ABSTRACT

This report includes the overview of **Case Study of Bell Type Rocket Nozzle**.

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 2023.

During the period of 21 days from 26th June 2023 to 16th July 2023, we were trained and explained about

- Introduction and History of Rocket
- Solid and Liquid Propellant Engines
- Hybrid Propellant and Nozzle Theory.

We were also given the task of doing a case study on a particular type of rocket nozzle of our choice which should consist of the following parameters:

Q. Case Study of any type of rocket nozzle.

1. Go through the research papers regarding the topic.
2. Collect all the required information for the design.
3. Make a design by using any designing software.

The report is made up of 6 chapters Chapter

I: Introduction

Chapter II: Rocket Nozzles

Chapter III: Application and advantages of Bell Rocket Nozzle

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CHAPTER I: INTRODUCTION

1.1 About Brahmastra Aerospace and Defence Pvt Ltd

Brahmastra Aerospace & Defence Pt. Ltd. is an Indian company founded in 2019 with a mission to provide top-quality resources, products, and services to the aerospace and defence sectors in India. They aim to bridge the gap between academia and industry by offering comprehensive training programs, technical publications, defence journalism, and R&D support.

1.1.1 Company and its Principles

Brahmastra Aerospace aspires to ascend to the pinnacle of the Aerospace and Defence industry worldwide by the year 2030. Our 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.

Our 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 Brahmastra Aerospace

Brahmastra Aerospace 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 is to do case study on Bell Type Rocket Nozzle with detailed explanation on various types of rocket engines and a detailed analysis on Bell Type Rocket Nozzle.

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.

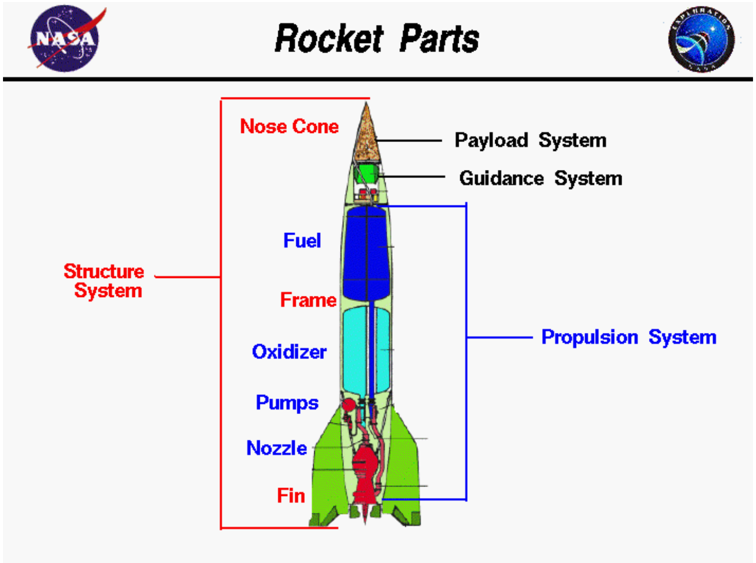


Fig 1.3 Basic Rocket Parts

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.

