

Aerospace : Re-entry Vehicle

ASB4341 - Design Project-1 Report

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ABSTRACT

The portion of a spacecraft that is meant to re-enter through Earth's atmosphere is known as a re-entry vehicle. It is designed to withstand extreme heat during high-velocity flight through the atmosphere while also protecting the crew and/or instruments until they reach Earth safely. Although technology has advanced, re-entry vehicles have utilized the same basic design concept since the early Mercury programme. The successful launch of the space shuttle in 1981 demonstrated a number of novel technologies, one of which was the thermal protection system.

The aim of this project is to design and conceptualize a space re-entry vehicle that can carry 4-5 people while re-entering the earth with minimal or no damage to both vehicle and humans. By doing this we can reuse the same re-entry vehicle for another launch mission. This vehicle allows for long range missions with better efficiency and reduced fuel consumption and comfortable journey with all the necessary needs in it.

In the market, a mission profile that is efficient as a result of a well-engineered space vehicle is expected. The above explanation demonstrates the critical role that the combined subject domains of aerodynamics and flight mechanics play in the successful design, accuracy, and evaluation of re-entry vehicles. In addition, the case of planetary probes entering the atmosphere will be explored. Although the ambient levels may change from those found on Earth, the technical formulations and techniques are nearly comparable, as is the methodology.

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SYMBOLS AND ABBREVIATIONS

- A.R - Aspect Ratio
- B - Wing span(m)
- Cd - Drag Coefficient
- CD,0 - Zero lift Drag coefficient
- CP - Specific fuel consumption (lbs / hp / hr)
- CL - Lift Coefficient
- D - Drag(N)
- E - Endurance (hr)
- e - Oswald efficiency factor
- L - Lift (N)
- M - Mach number of aircraft
- MFF - Mission fuel fraction
- R - Range (km)
- Re - Reynolds number
- T - Thrust (N)
- TCruise - Thrust at cruise (N)
- TTake-off - Thrust at take-off (N)
- VCruise - velocity at cruise (m/s)
- VStall - velocity at stall (m/s)
- Vt - Velocity at touch down (m/s)
- WCrew - Crew weight (kg)
- Empty - Empty weight of the vehicle (kg)
- WFuel - Weight of fuel (kg)
- WPayload - Payload of the vehicle (kg)
- W0 - Overall weight (kg)
- ρ - Density of air (kg/m³)
- μ - Dynamic viscosity (Ns/m²)
- R/C - Rate of Climb
- η - Kinematic viscosity (m²/s)

- AAAF - Association Aéronautique et Astronautique de France
- AIAA - American Institute of Aeronautic and Astronautic
- AoA - Angle of Attack
- CG - Center of mass
- CP - Aerodynamic center of pressure
- FPA - Flight Path Angle
- NS - Navier Stokes Code
- MECO - Main Engine Cut Off
- LV - Launch Vehicle
- TPS - Thermal Protection System

CHAPTER 1

INTRODUCTION TO RE-ENTRY MOTION

1.1 Introduction Re-Entry Motion

The entrance of an object from outer space into the atmosphere of the earth or an outer planet's atmosphere is known as atmospheric re-entry. Global strike and space transportation have sparked a surge of interest in hypersonic vehicles for military and civilian uses in recent decades. To satisfy the demand for effective and dependable access to space, the development of sophisticated navigation and control technology for hypersonic reentry vehicles is encouraged. The re-entry vehicle is the major part of a spaceship that returns to Earth. As they fly at speeds many times faster than the speed of sound (Mach No. more than 5), the problem of aerodynamic thermal protection and aerodynamic drag has always been a challenge to be considered in the reentry flight vehicle design. The earth's gravity is also a significant element that generates significant physical changes and phenomena in the vehicle. The inherent thermal resistance of the re-entry vehicle is determined by its form. The thermal environment at the bottom of the flight vehicle is cooler than it is at the top and throughout a vast region. The material, size, and weight of the bottom thermal protection system, on the other hand, have a direct influence on the entire design, thus the aerodynamic heating induced by the bottom flow has long been a matter of discussion.

Aerodynamics is the study of how air flows around an airplane. In order for an airplane to fly at all, air must flow over and under it. Every space vehicle goes through many changes in design before it is finally built in a factory. These steps between the first ideas for a spacecraft and the time when it is actually flown make up the design process. Along the way, engineers think about four main areas of aeronautics: Aerodynamics, Propulsion, Structures and Materials, and Stability and Control.

COMMAND MODULE AERODYNAMICS

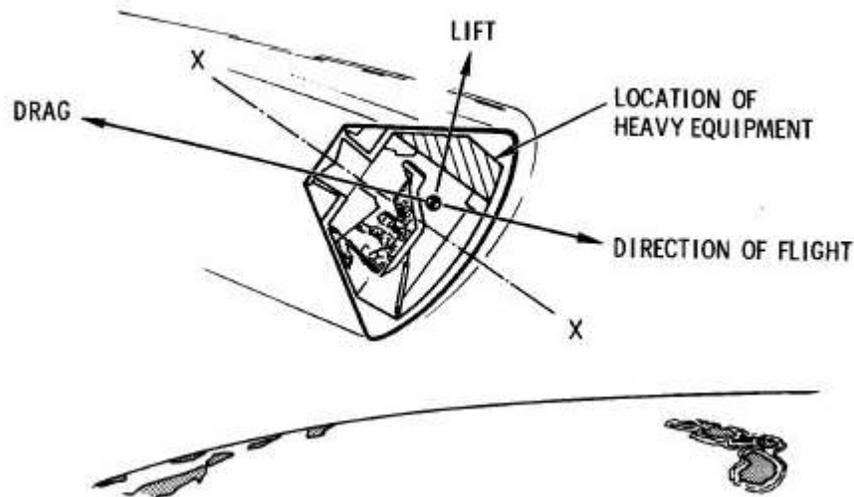


Fig 1.1 - Aerodynamics on Re-entry Vehicle

Propulsion is the research of what kind of engine and how much power a space vehicle needs. A vehicle's engine must be appropriate for the work at hand.

Structures And Materials is the study of the vehicle's strength and the materials that will be utilized to construct it. It's critical for the space vehicle to be as lightweight as feasible. The less weight a spacecraft has, the less work the engines have to do and the farther it can fly. It's difficult to create a space vehicle that is both lightweight and sturdy. Traditionally, reentry vehicles were composed of lightweight metals such as aluminum, but today, many engineers are considering employing composites in their designs. Composites have the appearance and feel of plastic, but they are far more durable than most metals. Engineers must also ensure that planes are not only safe to fly but also simple to construct and maintain.

Stability And Control is the research into how an re-entry vehicle responds to and interacts with pilot input and information. The vehicle's computers and screens provide a wealth of information to the pilots in the cockpit. The vehicle's speed, altitude, direction, and fuel levels, as well as anticipated weather conditions and other ground control instructions, might all be included in this data. The pilot must be able to quickly process the correct data, consider what

action should be done, and respond appropriately. Meanwhile, the vehicle should provide the pilot with information that is simple to read and comprehend. The cockpit controls should be easy to reach and exactly where the pilot expects them to be.

1.2 Defining Re-Entry Motion

The phase of return to Earth during which a spacecraft travels through the atmosphere before landing is known as re-entry. Due to the creation of a bow shock, the spacecraft decelerates and becomes very hot during reentry. As a plasma sheath (an envelope of ionized air) surrounds the spacecraft, several difficulties may occur, such as radio communication being blacked out for many minutes. When a spacecraft re enters the Earth's atmosphere, it travels at a significantly quicker rate than sound. It is claimed that the vehicle is hypersonic. Reentry speeds in low Earth orbit are typically around 20,000 km/h (17,500 mph), with a peak Mach number of nearly 25. The basic feature of reentry aerodynamics is that the flow temperature is so high that the chemical bonds between the air's diatomic molecules are disrupted. As the molecules disintegrate, an electrically charged plasma forms surrounding the vehicle.

Because reentry happens many kilometers above the earth's surface, the air density is likewise quite low. On the spacecraft's bottom surface, powerful shock waves are created.

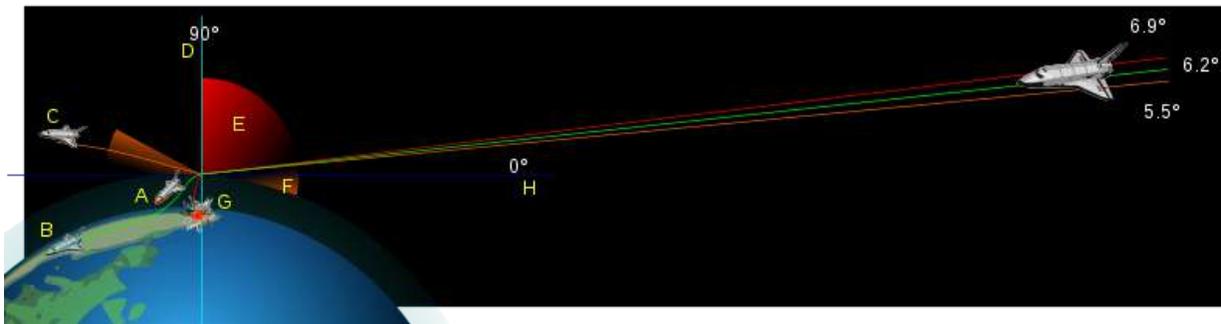


Fig 1.2 - Re-entry Corridor

1.2.1 Hypersonic Vehicle

A hypersonic vehicle is one that speeds at least four times the speed of sound, or faster than Mach 4. An airplane, missile, or spacecraft can all be classified as hypersonic vehicles. To fly

through the atmosphere, some hypersonic aircraft use a unique form of jet engine known as a Supersonic Combustion Ramjet or scramjet. A rocket engine is sometimes used in hypersonic planes. Another form of hypersonic vehicle is a re-entry vehicle.



Fig 1.3 - Hypersonic Vehicles

1.3 Describing Reentry Corridor

Any reusable first stage of a launch vehicle experiences identical occurrences and characteristics during re-entry and return flight. The stage is detached from the core stage/second stage and continues a ballistic trajectory following MECO (Main Engine Cutoff) of the LV's (Launch Vehicles) engines. Due to the high altitude at separation, there are normally low aerodynamic forces present throughout this ballistic flight phase. At suborbital velocity, the stage passes through apogee and begins falling back to Earth while increasing velocity. Once the vehicle enters the thicker sections of the atmosphere, the aerodynamic forces suddenly increase. At some point, the stage is subjected to enough aerodynamic forces to require the use of the vehicle's aerodynamic control surfaces. In addition, the body generates enough lift and drag to slow the aircraft down while maintaining a suitable altitude profile, ensuring that the aerothermal loads do not exceed structural limitations. The re-entry vehicle goes from supersonic to subsonic velocity after this period, where the majority of the deceleration occurs, and continues its flight as a subsonic glider.

Because the flight profiles of stated LV (Launch Vehicle) stages are similar, certain thresholds and boundaries may be calculated that are applicable to any LV (Launch Vehicle). As a result of the previous re-entry corridor. The heights and Mach numbers that characterize this corridor.

Physical processes happening during reentry can also be used to define and explain the re-entry corridor borders. A suborbital reentry's major goal is to reduce the greatest heat flow and integrated heat burden during reentry. The corridor's length is determined by three conflicting constraints: *deceleration, heating, and precision*. The size of the re-entry corridor is determined by the above three limitations, while the vehicle's capacity to navigate through the re-entry corridor is determined by the vehicle's control system. If the vehicle, for example, deviates significantly below the inferior portion (undershoots), it will encounter excessive drag, slowing down and heating up too quickly. If the spacecraft enters above the top barrier (overshoots), however, it will not feel enough drag and will simply skip off the atmosphere and back into space. These competing criteria may result in a reentry corridor that is too narrow for the vehicle to maneuver through if designers aren't cautious.

1.4 Basics Of Re-entry Motion

To determine the optimal trajectory for each vehicle, we must trade off deceleration, heating, and precision. Before we go any farther, we need to figure out how to analyze re-entry motion and understand how different trajectories and vehicle shapes affect re-entry, whether it's a pebble striking the sea or a spaceship crashing into the atmosphere. Below are the following factors to keep in mind : -

1.4.1 Re-entry coordinate system -

We still needed an inertial reference frame, which we call the re-entry coordinate system, to apply Newton's equations. The origin of the re-entry coordinate system is set at the vehicle's center of mass at the beginning of re-entry to make things simple. The motion is then analyzed in relation to a fixed center. The orbital plane is the primary plane of the vehicle. We may choose a useful major direction inside this plane that points "down" to the Earth's center. In the direction of motion, we define the direction along the local horizontal. The right-hand rule is completed with the direction. Direction does not play that important role because we presume all motion takes place on a plane.

