

ABSTRACT

This report includes the overview of **Reusable Launch Vehicle and Rocket study.**

The report shows an overview of the tasks done during the period of internship in detail. I tried to make this Internship report more precise, brief, and clear. The purpose of the report is to explain what I learned during the Internship period during the summer 2024.

During the period of 31 days from 1st of July 2024 to 1st of August 2024, we were trained and explained about

- Introduction and History of Rocket
- Solid and Liquid Propellant Engines
- Reusable Launch Vehicles and associated software's.

We were also given the task of doing a mini project on types of nozzle and major project on NASA CEA and Open rocket software, some of the topics are:

Q. Case Study of any type of rocket nozzle.

1. Basic 2D Design in Catia V5
2. Open Rocket software learning
3. NASA CEA software learning

The report is made up of 5 Chapter

Chapter I: Introduction

Chapter II: Reusable Launch Vehicles

Chapter III: CATIA V5

Chapter IV: Methodology: Open Rocket and CEA software

Chapter V: Result of the Project

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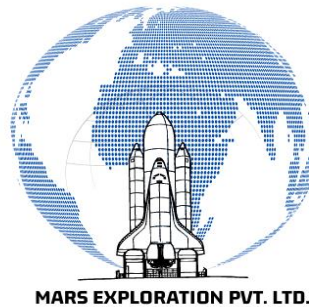
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CHAPTER I: INTRODUCTION

1.1 About Mars Exploration Pvt Ltd

MARS Exploration Private Limited is an aerospace startup company in Maharashtra that provides research and development information on topics related to aerospace. The company was established in 2021 and is integrated under the Ministry of Affairs, Government of India. Their expertise lies in reusable orbital launch vehicles (ROLV) and commercial projects related to aeronautical aerospace avionics and IT



1.1.1 Company and its Principles

MARS Exploration aspires to have a considerable presence in the Aerospace and Defence industry nationwide by the year 2030. Their vision is not only to achieve excellence in innovation, manufacturing, and service delivery but also to be recognized as the go-to solution provider for the most complex and critical challenges in these sectors.

Their pursuit of global leadership is characterized by several key principles:

1. **Innovation:** We will continuously push the boundaries of innovation, developing breakthrough technologies and solutions that redefine industry standards.
2. **Quality:** Quality will be the cornerstone of everything we do, ensuring that our products and services meet and exceed the highest international standards.
3. **Sustainability:** Our commitment to sustainable practices will underscore every aspect of our operations, from design and manufacturing to environmental stewardship.

4. Talent Development: We will invest in nurturing talent, both within our organization and through strategic partnerships with educational institutions, to cultivate the next generation of leaders in Aerospace and Defence.

5. Global Reach: We will expand our global footprint, establishing a strong presence in key markets, forging international alliances, and delivering world-class solutions to customers around the world.

1.1.2 Mission of MARS Exploration Pvt Ltd.

MARS Exploration is on a mission:

1. Global Leadership: To establish itself as a global leader in the aerospace and defence industry, setting new standards of excellence and innovation.

2. Manufacturing Excellence: To be a leading manufacturer in the Aerospace and Defence sector, delivering superior quality products and services.

3. Education Outreach: To educate and empower 1 million individuals with knowledge about aerospace and defence by the year 2030, fostering a new generation of experts and enthusiasts.

4. Drone Services: To pioneer and expand Drone as a Service by 2025, revolutionizing aerial solutions for a multitude of industries.

5. Defence Journalism Promotion: To champion the cause of Defence Journalism, ensuring that accurate and insightful reporting contributes to a well-informed public.

6. Security Solutions: To evolve into a world-class, state-of-the-art global enterprise, providing sophisticated solutions to meet the security system needs of our nation.

The mission is driven by unwavering commitment, innovation, and a profound sense of responsibility to our industry, society, and the security of the nation.

1.2 Introduction to Rockets

OBJECTIVE: - The objective of our internship was to

- a. To understand the industrial skills needed for Rocket design.
- b. To understand the historical progress in the field of Rocket design.
- c. To sketch 2D structures by understanding key features using CATIA V5.
- d. To understand the simulation procedures of rockets before building and flying them.
- e. To understand the properties of complex mixtures of fuel and oxidizers used for combustion.

Rockets are remarkable vehicles that have revolutionized our understanding of space exploration and enabled us to venture beyond the confines of Earth. Their ability to propel themselves through the air and reach incredible speeds has opened a world of possibilities, allowing us to launch satellites, send astronauts into orbit, and explore distant planets.

The fundamental principle behind rocket propulsion lies in Newton's third law of motion, which states that for every action, there is an equal and opposite reaction. In a rocket, the action is the forceful expulsion of hot gases from the combustion of fuel and oxidizer. As these gases escape through a nozzle at the rear of the rocket, they generate a thrust that propels the rocket in the opposite direction.

1.2.1 Brief History of Rocket

The history of rockets spans centuries, with contributions from various cultures and civilizations. Here's a brief overview:

1. Ancient China (9th-13th centuries): The earliest recorded use of gunpowder-propelled devices in warfare dates back to ancient China. The Chinese invented gunpowder and used it to create simple rockets, known as "fire arrows," during the Tang dynasty (9th century) and the Song dynasty (10th-13th centuries).
2. 13th-17th centuries: The knowledge of rockets spread to the Middle East and Europe during the Mongol invasions. In the 17th century, notable figures like Konrad Haas and Johann Schmidlap made advancements in rocket design in Europe.
3. 18th-19th centuries: Sir William Congreve, a British artillery officer, developed the Congreve rockets in the early 19th century. These rockets were used in various military conflicts, including the Napoleonic Wars and the War

of 1812. In the 19th century, pioneers like Konstantin Tsiolkovsky in Russia and Hermann Oberth in Germany laid the theoretical groundwork for space travel.

4. Early 20th century: Robert H. Goddard, an American physicist, is often regarded as the "father of modern rocketry." In 1926, he successfully launched the world's first liquid-fueled rocket. Goddard's work laid the foundation for future developments in rocket technology.

5. World War II: Rockets played a significant role in World War II. The German V-2 rocket, developed by Wernher von Braun, was the world's first long-range guided ballistic missile. After the war, von Braun and other German scientists played crucial roles in the development of rockets in both the United States and the Soviet Union.

6. Cold War and the Space Race (1950s-1960s): The Cold War rivalry between the United States and the Soviet Union led to rapid advancements in rocket technology. In 1957, the Soviet Union launched Sputnik 1, the first artificial satellite, marking the beginning of the space age. The United States followed with the successful launch of Explorer 1 in 1958. The space race culminated with the Apollo 11 mission in 1969, when NASA successfully landed the first humans on the Moon.

7. Post-Apollo era (1970s-present): After the Apollo program, space exploration continued with the development of space shuttles, space stations, and various robotic missions. The emergence of commercial space companies in recent years, such as SpaceX, has further expanded access to space.

8. 21st century: Advances in rocket technology continue with a focus on reusability, cost reduction, and new exploration initiatives. Private companies, including SpaceX, Blue Origin, and others, are playing an increasingly prominent role in shaping the future of space exploration.

The history of rockets reflects a combination of military applications, scientific curiosity, and the pursuit of space exploration, showcasing a fascinating journey of technological innovation over the centuries.



Fig 1.1 Chinese Rocket



Fig 1.2 Saturn V

1.2.2 Basic Components of Rocket

A rocket is a complex vehicle designed to propel itself through space by expelling exhaust gases in the opposite direction. The basic components of a rocket include:

1. Propellant: The propellant is the fuel and oxidizer mixture that undergoes combustion in the rocket engine. It can be solid, liquid, or hybrid. Solid propellants are preloaded into the rocket motor, while liquid propellants are stored in separate tanks and mixed in the combustion chamber.
2. Rocket Engine: The rocket engine is the device that converts the chemical energy stored in the propellant into kinetic energy (thrust) by expelling high-speed exhaust gases. Rocket engines can be either liquid-fueled or solid-fueled, and they come in various designs such as chemical rockets, ion drives, or nuclear thermal rockets.
3. Airframe: The airframe is the structure of the rocket that supports and contains all the other components. It includes the nose cone, body, and fins. The nose cone helps reduce air resistance, and the fins provide stability during flight.
4. Payload: The payload is the cargo or instruments that the rocket is designed to carry. It could be a satellite, scientific instruments, crewed spacecraft, or other equipment, depending on the mission.
5. Guidance System: The guidance system controls the rocket's trajectory and ensures that it follows the desired flight path. It typically includes sensors, a computer, and control mechanisms that adjust the rocket's orientation and thrust.
6. Avionics: Avionics, short for aviation electronics, encompasses the electronic systems used in the rocket. This includes communication systems, telemetry,

navigation equipment, and any other electronic components necessary for the rocket's operation and data transmission.

