# INTRODUCTION TO SPACE TECHNOLOGY

## MODULE-1

A rocket is a vehicle, missile, or spacecraft that obtains thrust from a rocket engine. Rockets work on the principle of Newton's third law of motion: for every action, there is an equal and opposite reaction.

Rockets operate by expelling mass at high speed from the rear end of the vehicle, creating a thrust force in the opposite direction. This allows them to lift off from the ground and travel through the vacuum of space.

Rocket propulsion is the method by which a rocket is propelled forward. It involves the generation of thrust by expelling mass (exhaust gases) in one direction, which propels the rocket in the opposite direction.

Rocket propulsion can be classified based on the type of propellant used and the method of expelling it. The main types are:

1. Chemical Rocket Propulsion
    a) Solid Rocket Propulsion
    b) Liquid Rocket Propulsion
    c) Hybrid Rocket Propulsion

2. Non- Chemical Rocket Propulsion (ex- Electrical Rocket propulsion )
3. Advance Rocket propulsion (Nuclear Rocket Propulsion)

## Solid Propellant Rockets: Detailed Exploration

Solid propellant rockets are one of the earliest and simplest forms of rocket technology. They are widely used due to their reliability and simplicity. Below is an in-depth look at their components, advantages, disadvantages, and examples.

**Solid Propellant:**

**Composition:** Solid propellant is a mixture of fuel and oxidizer. The fuel provides the chemical energy, while the oxidizer enables the fuel to burn in the absence of atmospheric oxygen.

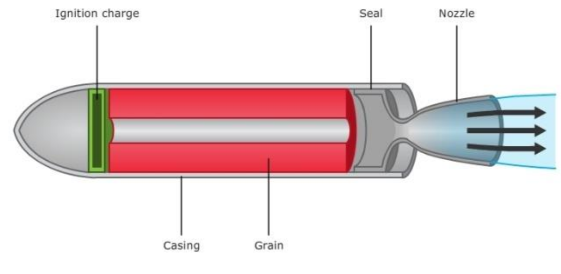
**Fuel:** Often consists of a powdered metal, such as aluminum.

**Oxidizer:** Commonly used oxidizers include ammonium perchlorate or ammonium nitrate.

**Binder:** A polymeric binder holds the fuel and oxidizer together and can also act as an additional fuel.

**Advantages**

**Simple Design: Fewer Moving Parts:** Solid rockets have no complex pumps or valves, reducing the likelihood of mechanical failure.



**Ease of Manufacturing:** The simplicity of their design makes them easier and cheaper to manufacture.

**Reliability: Proven Technology:** Solid rockets have been extensively used and tested, providing a high level of confidence in their performance.

**Operational Readiness:** Can be stored in a ready-to-launch condition for long periods without significant degradation.

**Storage and Handling: Long Shelf Life:** Solid propellants are chemically stable and can be stored for years.

**Ease of Transport:** The solid form of the propellant makes handling and transportation safer and more convenient compared to liquid propellants.

**Disadvantages**

**Thrust Control: Non-Throttleable:** Once ignited, the thrust cannot be adjusted or throttled.

**No Shutdown Capability:** The rocket cannot be shut down until all the propellant has been burned, limiting control over the mission.

**Efficiency: Lower Specific Impulse:** Generally less efficient than liquid propellant rockets in terms of specific impulse (Isp).

**Design Constraints: Fixed Thrust Profile:** The burn rate and thrust profile are fixed by the grain design, offering less flexibility for mission-specific adjustments.

## Liquid Propellant Rockets: Detailed Exploration

Liquid propellant rockets are a versatile and widely used type of rocket propulsion system. They are known for their efficiency and ability to be controlled during flight.

Components

**Propellant Tanks:**

Fuel Tank: Stores the liquid fuel, such as liquid hydrogen (LH2), kerosene (RP-1), or hydrazine.

Oxidizer Tank: Stores the liquid oxidizer, such as liquid oxygen

(LOX) or nitrogen tetroxide ($N_2O_4$).

**Pressurization System:** Keeps the propellants at the required pressure for smooth flow into the combustion chamber. Often uses helium or another inert gas.

