Acceleron Aerospace Journal || AAJ.11.2106-2457
Volume 3, Issue 4, pp (553-562)
Review Paper
E-ISSN- 2583-9942 || DOI: 10.61359/11.2106-2457

Aerodynamic Study of Successful Mars Entry Vehicles

Vishal S K *

ORCID: 0009-0005-7532-1460

Department of Aerospace Engineering, Amrita School of Engineering, Amrita Vishwa Vidyapeetham,
Amritanagar P.O., Ettimadai, Coimbatore, India – 641112.

Abstract: This paper presents a comprehensive aerodynamic study of successful Mars entry vehicles, focusing on the critical phases of Entry, Descent, and Landing (EDL). The study explores the aerodynamic challenges posed by Mars' thin atmosphere and the high entry velocities of spacecraft. By analyzing previous Mars missions, we investigate key design parameters such as heat shield effectiveness, parachute deployment dynamics, and vehicle stability. The findings highlight the importance of optimizing vehicle geometry and thermal protection systems to withstand the intense aerothermal loads during entry. We also examine innovative deceleration technologies, including Hypersonic Inflatable Aerodynamic Decelerators (HIADs) and Supersonic Retropropulsion (SRP), offering insights into their potential to enhance mission success. The results of this study provide valuable guidelines for the design and development of future Mars entry vehicles, contributing to ongoing efforts to improve landing accuracy and vehicle safety on the Martian surface.

Table of Contents

1. Introduction

The aerodynamic study of successful Mars entry vehicles is crucial for optimizing the Entry, Descent, and Landing (EDL) phases, focusing on advanced deceleration technologies such as Hypersonic Inflatable Aerodynamic Decelerators (HIADs), Supersonic Retropropulsion (SRP), magneto-hydro-breaking, and parachutes, along with the analysis of blunt body aerodynamics. HIADs and SRP enable safer, controlled deceleration in Mars' thin atmosphere, while magneto-hydro-breaking offers a novel method of speed reduction through magnetic interactions with the ionized atmosphere. Parachutes, essential for the subsonic phase, require specialized designs to function effectively in low-density conditions. Blunt body shapes, known for their aerodynamic stability and thermal management, remain integral to entry vehicle design. This research aims to enhance the reliability and precision of Mars missions by analyzing the interplay between these technologies and Delta-V management during EDL.

2. Landing Challenges on Mars

The challenges that are alarming during the EDL phase in the Martian Atmosphere are as follows:

- ✓ Inadequate Mission Designs
- ✓ Measurement of Distance to Surface
- ✓ Thinness of the Martian Atmosphere
- ✓ Inadequate Technology for Ballistic Aerocapture

---

[*] UG Research Scholar, Department of Aerospace Engineering, Amrita Vishwa Vidyapeetham, Coimbatore, India. **Corresponding Author: mr.vishal1915@gmail.com.**

** Received: 31-August-2024 || Revised: 28-September-2024 || Accepted: 30-September-2024 || Published Online: 30-September-2024.

- ✓ Shorter Time to Perform Entry, Descent and Landing (EDL)
- ✓ Inadequate Technology for Retropropulsive Powered Descent

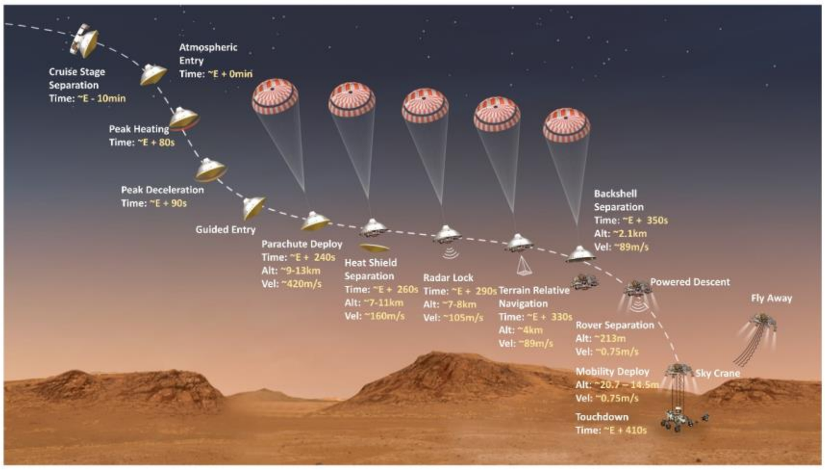

Figure 1 Δv variation in different phases of EDL [Image Courtesy: *Spaceflight Now]*