7. Staging Mechanism: Multi-stage rockets have multiple sections (stages), each with its own engines and propellant. As each stage burns out, it is jettisoned to reduce the overall weight of the rocket. This allows the remaining stages to accelerate the payload to higher velocities.

8. Ignition System: The ignition system initiates the combustion of the propellant in the rocket engine. For liquid rockets, this involves starting the flow of propellants and igniting them. In solid rockets, it usually involves igniting a pyrotechnic initiator to start the combustion.

9. Thrust Vector Control (TVC): TVC systems are used to control the direction of the rocket's thrust. By adjusting the direction of the exhaust gases, the rocket can change its orientation and trajectory.

10. Recovery System (optional): Some rockets, especially those used for suborbital flights or launching payloads to lower altitudes, may have a recovery system. This can include parachutes, aerodynamic surfaces, or other mechanisms to slow the descent and allow for a controlled landing.

These components work together to make a rocket a functional and effective vehicle for space exploration, satellite deployment, scientific research, and various other applications.

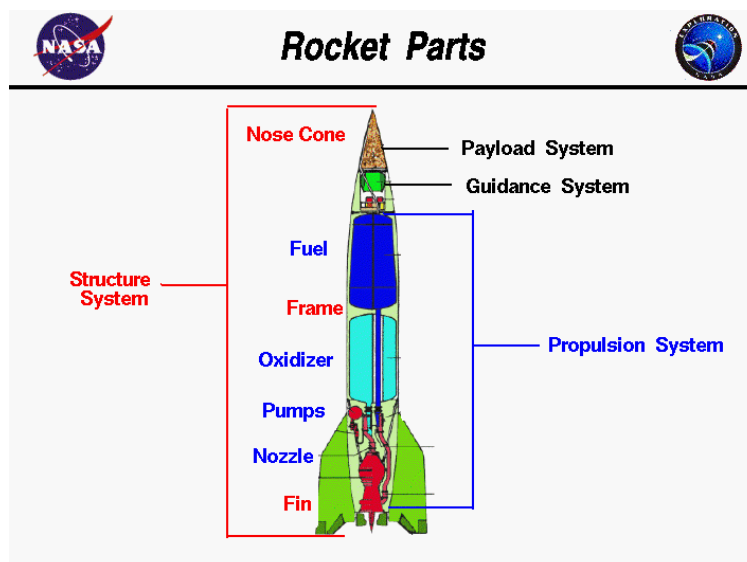


Fig 1.3 Basic Rocket Parts

1.3 Types of Rocket Engines

Let's delve deeper into the details of liquid rocket engines, solid rocket engines, and hybrid rocket engines

1.3.1 Solid Rocket Engine

A solid rocket engine (SRE) is a rocket engine that uses solid propellant as its fuel. The propellant is typically a mixture of fuel and oxidizer, which are intimately mixed and held together in a solid form. When ignited, the propellant burns rapidly, producing hot gases that are expelled through a nozzle at the rear of the rocket. This creates a thrust force that propels the rocket forward. SREs are relatively simple and reliable compared to liquid-propellant rockets, which use liquid fuel and oxidizer that are stored separately and injected into the combustion chamber.

This makes SREs well-suited for applications where reliability is critical, such as missile defence and space launches.

Here are some of the key characteristics of SREs:

- Reliable and easy to store: Once the propellant is loaded, an SRE is ready to launch, making it ideal for quick response applications.
- High thrust-to-weight ratio: SREs can generate a large amount of thrust for their weight, making them efficient for lifting heavy payloads.
- Simple and robust: SREs are relatively simple to design and manufacture, making them cost-effective for mass production.
- Limited thrust control: SREs typically have limited thrust control, which can make them challenging to use for precise manoeuvres.
- Fixed burn duration: Once ignited, an SRE will burn until all of the propellant is consumed, which can limit its flexibility for mission planning.

SREs are used in a wide variety of applications, including:

- Missile defence: SREs are used in a variety of missile defence systems, including interceptors and anti-aircraft missiles.
- Space launches: SREs are often used as the first stage of a rocket launch vehicle, providing the initial thrust needed to lift the rocket off the ground.
- Re-entry vehicles: SREs are used in re-entry vehicles, which are designed to safely bring spacecraft back into Earth's atmosphere from orbit.
- Model rockets: SREs are a popular choice for model rockets due to their simplicity and ease of use.

Overall, SREs are a versatile and reliable propulsion technology that is widely used in a variety of applications. Their simplicity, reliability, and high thrust-to-weight ratio make them a good choice for applications where cost, weight, and performance are critical factors.

1.3.2 Liquid Rocket Engine

A liquid rocket engine (LRE) is a type of rocket engine that uses liquid propellants as fuel and oxidizer. Propellant tanks store the fuel and oxidizer separately, and pumps are used to inject them into the combustion chamber, where they are ignited and burn to produce hot gases. The hot gases are then expanded through a nozzle, creating thrust that propels the rocket forward.

LREs offer several advantages over solid rocket engines (SREs), including:

- Higher specific impulse: LREs can achieve a higher specific impulse, which is a measure of the efficiency of propellant use. This means that LREs can generate more thrust for a given amount of fuel and oxidizer.
- More precise thrust control: LREs can be controlled more precisely than SREs, allowing for more controlled manoeuvres.
- Variable burn duration: LREs can be throttled, which means that the amount of propellant burned can be adjusted, allowing for variable burn durations. This is important for applications that require precise control of the rocket's trajectory.

However, LREs also have some drawbacks, including:

- More complex and expensive: LREs are more complex and expensive to design, manufacture, and operate than SREs.
- Susceptible to propellant boiloff: Liquid propellants can boil off in the vacuum of space, which can reduce the overall performance of the engine.
- Require complex plumbing: LREs require a complex plumbing system to transport propellants from the tanks to the combustion chamber.

Despite their drawbacks, LREs are the preferred choice for many applications, including:

- Spacecraft propulsion: LREs are used in the main engines of most spacecraft, including the Space Shuttle and the International Space Station.

- Upper stages of launch vehicles: LREs are often used in the upper stages of launch vehicles, where they provide the precise control and manoeuvrability needed for orbital insertion and manoeuvring in space.
- Experimental aircraft: LREs are used in some experimental aircraft, such as the X-15, to achieve high speeds and altitudes.

As technology advances, LREs are becoming increasingly efficient and reliable, making them even more attractive for a wider range of applications.

1.3.3 Hybrid Rocket Engine

A hybrid rocket engine is a type of rocket engine that combines the advantages of solid and liquid rocket engines. It uses a solid fuel and a liquid oxidizer. The solid fuel is typically stored in a grain in the combustion chamber, while the liquid oxidizer is stored in a separate tank and injected into the combustion chamber when needed.

Hybrid rocket engines offer several advantages over both solid and liquid rocket engines:

- Safety: Hybrid rocket engines are inherently safer than solid rocket engines because the oxidizer is stored separately from the fuel. This means that there is no risk of an explosion if the engine is damaged.
- Controllability: Hybrid rocket engines can be throttled and shut down, which gives the operator more control over the engine's thrust. This is not possible with solid rocket engines, which burn until all of the propellant is consumed.
- Efficiency: Hybrid rocket engines can achieve a higher specific impulse than solid rocket engines, which means that they can generate more thrust for a given amount of fuel and oxidizer.
- Scalability: Hybrid rocket engines can be scaled up to larger sizes than liquid rocket engines, which are limited by the complexity of their plumbing systems.

However, hybrid rocket engines also have some drawbacks, including:

- Complexity: Hybrid rocket engines are more complex to design and manufacture than solid rocket engines.
- Developmental stage: Hybrid rocket engines are still in the developmental stage, and there are not as many mature designs available as there are for solid and liquid rocket engines.

Despite their drawbacks, hybrid rocket engines have the potential to revolutionize rocket propulsion. They offer a safe, controllable, and efficient way to generate thrust, and they are scalable to larger sizes. As the technology

matures, we can expect to see hybrid rocket engines used in a wider range of applications, including space launches, satellite delivery, and hypersonic flight.

