

# A Brief Discussion about Reentry Vehicles

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**Abstract**— A re-entry vehicle is the segment of rocket which comes back on the earth’s surface through its atmosphere. This vehicle is highly affected by Earth’s gravity. Atmosphere also affects it while coming towards surface of earth. It is also affected by Atmospheric drag compression in atmosphere. While re-entry metals are highly heated and there are chances of melting of that metals then, Thermal Barrier Coating (TBC) is applied to resist large temperature gradients. Also, the reentry vehicles need thermal coating which is generally recognized as Thermal Protection System (TPS). Here we will be discussing the challenges faced while re-entry of that vehicle, attractive vehicle shapes, materials used in vehicles to prevent aerodynamic heating, also types of reentry vehicles and their analysis in brief.

**Keywords:** Reentry, Atmospheric Drag, Aerodynamic Heating, Inflatable Heat Shield Reentry

## I. INTRODUCTION

As we are sending many missions in space to other planets or much more for that we are sending artificial objects, but now we are developing various technologies by which we are able to send manned missions to explore and research more in space. In all this exploration we face various problems. In these various re-entry first we can say it could be (while doing entering in the earth's atmosphere or any other planets atmosphere) ballistic or non ballistic in nature. Also Reentry can be primarily divided into two basic classes: (I) Uncontrolled Reentry: Launcher upper stage, manned and unmanned capsules etc. (II) Controlled Reentry: Lifting body or control surfaces. While re-entry the capsule or the vehicle can get affected due to aerodynamic heating in atmosphere, in atmosphere it will get heated then for that we have to keep metals which have very high melting point, otherwise the astronauts which are inside the vehicle will not be safe.[1] The shapes of vehicles while re-entry with manned missions also plays important role for their safety. Then to resist large temperature gradients, In some components of the commercial gas turbine engines Thermal Barrier Coatings are widely used, including the blades, the nozzles, and the combustion chambers, entering to the structural components from the combustion gas to control the high heat flux. As re-entry vehicles need thermal protection system (TPS). If we consider a space shuttle, the Space Shuttle thermal protection system (TPS) is the barrier that protected the Space Shuttle Orbiter during the searing 1,650 °C (3,000 °F) heat of atmospheric reentry. A secondary goal was to protect from the heat and cold of space while in orbit.



Fig. 1: Apollo

As we can see in the fig-1 the capsule of Apollo which re-entering to the earth having some humans. Here we can see astronauts which are here in this capsule are getting affected by large amount of heat on their capsule. It is very high because at this time it is in free fall condition and here gravity also affects it. So, shape of that capsule and material of that capsule has a very important role in re-entry of that space vehicle. As in the fig-2 we can see the layers according to the thermal barrier protection coating of gas which is used in the re-entry of vehicles for resist that of heat.[2]

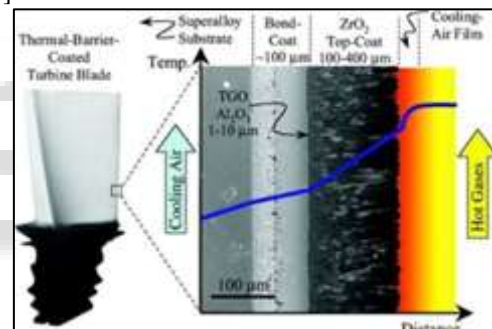


Fig. 2: Thermal barrier coating

Date	Incident	Mission	Fatalities	Cause
1967-04-24	Parachute failure	Soyuz1	Vladimir Komarov	During reentry due to improper opening of parachute, the capsule at hypersonic speed hit the ground.
1967-11-15	Control failure	X-15 Flight 3-65-97	Michael J. Adams	Due to the electrical problem with the plane, it was difficult to control when it was spinning and diving inverted at about hypersonic speed (Mach 5). This led to excessive loading and structural breakup at about 19.8km.
2003-02-01	Vehicle disintegration on reentry	Space Shuttle Columbia STS-107	Rick D. Husband William McCord Michael P. Anderson David M. Brown Kalpana Chawla Laurel B. Clark Ilan Ramon	The heat shield used in Space Shuttle Columbia are heat resistant tiles. Due to the damage caused in its TPS, during reentry it led to structural failure of the Shuttle's left wing and the spacecraft broke apart.

Table 1: History of some reentry incidents

## II. TWO FACTORS WHICH AFFECTS THE VEHICLE MOST ARE:

### 1) Atmospheric Drag:-

Due to frequent collisions of gas molecules with the spacecraft, when it approaches Earth's atmosphere it acts on the reentry vehicle. The drag force depends on the density of air, size of that vehicle, its drag coefficient and its velocity. We can express formula for drag force as follows:

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

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

$C_D$  = drag coefficient (unitless)

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

$\rho$  = atmospheric density ( $kg/m^3$ )

$V$  = vehicle's velocity (m/s)

### 2) Aerodynamic Heating:

When the vehicle starts to enter earth's atmosphere due to its high velocity it has a large amount of kinetic energy as it is now under the influence of gravitational pull of the earth. This kinetic energy gets converted to heat by friction which happens with surface of the vehicle. Also when it comes near the outer edge of the atmosphere, because of its high altitude vehicle gets large amount of potential energy. As when it comes on the surface of the earth its altitude becomes zero and its velocity becomes comparatively small. According to law of conservation of energy, all energy gained by vehicle is destroyed as by the heating up of the body and airflow around the body also gets heated up. Conduction, Convection and Radiation are the three ways in which vehicle and atmosphere takes place heat interaction. In lower atmosphere due to high density increases the friction, because of this vehicle speeds up in lower altitude then aerodynamic heating increases to a greater amount. For the safety measure vehicle has to be insulated by the use of ablative material and by using high temperature metals or alloys.