Previous technological limitations allowed for landing systems on Mars with a capacity below 0.6 metric tons. However, as technology has advanced, particularly with the development of the Sample Return Mission and future human space exploration, this threshold has increased. It was once unimaginable to achieve a landing capacity of at least 0.8 metric tons, but the Curiosity and Perseverance rovers proved otherwise, landing successfully with payloads of 899 kg and 1,025 kg, respectively. This not only demonstrates the improvement in payload capacity but also highlights the increased accuracy of landing systems. The Perseverance rover, for example, landed at the Jezero Crater with only a slight deviation of a few meters from the target, proving the precision of the system. Additionally, we have successfully demonstrated powered flight in Mars' thin atmosphere with the Ingenuity helicopter, completing 72 test flights before its propeller was damaged by dust particles. **[5]** Along with increased payload capacity, there is also a need to land at proper elevations. The Mars Orbiter Laser Altimeter (MOLA) has mapped altitude variations on Mars, ranging from -4 km to +2 km, which played a role in previous missions. Current plans for human exploration of Mars involve landing 40 to 80 metric tons of surface elements at scientifically interesting locations, within proximity (tens of meters) to pre-positioned robotic assets. For future human spaceflight to Mars, we must develop technologies that double the current payload landing capacity, increase landing accuracy by four times, and accommodate lower-density atmospheres and high surface elevations.

Moreover, the above challenges can be categorized under 3 sections and they are:

- ✓ An atmosphere which is thick enough to create substantial heating, but not sufficiently low terminal descent velocity.
- ✓ A Surface Environment of Complex Rocks, Craters, Dust, and Terrain Patterns.
- ✓ The cost of replicating a Mars – relevant environment for spaceflight qualification of new EDL technologies.

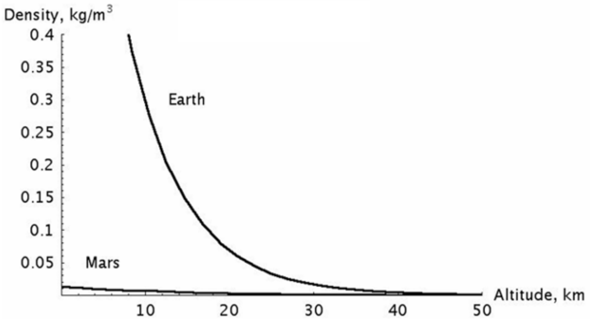

Figure 2 Comparison of Earth and Mars Atmospheric Densities

Source: Mars Exploration EDL Challenges

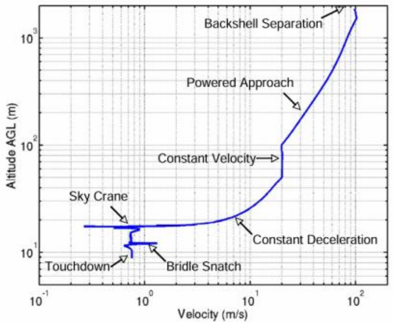

Figure 3 Variation of Velocity with respect to the Altitude During EDL

Source: MSL - EDL System Performance

3. Past Successful Attempts

The United States has successfully landed several missions on Mars, beginning with Viking 1 and 2 in 1976, the first spacecraft to land and send back images from the Martian surface. This was followed by Mars Pathfinder in 1997, which delivered the Sojourner rover, proving the viability of robotic exploration. The Mars Exploration Rovers, Spirit and Opportunity, landed in 2004 and made significant discoveries about Mars' past water activity. In 2008, the Phoenix lander confirmed the presence of water ice in the Martian soil. The Mars Science Laboratory (Curiosity) landed in 2012, exploring Gale Crater and finding evidence of ancient habitable conditions. In 2018, the InSight mission landed to study the interior structure of Mars. Most recently, in 2021, the Perseverance rover landed in Jezero Crater, tasked with searching for signs of ancient life and collecting samples for future return to Earth.