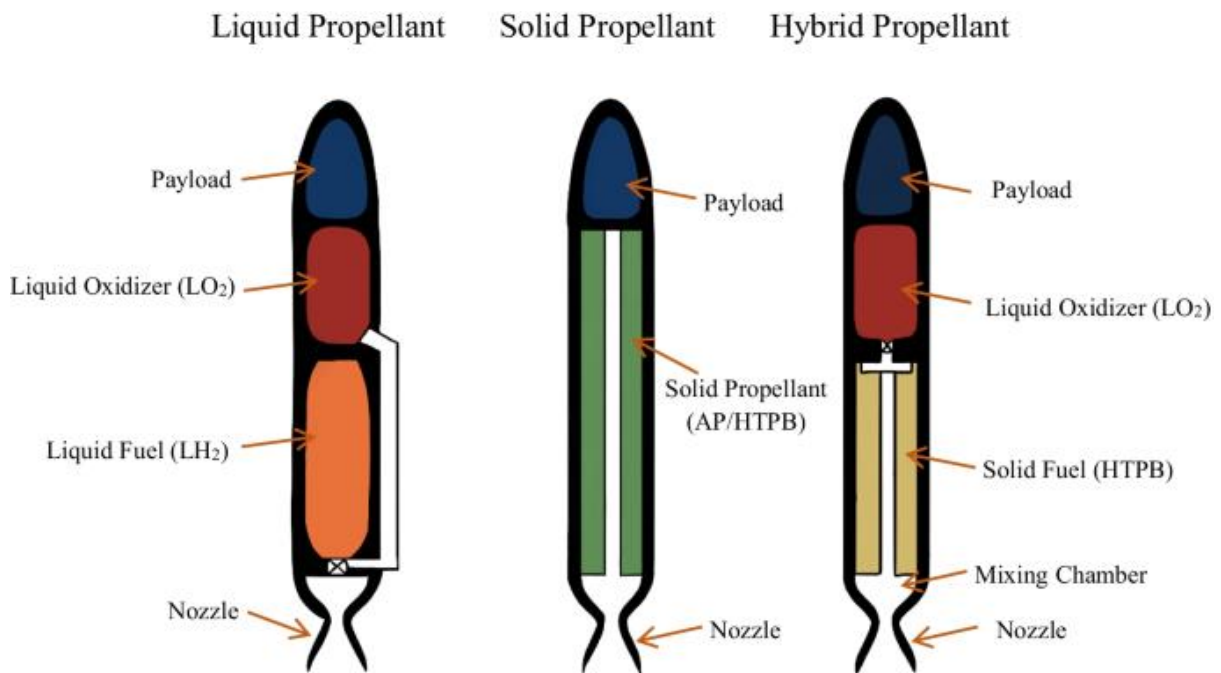


Fig 1.4 Types of Rocket Engine

CHAPTER II: REUSABLE LAUNCH VEHICLE

2.1 Introduction to Reusable Launch Vehicle

A Reusable launch vehicle has parts that can be recovered while carrying payloads from the surface to outer space. Rocket stages are the most common launch vehicle parts aimed for reuse. Smaller parts such as rocket engines and boosters can also be reused, though reusable spacecraft may be launched on top of an expendable launch vehicle. Reusable launch vehicles do not need to make these parts for each launch, therefore reducing their launch cost significantly. However, these benefits are diminished by the cost of recovery and refurbishment.

2.1.1 Importance of Reusable Launch Vehicle

A Reusable Launch Vehicle (RLV) is critical for the future of space exploration and development due to its potential to revolutionize the economics and accessibility of space missions. Here's why RLVs are important:

1. Cost Reduction

- **Significant savings:** Traditional launch vehicles are expendable, meaning they are used once and discarded. With RLVs, the same vehicle can be reused for multiple launches, drastically lowering the cost per launch by spreading development and manufacturing costs over many missions.
- **Lower barrier for entry:** Reduced costs make space more accessible to a broader range of actors, including private companies, universities, and smaller nations.

2. Increased Launch Frequency

- **Rapid turnaround:** RLVs can be refurbished and prepared for multiple missions within shorter timeframes, leading to higher launch frequencies. This is essential for deploying large constellations of satellites or supporting sustained exploration efforts like those planned for the Moon and Mars.
- **Supporting demand:** As commercial space ventures like satellite broadband, space tourism, and asteroid mining grow, the need for frequent, reliable, and cost-effective launches will increase.

3. Environmental Benefits

- **Reduced waste:** Expendable launch vehicles leave debris in space and require the production of new rockets for each mission, creating waste and resource use. RLVs minimize this by reusing the main components.
- **Efficient use of materials:** By reusing parts of the rocket, fewer materials are consumed over time, leading to a more sustainable approach to space exploration.

4. Technological Innovation

- **Advances in design:** Developing RLVs drives innovation in materials, propulsion systems, and avionics, as these vehicles need to withstand multiple re-entries and launches.
- **Fuel efficiency:** Reusable vehicles often incorporate advanced propulsion systems, improving fuel efficiency and opening the door to longer-range missions with fewer resources.

5. Space Exploration and Colonization

- **Sustaining exploration efforts:** For missions to the Moon, Mars, and beyond, RLVs offer a scalable solution for regular supply runs and crew rotations, which is crucial for maintaining a permanent human presence in space.
- **Enabling space infrastructure:** By making space access more economical, RLVs facilitate the construction of space stations, lunar bases, and even interplanetary transport networks.

2.1.2 Types of Reusable Launch Vehicle

There are several types of Reusable Launch Vehicles (RLVs), which differ based on their design, recovery methods, and reuse strategies. These types can be broadly categorized into the following:

1. Vertical Take-off, Vertical Landing (VTVL)

Description: The vehicle takes off vertically like traditional rockets and returns to land vertically.

Examples:

- **SpaceX Falcon 9:** The first stage of Falcon 9 is reusable, landing vertically after launch.
- **Blue Origin's New Shepard:** A suborbital vehicle that lands vertically after completing its mission.

Advantages: VTVL systems allow recovery of the main rocket stage and are suited for high-thrust, high-speed re-entry.

2. Vertical Take-off, Horizontal Landing (VTHL)

Description: The vehicle takes off vertically like a traditional rocket but lands horizontally like an aircraft, often using runways.

Examples:

- Space Shuttle: NASA's Space Shuttle was a VTHL system, where the shuttle orbiter landed on a runway after mission completion.
- Dream Chaser: Sierra Nevada Corporation's Dream Chaser takes off on a rocket and lands horizontally on a runway.

Advantages: Horizontal landing reduces the complexity of the landing process and allows integration with existing airport infrastructure.

3. Horizontal Take-off, Horizontal Landing (HTHL)

Description: These vehicles take off and land horizontally like airplanes. Typically, they may rely on a runway for takeoff and landing, or sometimes require an additional carrier aircraft for launching into space.

Examples:

- Skylon (Under development): The British spaceplane concept uses an air-breathing rocket engine to take off and land like an aircraft.
- SpaceShipTwo (Virgin Galactic): This system involves a carrier aircraft, White Knight Two, launching the spacecraft from mid-air.

Advantages: These systems can potentially use conventional airport infrastructure and might offer greater reusability with lower refurbishment costs.

5. Winged Spaceplanes

Description: These RLVs have wings and aerodynamic surfaces, allowing them to glide back to Earth and land like a conventional aircraft. They typically combine both aircraft-like and rocket-like features.

Examples:

- Buran (Soviet Space Shuttle): Similar to NASA's Space Shuttle, the Buran was a winged spaceplane that could land on a runway after re-entry.

- Advantages: Winged vehicles have more control during re-entry and landing and can make use of a wide range of landing sites.

6. Fully Reusable Launch Vehicles

Description: These systems aim to have all stages of the rocket fully reusable, not just the first stage.

Examples:

- SpaceX Starship: A fully reusable system where both the first stage (Super Heavy booster) and the second stage (Starship) are designed for reuse.
- Advantages: Complete reusability drives down costs further by eliminating the need for disposable components in every launch.

2.2 Technical Information

The bell-type rocket nozzle is a widely used and well-established design in rocket propulsion. Its characteristic bell shape, with a converging section leading to a throat and then a diverging section, enables efficient expansion of exhaust gases. As combustion gases pass through the converging section, they reach supersonic speeds at the throat, maximizing their kinetic energy. The subsequent diverging section allows for further expansion, converting the thermal energy of the exhaust gases into high-speed propulsive thrust. Bell nozzles are known for their simplicity, reliability, and effectiveness, making them a common choice for various rocket applications, including launch vehicles and spacecraft.

2.2.1 Selection Criteria

The selection criteria for a Reusable Launch Vehicle (RLV) are based on a range of technical, economic, and operational factors. These criteria are crucial for determining whether a particular RLV design can meet the desired mission objectives while maintaining cost-effectiveness, safety, and reliability.

Here are the key selection criteria for RLVs:

1. Reusability Efficiency

- Number of reuse cycles: The RLV should be able to undergo multiple reuse cycles with minimal refurbishment. The higher the number of reuses, the greater the cost savings.

- Turnaround time: How quickly the RLV can be inspected, refurbished, and prepared for the next mission is a critical factor. A shorter turnaround time increases launch frequency, which is essential for meeting demand.
- Refurbishment cost: The cost associated with preparing the vehicle for reuse must be low enough to justify the benefits of reusability. Vehicles that require extensive refurbishment may not be economically viable in the long term.

2. Payload Capacity

- Payload-to-orbit ratio: The RLV must be able to carry the required payload to the intended orbit. The payload capacity should be balanced with the cost of launching and reusability.
- Payload flexibility: The vehicle should be able to accommodate a variety of payloads (e.g., satellites, cargo, crew) and different mission profiles (e.g., low-Earth orbit, geostationary orbit, deep space).