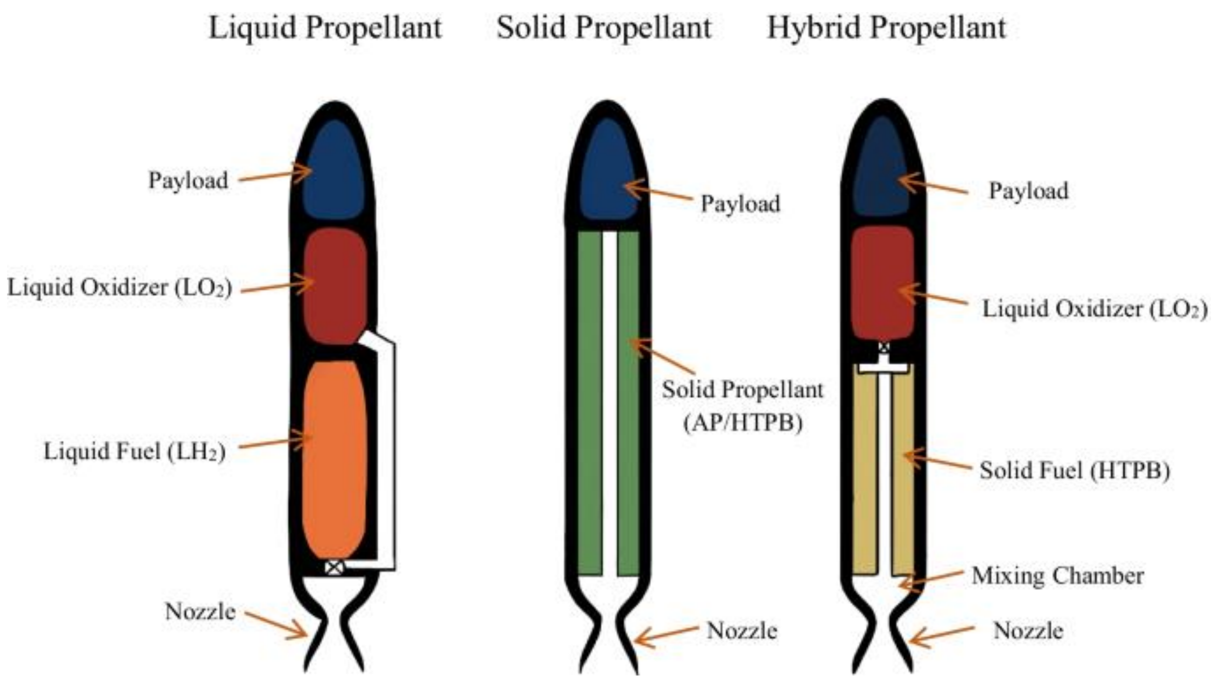


Fig 1.4 Types of Rocket Engine

CHAPTER II: ROCKET NOZZLES

2.1 Introduction to Rocket Nozzles

Rocket nozzles are crucial components of rocket engines that play a fundamental role in the propulsion process. They are designed to efficiently convert the high-pressure and high-temperature gases produced during combustion into a high-velocity exhaust jet, which generates the necessary thrust to propel the rocket through the air or space. The design and operation of rocket nozzles are based on principles of fluid dynamics and thermodynamics.

2.1.1 Importance of Rocket Nozzle

The rocket nozzle plays a crucial role in the performance of a rocket engine. It is a key component responsible for accelerating and directing the high-speed exhaust gases produced during combustion, converting thermal energy into kinetic energy to generate thrust. The design of the nozzle is paramount in optimizing the efficiency of the propulsion system, as it determines the speed of the exhaust gases and, consequently, the velocity of the rocket. A well-designed nozzle ensures that the exhaust gases exit the engine at the highest possible speed, maximizing thrust and fuel efficiency. In essence, the rocket nozzle is instrumental in achieving the necessary thrust for a rocket to overcome gravity and atmospheric resistance, enabling successful space exploration and satellite deployment.

Furthermore, the rocket nozzle is integral to achieving optimal thrust across different altitudes and atmospheric pressures. Its shape, often convergent-divergent, allows for the expansion of exhaust gases, taking advantage of changing environmental conditions during ascent. This adaptability is crucial for rockets traveling through Earth's atmosphere and into space. Additionally, the nozzle contributes to the rocket's stability and control by directing the exhaust in a specific direction. The careful design and engineering of rocket nozzles contribute significantly to the overall performance and success of space missions, making them a critical element in the advancement of space exploration technologies.

Fig 2.1 Rocket Nozzle

2.1.2 Types of Rocket Nozzle

1. Bell-type Rocket Nozzle:

The Bell-type rocket nozzle is a common design characterized by its bell-shaped contour. It consists of a converging section leading to a throat and then a diverging section. This shape allows for efficient expansion of exhaust gases, maximizing thrust. Bell nozzles are widely used in various rocket applications, including launch vehicles and spacecraft. Their simplicity and effectiveness make them a practical choice for many missions, balancing performance and engineering considerations.

