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Design and Analysis of a Space Capsule

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ABSTRACT: This paper deals with the thermal and static analysis on a space capsule returning from an interplanetary environment. Aerodynamic heating plays a crucial role in the thermal stability of the re-entry vehicle. The design of the space capsule demands an effective Thermal Protection System (TPS). The main objective of this paper is to present a thermal and static analysis for a re-entry space capsule with gravity and without gravity using the composite material Carbon Fiber Reinforced Plastic(CFRP), Hafnium diboride(HfB₂) and Zirconium diboride(ZrB₂). In this work special attention is devoted to the applying of thermal loads on the composite material and to observe the structure reaction with the temperature loads.

KEYWORDS: Space Capsule, TPS, CFRP, Hafnium diboride, Zirconium diboride.

I. INTRODUCTION

Space capsules are the compartments designed to support humans during their journey through space. They contain the basic elements that astronauts need to live like air to breathe, water to drink, and food to eat. They also have to protect the astronauts from the cold of space and space radiation. Capsules are well insulated and contain systems to adjust the internal temperature. There are seats with strap systems so that they can strap themselves in a seat to work or bed to sleep when they are in space because they will be weightless. Capsules have to be equipped with a way to communicate with mission control [1].

In the recent years space vehicles like rockets, reentry vehicles regardless their unique designs needed control surfaces at hypersonic speeds. Low-radius leading edges are subject to much greater aerodynamic heating than blunt edges, such as those on the Space Shuttle, and they thus will reach temperatures that may exceed 2000°C during reentry. Available thermal protection materials will not survive such extreme temperatures and new materials are required for advanced thermal protection systems. Thus they need advanced and latest ultra high temperature ceramic materials used as a TPS layer which have high resistance in heat and oxidation. Ronald Loehman, Erica Corral, Hans Peter Dumm, Paul Kotula and Raj Tandon described the qualities of Hafnium diboride (HfB₂) (melting temperature of 3250°C) and zirconium diboride (ZrB₂) (melting temperature of 3246°C) [2] for their existence in proving the further research activities of the hypersonic re-entry vehicles.

The space capsule experiences two biggest forces namely gravity and drag. As objects fall, they pick up momentum or accelerate until they impact the surface. When the space capsule comes through the atmosphere the capsule compresses the air in front of it which heats up to very high temperatures. During a planetary re-entry, when a capsule or a space vehicle approaches the relatively dense atmosphere a strong bow shock takes place ahead of the vehicle detached from its nose[3].

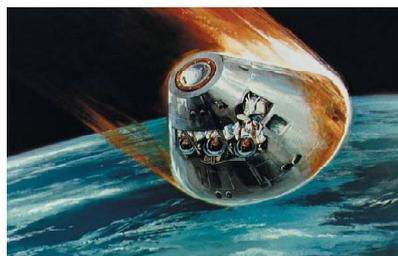


Fig 1: Apollo Capsule Re-entry, An artist's concept

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The above figure 1 shows the Apollo Capsule Re-entry vehicle which is drawn with an imagination of an artist. Apollo is the manned spacecraft. It consists of three crew members in the capsule.

II. METHODOLOGY AND MATERIALS

The shape of the space capsule is in a blunt nose shape. The materials used for this nose cone are the carbon epoxy, Hafnium diboride and Zirconium diboride when we compare all these materials the carbon epoxy material can sustain the thermal protection system located in the inner surfaces of the CFRP. A vehicle with less material will heat faster during re-entry.

S.no		Carbon Epoxy composite	Hafnium diboride (Hfb2)	Zirconium diboride (Zrb2)
1	E(N/mm ²)	1.81e5	0.75e5	4.2e5
2	1/m	0.36	0.37	0.34
3	P (kg/mm ³)	1.7e-6	10.5e-6	6.085e-6
4	α (⁰ k ⁻¹)	2e-6	7.6E-6	8.3e-6
5	K (W/mm-K)	7e-3	62e-3	70e-3

Table 1: Properties of the Materials Used

The table 1 shows the material properties of the Carbon Epoxy composite, Hafnium diboride(Hfb2) and Zirconium diboride(Zrb2) used for the space capsule thermal protection system(TPS).

