier detections of organic molecules by NASA's Curiosity rover and strengthens the hypothesis that Mars may have been habitable billions of years ago. Organic compounds detected by SHERLOC may indicate complex prebiotic chemistry, furthering our understanding of whether life once emerged on the red planet.

The Success of the MOXIE Experiment

Another pivotal discovery involves the MOXIE experiment (Mars Oxygen In-Situ Resource Utilisation Experiment), which successfully demonstrated the extraction of oxygen from Mars' carbon dioxide-rich atmosphere. This achievement represents a breakthrough for future human exploration of Mars, as it provides the groundwork for in-situ resource utilisation (ISRU) technologies essential for producing oxygen for life support systems and fuel for return journeys (Hecht et al., 2021). As Dr Morgan highlighted in her response, testing in Earth-based analog environments has been critical to ensuring MOXIE's success. Such simulations allow engineers to refine the technology before deployment on Mars, a key step for reducing the risks and costs associated with planetary exploration.

Aerial Exploration through the Ingenuity Helicopter

Moreover, the Ingenuity helicopter, an experimental technology demonstration, made history by achieving the first powered flight on another planet. This achievement opens new possibilities for aerial exploration of Mars, particularly in regions that are inaccessible to rovers. Ingenuity's success will likely influence future mission designs that incorporate aerial vehicles to explore rugged terrains, expanding humanity's ability to survey Mars in ways previously unimaginable.

Planetary Protection Protocols

Perseverance's scientific agenda also encompasses planetary protection protocols, as indicated by Dr Morgan, deputy director of NASA'S Mars Missions, during an email exchange . NASA prioritises both forward planetary protection—ensuring that Martian environments are not contaminated by Earth-based organisms—and backward planetary protection, preventing potential Martian organisms from being introduced to Earth. These protocols, implemented rigorously on missions like Perseverance, are integral to the integrity of astrobiological research and future human exploration missions.

## 2.3. ISRO's Mangalyaan Mission

### *2.3.1. Mission Objectives and Technology Overview*

Mangalyaan's contribution to the study of Mars, while more modest in terms of technological sophistication, has nonetheless been significant in advancing planetary science, particularly in the realm of atmospheric studies.

### *2.3.2. Scientific Contributions*

The Methane Sensor for Mars

The Methane Sensor for Mars (MSM) was designed to detect methane, a gas of interest due to its potential biological origins. Mangalyaan's detection of methane in Mars' atmosphere sparked considerable interest, as methane could indicate either biological activity or specific geological processes. Although the precise origin of the methane detected remains unclear, this discovery underscores the importance of continued atmospheric monitoring to unravel Mars' geological and possibly biological history.

The Mars Colour Camera

In addition to methane detection, Mangalyaan's Mars Colour Camera (MCC) provided significant imaging data of the Martian surface, capturing detailed observations of dust storms, surface morphology, and polar ice cap dynamics . Although the MCC's resolution is lower than NASA's instruments, it provided valuable insights into Mars' seasonal cycles and surface changes over time. These findings have enriched global efforts to understand the interplay between Mars' climate and geological processes.

ISRO's Remarkable Cost Efficiency

From a technological perspective, Mangalyaan's success lies in its remarkable cost-efficiency. With a total mission budget of just $74 million, ISRO demonstrated that interplanetary exploration could be achieved at a fraction of the cost typically associated with such endeavours. This achievement has implications for future mission planning, as it sets a precedent for how low-cost missions can be utilised to complement more expensive, technology-heavy endeavours like Perseverance.

## 2.4. Comparative Summary

To conclude, the primary discrepancies between the two missions include the search for organic molecules and biosignatures, the presence of methane in the atmosphere, their respective analysis of Mars' geology and their funding.

### *2.4.1. Search for Organic Molecules*

In the search for organic molecules and biosignatures, NASA's Perseverance rover, equipped with instruments like SHERLOC, detected organic molecules in Martian rocks, suggesting conditions conducive to life in Mars' ancient past. In contrast, ISRO's Mars Orbiter Mission did not include the detection of organic molecules or biosignatures among its primary objectives. Instead, Mangalyaan concentrated on studying Mars' atmosphere, filling a critical gap in planetary science by offering valuable data on the composition and behaviour of the Martian environment.

### *2.4.2. Methane Detection*

Methane detection represents another area of divergence between the two missions. NASA's Curiosity rover had previously identified sporadic methane emissions, but the Perseverance rover was not equipped to investigate atmospheric methane. Instead, Perseverance has focused on geological and astrobiological studies. On the other hand, Mangalyaan's Methane Sensor for Mars (MSM) made direct observations of methane in Mars' atmosphere, a discovery that drew global attention due to its potential implications for both biological and geological activity. While the MSM lacked the precision to determine the exact origin of the methane, its detection is an important milestone that highlights ISRO's ability to lead the research on Mars' atmospheric processes.