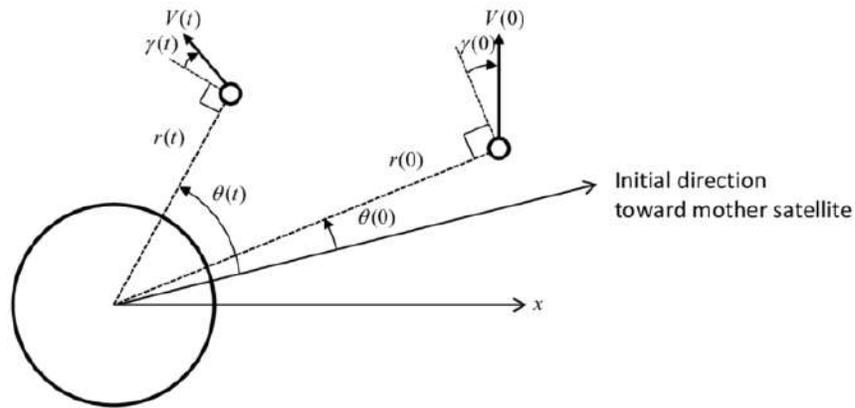


Fig 1.4 - Re-entry Coordinate System

1.4.2 Re-entry flight-path angle, γ -

It's the angle formed by the local horizontal and velocity vector. The orbital flight-path angle, (θ), is the same as this angle. A negative re-entry flight path angle (diving toward the ground) is negative, whereas a positive re-entry flight path angle (rising) is positive. The re-entry coordinate system and path angle is depicted in the diagram below.

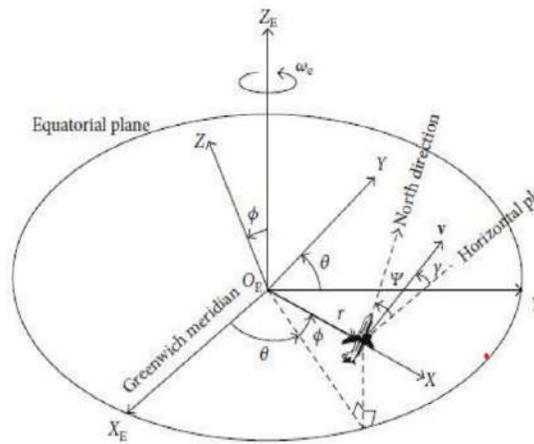
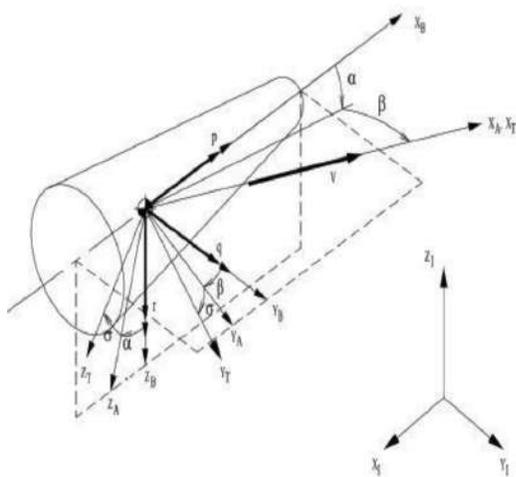


FIGURE 1: Geometric sketch of reentry flight.

Fig 1.5 - Re-entry Path Angle

1.4.3 Coefficient of drag, Cd -

The drag coefficient is a dimensionless number used to measure an object's drag or resistance in a fluid environment like air or water. In the drag equation, a lower drag coefficient means that the item will have less aerodynamic or hydrodynamic drag. A specific surface area is always related to the drag coefficient. The impacts of the two primary contributions to fluid dynamic drag: skin friction and form drag, are combined in the drag coefficient of every object. Lift-induced drag is included into the drag coefficient of a lifting airfoil or hydrofoil. The effects of interference drag are included in the drag coefficient of a full structure, such as an airplane.

$$F_{\text{drag}} = \frac{1}{2} \rho V^2 C_D A$$

where

F_{drag} = drag force on a vehicle (N)

C_D = drag coefficient (unitless)

A = vehicle's cross-sectional area (m^2)

ρ = atmospheric density (kg / m^3)

V = vehicle's velocity (m / s)

1.4.4 The force of gravity -

The force of attraction between two bodies is equal to the product of their masses and inversely proportional to the square of their distance.

1.4.5 The force of Drag -

Drag is a force in the atmosphere that opposes motion. You may feel the force of drag pressing back on your hand if you put your hand out the window of a fast-moving automobile and turn your palm into the wind. The drag force works in the opposite direction of your motion.

1.4.6 The force of lift -

Air passing over an object's surface produces lift, which is a force that is created at a right angle to the direction of motion. The precise form of an item, like an airplane wing, will provide enough lift force to overcome gravity and "lift" it into the air.

❖ Assumptions Taken:

1. The re-entry vehicle is a point mass.
2. Drag is the dominant force—all other forces, including lift and gravity, are insignificant.

When compared to drag, the vehicle lift during reentry is rather tiny. The above assumptions will be able to illustrate re-entry design patterns.

1.4.7 Important Concepts Regarding Drag Force:-

- a. Drag is proportional to the size of the vehicle (cross-sectional area exposed to the wind).
- b. The drag coefficient of the vehicle (how streamlined the vehicle is).
- c. The vehicle's speed (how fast the vehicle is moving).
- d. The volume of air in cubic meters.

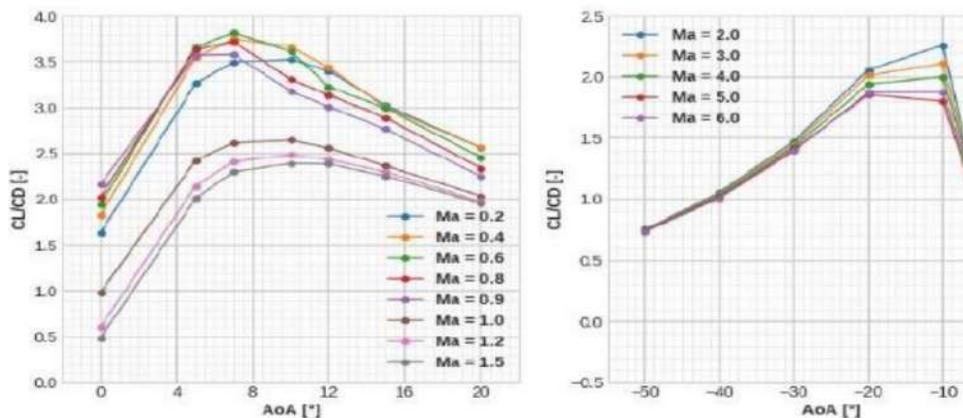


Fig 1.6 - AoA Vs CD Graph

CHAPTER 2

INTRODUCTION TO DESIGN OF RE-ENTRY VEHICLE

The fundamental design goal of a spacecraft's atmospheric entry is to dissipate the energy of a hypersonic spacecraft as it enters the atmosphere, slowing down equipment, cargo, and any passengers, and landing at zero velocity near a specific destination on the surface while keeping stresses on the spacecraft and any passengers within acceptable limits. Propulsive or aerodynamic (vehicle characteristics or parachute) means, or a mix of both, may be used to accomplish this. Engineers must examine the re-entry vehicle's aerodynamics, deceleration, and trajectory dynamics in order to build it. Aerodynamics is the science of predicting the forces exerted on a vehicle by the atmosphere. Deceleration is the process of safely lowering the extremely high speed required for space travel. The prediction of the vehicle's motion and steering as it flies through the atmosphere is called trajectory dynamics.

There are options for meeting mission criteria here.

2.1 Vehicle Shape -

The ballistic coefficient (BC) and the amount of lift generated by the re-entry vehicle are determined by the size and form of the vehicle. The drag coefficient, C_D , is the most difficult component of BC to calculate for re-entry vehicles since it is mostly determined by the vehicle's design. We could simply put a model of the vehicle in a wind tunnel and take precise measurements to determine C_D at low speeds. Wind tunnel testing isn't feasible at re-entry speeds nearing 25 times the speed of sound since no tunnels can operate at those speeds. Computational Fluid Dynamics, generally known as CFD, is one method we may utilize. We may also consider Newtonian flow, a method that has been used for almost 300 years. Newton thought that because he saw a fluid as a collection of separate particles, his laws of motion must still apply, at low speeds, however, they did not.

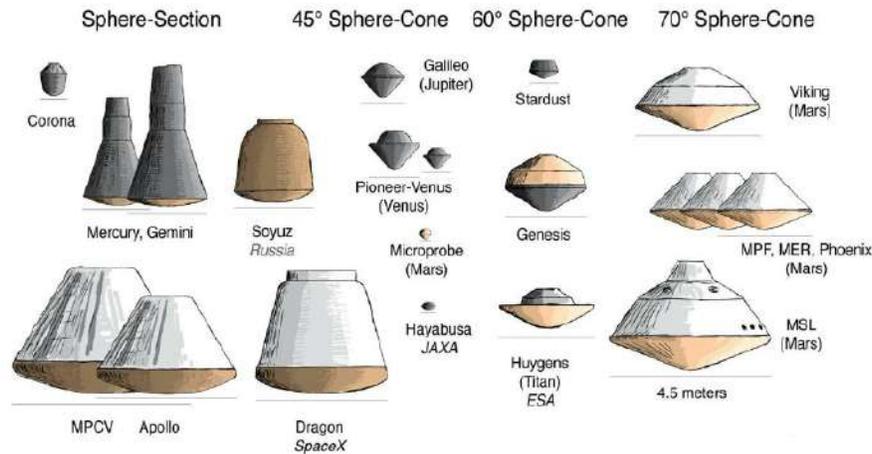


Fig 2.1 - Different Shapes Of Re-entry Vehicle

2.1.1 Effect of vehicle shape on deceleration -

The deeper the vehicle plunges into the atmosphere before reaching a max, the higher the BC (the more streamlined the vehicle). As a result, a streamlined vehicle spends less time in the atmosphere and arrives on the ground much sooner than a blunt vehicle.

2.1.2 Effect of vehicle shape on heating rate -

The high-BC (streamlined) vehicle's maximum heating rate is substantially higher and occurs at a much lower altitude in the environment. Shock waves for blunt and streamlined vehicles are depicted in the diagrams below. The heat of re-entry is dispersed across a rather broad volume in blunt vehicles due to disconnected shock waves. Furthermore, near-surface air movement inhibits convective heat transfer. As a result, the heating rate for blunt cars is low. Shock waves are related to streamlined vehicles, on the other hand. Because of this, a great quantity of heat is concentrated around the sharp point, leading it to reach extremely high temperatures—hot enough to melt most materials.

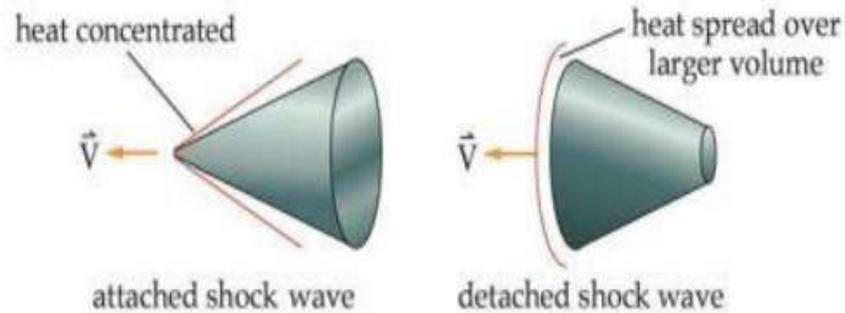


Fig 2.2 - Effect On Different Shape Of Vehicle

2.1.3 Effect of vehicle shape on accuracy -

As we've seen, a streamlined (high-BC) vehicle experiences maximum deceleration far lower in the atmosphere than a blunt (low-BC) vehicle, allowing it to reach the earth faster. We previously discussed how the atmosphere can significantly reduce re-entry accuracy, so we want our vehicle to spend as little time as possible in the atmosphere. As a result, we desire a more streamlined vehicle for greater precision, even if we have to endure higher heating rates.