The designing of re-entry vehicle manly depends on

- Vehicle size and shape
- Thermal protection systems(TPS)

In the thermal protection system the three approaches considered are Heat sinks, Ablation and Radiative cooling. In this paper we have considered the ablation type of approach. A re-entry-vehicle designer can take advantage of the concept of Ablation by coating the vehicle’s surface with a material having a very high latent heat of fusion, such as carbon or ceramics. As this material melts or vaporizes, it soaks up large amounts of heat energy and protects the vehicle. This melting process is known as Ablation. The nose cone is modelled in CATIA V5 and analysed for its thermal and static resistance in the space environment.

III. FINITE ELEMENT MODELING AND ANALYSIS

A. Design:

If the design did not contain the stabilizing core, only a skinned geometry would be required. This can be meshed with shell elements, SOLSH109 being the most widely used for composite materials. The spline model is designed in CATIAV5

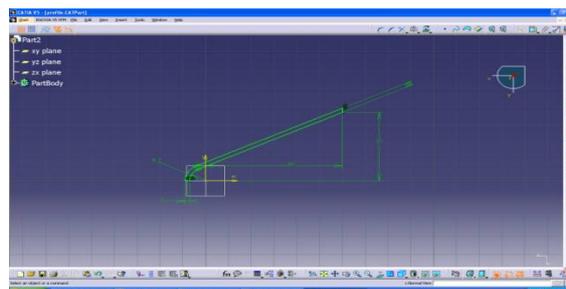


Fig 2: Spline model in CATIA V5

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B. Meshing

The design of the spline is imported into ANSYS after importing the spline model the new co-ordinate system is created for the sake of meshing we are going to use a new co-ordinate system (11-cordinate system) which was created by using the three KP (key points). Because of which the meshing and lay-ups of material will become easier. The boundary conditions are given

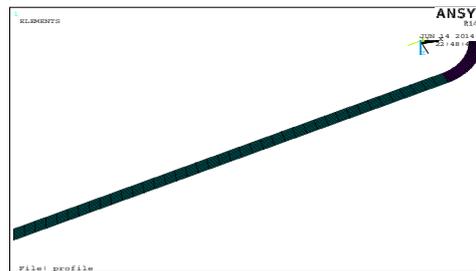


Fig 3: Spline model imported and meshed

C. Boundary Conditions

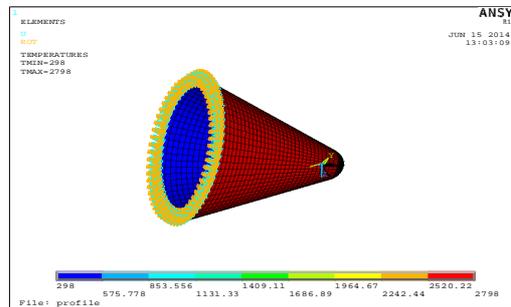


Fig 4: Displacement and Temperature Loads

The displacement loads are applied as a fixed loads at the back side of the nose cone, the temperature loads are applied, minimum temperature as 298K inner side of the nose cone the maximum temperature as 2798 K outer side of the nose cone as shown in the fig 4.

D. Applying Gravity

The inertial force is applied in the y-direction value is $-30g$ ($g=9.81n/mm$) as shown in fig5. This force is given because the space capsule will be re-entering into the earth's atmosphere without any additional propulsion system.