**Pumps and Turbopumps:**

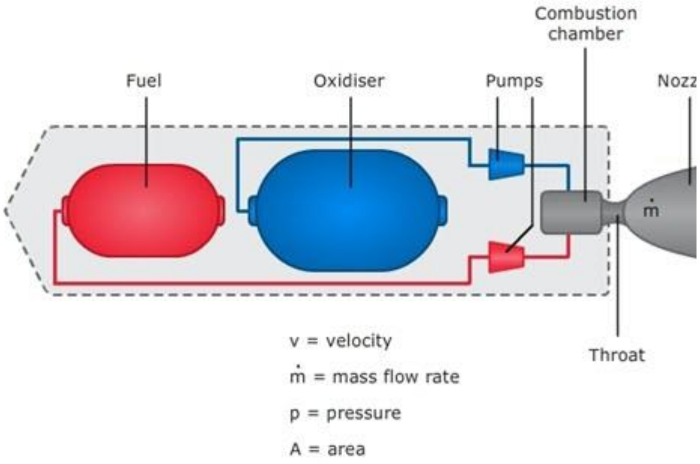
Function: Transfer the propellants from the tanks to the combustion chamber at high pressure.

Turbopumps: Combine a turbine driven by gas (usually from a small preburner) with a pump to move the propellants.

Combustion Chamber: Where the fuel and oxidizer mix and combust to produce high-temperature and high-pressure gases.

**Injector:** Delivers fuel and oxidizer into the combustion chamber in a manner that ensures efficient mixing and combustion.

**Nozzle:** Expands and accelerates the exhaust gases to produce thrust.



Types of Liquid Propellant Rockets

**1. Bipropellant Rockets:**

Components: Uses two separate components - a liquid fuel and a liquid oxidizer.

Fuel Examples: Liquid hydrogen ($LH_2$), kerosene (RP-1), ethanol.

Oxidizer Examples: Liquid oxygen (LOX), nitrogen tetroxide ($N_2O_4$).

**2. Monopropellant Rockets:**

Components: Uses a single chemical that decomposes in the presence of a catalyst to produce thrust.

Examples: Hydrazine ($N_2H_4$), hydrogen peroxide ($H_2O_2$).

## Advantages of Liquid Rocket Propulsion

**Throttling Capability:**

**Adjustable Thrust:** Liquid engines can vary thrust levels by controlling fuel and oxidizer flow, allowing precise control.

**Applications:** Essential for delicate maneuvers like docking with the ISS or landing on celestial bodies.

**Restart Capability:**

**Multiple Starts:** Engines can be shut down and restarted multiple times, useful for complex missions with multiple orbital adjustments.

**Examples:** Upper stages and spacecraft like the Apollo Lunar Module.

**Higher Specific Impulse (Isp):**

**Efficiency:** Liquid engines generally have higher specific impulse, providing more thrust per unit of propellant.

**Benefit:** Enables longer missions or heavier payloads with the same amount of propellant.

**Flexible Propellant Options:**

**Versatility:** Numerous combinations of fuels and oxidizers allow engineers to choose the best propellant pair for each mission.

**Examples:** Liquid hydrogen/liquid oxygen for deep space, hypergolic propellants for reliable spacecraft thrusters.

**Smooth Combustion:**

**Controlled Burn:** Liquid propellants burn more smoothly, resulting in less vibration and structural stress.

**Benefit:** Enhances safety and longevity of the rocket and payload.

## Disadvantages of Liquid Rocket Propulsion

**Complex Design:**

**Engineering Challenges:** Requires intricate systems for pumping, mixing, and burning propellants, increasing cost and potential points of failure.

**Components:** Includes turbopumps, injectors, combustion chambers, and cooling systems.

**Cryogenic Storage Requirements:**

**Temperature Management:** Some propellants need to be stored at cryogenic temperatures, requiring sophisticated insulation and refrigeration.

**Challenges:** Handling and storage infrastructure for cryogenic propellants is more complex and costly.

**Safety Risks:**

**Volatility:** Many propellants are highly reactive or toxic, posing significant handling risks.

**Hazards:** Accidental leaks or spills can lead to fires, explosions, or contamination.

**Operational Complexity:**

**Pre-launch Preparation:** Requires extensive preparation, including propellant loading and system checks.

**Time-Consuming:** These procedures need specialized ground support equipment and personnel.

**Cost:**

**Development and Maintenance:** Complexity and sophistication make liquid engines expensive to develop and maintain.

**Example:** High costs of Space Shuttle Main Engines due to advanced technology and reusable design.

## Hybrid Rocket Propulsion: Detailed Exploration

Hybrid rocket propulsion combines elements of both solid and liquid rockets, using a solid fuel and a liquid or gaseous oxidizer. This system leverages the simplicity of solid rockets and the controllability of liquid rockets.