Some vehicle capability factors that are considered when designing these vehicles are: -

- 1) Being launched by a variety of launch vehicles
- 2) Operating in low earth orbit as a free-flying unmanned laboratory.
- 3) An independent atmospheric re-entry with an air-snatch recovery or a soft landing at a preselected site (land or water), providing the experimenter with rapid access to the payload.

Some specific design considerations areas follows: -

- **Sizes** - For the most part, the size of a re-entry spacecraft has been determined by the capabilities of available launch vehicles. Other factors that influence size include the availability of resources for life science and other payloads, the amount of accessible electricity, and expenses. There are numerous more trade-offs and variables to consider while designing a re-entry vehicle. There are various shapes of re-entry vehicles for example: - Sphere , Biconic , Spherical Cone etc. For our model we have chosen SOYUZ which is a spherical cone type vehicle.

→ **Subsystems And Requirements** - In a re-entry vehicle, a payload module is utilized to segregate the experiment from the support systems. However, in extremely limited circumstances where an experimental payload does not require any support throughout the trip, the payload could be mounted inside the vehicle's payload envelope. Many of these systems provide the same services as any other orbiting satellite, such as supplying electrical power, temperature management, command communications, and telemetry capability to the payload. A re-entry vehicle, on the other hand, typically employs extra components to achieve controlled deorbit, re-entry, and a safe, soft landing or air recovery. Some typical spacecraft subsystems are as follows; systems that apply only to a re-entry vehicle are :

- Attitude and Spin Control Subsystems
- Deorbit Propulsion Subsystem
- Structures
- Power Subsystem
- Power Interface Units
- Tracking and Communications Subsystems

2.2 Explanation Of Design -

The Re-entry Vehicle has an external diameter of 2.17 m, an overall height of 27.1 m and a launch mass of 2950 Kg (Dry Mass) or 3100 Kg (Mass with propellant). Our model resembles a 70 percent scale Soyuz capsule, but with the notable exception that it integrates modern electronics. The Re-entry Vehicle has an air- and water-tight pressurized structure.

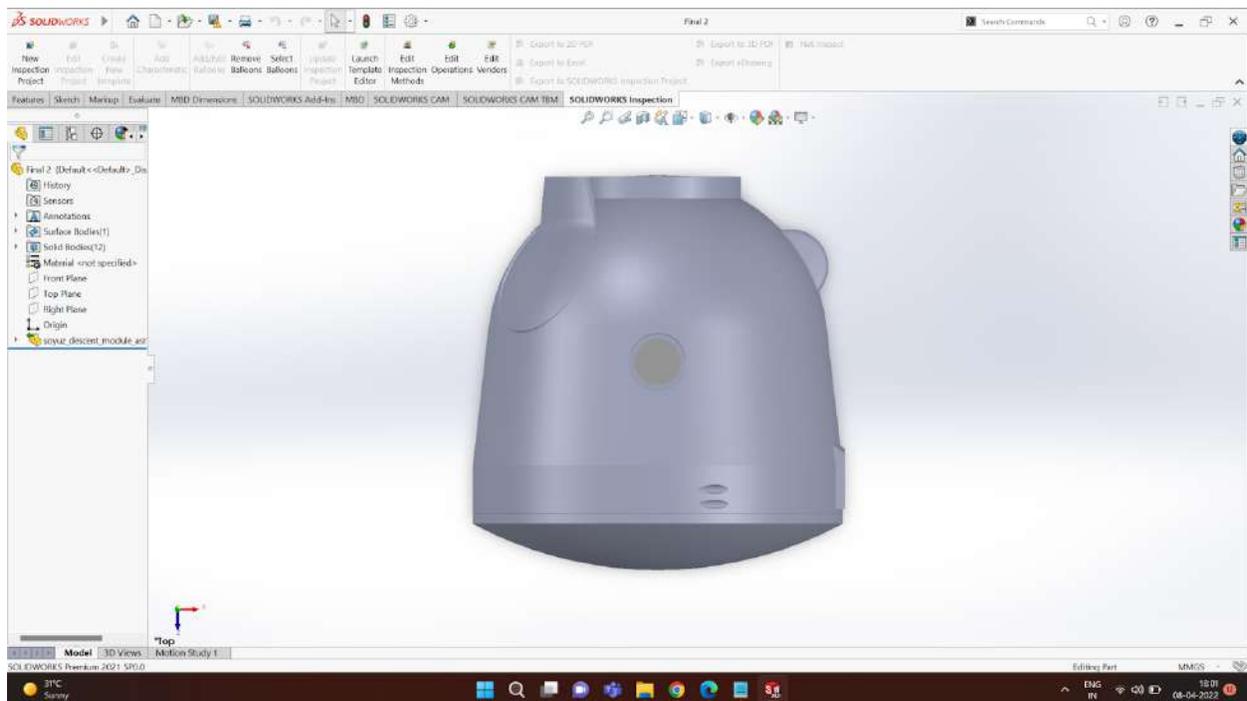


Fig 2.3 - Final Design 'SOYUZ'

CHAPTER 3

AERODYNAMIC DESIGN AND PRINCIPLE USED

3.1 Introduction To Aerodynamics

For manned interplanetary missions, atmospheric re-entry is a hurdle. Making a viable re-entry is critical since the re-entry method and trajectory dictate the g-loads and temperatures encountered by the crew. Also the importance of aerodynamics in the STS design process cannot be overstated. The vehicle's aerodynamic characteristics, external environment, and flow characteristics, as well as the steady and unsteady aerodynamic loads generated by the relative motion between the vehicle body and surrounding air during the vehicle's atmospheric flight phase, are the major inputs for the vehicle systems design. The aerodynamic axial force is used to design missions and evaluate vehicle performance. Vehicle control and structural system design require constant aerodynamic disturbance moments and loads operating on the vehicle.

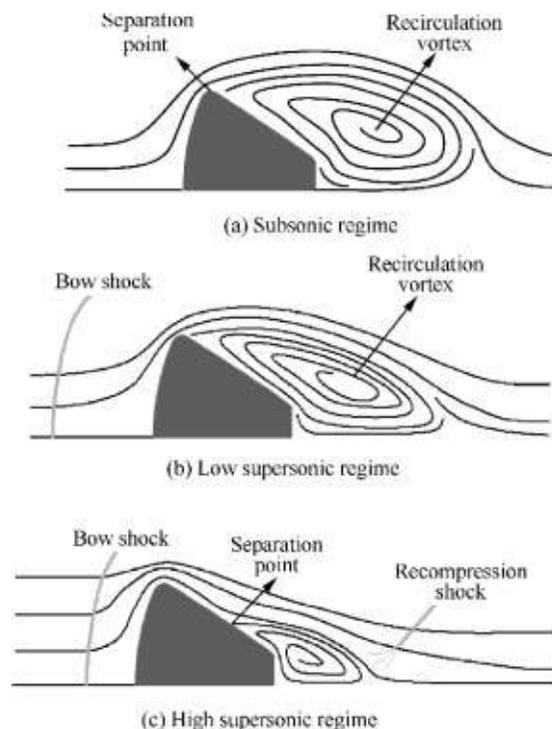


Fig 3.1 - Different Regimes Of Re-entry Vehicle

The parameters which should be taken into consideration while designing space re-entry vehicle are as follows:

3.1.1 Ballistic Coefficient -

A body's capacity to overcome air resistance in flight is measured by its Ballistic Coefficient (BC).

$$BC = \frac{M}{C_d \cdot A}$$

Where,

m = vehicle's mass (kg)

CD = vehicle's drag coefficient (unit less)

A = vehicle's cross-sectional area (m²)

A low BC object slows down significantly more quickly than a high BC thing.

3.1.2 Drag Forces -

Drag is determined by the density of the air, the square of the velocity, the viscosity and compressibility of the air, the size and shape of the body, and the inclination of the body to the flow. In general, the relationship between body shape, inclination, air viscosity, and compressibility is extremely complicated. One method for dealing with complex dependencies is to characterize the dependency with a single variable. This variable is known as the drag coefficient, abbreviated "Cd" for drag. This enables us to combine all of the effects, both basic and complex, into a single equation. Drag D is equal to the drag coefficient Cd multiplied by the

density 'rho' multiplied by half of the velocity V squared multiplied by the surface area A, according to the drag equation.

$$D = \frac{1}{2} * \rho * C_D * R V^2 * S$$

To calculate drag, we must establish a value for Cd based on the air conditions, shape, and tilt of the object. Form drag, skin friction drag, and wave drag are all included in the drag coefficient above. Almost all drag coefficients are determined experimentally in a wind tunnel.

3.2 Aerodynamic Design

Additional distinctions in approach were mirrored in the choice of reentry vehicle configuration. The severity, duration, and flight path of reentry are all determined by the aerodynamic form and configuration (ballistic or lifting) of a reentry vehicle.

3.2.1 Cross-Sectional Area -

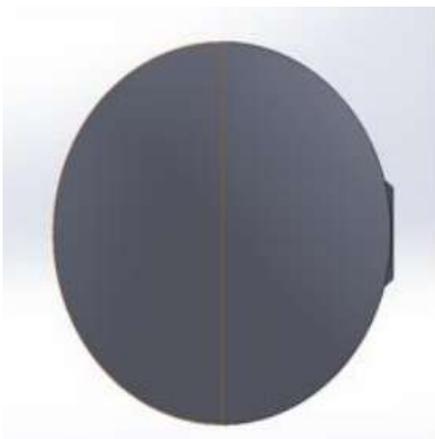


Fig 3.2 - Bottom View 'SOYUZ'



Fig 3.3 - Top View 'SOYUZ'

Light, blunt vehicle means low Ballistic Coefficient so the vehicle slows down quickly whereas on the other hand Heavy, streamlined vehicle with high Ballistic coefficient doesn't slow down quickly. In order to obtain a low ballistic coefficient, the Area of Impact (Lower Cross Section) has been made larger with heat resistant material in order to meet the goal of rapid deceleration. A blunt body design has been chosen in this case with an aim to slow down quickly considering heating aspect into consideration.

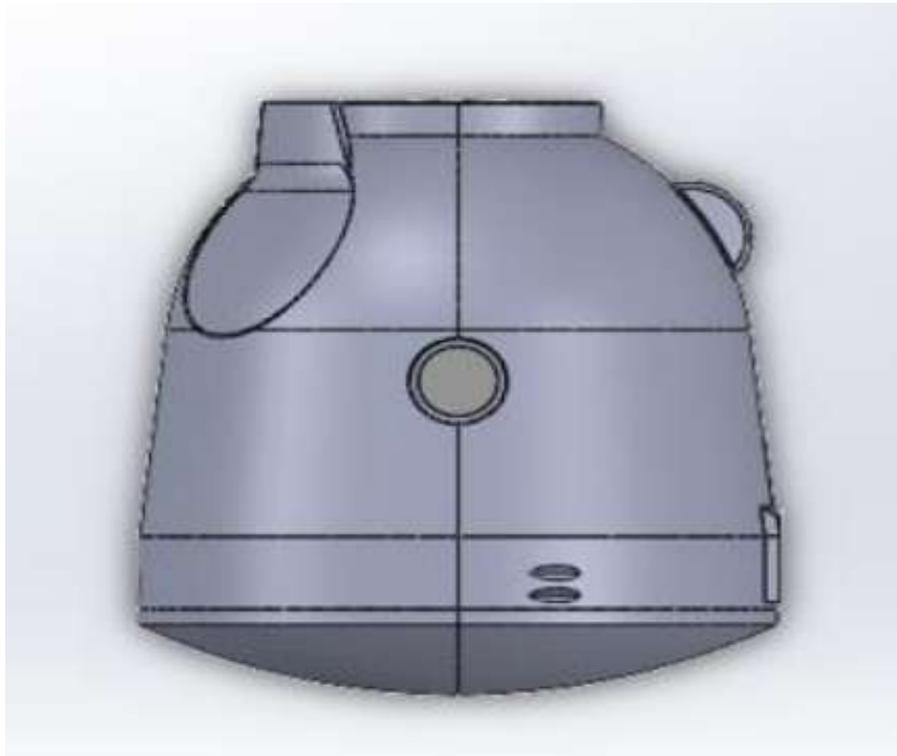


Fig 3.4 - Side View 'SOYUZ'

3.2.2 Spherical Vs Blunted Bodies -

The designers of the spacecraft considered several reentry vehicle forms and made decisions based on standards established within their own programmes. Some vehicles that were suited for certain missions were of spherical shape, for example lunar missions but for the orbital mission the blunted cone shape was much preferred.