Table 1 Represents Various Parameters of Systems on Martian Surface

Parameter	Viking	MPF	MER	Phoenix	MSL	Perseverance
Entry Mass (kg)	980	585	836	603	3257	1025
Landed Mass (kg)	612	370	539	364	850	899
Aeroshell Diameter (m)	3.5	2.65	2.65	2.65	4.5	4.5
Parachute Diameter (m)	16.15	12.4	15.09	11.5	19.7	21.5
Mach 24 L/D	0.18	0	0	0	0.24	0.24
Landing Site Altitude (km)	-3.5	-1.5	-1.3	-3.5	+1.0	-2.6
Landing Site	Chryse Planitia and Utopia Planitia	Ares Vallis	Gusev Crater and Meridiani Planum	Vastitas Borealis	Gale Crater	Jezero Crater

As discussed earlier, several parameters influence the Entry, Descent, and Landing (EDL) phase of a spacecraft on Mars. Some of these key factors include:

- ✓ **Atmospheric Density**
  Mars' thin atmosphere makes aerodynamic braking less effective, requiring precise control during descent. Variability in atmospheric density can affect the drag force experienced by the spacecraft.
- ✓ **Entry Angle**
  The angle at which the spacecraft enters the Martian atmosphere is critical. A shallow entry angle may cause the spacecraft to skip off the atmosphere, while a steep angle can result in excessive heat and force, potentially destroying the spacecraft.
- ✓ **Heat Shield Design**
  The heat shield must withstand the intense heat generated during entry. The spacecraft's velocity and the thin Martian atmosphere require a heat shield capable of managing both thermal protection and aerodynamic forces.
- ✓ **Spacecraft Velocity**
  The initial velocity of the spacecraft upon entering Mars' atmosphere significantly affects the EDL phase. High velocities necessitate robust deceleration methods to prevent a crash landing.
- ✓ **Parachute Deployment Timing and Design**
  The timing of parachute deployment is critical for slowing the spacecraft sufficiently before landing. The parachute must be capable of deploying in Mars' thin atmosphere and at high speeds.
- ✓ **Altitude and Terrain of Landing Site**
  The elevation and topography of the landing site affect the time available for deceleration. Higher altitudes provide less atmospheric drag, giving the spacecraft less time to slow down. Additionally, rough terrain can impact landing safety.
- ✓ **Spacecraft Mass and Centre of Gravity**
  The mass of the spacecraft influences the deceleration rate, while its center of gravity affects stability during descent. A well-balanced spacecraft will be more stable during atmospheric entry and descent.
- ✓ **Guidance, Navigation and Control (GNC) Systems**
  Accurate GNC systems are essential for making real-time adjustments during EDL. These systems control the spacecraft’s orientation, trajectory, and landing precision.

- ✓ **Retropropulsion**
  Missions such as the Mars Science Laboratory (Curiosity) and Perseverance used retropropulsion to slow the spacecraft before landing. The performance of these thrusters is crucial for a controlled touchdown.
- ✓ **Dust and Atmospheric Condition**
  Dust storms and atmospheric turbulence on Mars can impair visibility and sensor readings, affecting the spacecraft's ability to navigate and land safely.
- ✓ **Communication Delays**
  Due to the time delay between Earth and Mars, EDL must be fully autonomous, with the spacecraft making split-second decisions based on pre-programmed instructions and real-time sensor data.