2. Conical Rocket Nozzle:

Conical rocket nozzles have a simple and straightforward design, resembling a cone. They are typically used in smaller rockets or thrusters where simplicity and ease of manufacturing are essential. While conical nozzles may not provide the same level of efficiency as more complex designs, they are cost-effective and suitable for applications with specific size and weight constraints.

3. Aerospike Nozzle:

Aerospike nozzles are innovative designs that aim to improve performance across a range of altitudes. Unlike traditional nozzles, aerospike nozzles have a spike-shaped central structure rather than a closed bell. This design allows for better optimization of thrust at various altitudes, making aerospike nozzles particularly effective for single-stage-to-orbit (SSTO) vehicles. The unique design helps maintain high efficiency in both atmospheric and vacuum conditions.

4. Expansion-Deflection (E-D) Nozzle:

The Expansion-Deflection (E-D) nozzle is a versatile design that combines elements of a bell-type and an aerospike nozzle. It incorporates a movable central plug that can be adjusted during flight to optimize nozzle expansion for varying altitudes. This adaptability enhances efficiency across a range of atmospheric pressures. E-D nozzles are of interest in applications where altitude variability is significant, providing a compromise between the simplicity of traditional nozzles and the adaptability of aerospike designs.

In summary, the choice of rocket nozzle design depends on specific mission requirements, including altitude variation, payload characteristics, and cost considerations. Each nozzle type offers a trade-off between complexity, adaptability, and performance, allowing engineers to tailor their selection to the unique demands of a particular space mission.

2.2 Bell type Rocket Nozzle

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 Overview of Bell Rocket Nozzle

The bell-type rocket nozzle is a fundamental component in rocket propulsion, known for its distinctive bell-shaped design. Consisting of a converging section, a throat, and a diverging section, this nozzle efficiently directs and accelerates the high-speed exhaust gases produced during combustion. As the gases pass through the converging section, they reach supersonic speeds at the throat, optimizing kinetic energy. The subsequent diverging section allows for further expansion, converting thermal energy into propulsive thrust.

This design is valued for its simplicity, reliability, and effectiveness, making it a prevalent choice for a wide range of rocket applications, including launch vehicles and spacecraft. While its efficiency is tailored to specific altitudes, the bell-type rocket nozzle stands out for its practicality and proven performance in the realm of rocketry.

2.2.2 Working Principle

The working principle of Bell Type Rocket Nozzle are: -

1. <u>Conservation of Mass, Momentum, and Energy</u>:

- The operation of a bell nozzle is based on the fundamental principles of physics, including the conservation of mass, momentum, and energy.
- The nozzle ensures that the mass flow rate of the exhaust gases remains constant throughout its operation. This means that the mass entering the nozzle's inlet must be equal to the mass exiting the nozzle's exit.
- As the exhaust gases pass through the nozzle, momentum is conserved. The gradual decrease in the cross-sectional area in the converging section causes an increase in the gas velocity, in accordance with the principle of conservation of momentum.
- The nozzle also facilitates the conversion of the high-pressure energy of the exhaust gases from the combustion chamber into high-velocity kinetic energy. This conversion is achieved through the expansion of the gases in the diverging section, in accordance with the principle of conservation of energy.

2. <u>Converging Section</u>:

- The converging section of the bell nozzle is responsible for accelerating the exhaust gases. It has a gradually decreasing cross-sectional area, which causes the gases to accelerate as they pass through.
- The shape of the converging section is typically designed to follow a specific curve, such as the De Laval profile, which optimizes the gas flow for maximum efficiency.
- As the gases enter the converging section, they experience a decrease in the available volume, leading to an increase in their velocity. This acceleration ensures that the gases reach the throat at high velocities.