3. Safety and Reliability

- Safe recovery methods: The method of returning the vehicle safely to Earth is a key consideration. The landing system (e.g., vertical landing, horizontal landing, parachute) must ensure the safe recovery of the vehicle with minimal risk.
- Launch success rate: The vehicle's reliability during both launch and re-entry phases is critical. A proven track record of successful launches and recoveries builds confidence in the system.
- Human-rating certification: If the vehicle is designed to carry humans, it must meet stringent safety standards for crewed missions.

4. Cost Efficiency

- Per launch cost: The cost per launch (including vehicle recovery and refurbishment) must be significantly lower than that of expendable vehicles to justify RLV adoption.
- Development and operational costs: The overall development costs, including research, testing, and infrastructure, should be justified by the long-term savings gained through reuse. Additionally, operational costs for recovery, transportation, and maintenance should be minimized.

5. Mission Flexibility

- Multi-mission capability: The RLV should be able to support a wide range of missions, such as satellite deployment, space station resupply,

interplanetary missions, and crewed spaceflight. This flexibility ensures that the vehicle can be used for diverse applications.

- Adaptability to different orbits: The ability to deliver payloads to different types of orbits (low-Earth orbit, geostationary orbit, beyond) is important for commercial, defence, and scientific missions.
- Re-entry and landing site flexibility: The vehicle should be capable of landing at various locations to minimize mission constraints.

6. Technological Maturity

- Proven technology: The vehicle should be based on mature and well-understood technology to minimize the risk of failure. Revolutionary designs may offer advantages but also come with higher risks.
- Ease of integration: The RLV should integrate easily with existing launch infrastructure (e.g., launch pads, ground control systems) to avoid costly upgrades or new development of infrastructure.

7. Environmental Impact

- Re-entry effects: The vehicle's re-entry process should minimize damage to the atmosphere and environment (e.g., reduced atmospheric pollution, minimal debris generation).
- Fuel efficiency: Propellant efficiency during launch and re-entry should be optimized to reduce environmental impact and operational costs.

2.2.2 Launching Systems

Reusable systems can come in single or multiple (two or three) stages to orbit configurations. For some or all stages the following landing system types can be employed.

➤ SINGLE STAGE TO ORBIT:

1. A single-stage-to-orbit (SSTO) vehicle reaches orbit from the surface of a body using only propellants and fluids and without expending tanks, engines, or other major hardware.
2. The term usually, but not exclusively, refers to reusable vehicles.
3. To date, no Earth-launched SSTO launch vehicles have ever been flown; orbital launches from Earth have been performed by either fully or partially expendable multi-stage rockets.
4. The main projected advantage of the SSTO concept is elimination of the hardware replacement inherent in expendable launch systems.
5. However, the non-recurring costs associated with design, development, research and engineering (DDR&E) of reusable SSTO systems are much

higher than expendable systems due to the substantial technical challenges of SSTO, assuming that those technical issues can in fact be solved.

6. SSTO vehicles may also require a significantly higher degree of regular maintenance.
7. It is marginally possible to launch a single-stage-to-orbit chemically fuelled spacecraft from Earth.
8. The principal complicating factors for SSTO from Earth are high orbital velocity of over 7,400 metres per second (27,000 km/h; 17,000 mph); the need to overcome Earth's gravity, especially in the early stages of flight; and flight within Earth's atmosphere, which limits speed in the early stages of flight due to drag, g, and influences engine performance.
9. Advances in rocketry in the 21st century have resulted in a substantial fall in the cost to launch a kilogram of payload to either low Earth orbit or the International Space Station, reducing the main projected advantage of the SSTO concept.

➤ TWO STAGES TO ORBIT:

1. A two-stage-to-orbit (TSTO) or two-stage rocket launch vehicle is a spacecraft in which two distinct stages provide propulsion consecutively in order to achieve orbital velocity.
2. It is intermediate between a three-stage-to-orbit launcher and a hypothetical single-stage-to-orbit (SSTO) launcher.
3. At liftoff the first stage is responsible for accelerating the vehicle. At some point the second stage detaches from the first stage and continues to orbit under its own power.
4. An advantage of such a system over single-stage-to-orbit is that most of the dry mass of the vehicle is not carried into orbit.
5. This reduces the cost involved in reaching orbital velocity, as much of the structure and engine mass is ejected, and a larger percentage of the orbited mass is payload mass.
6. An advantage over three or more stages is a reduction in complexity and fewer separation events, which reduces cost and risk of failure.
7. It is not always clear when a vehicle is a TSTO, due to the use of strap-on booster rockets at launch. These are dropped early on in the flight and may or may not be considered an additional stage if the core engine(s) continue firing.

8. These are sometimes considered half a stage, leading to the expression one-and-a-half-stage-to-orbit (1.5STO) e.g., for the Long March 5B or the Atlas missile, which was a single core stage with additional boosters.
9. Similarly, two-stage designs with additional boosters can be referred to as 2.5-stage rockets e.g., the Ariane 5 or most Atlas V variants.

❖ **Landing Systems:**

BRAKING:

- These are landing systems that employ parachutes and bolstered hard landings, like in a splashdown at sea or a touchdown at land.
- Though such systems have been in use since the beginning of astronautics to recover space vehicles, particularly crewed space capsules, only later have the vehicles been reused.

E.g.:

1. Space Shuttle Solid Rocket Boosters.
2. Space Shuttle growth study recoverable liquid boosters.



Fig 2.1

HORIZONTAL:

Single or main stages, as well as fly-back boosters can employ a horizontal landing system.

Examples are:

1. Space Shuttle orbiter - as part of the main stage
2. Venturestar - a project of NASA
3. Space Shuttle's studied fly-back booster
4. Energia II ("Uragan") - an alternative Buran launch system concept



Fig 2.2

VERTICAL:

- Systems like the McDonnell Douglas DC-X (Delta Clipper) and those by SpaceX are examples of retrograde systems. Falcon 9 and Falcon Heavy boosters land using one of their nine engines.
- The Falcon 9 rocket is the first orbital rocket to vertically land its first stage on the ground. Both stages of Starship are planned to land vertically.
- Retrograde landing typically requires about 10% of the total first-stage propellant.



Fig 2.3

CHAPTER III: INTRODUCTION TO CATIA V5

3.1 Introduction

CATIA V5 (Computer-Aided Three-dimensional Interactive Application) is a powerful CAD (Computer-Aided Design), CAM (Computer-Aided Manufacturing), and CAE (Computer-Aided Engineering) software suite developed by Dassault Systèmes. It is widely used across various industries such as aerospace, automotive, shipbuilding, and industrial design. CATIA V5 is known for its versatility, advanced design tools, and ability to handle complex engineering projects. Here are some of its key features:

1. 3D Design and Modelling:

- Parametric Modeling: CATIA V5 allows users to create and modify 3D models using parametric constraints, which means that designs can be easily adjusted by changing key parameters, making the software highly adaptable.
- Wireframe, Surface, and Solid Modeling: CATIA V5 supports multiple types of modeling techniques including wireframe, surface, and solid modeling. This flexibility makes it suitable for designing complex shapes, from simple mechanical parts to intricate surfaces like car bodies or aircraft wings.
- Generative Shape Design (GSD): A specialized module for creating complex freeform surfaces using advanced surface modeling techniques. It is particularly useful in industries like automotive and aerospace for designing aerodynamic surfaces.

2. Assembly Design

- Top-Down and Bottom-Up Design: CATIA V5 supports both top-down and bottom-up assembly design approaches, allowing designers to create individual parts and assemble them or create a structure and build components within it.
- Constraint Management: CATIA V5 provides tools for applying and managing constraints between components in an assembly, ensuring that parts behave correctly in relation to each other when assembled.
- Large Assembly Management: CATIA V5 is optimized for handling large assemblies with thousands of parts, offering performance features

like visualization tools and simplified representations to manage complexity.

3. Product Lifecycle Management (PLM) Integration

- Integration with ENOVIA: CATIA V5 can integrate with ENOVIA, Dassault Systèmes' PLM (Product Lifecycle Management) software, enabling collaboration across the entire product lifecycle, from design to manufacturing and maintenance.
- Data Management: CATIA V5 supports the management of design data, including version control, allowing teams to track changes and collaborate efficiently on complex projects.

4. Advanced Simulation and Analysis

- Finite Element Analysis (FEA): CATIA V5 includes tools for structural analysis, enabling designers to perform FEA simulations to test how designs will react to real-world forces, stress, and environmental conditions.
- Kinematic Simulation: CATIA V5 can simulate the motion of mechanical systems, making it easier to analyze and validate complex assemblies with moving parts.
- Manufacturing Simulation (CAM): CATIA V5 offers integrated CAM functionality that allows users to simulate and optimize machining processes, reducing time-to-production and errors in manufacturing.