Components

Solid Fuel: Typically consists of a polymer like hydroxyl-terminated polybutadiene (HTPB) or rubber, sometimes mixed with metal powders for added energy.

Liquid or Gaseous Oxidizer: Liquid oxygen (LOX), nitrous oxide ($N_2O$), or gaseous oxygen (GOX).

Combustion Chamber: Where the solid fuel and oxidizer mix and combust to produce high-temperature and high-pressure gases.

Injector: Delivers the oxidizer into the combustion chamber, ensuring efficient mixing with the solid fuel.

Design: Similar to liquid rocket injectors, can be designed for optimal distribution of oxidizer.

Nozzle: Expands and accelerates the exhaust gases to produce thrust.

Oxidizer Feed System: Includes tanks, valves, and plumbing to transport the oxidizer from storage to the combustion chamber. Allows for throttling, starting, and stopping the flow of oxidizer.

## Advantages of Hybrid Rocket Propulsion

- Safety: Solid fuel is stable and less hazardous than liquid propellants. Fuel and oxidizer stored separately, reducing detonation risk.
- Throttling Capability: Oxidizer flow can adjust thrust. Engines can be stopped and restarted by controlling oxidizer flow.
- Simplicity: Combines solid and liquid rocket simplicity, avoiding turbopumps. Easier and cheaper to manufacture than liquid engines.
- Cost-Effective: Lower costs compared to liquid rockets. Solid fuels are cheaper and easier to store.
- Environmentally Friendly: Solid fuels like HTPB are less toxic. Oxidizers like $N_2O$ produce benign products.

## Disadvantages of Hybrid Rocket Propulsion

- Lower Performance: Typically lower specific impulse than liquid rockets. Less efficient combustion if fuel and oxidizer mixing isn't optimal.
- Complex Combustion: Uneven burn rate can lead to variable thrust. Challenging to maintain stable combustion at high thrust.
- Design Challenges: Needs careful injector design for efficient mixing. Combustion chamber must handle intense heat.
- Limited Throttle Range: Throttle range and responsiveness are less than liquid rockets.
- Oxidizer Storage: Some oxidizers need cryogenic storage, adding complexity. Gaseous oxidizers need high-pressure storage, requiring robust tanks.

## Applications

- Suborbital Launch Vehicles
- Educational and Experimental Rockets
- Sounding Rockets
- Military Applications

# Atmospheric Re-entry: A Comprehensive Study

## Introduction

Atmospheric re-entry refers to the process by which a spacecraft returns to Earth from space. This phase of the mission is critical and complex, requiring careful planning and execution to ensure the safety of both the vehicle and its occupants, as well as the success of the mission objectives. Several methods and techniques are employed during atmospheric re-entry, each with its advantages and challenges.

**Atmospheric entry** - is the movement of an object from outer space into and through the gases of the atmosphere of a planet, dwarf planet, or natural satellite. There are two main types of atmospheric entry: ***uncontrolled entry***, such as the entry of astronomical objects, space debris, or bolides; and ***controlled entry*** (or *reentry*) of a spacecraft capable of being navigated or following a predetermined course. Technologies and procedures allowing the controlled atmospheric *entry, descent, and landing* of spacecraft are collectively termed *EDL (*Entry, Descent, and Landing*)*

Objects entering an atmosphere experience atmospheric drag, which puts mechanical stress on the object, and aerodynamic heating—caused mostly by compression of the air in front of the object, but also by drag. These forces can cause loss of mass (ablation) or even complete disintegration of smaller objects, and objects with lower compressive strength can explode.

Reentry has been achieved with speeds ranging from 7.8 km/s for low Earth orbit to around 12.5 km/s for the **Stardust probe**. Crewed space vehicles must be slowed to subsonic speeds before parachutes or air brakes may be deployed. Such vehicles have high kinetic energies, and atmospheric dissipation is the only way of expanding this, as it is highly impractical to use **retrorockets** for the entire reentry procedure.