3. <u>Throat</u>:

- The throat is the narrowest point in the bell nozzle, located at the end of the converging section. It is a critical component that plays a significant role in the nozzle's operation.
- The throat is designed to achieve choked flow, which occurs when the flow velocity of the gases reaches the speed of sound. At choked flow conditions, the flow velocity remains constant regardless of the downstream pressure.
- To achieve choked flow, the throat area is carefully sized. The area ratio (AR), defined as the ratio of the exit area to the throat area, is an important parameter. A converging section with an optimal AR leads to the desired choked flow at the throat.

4. <u>Diverging Section</u>:

- The diverging section follows the throat and has an expanding cross-sectional area. It allows for further expansion and acceleration of the exhaust gases.
- The increasing cross-sectional area in the diverging section causes the gases to decelerate and convert their high-pressure energy into high-velocity kinetic energy.
- The design of the diverging section, including the rate of expansion, is crucial for maximizing the thrust efficiency of the nozzle.
- The expansion ratio, defined as the ratio of the exit area to the throat area, is an important parameter in the design of the diverging section. It determines the extent of expansion and the resulting gas velocity at the nozzle exit.

5. Thrust Generation:

- The operation of the bell nozzle results in the generation of thrust, which propels the rocket forward.
- According to Newton's third law of motion, for every action, there is an equal and opposite reaction. As the high-velocity exhaust gases exit the diverging section, they create a force in the opposite direction, known as thrust.
- The efficient expansion and acceleration of the gases in the bell nozzle maximize the momentum and energy imparted to the exhaust gases, resulting in a higher thrust.

In summary, the bell nozzle operates on the principles of conservation of mass, momentum, and energy. The converging section accelerates the exhaust gases, the throat achieves choked flow, and the diverging section further expands and accelerates the gases. These processes lead to efficient thrust generation, with the high-velocity exhaust gases creating a reaction force that propels the rocket forward.

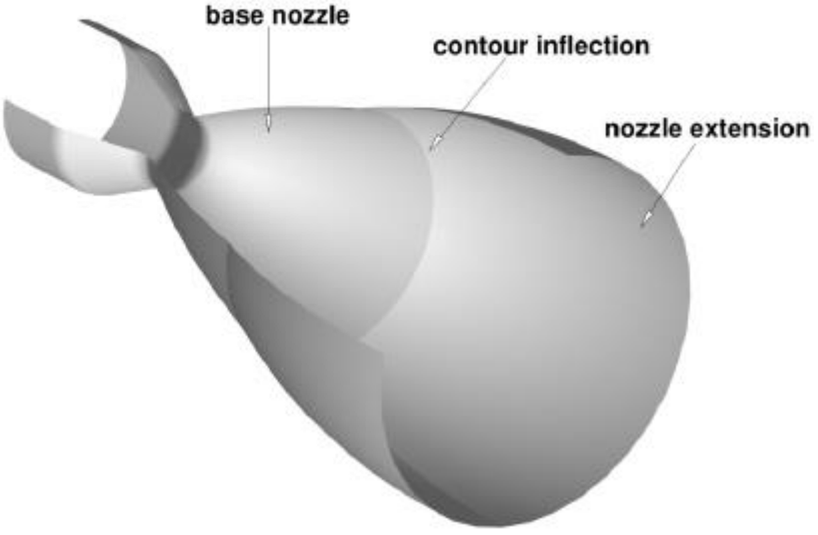


Fig 2.2 Bell Nozzle

CHAPTER III: APPLICATION AND ADVANTAGES OF BELL ROCKET NOZZLE

3.1 Application of Bell Rocket Nozzle

A bell-type rocket nozzle is a specific design of a rocket nozzle used in rocket propulsion systems. The shape of the nozzle is bell-like, and it is optimized for certain applications to improve rocket performance. Here are some applications of bell-type rocket nozzles:

1. High-Speed Rocketry:

- Bell nozzles are often used in high-speed rocketry, where the exhaust gases reach supersonic or even hypersonic speeds. The bell shape allows for efficient expansion of these high-speed gases, maximizing thrust and efficiency.

2. Space Launch Vehicles:

- Bell nozzles are commonly found in the upper stages of space launch vehicles. They are designed to operate efficiently in the vacuum of space, where atmospheric pressure is negligible. The bell shape is well-suited for optimizing the expansion of exhaust gases in a vacuum.