3.2 Minor Project

PROBLEM STATEMENT: - Gather information about nozzles and its type and create a 3D structure of any type of nozzle in Catia V5.

SOLUTION: - Here is the information about nozzle and its type and I have made a 3D Bell type nozzle in Catia V5.

NOZZLE

A nozzle is a device that controls the direction or characteristics of a fluid flow as it exits a pipe or enclosed chamber. It can be a short tube with a constriction or taper that is attached to the end of a hose to direct or speed up the flow of fluid.

Types of Nozzles are:

- a. **Conical Nozzle:** A conical nozzle is a type of rocket or jet engine nozzle with a conical or tapering shape, typically used to direct and accelerate exhaust gases from a combustion chamber to produce thrust. The nozzle converts the high-pressure, high-temperature gases produced by combustion into a high-speed exhaust stream, generating thrust according to Newton's third law of motion.



Fig 3.1

- b. **Bell Nozzle:** A bell nozzle (also known as a contour nozzle or de Laval nozzle) is a type of rocket engine nozzle designed to optimize the expansion and acceleration of exhaust gases, improving the efficiency of thrust generation compared to simpler designs like the conical nozzle. The bell-shaped contour helps to maximize the conversion of thermal energy from the combustion chamber into kinetic energy, resulting in higher exhaust velocities and more efficient thrust production.



Fig 3.2

- c. **Annular Nozzle:** An annular nozzle is a type of nozzle where the flow of fluid or gas is directed through an annular (ring-shaped)

opening, rather than a conventional circular or conical one. This design forms a thin, cylindrical sheet of gas or fluid as it exits the nozzle. Annular nozzles are often used in applications where a uniform, high-velocity flow over a large surface area is required



Fig 3.3

- d. **Aerospike nozzle:** An aerospike nozzle is an advanced type of rocket engine nozzle designed to maintain high efficiency across a wide range of altitudes, unlike traditional bell-shaped or conical nozzles that are optimized for either low or high altitude. Aerospike nozzles can self-adjust their exhaust flow based on atmospheric pressure, making them highly efficient for space launch systems.



Fig 3.4

CHAPTER IV: METHODOLOGY

4.1 NASA CEA: Introduction and Application

NASA CEA (Chemical Equilibrium with Applications) is a software tool developed by NASA that allows users to compute chemical equilibrium compositions and properties of complex mixtures. It is widely used in aerospace engineering, thermodynamics, and propulsion analysis.

Key features of NASA CEA include

- Thermodynamic Calculations: It calculates equilibrium compositions, thermodynamic properties, and combustion performance of mixtures. This includes properties like temperature, pressure, and specific heat.
- Rocket Propulsion Applications: One of its primary applications is in rocket propulsion analysis. CEA can compute the performance of rocket engines based on inputs like fuel type, oxidizer, chamber pressure, and mixture ratio.
- Wide Range of Reactions: The software supports a broad range of chemical reactions, including combustion and dissociation, which makes it useful in analysing combustion engines, gas turbines, and other high-temperature systems.
- Output Data: CEA provides detailed output such as adiabatic flame temperatures, isentropic expansion, and chemical species distributions.
- User Input Flexibility: The software accepts different types of input, including specific reactants, mixtures of gases, and initial conditions like pressure and temperature.

Due to its precision in simulating real-world chemical reactions and thermodynamic properties, NASA CEA is commonly used by engineers, scientists, and researchers involved in aerospace and combustion system design.

4.1.1 Application of NASA CEA

NASA CEA (Chemical Equilibrium with Applications) has a broad range of applications, particularly in fields related to thermodynamics, combustion, and propulsion. Here are some key areas where CEA is commonly used:

1. Rocket Propulsion Design

- Performance Analysis: NASA CEA is extensively used to predict the performance of rocket engines. It helps in calculating thrust, specific

impulse, and exhaust velocity based on the chosen propellant mixture, chamber pressure, and nozzle expansion ratio.

- Propellant Selection: By simulating various fuel and oxidizer combinations, CEA aids in choosing optimal propellants for rocket engines to achieve maximum efficiency.
- Combustion Chamber Analysis: It provides insights into combustion processes inside rocket engines, including flame temperature, pressure distribution, and chemical species present.

2. Gas Turbine Engines

- Combustion Process Simulation: CEA helps in modeling and optimizing the combustion process within gas turbine engines. It calculates temperatures, pressures, and compositions to ensure efficient combustion and minimal pollutants.
- Fuel Optimization: The software is used to evaluate different fuel types and their performance in gas turbines, helping with the design of more efficient and environmentally friendly engines.

3. Aerospace Vehicle Design

- Atmospheric Entry: CEA helps in understanding the thermodynamics and chemical reactions that occur during high-speed atmospheric re-entry of spacecraft. The software predicts how various gases will react and behave under extreme temperatures and pressures.
- High-Speed Flight: For hypersonic aircraft and spacecraft, CEA is used to model the chemical behaviour of air (or other atmospheres) as it is compressed and heated in engines or during re-entry.

4. Combustion Analysis

- Flame Temperature Prediction: The software can predict adiabatic flame temperatures for various fuels and oxidizers, which is essential for designing efficient combustion systems.
- Emissions Control: It helps in understanding the formation of pollutants like NO_x and CO during combustion processes, which is important for designing low-emission engines.

4.2 NASA CEA Project:

PROJECT Statement: Calculate specific impulse for different rocket fuels and oxidisers for different cases and paste the results.

CASE 1

THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM

COMPOSITION DURING EXPANSION FROM INFINITE AREA COMBUSTOR

Pin = 14.7 PSIA
CASE = _____

	REACTANT	WT FRACTION (SEE NOTE)	ENERGY KJ/KG-MOL	TEMP K
FUEL	RP-1	1.0000000	-24717.700	298.150
OXIDANT	O2(L)	1.0000000	-12979.000	90.170

O/F= 2.00000 %FUEL= 33.333333 R,EQ.RATIO= 1.702833 PHI,EQ.RATIO= 1.702833

	CHAMBER	THROAT	EXIT	EXIT	EXIT
Pinf/P	1.0000	1.7329	95.000	1.0032	146.14
P, BAR	1.0132	0.58473	0.01067	1.0100	0.00693
T, K	2958.91	2808.69	1567.59	2958.04	1443.74
RHO, KG/CU M	8.2964-2	5.1106-2	1.7371-3	8.2732-2	1.2261-3
H, KJ/KG	-859.93	-1509.99	-5017.37	-863.80	-5271.23
U, KJ/KG	-2081.23	-2654.13	-5631.37	-2084.65	-5836.68
G, KJ/KG	-41022.3	-39633.4	-26294.9	-41014.4	-24867.7
S, KJ/(KG)(K)	13.5734	13.5734	13.5734	13.5734	13.5734
M, (1/n)	20.144	20.411	21.228	20.145	21.229
(dLV/dLP)t	-1.02855	-1.02121	-1.00005	-1.02850	-1.00001
(dLV/dLT)p	1.5791	1.4511	1.0017	1.5783	1.0005
Cp, KJ/(KG)(K)	7.0311	6.0755	2.0585	7.0259	2.0487
GAMMAS	1.1336	1.1363	1.2359	1.1336	1.2366
SON VEL, M/SEC	1176.6	1140.2	871.1	1176.4	836.2
MACH NUMBER	0.000	1.000	3.310	0.075	3.552

PERFORMANCE PARAMETERS

Ae/At	1.0000	11.634	8.0000	16.000
CSTAR, M/SEC	1738.8	1738.8	1738.8	1738.8
CF	0.6558	1.6584	0.0506	1.7082
Ivac, M/SEC	2143.7	3096.5	13954.4	3160.7
Isp, M/SEC	1140.2	2883.6	88.0	2970.3

Fuel: RP-1 (Kerosene)

Oxidizer: Liquid Oxygen

Specific Impulse: 302.78 sec

CASE 2

THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM
COMPOSITION DURING EXPANSION FROM INFINITE AREA COMBUSTOR

Pin = 14.7 PSIA
CASE = _____

	REACTANT	WT FRACTION (SEE NOTE)	ENERGY KJ/KG-MOL	TEMP K
FUEL	RP-1	1.0000000	-24717.700	298.150
OXIDANT	N2O4(L)	1.0000000	-17549.000	298.150