4. Advanced Deceleration Technologies

Delta – v

Delta - v (Δv) is a measure of the change in velocity that a spacecraft needs to achieve during its mission, essential for maneuvers such as entering or leaving orbits, landing, or rendezvous. In the context of Mars entry, delta-v represents the velocity reduction required for a spacecraft to transition from high-speed atmospheric entry to a safe landing. This reduction is accomplished through a combination of aerodynamic drag, parachute deployment, and retropropulsion. Delta-v directly impacts fuel requirements, propulsion efficiency, and overall mission success, making it a critical parameter in space mission planning and execution.

The total Δv required across the EDL phases determines the spacecraft's ability to safely decelerate from orbital speeds to a soft landing on the Martian surface. Proper management of Δv is essential for controlling heat loads, maintaining stability during descent, and achieving the correct landing velocity. Therefore, it is a central factor in the design and execution of Mars missions.

Hypersonic Inflatable Aerodynamic Decelerator (HIADs)

HIADs consist of a series of concentric, toroidal (donut-shaped) rings made from strong, flexible materials. These rings are inflated in space, increasing the surface area of the vehicle and enhancing atmospheric drag and deceleration. By inflating to a larger diameter, HIADs significantly increase the drag area compared to traditional rigid aeroshells.

Table 2 HIADs Type and its Mass Delivering Capacity

Type	Diameter	Mass Delivering Capacity
Small Diameter HIAD	3 m – 6 m	Up to 1 ton
Medium Diameter HIAD	6 m – 12 m	Up to 10 tons
Large Diameter HIAD	12 m – 20 m	Up to 50 tons
Extra – Large HIAD	Above 20 m	Above 50 tons

Supersonic Retropropulsion (SRP)

Unlike traditional descent methods that rely solely on aerodynamic drag, Supersonic Retropropulsion (SRP) actively slows the vehicle by applying thrust in the opposite direction of motion. This approach is particularly effective in Mars' thin atmosphere, where aerodynamic drag alone may not be sufficient to decelerate the vehicle. SRP enables precise control of the descent trajectory, allowing for more accurate targeting of the landing site. Additionally, it offers greater flexibility in managing the descent profile, which is beneficial for landing large payloads.

Magnetohydrodynamic Braking (MHD)

Magnetohydrodynamic (MHD) braking is a concept that utilizes magnetic fields and electrically conductive fluids or gases to slow down or decelerate an object. In the context of spacecraft entry into a planetary atmosphere, MHD braking aims to provide an additional means of deceleration by interacting with the ionized gas of the atmosphere. This method can complement traditional deceleration techniques, such as aerodynamic drag and parachutes, by offering enhanced control over the descent phase. By using MHD braking to reduce velocity, the thermal load on the spacecraft's heat shield may also be minimized, potentially simplifying the thermal protection system.

However, generating and maintaining a strong magnetic field in space and efficiently interacting it with the ionized plasma pose significant engineering challenges. While the concept is theoretically promising, practical implementations and detailed testing are still in the early stages, and the effectiveness of MHD braking in various atmospheric conditions requires further exploration. For Mars missions, MHD braking could provide a novel approach to managing the intense deceleration required during atmospheric entry. By integrating MHD braking with existing technologies like HIADs and SRP, spacecraft could achieve more controlled and efficient landings, potentially enhancing mission safety and performance. **[6]**

As of now, MHD braking systems remain primarily in the research and theoretical stages, with no concrete proposals for their use in near-term Mars missions. The concept has been explored in academic and research settings, particularly regarding its potential to enhance entry, descent, and landing (EDL) technologies for planetary missions. However, the technology has not yet matured to the point where it is actively considered for upcoming Mars missions by major space agencies like NASA or ESA.