3. Interplanetary Missions:

- Spacecraft that travels to other planets or celestial bodies often use bell-type nozzles. These missions require efficient propulsion systems to cover large distances in space. The bell design helps achieve optimal performance in the vacuum of outer space.

4. Satellite Manoeuvring:

- Satellites and spacecraft often need to perform orbital manoeuvres and adjust their trajectories. Bell-type nozzles can be used in small thrusters for precise and efficient control of the spacecraft's orientation and movement.

5. Military Applications:

- Some military rockets and missiles use bell-type nozzles for their propulsion systems. These nozzles can provide the high thrust and efficiency needed for rapid and agile manoeuvres.

6. Space Exploration:

- Bell-type nozzles are used in robotic probes and exploration vehicles sent to other planets or celestial bodies. Their design allows for efficient propulsion in the vacuum of space.

7. Re-entry Vehicles:

- Vehicles re-entering the Earth's atmosphere from space need to manage the intense heat generated during re-entry. Bell nozzles can be part of a propulsion system that assists in controlling the descent and managing the thermal loads.

8. Commercial Rocketry:

- In addition to government and military applications, commercial space companies use bell-type nozzles in their rockets for various purposes, including satellite deployment and space tourism.

In summary, bell-type rocket nozzles find application in a range of scenarios where efficient and optimized propulsion is essential, especially in high-speed and space environments. Their design allows for effective expansion of exhaust gases, maximizing thrust and overall rocket performance.

3.2 Advantages of Bell Rocket Nozzle

The bell-type rocket nozzle offers several advantages that contribute to its widespread use in various rocket propulsion applications. Here are some key advantages:

1. <u>Optimal Thrust Efficiency</u>:

- The bell-shaped design of the nozzle allows for efficient expansion of exhaust gases, maximizing thrust. This is especially crucial in high-speed and space environments where achieving the highest possible velocity is essential for mission success.

2. Adaptability to Variable Pressure Conditions:

- The bell nozzle is versatile and can operate efficiently in both atmospheric and vacuum conditions. It can adapt to changing pressure environments during a rocket's ascent and descent phases, providing consistent performance.

3. High-Speed Performance:

- Bell nozzles are well-suited for applications where rocket speeds reach supersonic or hypersonic levels. The design minimizes losses due to shockwaves and helps maintain high-speed performance.

4. Vacuum Operation:

- In the vacuum of space, traditional nozzles designed for atmospheric conditions may not perform optimally. Bell-type nozzles are designed to operate efficiently in the absence of atmospheric pressure, making them suitable for upper stages of space launch vehicles.

5. Spacecraft Manoeuvrability:

- For space missions requiring precise control and manoeuvrability, bell nozzles provide the necessary thrust with high efficiency. This is crucial for orbital adjustments, trajectory changes, and rendezvous manoeuvres.

6. Thermal Protection during Re-entry:

- In re-entry scenarios, where a spacecraft or re-entry vehicle is transitioning from space to Earth's atmosphere, the bell-type nozzle can assist in managing the intense heat generated during the descent. This is important for the safety and integrity of the vehicle.

7. Payload Flexibility:

- The efficiency of bell nozzles allows for optimization of payload capacity. Rockets equipped with bell-type nozzles can carry larger payloads into space due to the increased thrust efficiency.

8. Proven Technology:

- Bell-type nozzles have been extensively used and tested in various space missions over the years. Their reliability and performance make them a trusted choice for a wide range of applications, from satellite launches to interplanetary exploration.

9. Controlled Combustion and Flow:

- The design of the bell nozzle helps in controlling the combustion and flow of exhaust gases, contributing to stable and predictable rocket performance.

10. Applicability to Different Propellants:

- Bell nozzles can be designed and optimized for different types of propellants, allowing for flexibility in choosing the most suitable fuel for a particular mission.