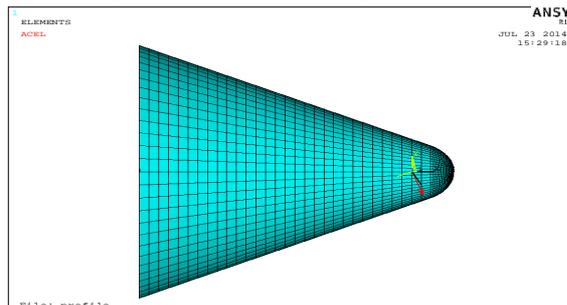


Fig 5: Gravity direction for a meshed nose cone

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C. Lay Ups

The Hafnium diboride and Zirconium diboride are applied in layers. They are given as layers in the ANSYS each having the thickness of 0.25 and with different orientations. The orientations of the material in each layer are as shown in the table 2 and after applying the layers in ANSYS are shown in the fig 6.

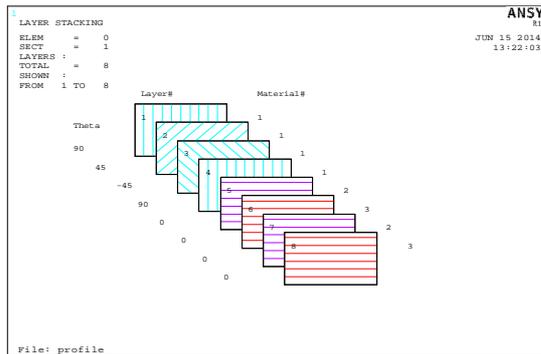


Fig 6: Lay ups with different orientations

S. No	Thickness	Material-Id	Orientation	Integration Pts
1	0.25	1	90	3
2	0.25	1	45	3
3	0.25	1	-45	3
4	0.25	1	90	3
5	0.25	2	0	3
6	0.25	3	0	3
7	0.25	2	0	3
8	0.25	3	0	3

Table 2: Orientation of layers with material id

IV. RESULTS AND DISCUSSIONS

A. Stress Reactions

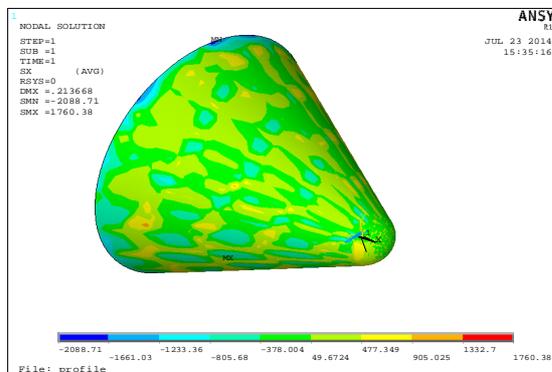


Fig 7: Stress reaction in X-direction with gravity

The figure7 shows the stress area of the space cone with applied gravity and is effected more at the front side because the maximum temperature is applied at the front side upper layer of the space cone(i.e., 2798K). The stress in the X direction is shown here which shows that the front side of the cone is more affected than the end part this is

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because when the space capsule is returning into the earth's atmosphere the force at the front side will be more effected than the end of the space cone section. The table 3 shows the increment to the decrement clearly.

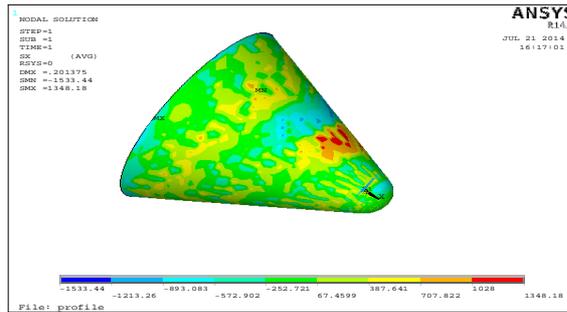


Fig 8: Stress reaction in X-direction without gravity

The figure8 shows the stress reaction without gravity reaction. If the gravity is applied on the nose cone the stress at X-direction will be more when compared to the stress reaction applied without gravity the table 3 shows the clear difference between with gravity and without gravity of stress reactions at X-direction.