5. Aerodynamic Analysis for Mars Entry (Blunt Body)

The design consists of a blunt body resembling an Apollo-shaped capsule, measuring approximately 5 meters in diameter. It features a nose radius of 6.05 meters, a sidewall angle of 33 degrees, and an overall height of 3.8 meters. **[16]**

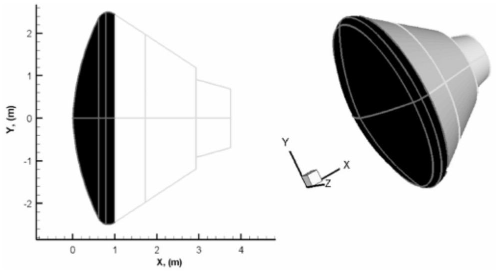

Figure 4 Martian Landing Capsule - Blunt Body

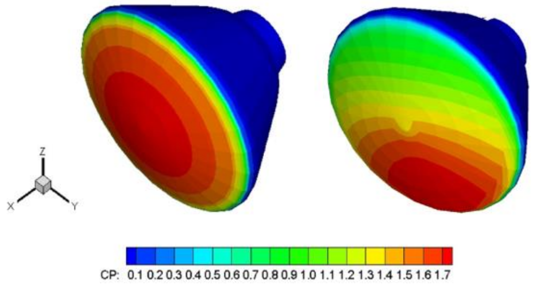

Figure 5 Pressure Coefficient at 0 degrees AoA and 20 degrees AoA at Mach 20

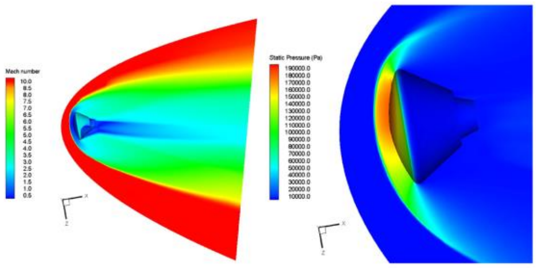

Figure 6 Mach number and Static Pressure Contours for Mach 5 and 10 degrees AoA

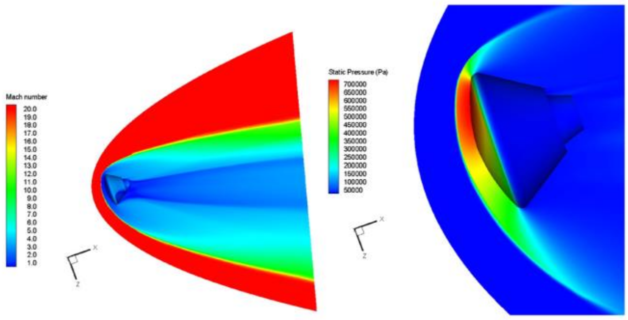

Figure 7 Mach number and Static Pressure Contours for Mach 20 and 20 degrees AoA

Source: Aerodynamic Analysis of Mars Exploration Capsule

When a vehicle enters the Martian atmosphere, several key aerodynamic and thermodynamic parameters come into play, influencing its behavior and performance. The Pressure Coefficient, Mach Number, Temperature, Static Pressure, and Angle of Attack are all intricately interconnected in this process.

The Mach Number, which is the ratio of the vehicle's speed to the local speed of sound, is a critical factor during entry. As the vehicle descends through the Martian atmosphere, it transitions from hypersonic to subsonic speeds. This change in Mach Number affects the formation of shock waves around the vehicle, leading to significant temperature increases and alterations in pressure distribution. The Pressure Coefficient, which describes the relative pressure across the vehicle's surface, is directly influenced by these changes. Higher angles of attack, often employed to control descent and trajectory, result in asymmetric pressure distributions, altering the Pressure Coefficient (Cp) and impacting the vehicle's stability and control.

Temperature also plays a vital role during entry. The high temperatures generated by aerodynamic heating due to shock waves increase the thermal load on the vehicle. This, combined with variations in static pressure as the vehicle descends through different layers of the Martian atmosphere, affects the overall aerodynamic forces experienced by the vehicle. The Angle of Attack, carefully managed during entry, helps control these forces, ensuring that the vehicle remains on its intended trajectory while minimizing thermal and mechanical stresses.

6. Parachutes and their Designs

A parachute slows down a spacecraft by creating a large surface area that generates drag force, which opposes the spacecraft's descent. This drag is crucial for reducing the spacecraft's speed as it enters and travels through the atmosphere. On Mars, where the atmosphere is much thinner than Earth's, the parachute must be designed to maximize drag effectively despite the lower density.