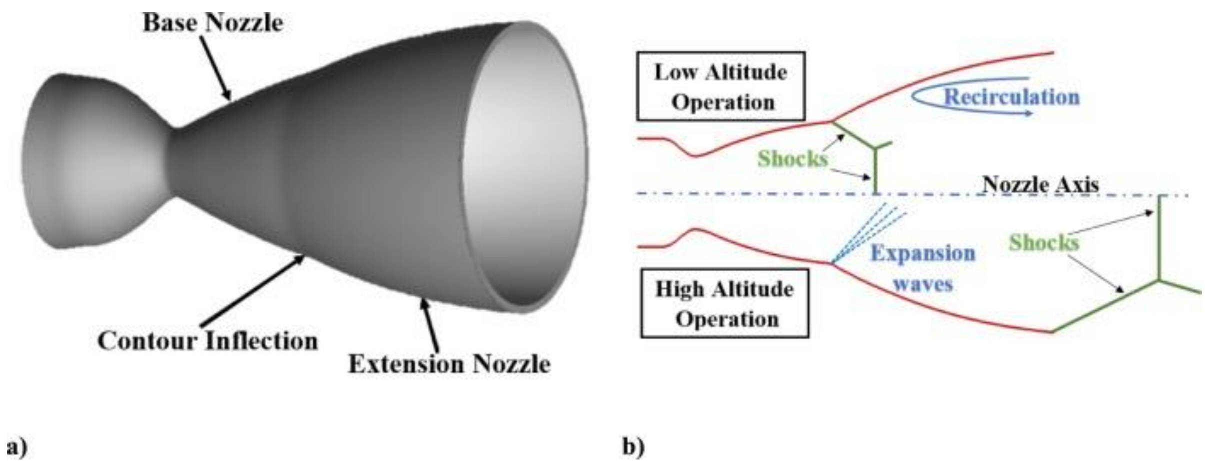


Fig 3.1 Working of Bell Nozzle

CHAPTER IV: METHODOLOGY

4.1 Throat Area:

Throat Area **(A_t)** Calculation Formula:

The throat area is a crucial parameter in rocket nozzle design and is determined by the mass flow rate($\dot{m}$), density at the throat (ρ_t), and velocity at the throat (V_t). Here's a step-by-step breakdown of the calculation:

1. **Mass Flow Rate Of Propellant($\dot{m}$) and Density (ρ_t)**

   - The mass flow rate of propellant through the nozzle is a key parameter and is typically determined based on the desired thrust and other performance criteria. It is given by:

$$\dot{m}=\rho_t \cdot A_t \cdot V_t$$

where ρ_t Is the density at the throat, A_t is the throat area, and V_t is the velocity at the throat.

2. Throat Area Calculation:

   Rearrange the equation to solve for throat area (A_t)

$$A_t=\frac{\dot{m}}{\rho_t \cdot V_t}$$

This equation expresses the throat area in terms of the mass flow rate, density at the throat, and velocity at the throat.

3. Practical Considerations:

   - The throat area is a critical design parameter, and its value is influenced by factors such as the desired thrust, chamber pressure, and the specific impulse of the rocket engine. It is often determined through iterative design processes and may be influenced by empirical data and testing.

4. Units:

- Ensure that the units are consistent throughout the calculation. Mass flow rate is typically in kilograms per second (kg/s) density in kilograms per cubic meter (kg/m^3), and velocity in meters per second (m/s). The resulting throat area will be in square meters (m^2).

5. Verification:

- Verify the calculated throat area against any design constraints or specifications. It's common to iterate on the design to achieve the desired performance characteristics.

In summary, the throat area is calculated by considering the mass flow rate, density at the throat, and velocity at the throat. This calculation is foundational in rocket nozzle design and plays a key role in achieving the desired propulsion performance.

4.2 Exit Area:

The equation you provided is related to the exit area (A_e) calculation in the context of compressible fluid flow, often associated with the isentropic flow equations. The equation you gave is:

$$A_e = A_t \times R \times \left(\frac{P_c}{P_e}\right)^{\frac{2\times(k-1)}{k+1}}$$

Here are the explanations for the variables:

- A_e is the exit area.
- A_t is the throat area.
- P_e is the pressure at the exit.
- P_c is the critical pressure.
- k is the ratio of specific heats.
- R could be the gas constant.