### *2.4.3. Analysis of Geology*

Meanwhile, Perseverance has delivered highly detailed findings about Mars' geological past, uncovering evidence of an ancient lakebed, interactions with water, and volcanic activity in the Jezero Crater. These findings have provided a nuanced view of Mars' complex geological history, while Mangalyaan's Mars Colour Camera (MCC) offered a broader perspective of the Martian surface, capturing images of dust storms, polar ice caps, and surface morphology. Although MCC's imaging resolution was less detailed, it provided valuable insights into seasonal and climatic changes on Mars.

### *2.4.4. Expenditure*

In terms of costs, NASA's Perseverance rover and ISRO's Mangalyaan offer highly contrasting approaches to Mars exploration. NASA's Perseverance, with its broad scope and advanced technology, has focused on astrobiology, uncovering organic molecules in the Jezero Crater and advancing our understanding of Mars' potential for life. This mission's high cost allowed for sophisticated instruments like SHERLOC, MOXIE, and Ingenuity, which aim to support future human exploration and test groundbreaking technologies. Comparatively, ISRO's Mangalyaan was designed with a focus on cost-efficiency, accomplishing key objectives within its budget of just $74 million. Mangalyaan concentrated on Mars' atmosphere, detecting methane and providing valuable data on seasonal and climatic changes. Though its capabilities were limited compared to the Perseverance, Mangalyaan's success in delivering high-quality results on a modest budget highlights ISRO's ability to execute precise, low-risk missions targeting specific areas of study.

## 2.5. Research Approach

The two Mars missions have been analysed in this paper on the basis of their mission objectives, technological innovations, budget constraints and cost efficiency and scientific impacts.

#### *2.5.1. Mission Objectives*

The analysis begins by examining the primary objectives outlined for each mission. Perseverance, as part of NASA's Mars 2020 programme, is designed to address questions related to astrobiology, specifically the search for evidence of ancient microbial life on Mars and the collection of Martian soil samples for possible return to Earth. Mangalyaan, in contrast, was launched with the dual objectives of developing low-cost interplanetary technologies and conducting atmospheric and surface studies of Mars. This section assesses how the differences in mission goals reflect each agency's strategic priorities in Mars exploration.

#### *2.5.2. Technological Innovations*

Technological advancements are analysed to identify the key instruments and methodologies employed by each mission. For Perseverance, the evaluation includes an analysis of advanced instruments such as SHERLOC, MOXIE, and Ingenuity. Mangalyaan's focus on cost-effective technology is examined through its Methane Sensor for Mars and Mars Colour Camera, noting its emphasis on optimising scientific output within a limited budget. Each mission's technological choices are contextualised within its overarching goals, exploring how resource constraints shape innovation.

#### *2.5.3. Budget Constraints and Cost Efficiency*

This section emphasises the sharp contrast between Perseverance's $2.7 billion budget and Mangalyaan's $74 million. It discusses the implications of these budget differences, specifically how cost constraints impact mission design, scientific scope, and overall contributions to Mars exploration. The analysis also includes a discussion of ISRO's emphasis on engineering efficiency and cost-effectiveness, offering insights into alternative mission-planning strategies that could benefit future exploration efforts.

#### *2.5.4. Scientific Impacts*

Scientific achievements are evaluated by examining the data and findings generated by each mission. Perseverance's contributions are assessed based on its geological and astrobiological discoveries, particularly the identification of organic molecules and volcanic rocks within the Jezero Crater. Mangalyaan's contributions are analysed primarily through its atmospheric studies and methane detection. The analysis considers how these findings add to the collective understanding of Mars and lay the groundwork for future exploration initiatives.

## 3. Discussion

### 3.1. Comparative Analysis of Mission Focuses

#### *3.1.1. Astrobiological Focus*

NASA's Perseverance and ISRO's Mangalyaan missions were guided by fundamentally different objectives that reflect their agencies' priorities and constraints. Perseverance's primary objective centers on astrobiology, aiming to explore the ancient habitability of Mars through direct sampling and analysis of Martian rocks and soil. This mission is an essential component of NASA's Mars Sample Return (MSR) initiative, intended to retrieve Martian samples for in-depth analysis on Earth, thereby advancing our understanding of the planet's geological history and potential for hosting life.

#### *3.1.2. Atmospheric Focus*

In contrast, Mangalyaan's main objectives were twofold: to develop low-cost interplanetary technology and to gather atmospheric data on Mars. As ISRO's first interplanetary mission, Mangalyaan represented a significant step for India in terms of technological achievement, placing India in the select group of nations capable of reaching Mars on a limited budget. The mission prioritised atmospheric studies over in-depth surface exploration, focusing on detecting methane and analysing seasonal atmospheric variations. This objective was strategic for ISRO, positioning Mangalyaan as a proof-of-concept mission aimed at demonstrating India's engineering capabilities in space while gathering preliminary data on Martian atmospheric composition.