Several key parameters affect parachute performance. The diameter of the parachute directly influences its drag capabilities; a larger diameter increases the surface area exposed to the airflow, thereby generating more drag and slowing the spacecraft more efficiently. The material used for the parachute needs to be strong and flexible enough to withstand the forces during deployment and descent.

The shape of the parachute also plays a role in its effectiveness. Different shapes, such as circular or conical, affect how air is channeled and distributed, influencing the parachute's stability and drag force. The deployment mechanism must be precisely timed and reliable to ensure the parachute opens correctly at the optimal altitude and speed, as incorrect deployment can significantly affect landing accuracy.

On Mars, the lower atmospheric density requires parachutes to be specially designed to compensate for the reduced drag. The parachute's descent speed and deployment stability are critical factors; it must handle high-speed entry and transition to slower speeds while maintaining stability to avoid oscillations or tumbling. Proper load distribution is also essential to prevent tearing and ensure consistent performance throughout the descent.

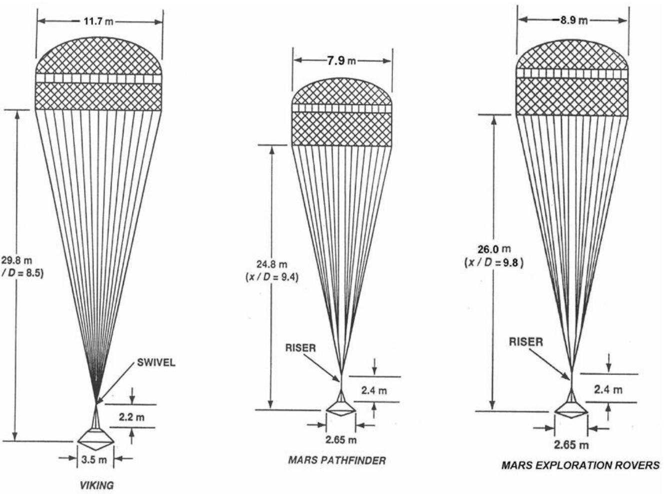

Figure 8 Viking Derived Parachute System

Source: Mars Exploration EDL Challenges

The Ballistic Coefficient (β) is a measure of an object's ability to overcome air resistance during flight. It describes the behavior of a projectile, such as a spacecraft or a bullet, as it travels through a fluid medium like the atmosphere. In the context of space missions, particularly during the Entry, Descent, and Landing (EDL) phase on Mars, the ballistic coefficient is a critical factor that influences how quickly the object slows down as it enters the atmosphere.

$$\boldsymbol{\beta = \frac{m}{C_d A}}$$

where,

$m = Mass\ of\ the\ Object$
$C_d = Drag\ Coefficient$
$A = Area\ of\ Cross - Section\ facing\ the\ Airflow$

Based on the Ballistic Coefficient and the Diameter of the Aeroshell for different missions, the following conclusions were obtained with respect to the Mass and the Elevation of the Martian Surface.

Table 3 Landed Mass on Martian Surface as a Function of Elevation

Surface Elevation (MOLA in km)	Maximum β in kg/m^2	Landed Mass for 2.65 m Diameter Aeroshell	Landed Mass for 4.5 m Diameter Aeroshell
-2.0	160	350	1000
0.0	135	300	850
+2.0	115	250	750