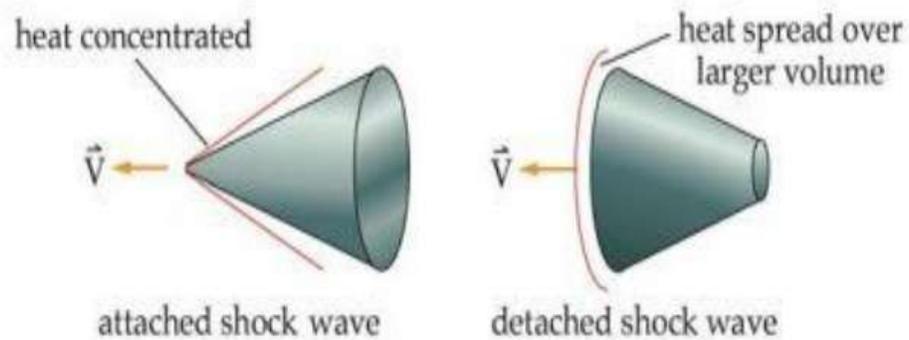


Fig 3.5 - Streamlined Vs Blunt Sphere Shapes

CHAPTER 4

WEIGHT ESTIMATION AND PERFORMANCE CALCULATIONS

4.1 Flight Profile

The altitude, speed, and distance of flight, as well as the maneuvers to be executed and the number of stops, are all part of the flight profile. A flight plan is essential since it allows us to prepare ahead of time. Spacecraft's flight profile is shown below.

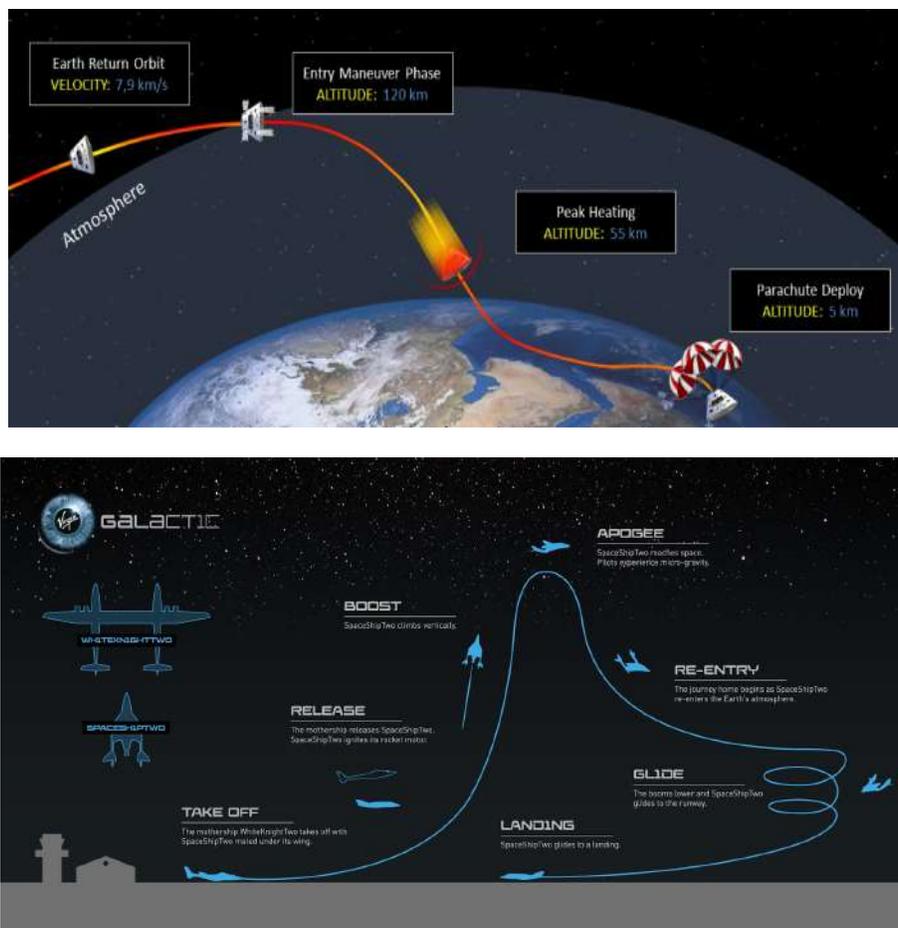


Fig 4.1 - Re-entry Flight Path

I. Horizontal Takeoff From The Launchpad:

The space vehicle takes off into air from the ground surface.

II. Powered Ascent / Climb:

The spacecraft climbs to reach its maximum altitude by boosting up the engine to maximum capacity.

III. Coast Upwards:

The spacecraft moves upwards with the help of absence of gravitational force (microgravity area).

IV. Starting/Finishing Off The Mission:

The spacecraft starts doing the mission for which it was designed for then after taking necessary data it finishes up the mission.

V. Descent / Pullout:

After the spacecraft has completed the mission, the spacecraft starts to descend for landing. During this phase a high G-Force is applied on both vehicle and pilot/operator in it.

VI. Loiter / Glide & Circle:

To reduce the speed of the vehicle, it is meant to be loitered in the atmosphere. Sometimes the reason for loitering is that there is no proper landing area for the vehicle.

VII. Vertical/Horizontal Landing:

The spacecraft completes the journey and lands most probably in sea or any open surface. After landing, the aircraft is taken to the base/warehouse.

- **Gross weight - $W_0 = W_{crew} + W_{payload} + W_{fuel} + W_{empty}$**

$W_{crew} = 500 \text{ kg}$ (5 cabin crew) (Assumed)

$W_{payload} = 2450 \text{ kg}$ (Including fuel and survival stuff)

Gross weight - $W_0 = W_{crew} + W_{payload} = 500 \text{ Kg} + 2450 \text{ Kg} = 2950 \text{ Kg}$

- **Estimation of empty weight fraction (W_e/W_0)**

$$W_e/W_0 = A * W_0^c * kvs$$

Where, A = Constant

W_0 = Gross Weight

Kvs = Variable Sweep

C = Constant

A and C are calculated from statistical curve fits.

$$= [1.0595 * (2950)^{-0.0598} * 1.04]$$

$$= \mathbf{0.683}$$

4.3 Performance Parameters -

During re-entry there are several factors and parameters that affect the re-entry trajectories and also the performance of the vehicle. Calculations of some of the important parameters are done below:

4.3.1 Coefficient Of Drag -

$$C_d = (1 - \sin^4 \Delta c) (R_n/R_c)^2 + 2\sin^2 \Delta c (1 - (R_n/R_c)^2 \cos^2 \Delta c)$$

$$C_d = (1 - \sin^4 (15)) (3/9)^2 + 2\sin^2 (15) (1 - (3/9)^2 \cos^2 (15))$$

$$\mathbf{C_d = 0.386}$$

4.3.2 Drag Forces -

Mach No. Assumed - 29 M

$$\begin{aligned} D &= (\text{Rho} * \text{Cd} * (\text{V})^2 * \text{A}) / 2 \\ &= [500 * 0.386 * (\text{M} * \text{a})^2 * 12.18] / 2 \\ &= [500 * 0.386 * (9953)^2 * 12.18] / 2 \\ &= \mathbf{4.786 \times 10^{11} \text{ MN}} \end{aligned}$$

4.3.3 Ballistic Coefficient -

$$\begin{aligned} \text{BC} &= \text{M} / \text{Cd} * \text{A} \\ &= 2950 / 0.386 * 12.18 \\ &= \mathbf{627.46 \text{ Kg/m}^2} \end{aligned}$$

4.3.4 Skin Friction Drag -

$$\begin{aligned} \text{Cf} &= \text{Cd} / 4 \\ &= 0.386 / 4 \\ &= \mathbf{0.097} \end{aligned}$$

4.3.5 Heat Load -

$$\begin{aligned} \text{Qtotal} &= 1/2 * \text{Cf}/\text{Cd} * 1/2 * \text{M} * (\text{V})^2 \\ &= 1/2 * 0.4/0.386 * 1/2 * 2950 * (9953)^2 \\ &= \mathbf{1.826 * 10^{10} \text{ kW}} \end{aligned}$$

4.3.6 Heating Rate -

$$\begin{aligned} q^* &= 1.83 * 10^{-4} * \text{V}^3 * \text{sqrt}(\text{rho}/r) \\ &= 1.83 * 10^{-4} * (9953)^3 * \text{sqrt}(500/1.085) \\ &= \mathbf{3.872 \text{ MW}} \end{aligned}$$

CHAPTER 5

PREPARATION OF COMPARATIVE DATA OF VEHICLES

5.1 Introduction

The development of early re-entry vehicles was largely influenced by ballistic missile research. Initially, designers imagined a re-entry vehicle with a sleek aerodynamic shape, but launch and wind tunnel experiments revealed that no known material with that shape could sustain the heat of re-entry. Engineer Harvey Allen of the National Aeronautics and Space Administration (NASA) decided on a blunt-shaped vehicle. Like the bow of a ship in the water, the increased air resistance of that type of vehicle would produce a "shock wave" that would absorb most of the vehicle's kinetic energy before it was converted to heat when it entered the atmosphere. Intercontinental ballistic missile (ICBM) warheads and subsequently piloted and unpiloted spacecraft have successfully used blunt re-entry vehicles. Although NASA's first re-entry vehicles were ballistic capsules, another vehicle type had been proposed by them at the same time: the lifting body, which merged the blunt-body concept with glider aerodynamics.

For capsules, high-temperature and dynamic loading reentries were optimal. While delta-wing gliders, also known as the lifting body like the Space Shuttle, can reenter from as far as the Moon, lifting bodies can only reenter from Earth orbit. For example the Apollo CM had a lift-to-drag ratio of about 0.35. In the absence of lift, the Apollo capsule would have decelerated by around 20g (8g for low-Earth-orbiting spacecraft), but the trajectory was reduced to around 4g by using lift.

5.2 Classifications of Re-entry Vehicle (Shapes)

5.2.1 Sphere or spherical section -

The sphere or spherical section is the most basic axisymmetric shape. This can be a whole sphere or a body with a converging conical afterbody made up of spherical type sections. Using Newtonian impact theory, the aerodynamics of a sphere or spherical portion are simple to study analytically. Similarly, the heat flux of a spherical portion can be precisely predicted using the Fay–Riddell equation. If the vehicle's center of mass is upstream from the center of curvature, the spherical section's static stability is assured (dynamic stability is more problematic). There is no lift in pure spheres. A spherical portion, on the other hand, has small aerodynamic lift while flying at an angle of attack, offering some cross-range capabilities and widening its entry corridor. When the spherical section was discovered to be amenable to closed-form analysis in the late 1950s, that geometry became the standard for conservative design. As a result, the spherical part was used in crewed capsules of the time.



Fig 5.1 - Spherical Shape Vehicle

5.2.2 Sphere-cone -

A sphere-cone is a spherical segment with an attached frustum or blunted cone. The dynamic stability of a sphere-cone is often higher than that of a spherical segment. The car is the first to enter the sphere. A sphere-cone can provide aerodynamic stability from Keplerian entrance to surface impact if the half-angle is short enough and the center of mass is suitably positioned. In early times the re-entry vehicle of this shape loitered too long in the upper atmosphere due to its lower ballistic coefficient and also trailed a stream of vaporized metal making it very visible to radar but in today's modern era space agencies have overcome all those defects due to improved technology.



Fig 5.2 - Spherical Cone Shaped Vehicle

5.2.3 Biconic -

A biconic is a sphere-cone with a frustum linked to it. The L/D ratio of the biconic is greatly enhanced. Because of the lower peak deceleration, a biconic form with a larger L/D is better suited for delivering people to outer space. The Advanced Maneuverable Reentry Vehicle was arguably the most significant biconic ever flown (AMaRV). The attitude of the AMaRV was controlled by a split body flap (also known as a split-windward flap) and two yaw flaps located

on the vehicle's sides. The flaps were controlled by hydraulic actuation. AMaRV was piloted by a fully autonomous navigation system designed to avoid anti-ballistic missile (ABM) intercept.