Ballistic warheads and expendable vehicles do not require slowing at reentry, and in fact, are made streamlined to maintain their speed. Furthermore, slow-speed returns to Earth from near-space such as high-altitude parachute jumps from balloons do not require heat shielding because the gravitational acceleration of an object starting at relative rest from within the atmosphere itself (or not far above it) cannot create enough velocity to cause significant atmospheric heating.

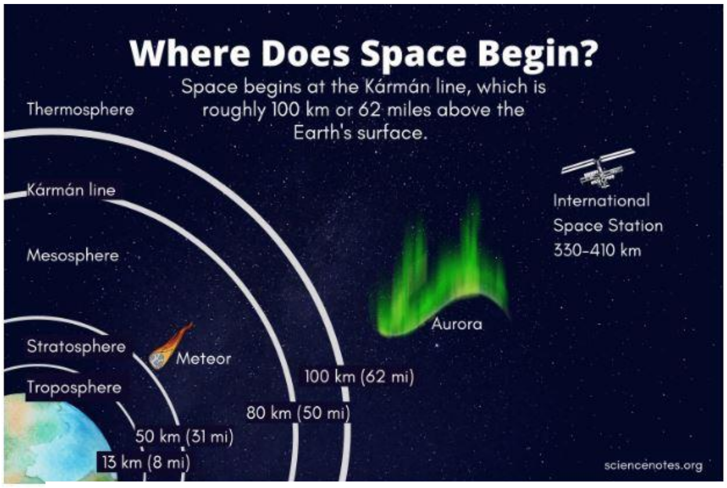
For Earth, atmospheric entry occurs by convention at the **Kármán line** at an altitude of 100 km (62 miles; 54 nautical miles) above the surface, while at Venus atmospheric entry occurs at 250 km (160 mi; 130 nmi), and at Mars atmospheric entry at about 80 km (50 mi; 43 nmi). Uncontrolled objects reach high velocities while accelerating through space toward the Earth under the influence of Earth's gravity, and are slowed by friction upon encountering Earth's atmosphere. Meteors are also often traveling quite fast relative to the Earth simply because their orbital path is different from that of the Earth before they encounter Earth's gravity well. Most objects enter at hypersonic speeds due to their sub-orbital (e.g., intercontinental ballistic missile reentry vehicles), orbital (e.g., the Soyuz), or unbounded (e.g., meteors) trajectories. Various advanced technologies have been developed to enable atmospheric reentry and flight at extreme velocities. An alternative method of controlled atmospheric entry is buoyancy which is suitable for planetary entry where thick atmospheres, strong gravity, or both factors complicate high-velocity hyperbolic entry, such as the atmospheres of Venus, Titan , and the gas giants.

Terms

A **retrorocket** (short for *retrograde rocket*) is a rocket engine providing thrust opposing the motion of a vehicle, thereby causing it to decelerate. They have mostly been used in spacecraft, with more limited use in short-runway aircraft landings. New uses have emerged since 2010 for retro-thrust rockets in reusable launch systems.

The **Kármán line** (or **von Kármán)**is a proposed conventional boundary between Earth's atmosphere and outer space set by the international record-keeping body FAI (Federation aéronautique internationale) at an altitude of 100 kilometers (54 nautical miles; 62 miles; 330,000 feet) above mean sea level. However, such a definition of the edge of space is not universally adopted.

The Kármán line has no particular physical significance, in that there is no noticeable difference between the characteristics of the atmosphere above and below it, but it is important for legal and regulatory purposes since aircraft and spacecraft are subject to different jurisdictions and legislations. International law does not define the edge of space or the limit of national airspace. LINK- https://www.youtube.com/watch?v=EQcOK8NObh0



## Central Idea

- Boundaries serve a crucial purpose in scientific understanding by providing clarity and distinction to elements that might otherwise merge.
- One such significant boundary is the Karman Line, which plays a pivotal role in delineating Earth's atmosphere from outer space.

## What is Karman Line?

- The Karman Line is an abstract boundary positioned at an altitude of 100 kilometers above sea level.
- Its primary function is to establish the separation between Earth's atmosphere and the vast expanse of space.
- Although not universally accepted by all scientists and space explorers, the majority of countries and space organizations acknowledge this demarcation.
- It was formally established in 1960s by the Federation Aeronautique Internationale (FAI), a body responsible for record-keeping.
- Crossing the Karman Line designates an individual as an astronaut.