To use this formula, we would need to know the values of the throat area (A_t), critical pressure (P_c), pressure at the exit (P_e), ratio of specific heats (k), and possibly the gas constant (R).

4.3 Expansion Ratio:

The expansion ratio (ER) in the context of fluid dynamics is typically defined as the ratio of the exit area (A_e) to the throat area (A_t). The expansion ratio is an important parameter in the design and analysis of nozzles and diffusers in fluid flow systems. The formula for expansion ratio is given by:

$$ER = A_t A_e$$

Here:

- ER is the expansion ratio.
- A_e is the exit area.
- A_t is the throat area.

The expansion ratio provides information about how much the cross-sectional area of a flow path increases from the throat to the exit. It is a crucial factor in determining the performance of nozzles and diffusers, especially in the context of compressible fluid flow.

If we have specific values for the exit area (A_e) and throat area (A_t), we can use this formula to calculate the expansion ratio.

4.4 Characteristic Velocity Formula

The characteristic velocity in fluid dynamics is often associated with the speed of sound (a) and the specific heat ratio (k). The formula for characteristic velocity ($*C_*$) is given by:

$$C_* = a \cdot k$$

Here:

- $*C_*$ is the characteristic velocity.
- a is the speed of sound in the fluid.
- k is the ratio of specific heats.

The speed of sound (a) is determined by the properties of the fluid and can be calculated using the following formula:

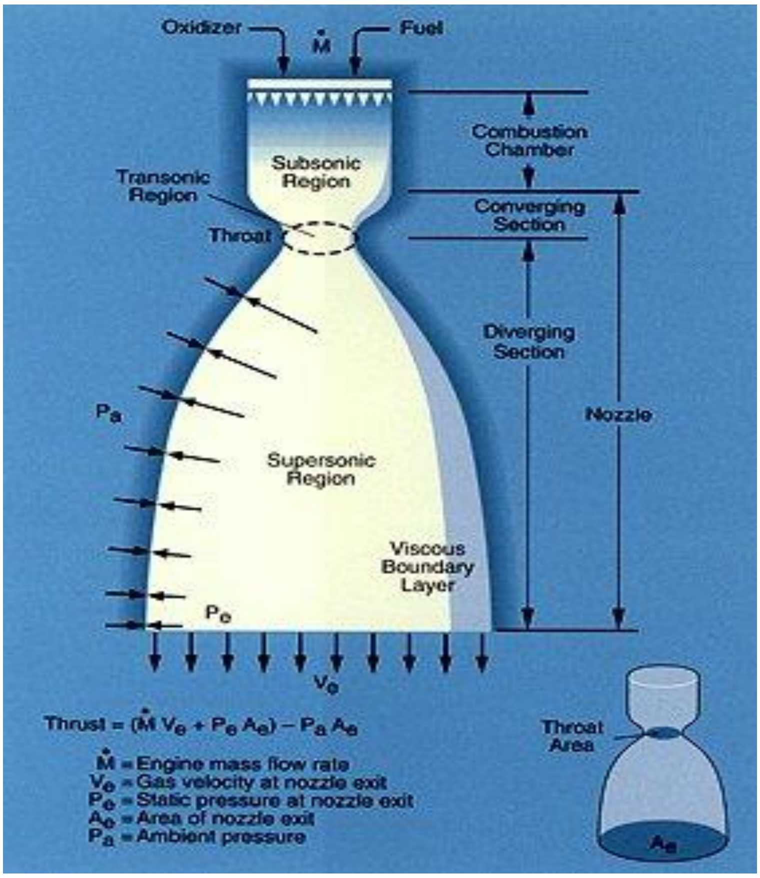
$$\cdot a = \gamma R \cdot T$$

Here:

- R is the specific gas constant.
- T is the absolute temperature of the fluid in Kelvin.
- γ is the ratio of specific heats.