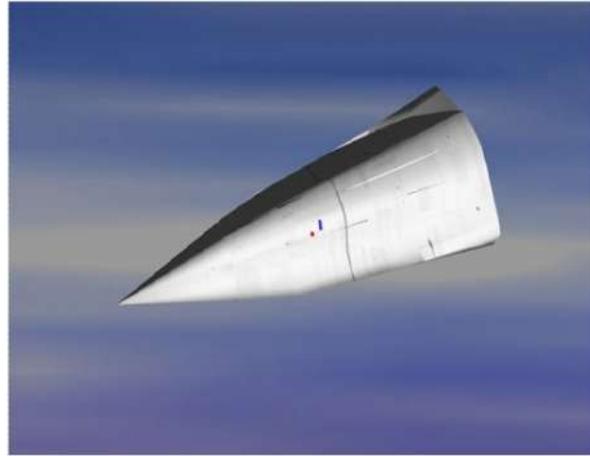


Fig 5.3 - Biconic Shaped Vehicle

5.2.4 Non-axisymmetric shapes -

For crewed entry vehicles, non-axisymmetric shapes have been used. The winged orbit vehicle, for example, uses a delta wing for maneuvering during descent, similar to a standard glider. The American Space Shuttle and the Soviet Buran also used this method. Another entrance vehicle shape that was employed with many other launching aircraft is the lifting body.



Fig 5.4 - Non-axisymmetric Shape Vehicle

5.3 Current Re-entry Vehicles Present -

There are several no. of re-entry vehicles present in today's time for example mercury, gemini, apollo, dragon etc. There are some other vehicles about which we will be discussing below:

5.3.1 Soyuz -

Soyuz (A Russian Vehicle) is a series of spacecraft that has flown over 140 times since its manufacturing in the 1960s. The Korolev Design Bureau created it for the Soviet space programme. The Soyuz spacecraft succeeded the Voskhod and was designed as part of the Soviet crewed lunar programmes.

A Soyuz spacecraft consists of three parts (from front to back) among which one module is used for re-entry which is known as a descent module. A heat-resistant covering covers half of the descent module, which faces forward during reentry to protect it from the elements. The environment slows it down first, then a brake parachute, and finally the main parachute, which slows it down for landing. Solid-fuel braking engines located beneath the heat shield are fired at a height of one meter above the ground to ensure a smooth landing. The maximum potential volumetric efficiency was one of the design requirements for the descent module. A hemispherical forward region is linked to a conventional spherical section heat shield by a barely inclined (seven degrees) conical section. Because of the unequal weight distribution, this design allows for a limited amount of lift for this vehicle.



Fig 5.5 - Soyuz Descent Module

5.3.2 Shenzhou -

Shenzhou is a Chinese spacecraft that supports China's crewed spaceflight programme, the China Manned Space Program. Its design is similar to that of the Russian Soyuz spacecraft, however it is larger. On November 19, 1999, the first launch was placed, and on October 15, 2003, the first crewed launch took place. It is roughly 10% larger than the Soyuz spacecraft. In the event of a splashdown, there is adequate room to transport an inflatable raft, whereas Soyuz astronauts must jump into the sea and swim. On both spacecraft, the commander sits in the middle seat. The copilot, on the other hand, sits in the left seat on the Shenzhou and the right seat on the Soyuz. A Shenzhou spacecraft also consists of three parts (from front to back) among which one module is used for re-entry and is known simply as a re-entry module. The crew is seated in the reentry module, which is placed in the spacecraft's central part. It is the only part of Shenzhou that returns to the surface of the Earth. Its design strikes a balance between maximizing living space and retaining some aerodynamic control upon reentry.

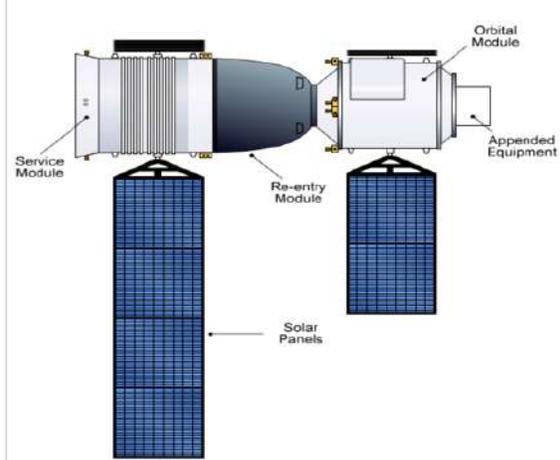


Fig 5.6 - Shenzhou Descent Module

5.3.3 Apollo -

The Apollo spacecraft was made up of three sections that were designed to help the American Apollo programme achieve its objective of landing astronauts on the Moon by the end of the 1960s and safely returning them to Earth. The expendable (one-time use) spacecraft was made up of a command and service module (CSM) and an Apollo Lunar Module (LM). The spacecraft stack was supplemented by two additional components for space vehicle assembly: a spacecraft-LM adapter (SLA) designed to shield the LM from the aerodynamic stress of launch and connect the CSM to the Saturn launch vehicle, and a launch escape system (LES) designed to safely transport the command module crew away from the launch vehicle in the event of a launch emergency. The Apollo spacecraft was primarily a three-man vehicle built for Earth orbital, translunar, and lunar orbital travel, as well as return to Earth. North American Aviation developed this, which consisted of a command module supported by a service module.



Fig 5.7 - Apollo Module

Re-entry Module Specifications					
S no.	Fields	Soyuz	Shenzhou	Apollo	SpaceX CRS - 20
1	Crew Size	04-May	5	3	
2	Mass	2950 Kg	3240 Kg	5560 Kg	4200 Kg
3	Length	2.24 m	2.50 m	3.5 m	6.1 m
4	Diameter	2.17 m	2.52 m	3.91 m	3.7 m
5	Heat Shield Mass	350 Kg	450 Kg	535 Kg	478 Kg
6	Volume	3.50 m ³	6.00 m ³	5.9 m ³	6.35 m ³
7	Vehicle Life	25 Years	20 Years	15 - 16 Years	25-30 Years

Fig 5.8 - Comparative Study

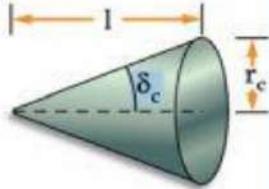
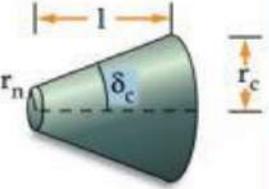
Shape	Example Values	Estimated Ballistic Coefficient
Sphere 	$D = 2 \text{ m}$ $C_D = 2.0$ $m = 2094 \text{ kg}$ (Assumes density = 500 kg/m^3)	$BC = 333 \text{ kg/m}^2$
Cone 	$l = 3.73 \text{ m}$ $\delta_c = 15^\circ = \text{cone half angle}$ $r_c = 1 \text{ m} = \text{cone radius}$ $C_D = 2 \delta_c^2 = 0.137$ $m = 1954 \text{ kg}$ (Assumes density = 500 kg/m^3)	$BC = 4543 \text{ kg/m}^2$
Blunted cone 	$l = 3.04 \text{ m}$ $\delta_c = 15^\circ = \text{cone half angle}$ $r_c = 1 \text{ m} = \text{cone radius}$ $r_n = 0.304 \text{ m}$ $m = 1932 \text{ kg}$ (Assumes density = 500 kg/m^3) $C_D = (1 - \sin^4 \delta_c) \left(\frac{r_n}{r_c}\right)^2 + 2 \sin^2 \delta_c \left[1 - \left(\frac{r_n}{r_c}\right)^2 \cos^2 \delta_c\right]$ $C_D = 0.188$	$BC = 3266 \text{ kg/m}^2$

Fig 5.9 - Comparing Ballistic Coefficient Sample

CHAPTER 6

FINAL DESIGN SPECIFICATION

The Re-entry Vehicle which we have chosen is SOYUZ. We chose this re-entry vehicle because it has a low Ballistic Coefficient (BC). A blunt shaped vehicle having less ballistic coefficient has an external diameter of 2.17 m, an overall height of 2.241 m and a launch mass of 2950 Kg (Dry Mass) or 3100 Kg (Mass with propellant). Our model resembles a 70 percent scale Soyuz capsule, but with the notable exception that it integrates modern electronics. The Re-entry Vehicle has an air- and water-tight pressurized structure.

It can carry up to 4 crew members for any space exploration mission. Below in the table we have mentioned all the specifications that we took for designing our model in solidworks 2022. All the calculations for important parameters are done in the above chapters which you can go through and also we have performed some analysis on the vehicle using ANSYS R2022 which you will be seeing in upcoming chapters.

S No.	Name	Mass	Length	Diameter	Volume
1	Shenzhou	3240 kg (7,140 lb)	2.50 m (8.20 ft)	2.52 m (8.26 ft)	6.00 m ³ (211.8 cu ft)
2	Soyuz	2,950 kg (6,500 lb)	2.24 m (7 ft 4 in)	2.17 m (7 ft 1 in)	3.50 m ³ (124 cu ft)
3	Apollo	5,560 kg (12,250 lb)	3.5 m (11.4 ft)	3.9 m (12.8 ft)	5.9 m ³ (210 cu ft)
4	Vozvrashcheniye Apparat Capsule	7,300 kg (16,100 lb)	10.3 metres (34 ft)	2.79 metres (9 ft 2 in)	4.56 m ³ (161 cu ft)
5	SpaceX CRS - 20	1,977 kg (4359 lb)	6.1 metre (20.1 ft)	3.7 metre (12 ft 1 in)	0.1 m ³ (3.5 cu ft)