## Challenges to the Karman Line's Significance

- Nature rarely conforms to human-made boundaries.
- Physically crossing the Karman Line does not result in substantial changes.
- In the immediate vicinity, there is minimal difference in air pressure or composition.
- Earth's gravitational force remains influential, and the atmosphere persists beyond this line.

## Why is the Karman Line relevant?

- **Airspace Regulation:** The Karman Line primarily serves as a regulator of airspace. It represents an approximate altitude beyond which conventional aircraft cannot operate effectively. Aircraft venturing beyond this threshold require propulsion systems to counteract Earth's gravitational pull.
- **Legal Reference:** Additionally, the Karman Line acts as a legal benchmark that distinguishes airspace, which nations can claim ownership of, from the realm of outer space. Outer space is governed similarly to international waters, emphasizing the importance of this boundary in legal and governance contexts.

***Stardust*** was a 385-kilogram robotic space probe launched by NASA on 7 February 1999. Its primary mission was to collect dust samples from the coma of comet Wild 2, as well as samples of cosmic dust, and return them to Earth for analysis. It was the first sample return mission of its kind. En route to Comet Wild 2, it also flew by and studied the asteroid 5535 Annefrank. The primary mission was successfully completed on 15 January 2006 when the sample return capsule returned to Earth.

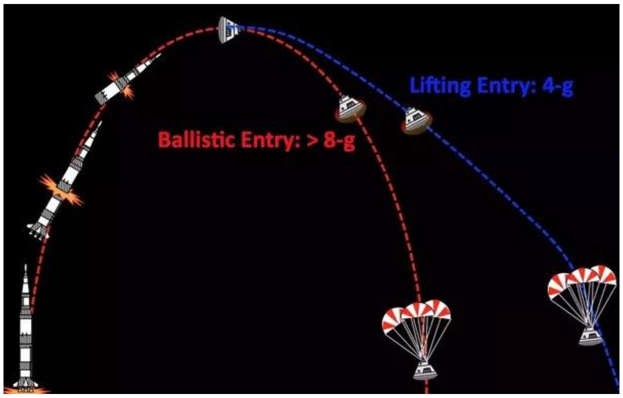
There are two mechanism principles commonly used to design the entry mission.

    1. Ballistic Entry Mission
    2. Lifting Entry mission
1. Ballistic Reentry Strategies
    a) Steep Ballistic Trajectory
    b) Orbital Ballistic Trajectory

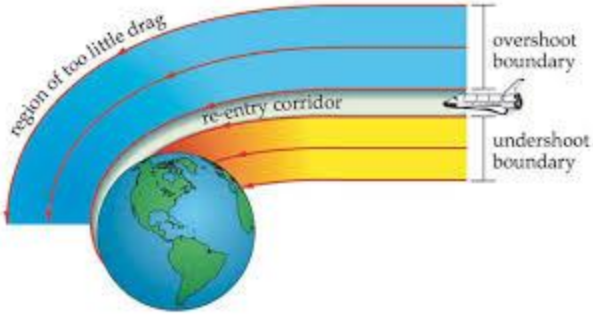
### Steep Ballistic Re-entry

In steep ballistic re-entry, the spacecraft follows a steep trajectory, entering the Earth's atmosphere at a high angle of attack. This approach is commonly used for capsules and re-entry vehicles designed to withstand high temperatures and G-forces. The steep angle helps to dissipate the vehicle's kinetic energy rapidly, reducing the heat generated during re-entry. However, it also subjects the occupants to higher gravitational forces, requiring robust thermal protection systems and structural integrity.

Steep ballistic reentry is used for **unmanned** capsule which are stable bodies offering maximum frontal area to wind and have no specific heat-related requirements.



However it is found that steep ballistic entry has a very small entry corridor (feasible domain), and generates a large amount of heat passing other design issues.



### Ballistic Orbital Re-entry (shallow ballistic entry concept)

Ballistic orbital re-entry involves returning to Earth from a stable orbit without significant aerodynamic maneuvering. The spacecraft follows a ballistic trajectory dictated by its velocity and gravity, experiencing high temperatures and deceleration as it enters the atmosphere. This method is used by space capsules and vehicles not equipped for aerodynamic flight. Precise calculations are essential to ensure the vehicle enters the atmosphere at the correct angle and velocity for a safe re-entry.