O/F= 2.00000 %FUEL= 33.333333 R, EQ. RATIO= 2.448207 PHI, EQ. RATIO= 2.448207

	CHAMBER	THROAT	EXIT	EXIT	EXIT
Pinf/P	1.0000	1.8247	95.000	1.0035	161.02
P, BAR	1.0132	0.55528	0.01067	1.0097	0.00629
T, K	2038.56	1788.19	809.76	2037.06	784.01
RHO, KG/CU M	1.0992-1	6.8709-2	2.9775-3	1.0962-1	1.8428-3
H, KJ/KG	-716.67	-1236.37	-3354.39	-719.86	-3538.91
U, KJ/KG	-1638.46	-2044.54	-3712.60	-1640.97	-3880.40
G, KJ/KG	-27950.4	-25125.3	-14172.2	-27933.5	-14012.7
S, KJ/(KG)(K)	13.3593	13.3593	13.3593	13.3593	13.3593
M, (1/n)	18.388	18.397	18.795	18.388	19.089
MW, MOL WT	18.388	18.397	18.473	18.388	18.466
(dLV/dLP)t	-1.00032	-1.00007	-1.06228	-1.00032	-1.06358
(dLV/dLT)p	1.0086	1.0020	2.4650	1.0085	2.5474
Cp, KJ/(KG)(K)	2.1444	2.0391	17.3575	2.1436	18.5466
GAMMAS	1.2725	1.2861	1.1020	1.2726	1.0975
SON VEL, M/SEC	1083.1	1019.5	628.3	1082.7	612.2
MACH NUMBER	0.000	1.000	3.656	0.074	3.881

PERFORMANCE PARAMETERS

Ae/At	1.0000	10.243	8.0000	16.000
CSTAR, M/SEC	1446.5	1446.5	1446.5	1446.5
CF	0.7048	1.5879	0.0552	1.6425
Ivac, M/SEC	1812.2	2452.8	11611.8	2519.5
Isp, M/SEC	1019.5	2296.8	79.9	2375.8

Fuel: RP-1 (Kerosene)

Oxidizer: Nitrogen Tetroxide

Specific Impulse: 242.18 sec

CASE 3

THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM

COMPOSITION DURING EXPANSION FROM INFINITE AREA COMBUSTOR

Pin = 14.7 PSIA
CASE = _____

	REACTANT	WT FRACTION (SEE NOTE)	ENERGY KJ/KG-MOL	TEMP K
FUEL	paraffin	1.000000	-1860600.000	298.150
OXIDANT	O2(L)	1.000000	-12979.000	90.170

O/F= 2.00000 %FUEL= 33.333333 R,EQ.RATIO= 1.661005 PHI,EQ.RATIO= 1.661005

	CHAMBER	THROAT	EXIT	EXIT	EXIT
Pinf/P	1.0000	1.7304	95.000	1.0032	142.78
P, BAR	1.0132	0.58556	0.01067	1.0100	0.00710
T, K	2985.05	2839.27	1625.66	2984.20	1505.35
RHO, KG/CU M	8.5786-2	5.2836-2	1.7563-3	8.5546-2	1.2621-3
H, KJ/KG	-889.51	-1517.03	-4947.05	-893.25	-5185.21
U, KJ/KG	-2070.65	-2625.30	-5554.33	-2073.96	-5747.48
G, KJ/KG	-40086.6	-38800.0	-26293.8	-40079.2	-24952.2
S, KJ/(KG)(K)	13.1312	13.1312	13.1312	13.1312	13.1312
M, (1/n)	21.013	21.301	22.258	21.015	22.260
(dLV/dLP)t	-1.03180	-1.02424	-1.00008	-1.03175	-1.00003
(dLV/dLT)p	1.6430	1.5136	1.0028	1.6423	1.0010
Cp, KJ/(KG)(K)	7.2443	6.3341	1.9952	7.2393	1.9751
GAMMA _s	1.1308	1.1324	1.2318	1.1308	1.2337
SON VEL, M/SEC	1155.7	1120.3	864.9	1155.5	832.9
MACH NUMBER	0.000	1.000	3.294	0.075	3.519

PERFORMANCE PARAMETERS

Ae/At	1.0000	11.830	8.0000	16.000
CSTAR, M/SEC	1711.8	1711.8	1711.8	1711.8
CF	0.6544	1.6641	0.0505	1.7123
Ivac, M/SEC	2109.6	3061.9	13737.9	3122.9
Isp, M/SEC	1120.3	2848.7	86.5	2931.1

Fuel: Paraffin wax

Oxidizer: Liquid Oxygen

Specific Impulse: 298.78 sec

CASE 4

THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM

COMPOSITION DURING EXPANSION FROM INFINITE AREA COMBUSTOR

Pin = 14.7 PSIA

CASE = _____

	REACTANT	WT FRACTION (SEE NOTE)	ENERGY KJ/KG-MOL	TEMP K
FUEL	paraffin	1.000000	-1860600.000	298.150
OXIDANT	N2O4(L)	1.000000	-17549.000	298.150

O/F= 2.00000 %FUEL= 33.333333 R, EQ. RATIO= 2.388069 PHI, EQ. RATIO= 2.388069

	CHAMBER	THROAT	EXIT	EXIT	EXIT
Pinf/P	1.0000	1.8242	95.000	1.0035	161.48
P, BAR	1.0132	0.55544	0.01067	1.0098	0.00627
T, K	2058.11	1806.17	815.41	2056.60	789.41
RHO, KG/CU M	1.1343-1	7.0891-2	3.0790-3	1.1312-1	1.9007-3
H, KJ/KG	-746.26	-1249.77	-3303.01	-749.35	-3482.39
U, KJ/KG	-1639.56	-2033.28	-3649.41	-1641.99	-3812.53
G, KJ/KG	-27371.0	-24615.2	-13851.5	-27354.5	-13694.6
S, KJ/(KG)(K)	12.9365	12.9365	12.9365	12.9365	12.9365
M, (1/n)	19.156	19.167	19.572	19.156	19.881
MW, MOL WT	19.156	19.167	19.230	19.156	19.224
(dLV/dLP)t	-1.00035	-1.00008	-1.06218	-1.00035	-1.06422
(dLV/dLT)p	1.0093	1.0022	2.4677	1.0092	2.5693
Cp, KJ/(KG)(K)	2.0674	1.9626	16.7041	2.0665	18.0512
GAMMAS	1.2715	1.2853	1.1022	1.2716	1.0974
SON VEL, M/SEC	1065.7	1003.5	617.9	1065.4	601.9
MACH NUMBER	0.000	1.000	3.660	0.074	3.887

PERFORMANCE PARAMETERS

Ae/At	1.0000	10.217	8.0000	16.000
CSTAR, M/SEC	1424.3	1424.3	1424.3	1424.3
CF	0.7045	1.5876	0.0552	1.6424
Ivac, M/SEC	1784.3	2414.5	11433.9	2480.4
Isp, M/SEC	1003.5	2261.3	78.6	2339.3

Fuel: Paraffin wax

Oxidizer: Nitrogen Tetroxide

Specific Impulse: 238.46 s

4.3 OPEN Rocket: Introduction and Application

Open Rocket is an open-source software designed for the simulation, design, and analysis of model rockets. It is a powerful tool for hobbyists, educators, and engineers who are involved in rocketry projects, particularly for those building small or amateur rockets. The software provides a user-friendly interface and a wide range of features to help users simulate rocket flights and analyse various aspects of rocket performance.

Key Features of Open Rocket:

Rocket Design:

- 3D Design Interface: Open Rocket offers a graphical interface that allows users to design rockets in a 3D environment, specifying components such as body tubes, nose cones, fins, and motors.
- Component Library: It includes a vast library of common rocket parts, and users can also input custom parts for their designs.

Flight Simulation:

- Trajectory Prediction: The software simulates the flight path of the rocket, considering factors like wind, weight distribution, motor thrust, and drag. Users can predict apogee, descent rates, and landing locations.
- Multiple Stages: Open Rocket supports the design and simulation of multi-stage rockets, which are common in advanced rocketry.
- Recovery Systems: The software models the behaviour of recovery systems, such as parachutes, to estimate safe landings and deployment success.

Aerodynamic Analysis:

- Stability Calculations: Open Rocket automatically calculates the centre of gravity (CG) and centre of pressure (CP), helping to ensure that the rocket is stable during flight.
- Drag Estimation: It estimates aerodynamic drag and its impact on flight performance using empirical models.

Motor Performance:

- Thrust Curves: The software integrates motor performance data (thrust curves) to simulate realistic motor behaviour. It supports a wide range of motors, including commercial model rocket motors.

- **Motor Selection:** Users can choose from various rocket motors to see how different propulsion choices affect rocket performance.

Graphical Outputs:

- **Flight Analysis Graphs:** Open Rocket provides detailed graphs for various flight parameters such as altitude, velocity, acceleration, and thrust over time.
- **Wind Effects:** Users can simulate different wind conditions and visualize how they affect the rocket's trajectory and stability.

4.4 OPEN Rocket: Project

PROJECT Statement: Design a rocket and do the simulation by comparing the results of using different rocket engines and plot the graph for the same.