Fig 6.1 - Final Design Specifications

7.2 Top View -

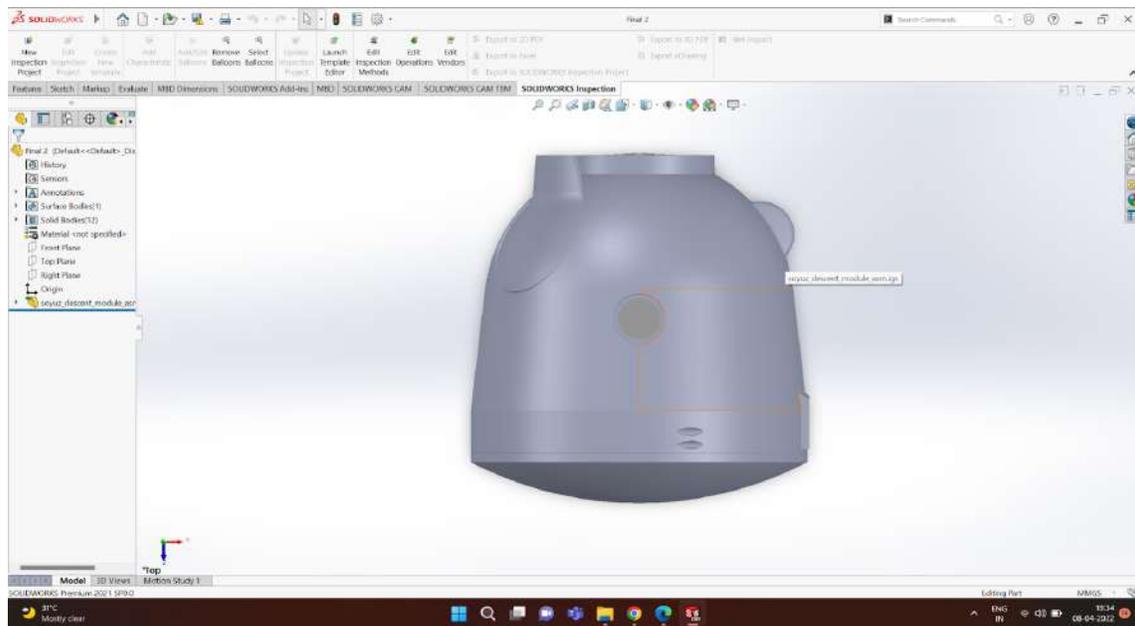


Fig 7.2 - Top View Soyuz Model

7.3 Bottom View -

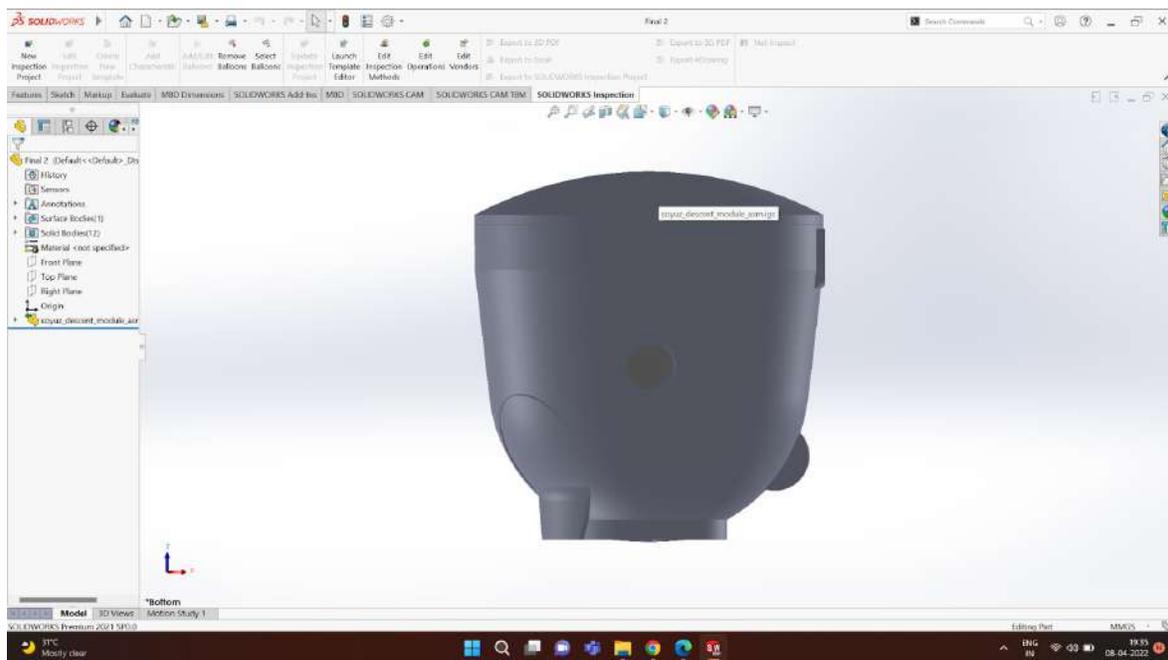


Fig 7.3 - Bottom View Soyuz Model

7.4 Back View -

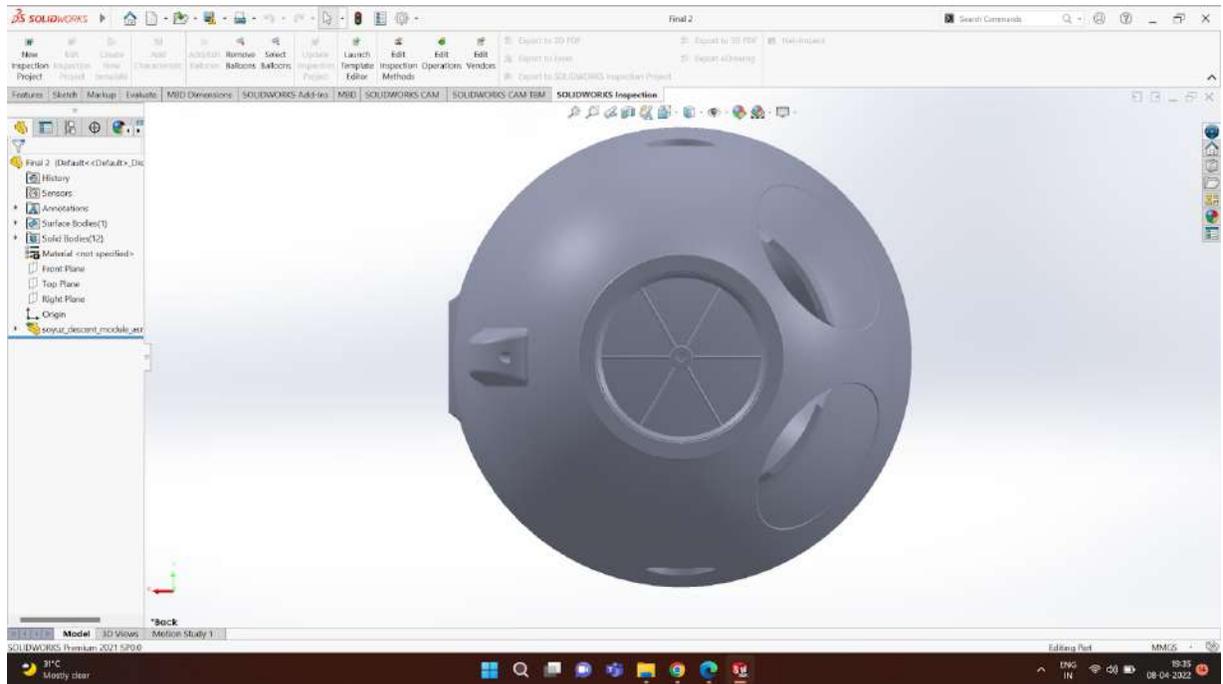


Fig 7.4 - Back View Soyuz Model

CHAPTER 8

DESIGN ANALYSIS

After completing our design on solidworks we tried to do analysis of a re-entry model using ANSYS 2017. The analysis not only included our model but the launch vehicle also which is used to give flight to re-entry vehicles. We could find plots for various parameters like temperature, density, angle of attack, density, altitude vs range etc.

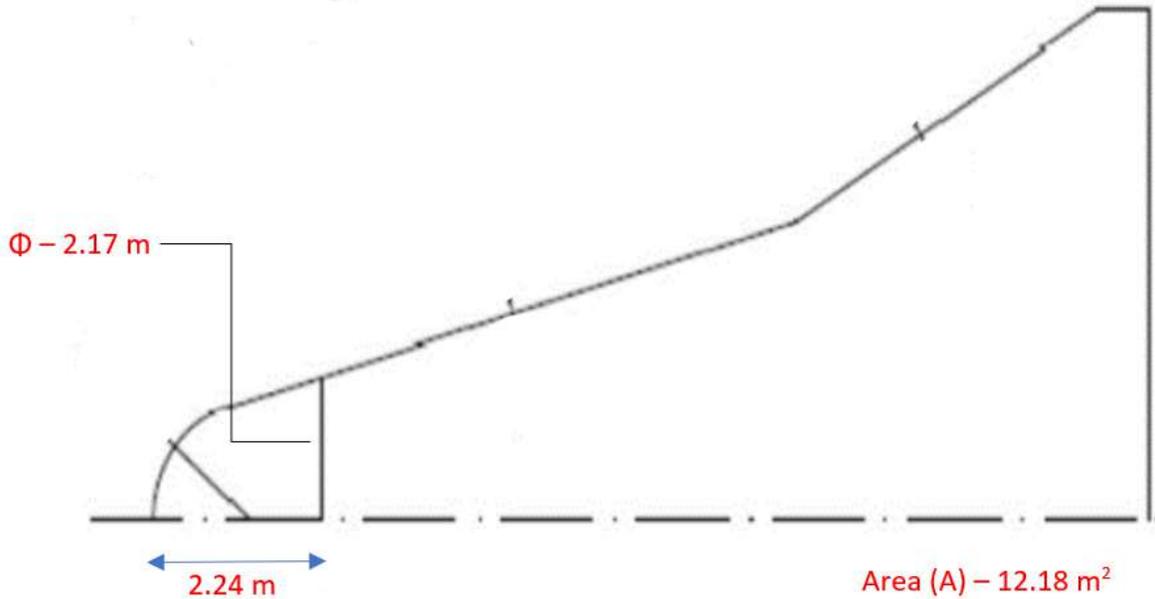


Fig 8.1 - Space Vehicle Geometry

Graphs -

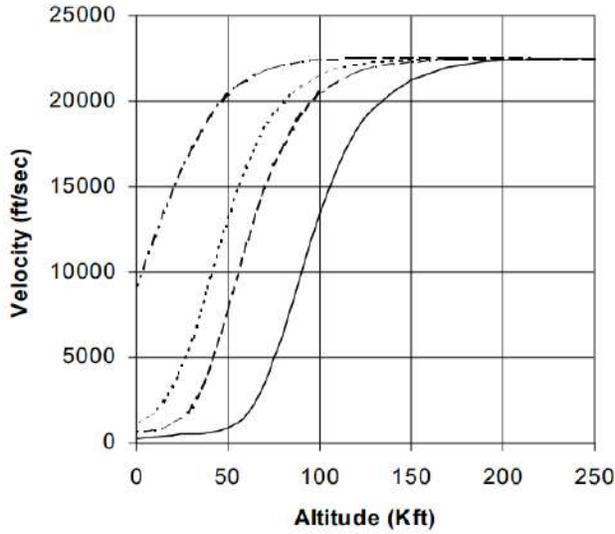


Fig 8.5 - Altitude Vs Velocity Graph

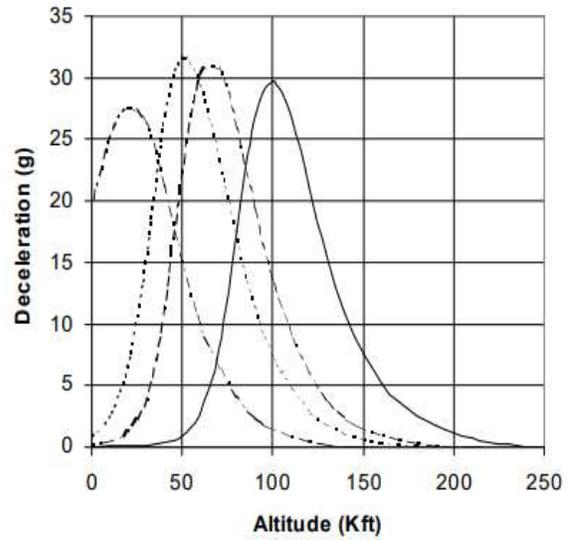


Fig 8.6 - Altitude Vs Deceleration Graph

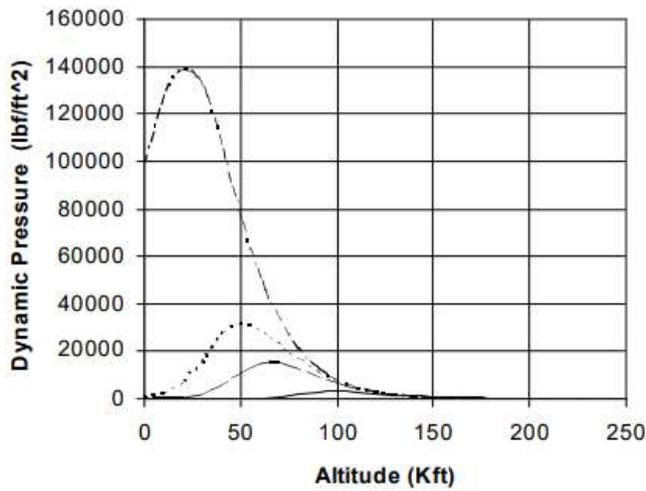


Fig 8.7 - Altitude Vs Dynamic Pressure

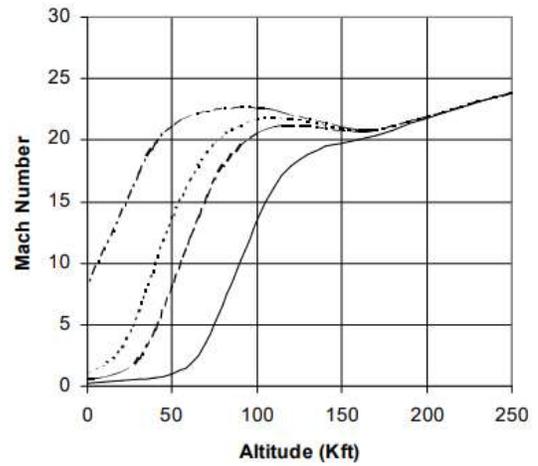


Fig 8.8 - Altitude Vs Mach No.

CHAPTER 9

INTRODUCTION TO DIFFERENT MATERIALS

The selection of a material is a critical consideration in the design of any space spacecraft. Aerodynamic heating is a serious issue during atmospheric re-entry. As a result, a substance that combats this scenario is required. In order to select an appropriate material the following points should be considered:

- High capability material
- Material should be reusable
- Material must be test in relevant environment
- Ablative material

High temperature capability, high strength at extreme temperatures, high toughness, light weight, and environmental resilience are all requirements for hypersonic air breathing vehicles. A requirement for the materials is that they have a high specific strength (strength divided by density) when exposed to high temperatures.

Due to launch vehicle aerodynamic limitations, reentry capsules have traditionally been smaller in diameter. Because the capsule design is both volumetrically efficient and structurally strong, compact capsules with performance comparable to lifting body or spaceplane designs in all but lift-to-drag ratio can often be built for less money. The capsule's materials are designed in a variety of ways, such as the aluminum honeycomb structure of the Apollo command module.

9.1 Some of the materials used to make the body of the re-entry space vehicle are as follows: -

9.1.1 Aluminum -

Aluminum is a light metal with a strong structure that adds strength to the capsule.



Fig 9.1 - Aluminum Sheets

9.1.2 Glass With Synthetic Resin -

Optical payload applications primarily utilize glass materials.