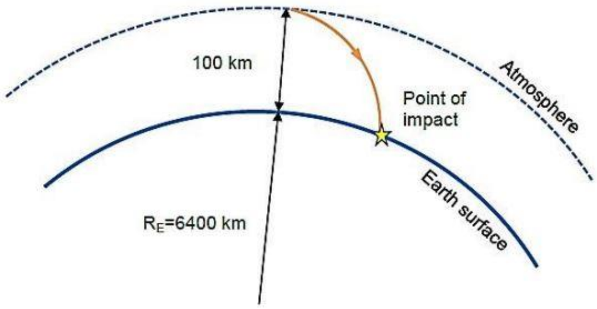


Figure 2.5 Ballistic reentry from space

### 4. Skip Re-entry

Skip re-entry involves using the Earth's atmosphere to slow down and change trajectory multiple times before finally entering for re-entry. This technique allows for greater control over the descent path and can be used to adjust the landing site or distribute heat load more evenly. Skip re-entry requires precise navigation and guidance systems to execute the necessary maneuvers successfully.

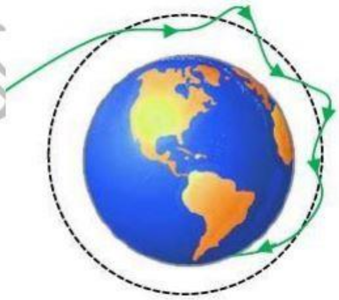


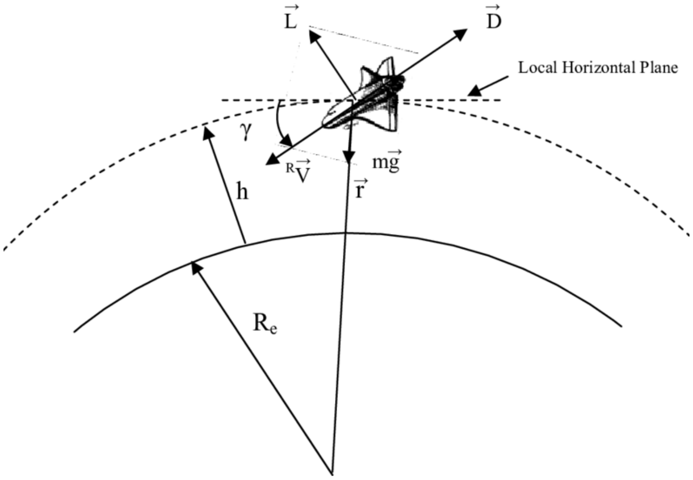
Figure 2.6 Skip Reentry for the spacecraft with lifting surfaces

### 5. "Double-Dip" Re-entry

"Double-dip" re-entry refers to a technique where the spacecraft enters the atmosphere, skips out again into space, and then re-enters for a second time. This approach can help dissipate heat more gradually and reduce the peak temperatures experienced during re-entry. It is often used for vehicles with limited thermal protection capabilities or when landing at higher velocities. However, it requires precise timing and control to ensure a safe and accurate landing.

### 6. Aero-braking

Aero-braking involves using the drag force generated by the atmosphere to slow down a spacecraft without the need for propulsion. By dipping into the upper layers of the atmosphere, the spacecraft experiences drag, gradually reducing its velocity and altering its orbit. Aero-braking can be used to fine-tune a spacecraft's trajectory, reduce fuel consumption, or facilitate orbital insertion. Careful planning and monitoring are required to prevent excessive heating or loss of control during aero-braking maneuvers.



### 7. Lifting Body Re-entry

Lifting body re-entry utilizes the aerodynamic lift generated by the spacecraft's shape to control its descent and trajectory during re-entry.

Unlike traditional capsules, lifting bodies have aerodynamic surfaces that allow for greater maneuverability and control during atmospheric flight.

This method enables precision landing and can reduce the stress experienced by the occupants during re-entry. However, it requires careful design and testing to ensure stability and control throughout the descent phase.

**In conclusion, atmospheric re-entry is a complex and challenging phase of space missions, requiring careful consideration of various factors such as vehicle design, trajectory planning, and thermal protection. Each re-entry method offers its advantages and trade-offs, and the choice of technique depends on mission objectives, spacecraft design, and operational requirements. Through continued research and technological advancements, scientists and engineers strive to improve the safety and efficiency of atmospheric re-entry for future space exploration endeavors.**

Links

https://slideplayer.com/slide/4475583/