### A. Thermal protection system:-

We can define thermal protection system as the system which protects the object from extremely high heat and cold. In reentry we have various systems for protection of that shuttle of capsule in atmospheric heat, one of those systems is space shuttle thermal protection system which can protect that space shuttle up to approximately 1,650 °C heat. When space shuttles are returning from space to surface of earth with humans or without humans it is affected by gravity, because of this its speed increases in atmosphere and friction and aerodynamic heating occurs. Various types of different materials are used which have the capability to resist the high amount of heat and cold and have long durability. For more safety technologies are developing day by day.[3] Today Reinforced Carbon-Carbon Coating, High-temperature Reusable Surface Insulation Tile, Low-temperature Reusable Surface Insulation Tile, Advanced Flexible Reusable Surface Insulation Blanket, Flexible Reusable Surface Insulation Blanket are used in the space shuttle in this space shuttle according to NASA's details. Also in ISRO SSF P70 is the thermal protection system used is a low density Thermal Protection System (TPS) based on silicone polymer, with microballoon and other fillers as compounding ingredients. The special features of this systems are that this system includes high specific heat,

good ageing resistance, lower thermal conductivity, low density and compatibility with wide variety of substrates.

### B. Thermal Barrier Coating:

Thermal Barrier Coatings are advanced materials used on elevated temperatures, such as aero-engines parts, gas turbines, etc. These thermal barrier coating is characterized by their low thermal conductivity, the coating bearing a large temperature gradient when exposed to heat flow. The commonly used material in this coating is Yttrium Stabilized Zirconia.[4] Also the coating material should be having low weight and density in order to reduce payload. The layers of Thermal Barrier Coating which is the outermost covering which resist the elevated temperature produced by hot gas. We can summarize general requirements for an effective Thermal Barrier Coating as it is needing: 1) Low sintering rate for a porous microstructure. 2) Chemical inertness. 3) a high melting point. 4) no phase transformation between room temperature and operating temperature. 5) low thermal conductivity. 6) good adherence to the substrate. 7) similar thermal expansion match with the metallic substrate. As from the figure we can say that Thermal Barrier Coating generally consist of four layers: ceramic topcoat, thermally-grown oxide (TGO), metallic bond coat, and the metal substrate. The ceramic layer present here keeps the lower layers at lower temperature than the surface and creates the largest thermal gradient of the TBC. Because of all these properties it can resist environmental pressure and high amount of heat.[5]

## III. TYPES OF REENTRY VEHICLES

Reentry can be divided into two types:

### 1) Controlled Reentry: (Lifting body or control surfaces)

When forces other than drag force also acts on the spacecraft, then it is called controlled reentry. Because of controlled reentry we can choose a location for the impact of vehicle, by this we will be able to minimize the hazard to crew and that of vehicle at lower altitudes.



Fig. 3: Lifting reentry of space shuttle

In the fig-3 it's a reentry of space shuttle with high angle of attack, we can also say it's a lifting reentry. This is a winged reusable spacecraft, it reenters horizontally on a runway. It is designed for achieving large atmospheric maneuverability, also it has aspect ratio wings, vertical stabilizer, body flaps with landing parachute.[6]

2) *Uncontrolled Reentry: (Launcher upper stage, manned and unmanned capsules etc.)*

This is the type of reentry when the vehicles accelerates through the atmosphere under the influence of Earth's gravity at extreme velocities. Such reentries are ballistic in nature. Deceleration and thermal loads cause destruction and fragmentation of the spacecraft. Examples of this type of reentry includes capsules such as Soyuz, Apollo, Orion, etc. we can see the reentry of Orion capsule in the fig-4



Fig. 4: Orion

IV. MODERN REENTRY VEHICLE: IXV

This is one of the modern spacecraft developed by ESA. IXV is the Intermediate eXperimental Vehicle which falls under controlled reentry.[7] It is having a lifting body of conic shape. This makes it highly aerodynamic and easy to manoeuvre. The successful flight of IXV was on 11th February 2015.



Fig. 5: IXV

The IXV is shown in the fig-5 which is having weight nearly 2 tonnes. It is 5 meters long, 1.5 meters high and 2.2 meters wide. The heat shield material used in this is ceramic and for flight control it has a combination of flaps and thrusters, also having ratio of hypersonic lift-to drag: 0.7.

The outer surface of this spacecraft consists of advanced ceramic ablative thermal protection materials which can resist severe reentry environment and protect the spacecraft. Inner elements are built around the structural panels of carbon reinforced polymer, that provide the stiffness and strength to resist the extreme forces which are experienced during launch and landing. Its thrusters and flaps operate together for changing the flight altitude of the

vehicle. While descending into Earth's atmosphere IXV travels at the speed of around 27,000km/h.



Fig. 6: IXV's Thermal protection panels

As we can see in the fig-6 black coloured tiles present on it and flaps are thermal protection panels. These thermal protection panels shield can resist upto 1700 degree celsius in the process of reentry. The key technologies in this IXV includes Thermal Protection Systems (TPS), Guidance, Navigation and Control (GNC).

V. CONCLUSION:

From the overall upper discussion we can say one of the most crucial part in the space mission is reentry of vehicles which is the interactions with the atmosphere of planet. This reentry must include the safety for which the surface should be of high resistance and high strength materials like ceramics, SiC, etc. Also we are working on the more materials which will be having more resistance and it will be more strength than those which are used now. As new technologies are making the controlled reentry better as we can control it for its landing. Also in landing methods such as by using parachute are also getting developed. Because of parachute system velocity of space shuttle get decrease from 8km/s to 11km/s and heat flow by 3-4 times, high temperature fibers are used by it.

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