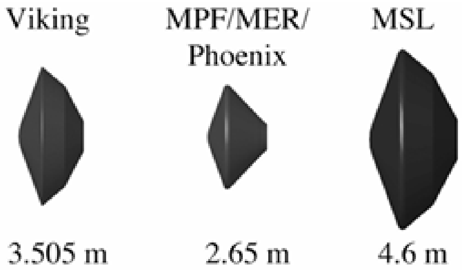

Figure 9 70 Degrees Sphere - Cone Aeroshells

Source: Mars Exploration EDL Challenges

7. Future Implications and Innovations

As Mars exploration progresses, the future of Entry, Descent, and Landing (EDL) technologies is pivotal for advancing human missions and establishing a sustained presence on the Red Planet. One significant challenge is developing EDL systems capable of handling much larger payloads, which are necessary for crewed missions and heavy equipment. Future missions will require enhanced versions of current technologies, such as Hypersonic Inflatable Aerodynamic Decelerators (HIADs) and Supersonic Retropropulsion (SRP). Scaling these systems to manage the increased mass while ensuring redundant safety mechanisms will be crucial for mitigating risks associated with human landings. Advancements in materials and thermal protection are essential for managing the extreme conditions of Martian entry. Next-generation heat shields and adaptive materials capable of real-time adjustments will be necessary to protect spacecraft from high temperatures while minimizing mass. Additionally, precision landing technologies will see significant improvements. Enhanced Terrain-Relative Navigation (TRN) and the integration of AI and machine learning will enable spacecraft to autonomously navigate and land with greater accuracy, avoiding hazards and landing in scientifically valuable areas. The concept of reusable EDL technologies is also gaining traction. Reusable landers and modular systems that can be adapted for different missions will reduce costs and increase mission flexibility. In-Situ Resource Utilization (ISRU) technologies will play a critical role by enabling the production of propellants and other resources on Mars, thereby reducing dependency on Earth-launched supplies. The development of infrastructure, such as landing pads and automated supply drops, will further support sustained exploration and human presence. Emerging technologies like Magnetohydrodynamic (MHD) braking and electric propulsion for EDL phases are being explored to enhance deceleration and precision. These innovations, along with potential orbiting relay stations and autonomous cargo landers, will support future missions by providing continuous communication, navigation assistance, and precise landing capabilities. Collectively, these advancements will pave the way for more ambitious Mars missions, bringing humanity closer to a long-term presence on the Red Planet.

8. Conclusion

In conclusion, the aerodynamic study of successful Mars entry vehicles provides a comprehensive understanding of the critical design principles that have enabled the safe landing of spacecraft on the Martian surface. This analysis highlights how the interplay of key aerodynamic factors—such as the ballistic coefficient, entry angle, and atmospheric drag—must be meticulously managed to navigate the unique challenges posed by Mars’s thin atmosphere. The study demonstrates that past missions, including Viking, Pathfinder, the Mars Exploration Rovers (MER), the Mars Science Laboratory (MSL), and Perseverance, achieved success through a combination of advanced heat shield technologies, precisely engineered parachute systems, and sophisticated guidance and control mechanisms. These elements were tailored to maximize deceleration and stability during the high-speed Entry, Descent, and Landing (EDL) phases, ensuring that the spacecraft could withstand the harsh conditions and achieve a controlled touchdown. The insights gained from these missions have not only validated the aerodynamic strategies employed but have also set the foundation for future Mars missions, underscoring the necessity of careful design optimization. As we look ahead to more ambitious exploration goals, this study reaffirms the importance of balancing vehicle mass, aerodynamic efficiency, and material durability to continue the legacy of successful Mars landings.

9. References

[1] Malaya Kumar Biswal, M. and Ramesh Naidu Annavarapu, January 2021, “Conceptual Design of Mars Landers with Novel Impact Intriguing Systems”, Conference Paper – ResearchGate.

[2] Andrew, J., Brune; Serhat Hosder; Karl, T., Edquist and Steven, A., Tobin, November 2016, “Thermal Protection System Response Uncertainty of a Hypersonic Inflatable Aerodynamic Decelerator”, Aerospace Research Central.

[3] Francois Cadieux; Scott Neuhoff; Michael, F., Barad and Cetin Kiris, November 2021, “Simulating a Mars Supersonic RetroPropulsion Concept Vehicle”, Human Space Flight Research Project, NASA Ames Research Centre.

[4] Li, S.; Jiang, X., August 2014, “Review and Prospect of Guidance and Control for Mars Atmospheric Entry”, Progress in Aerospace Sciences, Science Direct.