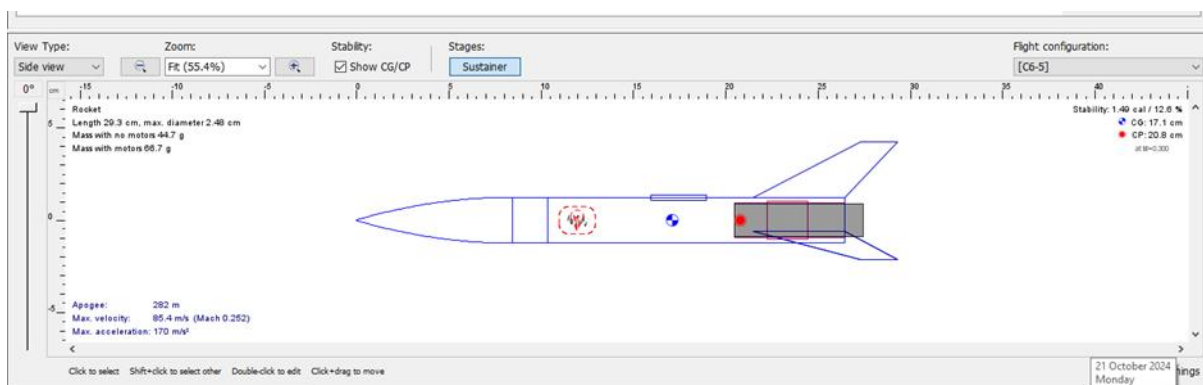


Fig 4.1 2D Model of Rocket (Side)

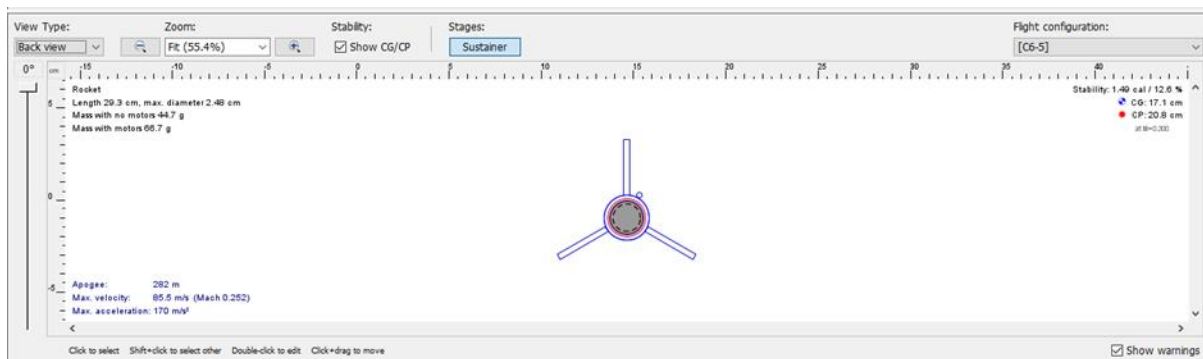


Fig 4.2 2D Model of Rocket (Back)

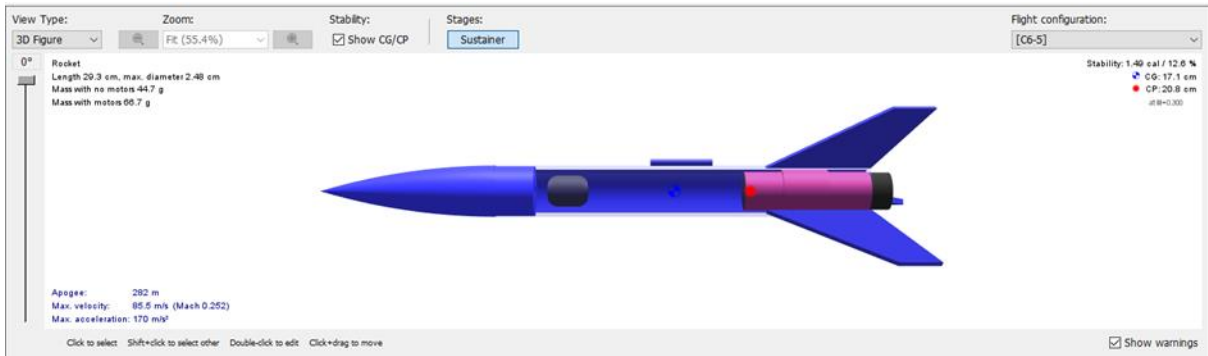


Fig 4.3 3D Model of Rocket (Internal)

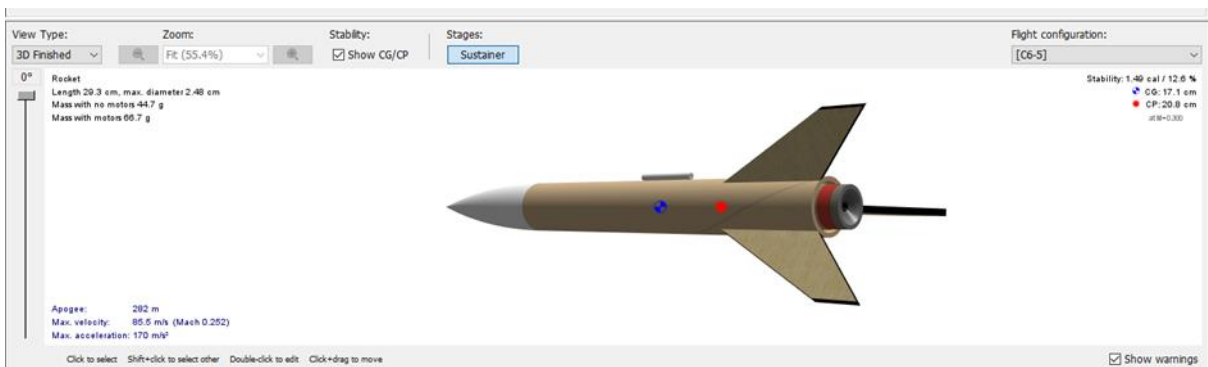


Fig 4.4 3D Model of Rocket (Exterior)