9.1.3 Carbon-fiber-reinforced polymers -

During atmospheric re-entry, it can sustain temperatures of up to 2300 degrees Fahrenheit. As a result, it's commonly found in the leading edge, wing, and nose cap, among other places. Carbon fiber and graphite matrix with reinforcement makeup this composite material. It possesses a very low coefficient of thermal expansion, strong fatigue resistance, and great thermal shock resistance, as well as a low density of 1830 kg/m³, a high modulus of stiffness of 200GPa, and a

high thermal conductivity of $100\text{W/m}\cdot\text{k}$. Carbon fiber breaks or shatters when crushed, pressed beyond its strength limitations, or subjected to high impact.



Fig 9.2 - Carbon Fiber Reinforced Polymer

9.1.4 Ceramic -

Ceramic is one of the best viable options present for construction of re-entry vehicle bodies but the only major drawback is that it can withstand heat up to a certain temperature.



Fig 9.3 - Ceramic Fiber

9.1.5 Nanomaterials -

The nanomaterial is a material with a single unit size ranging from 1 to 1000 nanometres. Because the materials are so tiny, they have a huge exposed surface area, which has a variety of applications and provides a better platform for chemical reactions to occur. The overall efficiency of the vehicle can be boosted by reducing the vehicle's weight, safety, and performance by using nanomaterial for developing various sections of spacecraft. The nanomaterial can withstand a lot of harm. Because the re-entry vehicle is not streamlined and is traveling at hypersonic speeds, it produces a bow shock wave. High drag and aerodynamic heating were caused by the bow shock wave's existence. During this moment, radiation heat transmission peaks, causing the re-entry vehicle to be damaged.

Nanomaterial-based coatings can significantly reduce the heat transmission from radiation. It also aids the vehicle's protection system and decreases fouling. The nanomaterial covering acts as an oxidation barrier, improves wear resistance, and improves detector characteristics. We can save half the weight by using nanomaterials instead of traditional ablative materials like carbon phenol. When nanomaterials are used to build electric components, they have improved efficiency at high working temperatures and in radiation conditions. It contributes to lower power usage as well as component weight reduction. One of the nanomaterial's biggest drawbacks is its high cost. Nanomaterial production is both expensive and challenging. In addition, ground testing facilities are scarce. The actual flight condition implementation is difficult.

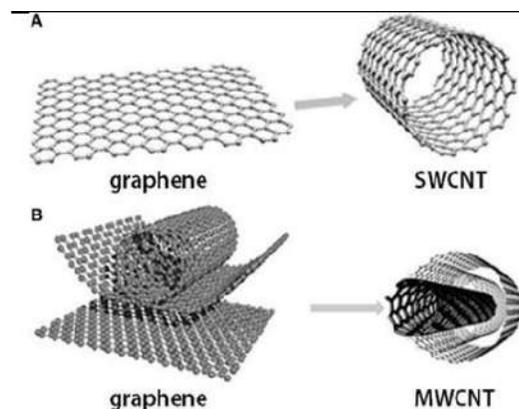


Fig 9.4 - Nanomaterials

9.1.6 Aerogels -

They are materials with a low density and low thermal conductivity that can be used in a variety of space applications. Because of their weak durability and mechanical qualities, they are rarely used in space applications. It is a good thermal insulator and hence can be used for insulation in spacecraft. Warm electronics boxes are made of aerogel packed in a composite box and can be used to safeguard batteries, computers, and other electronic components. Because it is a good thermal insulator, it can be used to insulate spacecraft. Warm electronics boxes are made of aerogel packed in a composite box and can safeguard batteries, computers, and other electrical components. Aerogels aid in the preservation of the fuel's liquid condition. They contribute to the development of fire-resistant space suits.

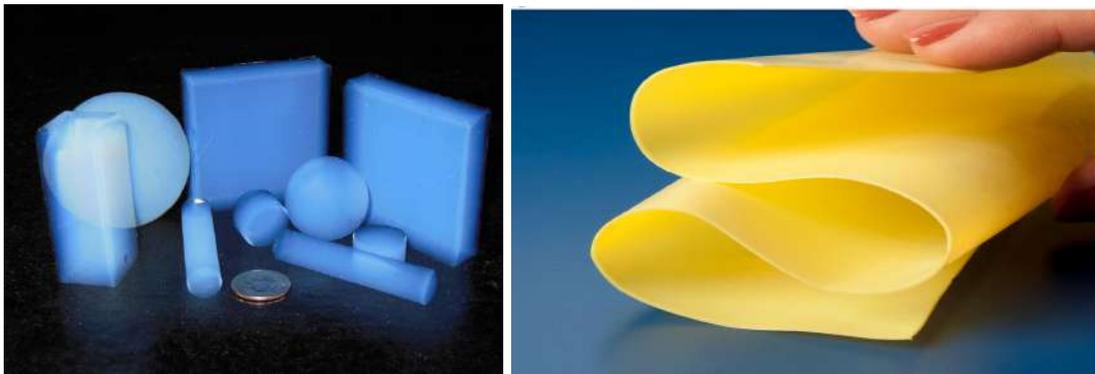


Fig 9.5 - Aerogels

9.1.7 Inconel Alloy 625 -

Inconel Alloy is a unique alloy composed of Molybdenum and Niobium embedded in a nickel-chromium matrix. High tensile, creep, and rupture strength, as well as outstanding weldability and braze ability, make it ideal for the aerospace industry. It is a high corrosion resistant alloy. Inconel Alloy 625 has a good resistance to oxidation and scaling at high temperatures, which is a key attribute. It has the unique capability of providing a protective oxide coating under extreme cycling circumstances. It can be used for thermal stability and micro structural evolution. Hence these alloys play an important role in aerospace industries these days.



Fig 9.6 - Alloy Sheets

9.2 So the different types of materials used for manufacturing heat tiles are stated below:

The heat tiles that are used at the nose tip of the vehicle are also made up of different materials and in modern technology there are heat tiles that can be reused with a different vehicle for different missions and its shelf life is about 30 years.

9.2.1 HRSI -

One type of the tiles utilized in the lower side of the re-entry vehicle is high temperature reusable surface insulation, which is covered with Li-900 silica ceramics. HRSI is employed when the re-entry temperature is less than 1200 degree celsius.



Fig 9.7 - HRSI Tiles

9.2.2 LRSI -

Another type of tile is low temperature reusable surface insulation, which is mostly utilized on the upper section of the fuselage but is occasionally used instead of flexible insulation blankets. When the temperature is below 649 0 C, it is used (12000 F).



Fig 9.8 - LRSI Tiles

CHAPTER 10

THERMAL PROTECTION SYSTEM

10.1 Introduction

The term thermal protection system (TPS) refers to a set of materials applied externally to a space vehicle's outer structural skin to keep it cool, especially during the reentry phase of a mission. TPS materials are chosen for their high-temperature stability and weight efficiency. Thermal protection systems are required for spacecraft that enter the earth's atmosphere to safeguard them from aerodynamic heating. By combining an underlying layer of thermal insulation with high-temperature resistant surface materials, the TPS system employed by space spacecraft prevents heat transfer on the vehicle's interior.

We'll look at some major approaches to Thermal Protection Systems (TPS) :-

10.2 Heat Shields

The heat generated upon re-entry can be extremely damaging to delicate instruments on board as well as any prospective humans on board. As a result, it is critical for spacecraft designers and engineers to devise a technique for safeguarding the spaceship's contents. Heat shields are used to do this. Heat shields used are mainly of two types. They can be an **ablative heat shield** or a **heat sink heat shield**.

- Heat Sink heat shield -

Heat sinks work on the premise that certain sections of the spacecraft absorb the majority of the heat and direct it away from the spacecraft's main body. These materials then dissipate the energy into the environment. Originally, sinks were built of titanium and beryllium alloys, but they were eventually replaced with a lighter, more sophisticated composite. These heat sinks are fashioned like floor tiles and are installed on the spacecraft's body like regular flooring. The composition of the heat sinks varies across the spacecraft's body. For example, the heat sinks at the bottom of a

space shuttle are built of silica, which is around 90% porous. This porosity allows the sink to absorb a substantial quantity of heat without allowing it to reach the main body. The heat sink here is made of carbon fiber reinforced carbon. The biggest issue with the heat sink is that the tiles are extremely brittle and fragile, and dirt can easily break them off.



Fig 10.1 - Heat Sink

- Ablative heat shield -

Ablative materials are materials that are designed to burn slowly and in a controlled manner, allowing heat to be directed away from the spacecraft interiors while the burnt ablative materials remain on the spacecraft exterior, insulating the spacecraft from the surrounding heat. An ablative is a composite material made up of a flammable matrix and a mesh-like passive reinforcing material. The combustible matrix ash is trapped in the reinforcing mesh, allowing the ash to insulate the spacecraft. Another way is to burn the matrix, which creates a layer of non-combustible vapors over the vehicle's surface, which protects the spacecraft. A matrix of epoxy novolac resin with fiberglass meshing is a popular ablative shield composite. The Apollo, Mercury, and Gemini spacecrafts all utilized this kind of heat shielding. These shields are effective at keeping spacecraft from catching fire, but they can't be intricately built for payloads that aren't shaped like rovers. Furthermore, these heat shields must be transported as a single unit around the spacecraft, resulting in an unwelcome weight gain.

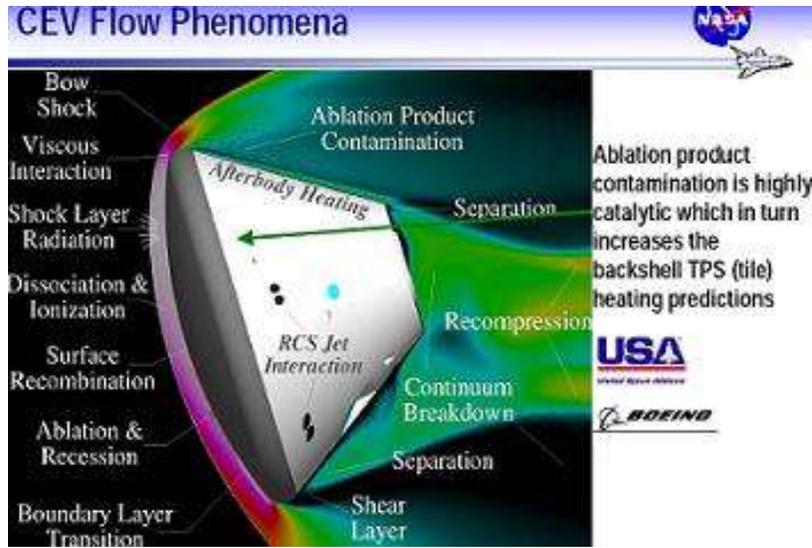


Fig 10.2 - Ablation

One of the major incidents that took place due to the failure of the thermal protection system is Space Shuttle Columbia STS-07. The Columbia accident, in which Kalpana Chawla and six others died when the space shuttle Columbia destroyed on re-entry following a 16-day research mission in 2003, is still unknown. The Columbia Accident Investigation Board determined that one of the wings' leading edges had been punctured. During launch, one of the insulating tiles peeled off and impacted the left wing, creating the hole. Hot gasses reached this hole during re-entry, damaging the internal hydraulics and causing control surfaces to fail. This resulted in the shuttle's loss of control and subsequent destruction.



Fig 10.3 - Kalpana Chawala's Team

10.3 Reinforced Carbon-Carbon

During atmospheric re-entry, it can sustain temperatures of up to 2300 degrees Fahrenheit. As a result, it's commonly found in the leading edge, wing, and nose cap, among other places. Carbon fibre and graphite matrix with reinforcement make up this composite material. It has a very low thermal expansion coefficient, a good fatigue resistance, and a low density. An amorphous carbon matrix is used to make a Reinforced Carbon-Carbon Composite. It has some properties like:

- Excellent thermal shock resistance.
- Low density (1830 kg/m³).
- High modulus of rigidity(200GPa).
- High thermal conductivity(100W/m*k).
- In a non-oxidizing atmosphere it should have thermal resistance.