### 3.2. Comparative Analysis of Technological Innovations

#### *3.2.1. Perseverance's Advanced Instrumentation*

Perseverance represents a pinnacle of NASA's technological innovation, incorporating multiple advanced instruments designed to analyse Mars' geology and atmosphere comprehensively. Among its suite of tools, SHERLOC, a Raman spectrometer, stands out for its capacity to detect organic molecules in Martian rocks, adding depth to the search for ancient life. Another major component, MOXIE, successfully demonstrated oxygen production from Mars' $CO_2$-rich atmosphere, marking a critical milestone in resource utilisation, which could support future manned missions. The Ingenuity helicopter, an experimental component of the mission, accomplished the first controlled flight on another planet, establishing a new paradigm for Mars exploration.

#### *3.2.2. Mangalyaan's Resourceful and Cost-Efficient Technology*

In comparison, Mangalyaan's technological strategy emphasised resourceful and cost-effective solutions, with a relatively simple suite of instruments focused on studying Mars' atmosphere. Its Methane Sensor for Mars (MSM) and Mars Colour Camera (MCC) provided valuable data on methane concentrations, dust storms, and surface morphology. Though less complex than Perseverance's instruments, these tools contributed valuable information at a fraction of the cost, highlighting ISRO's commitment to maximising scientific return on limited resources. By focusing on affordability, ISRO positioned Mangalyaan as an accessible model for future low-cost planetary missions, suggesting alternative pathways to gathering valuable scientific data.

### 3.3. Budget Constraints and Cost Efficiency:

#### *3.3.1. Perseverance's High Budget, High Technology Approach*

The Perseverance mission's budget of approximately $2.7 billion allowed for sophisticated instrumentation, extensive mission planning, and the integration of advanced technologies. This financial commitment reflects NASA's broader strategy of achieving high scientific yield through robust technological investment. Such resources support an array of research goals, enabling the Perseverance mission to conduct a broad range of scientific experiments and to operate as a crucial component in a planned Mars Sample Return mission.

#### *3.3.2. Mangalyaan's Low Budget, Effective Approach*

Mangalyaan, by contrast, was developed with a total budget of only $74 million, demonstrating ISRO's expertise in cost-efficient mission planning. By prioritising mission efficiency and focusing on key scientific goals, ISRO achieved substantial results despite financial limitations. This approach involved innovative cost-saving measures, including a simpler spacecraft design and a focus on atmospheric studies rather than more technologically demanding surface exploration. Mangalyaan's success underscores the potential of low-cost missions as a viable model for space exploration, particularly for emerging space agencies and countries with limited resources.

### 3.4. Scientific Impact

Perseverance has made significant strides in understanding Mars' geological and astrobiological history. Its study of Jezero Crater, a region believed to have once held a large body of water, has revealed volcanic and sedimentary rocks that indicate Mars' complex geological past. The rover's discovery of organic molecules within these rock formations suggests that Mars may have once been habitable, further supporting the possibility of ancient life. These findings are anticipated to be expanded upon by future sample return missions, which will analyse Martian rocks on Earth with techniques beyond those available on the rover.

Mangalyaan's contributions have also added important insights into the Martian atmosphere. Its observations of methane levels, seasonal atmospheric changes, and surface features have contributed to a foundational understanding of Mars' climate and atmospheric composition. This preliminary data provides a basis for future exploration and highlights the role of low-cost missions in planetary science. Mangalyaan's achievements underscore the value of focused, efficient research models, suggesting that high scientific returns can be achieved without extensive budgets.

## 4. Conclusion

### 4.1. Summary

In summary, NASA's Perseverance and ISRO's Mangalyaan offer two distinct yet complementary approaches to Mars exploration, reflecting differing priorities in mission design, scientific objectives, and budgetary constraints. Perseverance exemplifies a high-budget mission characterised by advanced technology and a broad scientific mandate, enabling NASA to gather detailed data on Mars' geological history and potential habitability. Mangalyaan, in contrast, demonstrates ISRO's capability to conduct cost-effective, focused missions that yield important insights into the Martian atmosphere and seasonal patterns, using a fraction of NASA's resources.

### 4.2. Future of Mars Exploration

Looking to the future, several factors suggest that ISRO may emerge as a strong leader in the race toward Mars colonisation. Firstly, ISRO's expertise in cost-efficient mission design allows it to accomplish substantial scientific goals within constrained budgets, a critical advantage as Mars exploration increasingly emphasises sustainability and long-term presence. By refining low-cost technologies for interplanetary travel, ISRO is developing the foundation for scalable space missions that could support sustained human habitation on Mars. Secondly, ISRO's strategic focus on engineering efficiency and innovation—demonstrated by Mangalyaan's low-cost instrumentation and successful navigation—positions the organisation as a leader in developing practical technologies essential for Mars colonisation. This approach aligns with the financial realities of long-term space colonisation, where the ability to balance high-impact scientific output with budget-conscious planning could prove essential. Finally, as ISRO strengthens its international collaborations and enhances its mission planning capacity, it may gain increased access to shared resources and expertise, enabling it to leverage both local and global partnerships to advance its Mars exploration and potential colonisation initiatives.

Thus, while NASA's Perseverance showcases the strengths of advanced technology in planetary exploration, ISRO's commitment to affordable, practical solutions suggests that it may be well-positioned to lead future efforts toward Mars colonisation.

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