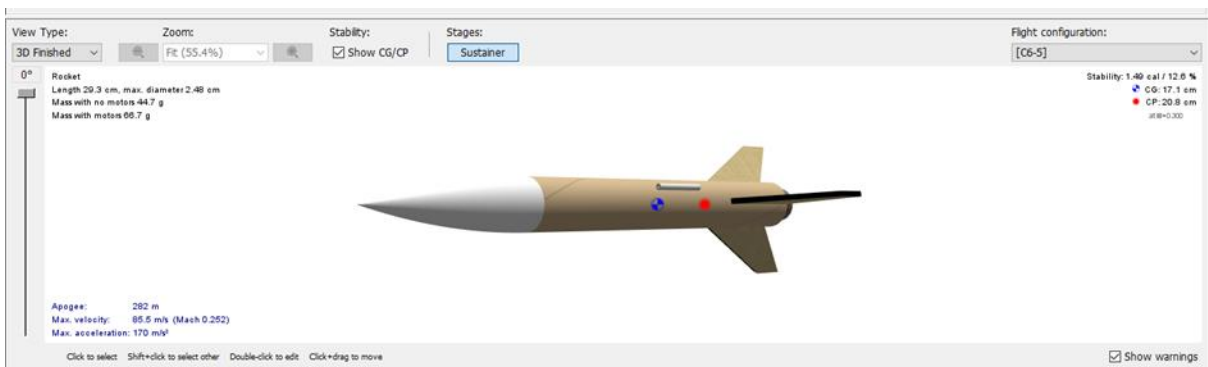
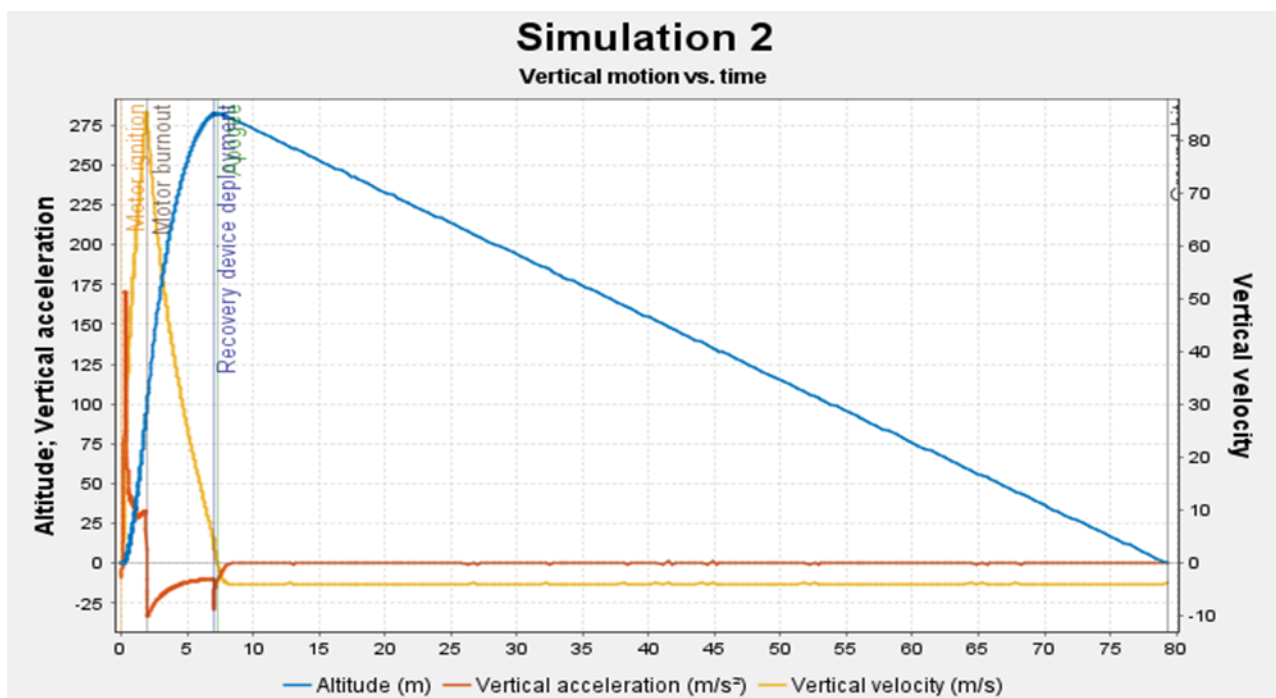
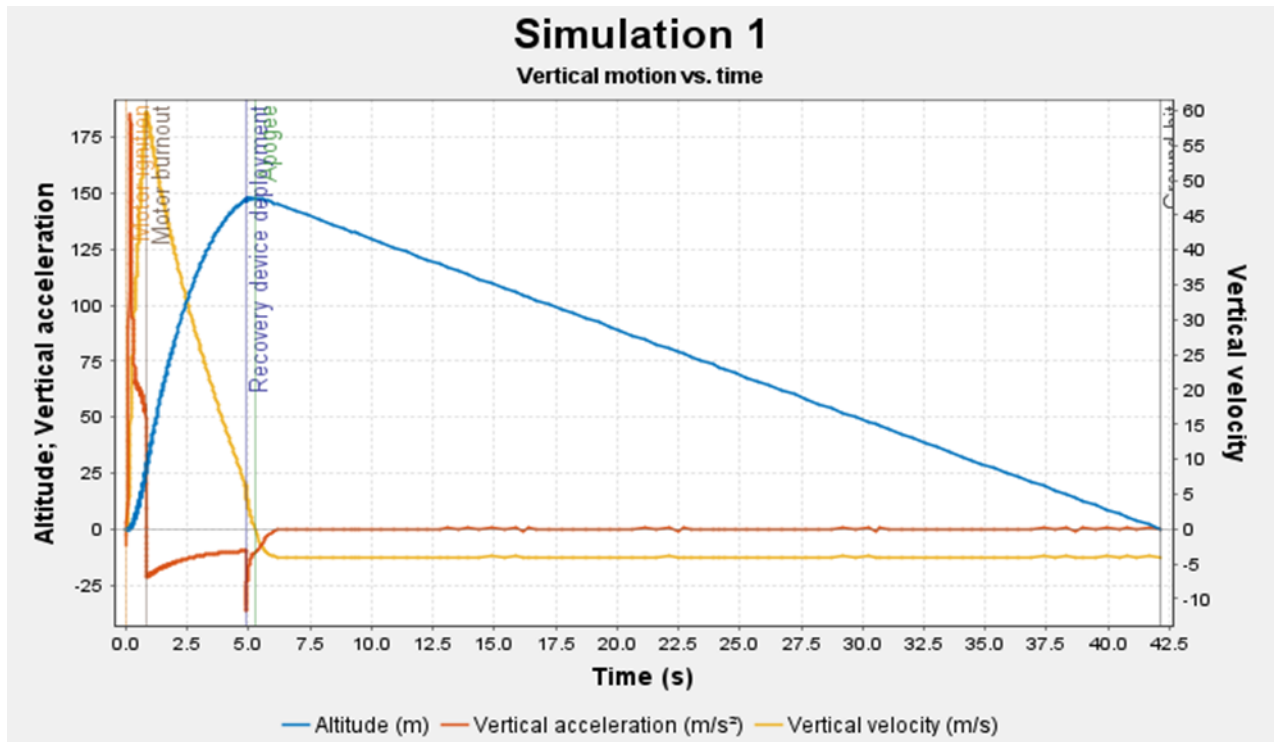


Fig 4.5 3D Model of Rocket (Exterior)

CHAPTER V: - RESULT OF PROJECT

5.1 Graph Result:



Simulation 1 Interpretation:

The graph titled "Simulation 1: Vertical motion vs. time" shows three variables—altitude (m), vertical acceleration (m/s^2), and vertical velocity (m/s)—plotted over time (in seconds). Here's a breakdown of the key features:

Altitude (Blue Line, left axis):

1. The altitude rises sharply at the beginning, reaching a peak at around 4 seconds, after which it starts to decrease gradually.
2. This pattern suggests that the object, perhaps a rocket or projectile, undergoes a rapid ascent, followed by a gradual descent.

Vertical acceleration (Orange Line, left axis):

1. There is a steep rise in acceleration initially, peaking around 1.5 seconds, followed by a sharp drop into negative values by about 2.5 seconds.
2. After this point, the acceleration fluctuates slightly around zero, indicating that the object experiences some form of stabilization.
3. The initial positive acceleration represents the powered phase, while the negative acceleration corresponds to deceleration (possibly due to gravity or air resistance) after motor burnout.

Vertical Velocity (Yellow Line, right axis):

1. The vertical velocity increases during the initial ascent (positive values), reaches a peak, and then starts decreasing.
2. Around the 3-second mark, the velocity crosses zero, which suggests the object has reached its peak altitude and begins descending.
3. The velocity stabilizes at a small negative value, indicating a controlled or slowed descent, likely due to a parachute or another recovery device.

Key Phases:

- Motor Burnout: Around 1.5-2 seconds, the acceleration sharply turns negative, marking the end of the propulsion phase.
- Apogee (Peak Altitude): At about 4 seconds, the altitude peaks, and the velocity crosses zero, indicating the transition from ascent to descent.
- Recovery Device Deployment: The graph suggests stabilization of velocity and acceleration after around 4-5 seconds, likely due to the deployment of a parachute or some other recovery mechanism, as indicated by the relatively slow and controlled descent.

Overall Interpretation:

The graph represents a typical flight profile of a rocket or similar object. The object is propelled upwards, reaches a peak altitude, and then decelerates due to gravity. After reaching apogee, it descends, with a recovery system stabilizing the fall, ensuring a controlled landing.

Simulation 2 Interpretation:

The graph, titled "Simulation 2: Vertical motion vs. time," shows the vertical dynamics of an object like the first simulation, but with some key differences in scale and duration. Here's an analysis of the data presented:

Variables:

Altitude (Blue Line, left axis):

1. The object climbs more gradually compared to Simulation 1, reaching a peak altitude of around 275 meters at approximately 6 seconds.
2. After reaching the peak altitude, the object begins a slow and steady descent over a much longer period than in Simulation 1, with the descent extending until around 75 seconds.

Vertical Acceleration (Orange Line, left axis):

1. The vertical acceleration starts with a sharp increase, similar to Simulation 1, and reaches a peak around 2 seconds.
2. After motor burnout (around 2.5 seconds), the acceleration quickly drops into negative territory, indicating deceleration due to gravity.
3. The acceleration levels out around 5 seconds, hovering close to zero for the remainder of the simulation, which implies a more stable, controlled descent.

Vertical Velocity (Yellow Line, right axis):

1. The velocity increases rapidly in the first few seconds, reflecting the upward thrust during the powered ascent.
2. As the velocity peaks, it crosses zero around 6 seconds (the point of maximum altitude or apogee), after which the object starts descending.
3. The velocity remains negative during descent, indicating a controlled fall at a stable rate, like Simulation 1 but more prolonged.

Conclusion of the results:

This simulation reflects the flight profile of an object, such as a rocket, that ascends to a higher altitude and takes longer to descend compared to Simulation 1. The increased altitude and longer descent time suggest a more powerful launch and a more gradual recovery system, possibly involving a larger parachute or other deceleration mechanisms. The object follows the same basic phases of thrust, apogee, and controlled descent but over a much larger time and altitude scale.

CONCLUSION

During the internship, I learnt the intricacies of rocket propulsion systems, gaining hands-on experience in designing and analysing them and applying theoretical knowledge to tackle real-world aerospace engineering challenges. The internship provided me with advanced knowledge of rocket propulsion principles, nozzle design, and engine performance, alongside proficiency in using software tools for Rocket simulations and performance analysis in CEA and Open Rocket. I gained a deeper understanding of multidisciplinary collaboration within the aerospace industry and honed my problem-solving and critical thinking skills through real-world challenges. This transformative experience has deepened my passion for aerospace engineering, inspiring me to pursue a career in rocket propulsion and space exploration.

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