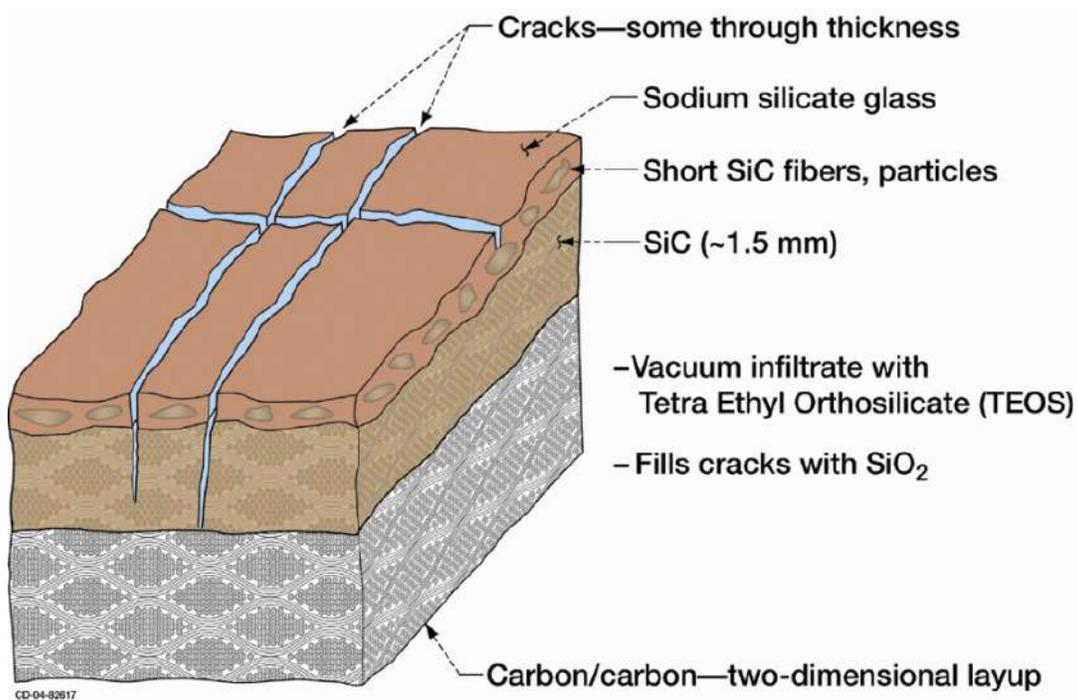


Fig 10.4 - Reinforced Carbon-Carbon Layers

10.4 2SLA-561V

The abbreviation SLA refers to a super light-weight ablator. On all 700 sphere cone entrance vehicles, the SLA-561V was used as the primary thermal protection system vehicle. SLA-561V is applied to the ablative material inside the honeycomb cave and bounced back to the structure of the aero shell.

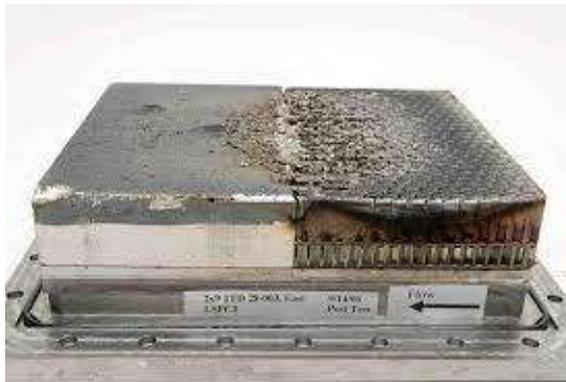


Fig 10.5 - Lightweight Ablator

10.5 PLCA

It stands for phenolic impregnated carbon ablator, or PLCA, which is a carbon fibre that has been impregnated with phenolic resin. It's a cutting-edge thermal-protection system. Its key advantage is its low density, which makes it significantly lighter than carbon phenolic. When compared to other high heat flux ablative materials, such as convectional carbon phenolic, this PLCA has a low thermal conductivity.



Fig 10.6 - Carbon Ablator

CHAPTER 11

MANUFACTURING TECHNIQUES

11.1 Manufacturing Techniques

When a reentry vehicle's manufacturing process is started, the whole vehicle is not manufactured in one go rather the different parts are manufactured and then welded together. The first part that is manufactured is the outer shell or we can say the structure of the vehicle and taking that as reference the further manufacturing is done. Then the manufacturing of the interior part of the vehicle is started. It is made up of a very thick layer of different materials stated in the above chapters. Then manufacturing of heat tiles is done which protects the space vehicle and crew during re-entry.

Several techniques of manufacturing of different parts given below: -

11.1.1 3D Printing or Additive Manufacturing -

In 3D printing, one generates an object's design using software, and the 3D printer builds the object by layering material on top of layer until the desired shape is achieved. Plastics, powders, filaments, and paper are among the printing materials that can be used to create the object. In the infographic below, 50 space enterprises are using 3D printing to help construct an off-Earth ecology, which is also included in our new Space Zone. 62 % of corporations build spacecraft and technologies to travel to LEO and the International Space Station, which is 220 miles above Earth (ISS). Despite the fact that 72 percent of these 50 enterprises are based in the United States, they are springing up all over the world, from Germany to India.

It's only natural for producers of re-entry vehicles to look into the possibilities of using additive manufacturing technology in space, where additive manufacturing has the ability to:

- Reduce re-entry vehicle's volumes as compared to an equivalent spacecraft.
- Enable tailoring of re-entry vehicle's systems that come back to the earth.
- Allow for the creation of new materials and parts that have never been seen before, potentially resulting in space-only parts that work well in zero gravity.
- Transform operations and logistics planning by launching a broad range of materials that can be created in a situation into a variety of parts with a wide range of functionality.
- When developing space hardware and robotic systems, it may even modify the trade space such that functional, small spacecraft can be entirely made in space to meet the needs of unique owners.



Fig 11.1 - Manufacturing



Fig 11.2 - 3D Printing Of Materials



Fig 11.3 - Companies Involved In Manufacturing

11.1.2 Manufacturing of Thermal Protective coating for Re-Entry Vehicle -

The Rocket-Space Corporation "Energy" (RSCE) named after S P Korolyov invented the production technology for a thermal protection cover for reusable spaceships. RSCE is now the only organization in Russia that owns and develops spaceship and man-controlled space travel technologies. The creation of heat protection ensured that the descending spaceship "Soyuz" maintained its outstanding aerodynamic quality and durability. The thermal protection of the descending vehicle "Zond " thermal protection, built for manned trips to the Moon and overcoming the Earth's atmosphere during the return with a velocity of 11km/s, provided invaluable knowledge. The results of experimental and theoretical research were described in joint works by specialists from RSCE and Bauman Moscow State Technical University (BMSTU) [7-23], which included the use of an autoclave to cure and form the composite under the action of hot nitrogen pressure. The TPC's requisite porosity is obtained by repeatedly filling a porous workpiece with binder and curing it. The secondary porosity created by the evaporation of alcohol in the binder necessitates repeated filling.

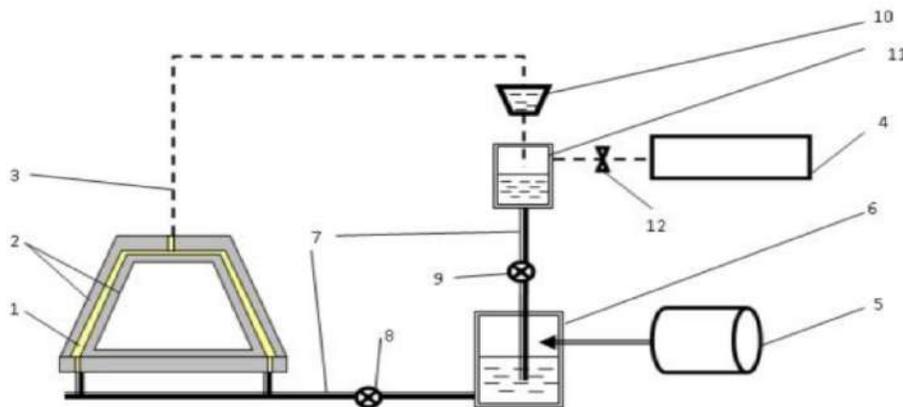


Fig 11.4 - Coating Process

Where,

1 – workpiece, 2 – manufacturing jig, 3 – vacuum line, 4 – vacuum pump, 5 – compressed gas bottle
6 – the binder container, 7 – the pipeline for supplying the binder, 8 and 9 – valves, 10 – binder indicator, 11 – binder collector, 12 – valve.

CHAPTER 12

APPLICATIONS STRATEGY

12.1 Applications

Space re-entry vehicle is a cornerstone for a wide range of applications in:

12.1.1 Next – Generation Launchers -

The space reentry vehicles can be utilized as launchers from a desired altitude in space and for a variety of applications.



Fig 12.1 - Future Vehicles

12.1.2 - Inter - Planetary Exploration -

Crewed or uncrewed travel between stars and planets, usually within a single planetary system, is known as interplanetary spaceflight or interplanetary travel. If upgraded to the necessary configuration, the space re-entry spacecraft can also do interplanetary trips. All of the known

planets in the Solar System, as well as the dwarf planets Pluto and Ceres, and several asteroids, can be visited by unmanned space probes.

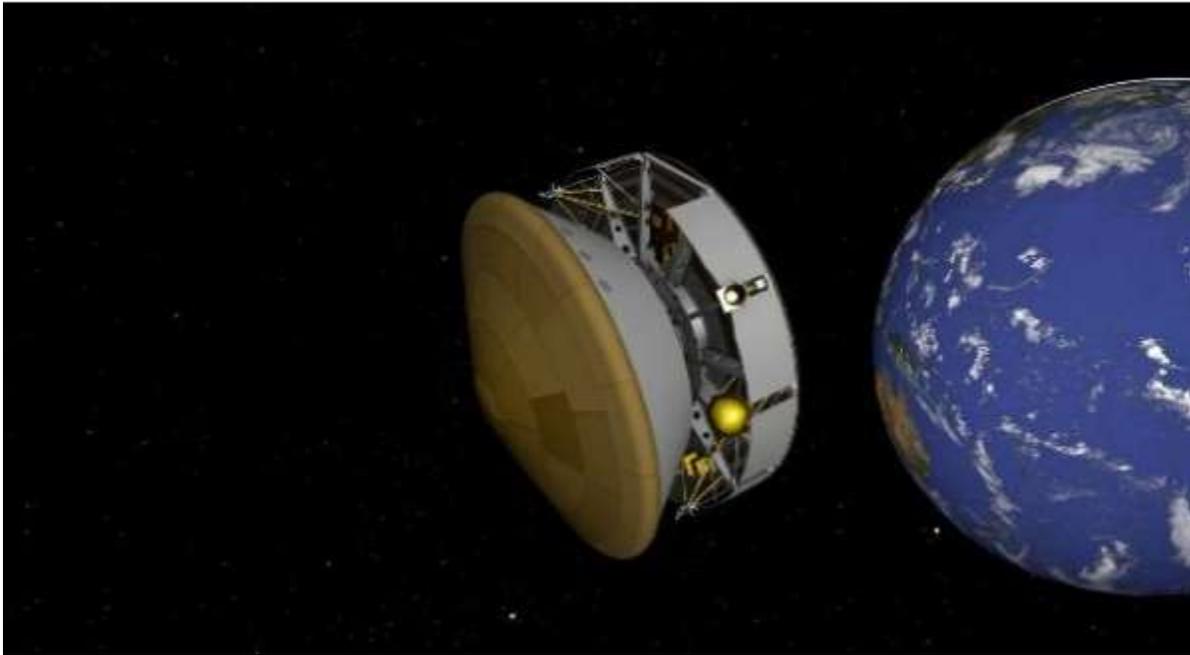


Fig 12.2 - Space Exploration

12.1.3 Crew & Cargo Transportation -

One of the vital uses of the Space Re-Entry vehicles is in transportation of Crew or Cargo to the International Space Station (ISS), in any orbital or sub-orbital missions, test flights for future crewed missions etc.



Fig 12.3 - Transportation

CONCLUSION

The preliminary design of a re-entry is done and the various design considerations and performance parameters required are calculated and found out. The obtained design values are not necessarily a definite reflection of a true re-entry vehicle, but the basic outlay of development has been obtained. Also we learned about different parameters of reentry vehicles, such as the idea behind it, the trajectory, and the shape of the vehicle, as a result of our research. Materials used in a reentry vehicle ablative and non-ablative manufacturing nanomaterials. From the standpoint of aerodynamics, We discovered that a Blunt Body would be more appropriate. If you're looking to reenter the country, you'll need to be in good form. As compared to the sleek body In addition, We discovered some fascinating information regarding the manufacturing industry. Technology such as 3D printing, which were previously utilized to Many of the company's best parts are made in-house. Our efforts also shows the applications that will be used in the future in a variety of spatial domains.

The challenges we faced at various phases of the project made clear the fact that experience plays a vital role in successful design of any re-entry vehicle or any aircraft/spacecraft component. A lot of effort has been put into this project and as much as we have worked, we have learnt in turn

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