[5] Robert, D., Braun and Robert, M., Manning, April 2007, “Mars Exploration Entry, Descent, and Landing Challenges”, Journal of Spacecraft and Rockets.

[6] Viktor, Sukhotskiy; Kareem, Tawil and Erik, Einarsson, April 2021, “Printability Regimes of Pure Metals using Contactless Magnetohydrodynamic Drop-on-Demand Actuation”, AIP Publishing.
[7] Desai, P., and Knocke, P., “Mars Exploration Rovers Entry, Descent, and Landing Trajectory Analysis,” AIAA/AAS Astrodynamics Specialist Conference and Exhibit, AIAA, Reston, VA, 2004.
[8] Steltzner, A., Lee, W., Bruno, R., and Desai, P., “Mars Exploration Rovers Entry, Descent, and Landing Phase and the Use of Aerodynamic Decelerators,” 17th AIAA Aerodynamic Decelerator Systems Technology, AIAA Paper 2003-212, Reston, VA, May 2003.
[9] Witkowski, A., Kandis, K., Bruno, R., and Cruz, J., “Mars Exploration Rover Parachute System Performance,” 18th AIAA Aerodynamic Decelerator Systems Technology Conference, Munich, Germany, AIAA Paper 2005-1605, May 2005
[10] Witkowski, A., and Brown, G., “Mars Deployable Decelerators Capability Roadmap Summary,” 2006 IEEE Aerospace Conference, Big Sky, MT, Inst. of Electrical and Electronics Engineers, Paper 1585, March 2006.
[11] David, W., Way; Richard, W., Powell; et. al., March 2006, “Mars Science Laboratory: Entry, Descent, and Landing System Performance”, NASA Langley Research Centre, IEEE Aerospace Conference.
[12] Lockwood, M. K., Sutton, K., Prabhu, R., and Powell, R. W., “Entry Configurations and Performance Comparisons for the Mars Smart Lander,” AIAA Paper 2002-4407, AIAA Atmospheric Flight Mechanics Conference & Exhibit, Monterey, CA, Aug. 2002.
[13] Way, D.W., Powell R.W., Chen A., Steltzner, A.D., “Asymptotic Parachute Performance Sensitivity”, IEEEAC #1465, IEEE Aerospace Conference, March 4-11, 2006, Big Sky, MT.
[14] Justus, C. G., Johnson, D. L., “Mars Global Reference Atmospheric Model 2001 Version (Mars-GRAM 2001): Users Guide,” NASA TM-2001-210961, April 2001.
[15] Moog, R. D. and Michel, F. C.: Ballon Launched Decelerator Test Program Summary Report, NASA-CR-112288, 1973.
[16] Giuseppe, Pezzella and Antonio, Viviani, December 2011, “Aerodynamic Analysis of a Mars Exploration Manned Capsule”, Acta Astronautica - Elsevier.

10. Conflict of Interest

The author declares no competing conflict of interest.

11. Funding

No funding was received to support this study.

12. Acknowledgement

The author would like to express his heartful gratitude to Mr. Malaya Kumar Biswal M, Managing Director and Chief Executive Officer, Acceleron Aerospace for his guidance throughout the research work. The author would also like to thank his family, friends, and mentors for their constant support.

13. Author Biography

Vishal S K, a dedicated Final Year Undergraduate Student in Aerospace Engineering at Amrita Vishwa Vidyapeetham University, Coimbatore, India with a strong passion for space technology and innovation. Throughout his academic journey, he has gained hands - on experience on Analyzing and Designing an Indigenous Thermally Locked Differential Pressure Indicator for Aerospace Mechanical Filters in Combat Vehicles Research and Development Establishment (CVRDE), Defense Research and Development Organization (DRDO), Avadi, Chennai. Alongside, worked on Kinematic Synthesis and Force Analysis of Rudder and Aileron Control Surfaces for a Typical Fixed Wing Aerial Vehicle in Council of Scientific and Industrial Research – National Aerospace Laboratory (CSIR – NAL), Bengaluru, India. In addition to his technical expertise, he is also involved in various club activities in university.