Once you have the speed of sound (a), you can use it in the first formula to find the characteristic velocity ($*C*$).

We have to Keep in mind that these formulas are based on certain assumptions, such as isentropic flow conditions. If our situation deviates from these assumptions, adjustments may be necessary.



4.1 Flow Rate and Throat Area

CHAPTER V: - Result of Case Study

5.1 CAD (Computer Aided Design)

CAD stands for Computer-Aided Design. It is a technology that uses computer systems to assist in the creation, modification, analysis, or optimization of a design. CAD software is used in various industries, including architecture, engineering, product design, and manufacturing.

Key features of CAD include:

1. Precision and Accuracy: CAD software allows designers to create highly accurate and precise drawings or models.

2. Efficiency: CAD tools streamline the design process and make it more efficient compared to traditional manual drafting methods.

3. 3D Modelling: CAD often includes 3D modelling capabilities, allowing designers to create three-dimensional representations of objects or structures.

4. Visualization: CAD allows designers to visualize their designs in a realistic way, facilitating better understanding and communication of the design intent.

5. Collaboration: CAD software often supports collaboration among multiple users, allowing teams to work on a project simultaneously and share design data.

6. Analysis: Some CAD programs offer analysis tools to assess the structural, thermal, or fluid dynamics aspects of a design.

7. Documentation: CAD software enables the creation of detailed documentation, including drawings, specifications, and other necessary information for manufacturing or construction.

CAD has become an integral part of the design and engineering process in many industries, contributing to increased efficiency, reduced errors, and faster product development cycles.

5.2 CAD Model of Bell Type Rocket Nozzle

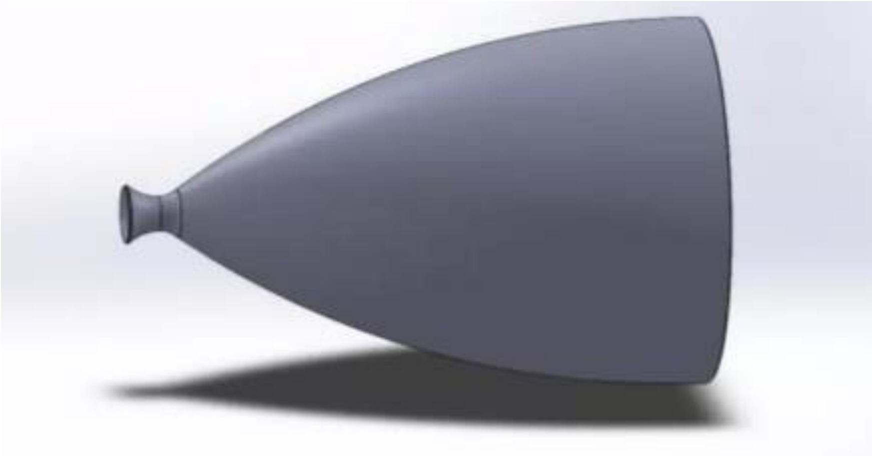


Fig 5.1 Cad Model

5.3 Conclusion of case study

This report studied in detail the design parameters of bell-shaped nozzle with G.V Rao design method. It discussed in detail the contour of bell nozzle, the design of combustion chamber and the materials to be used for walls of nozzle components. The case study on the Bell-type rocket nozzle provides compelling evidence supporting its efficacy and efficiency in rocket propulsion systems. The Bell-type nozzle has proven to be a pivotal component in enhancing the performance of rockets, offering a range of advantages that contribute to its widespread adoption in the aerospace industry.

The efficiency of the Bell-type rocket nozzle is notable in its ability to optimize the exhaust velocity, a critical parameter influencing overall rocket performance. The bell-shaped design allows for controlled and gradual expansion of exhaust gases, preventing shockwaves and ensuring a more efficient conversion of thermal energy. This, in turn, results in improved thrust and fuel efficiency, ultimately enhancing the rocket's overall effectiveness in achieving its mission objectives.

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 CFD simulations and performance analysis. 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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