B. Von-Mises Stress Reaction with and without gravity

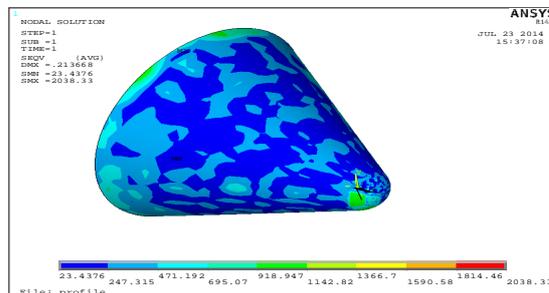


Fig 9: Vonmises stress with gravity

The figure9 shows the Von Mises stress on the nose cone structure when the gravity is applied and observed that the Von Mises stress is distributed on the whole body of the nose cone structure the failure section will be less affected and is protected. So the forces applied on the nose cone structure will be distributed failure area will be less on the nose cone structure.

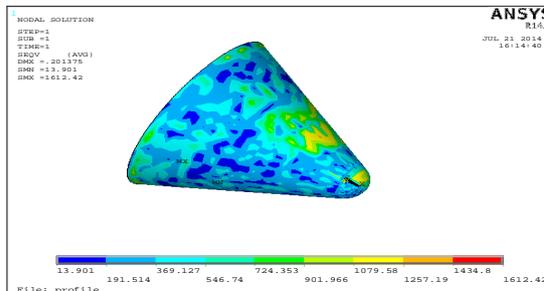


Fig 10: Von Mises stress without Gravity

The figure10 shows the stress reaction when the gravity is not applied on the nose cone structure and the table3 shows the comparison between gravity applied and not applied on the nose cone structure. By applying gravity the Von Mises stress is stable on the nose cone structure.

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C. Displacement Vector Reaction with and without gravity

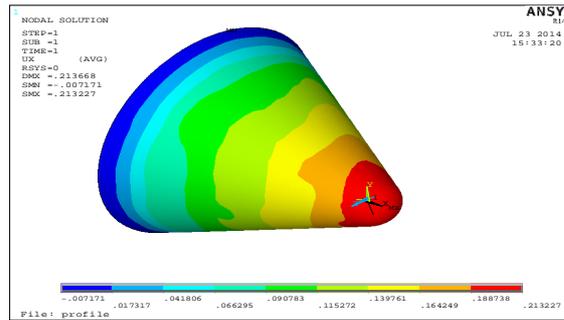


Fig 11: Displacement vector in X-direction with gravity

The figure 11 shows the displacement through X-direction when gravity is applied on the nose cone structure here we can observe that the front side area is more affected because when the space capsule is returning to the atmosphere the front side will be more affected, blue. The table 3 gives more information of the affected forces on the nose cone structure.

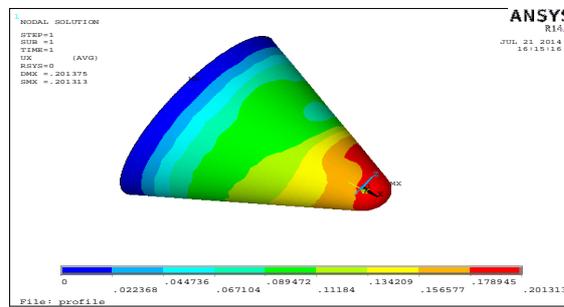


Fig 12: Displacement vector in X-direction without gravity

The figure 12 shows the displacement vector through X-direction when gravity is not applied on the nose cone structure here we can observe that on the front side of the nose cone the displacement is more compared to the end part of the cone. Table 3 shows the difference when the gravity is applied the reaction of displacement.

NAME	WITH GRAVITY	WITH OUT GRAVITY
Displacement- X	.213227	.201313
Displacement -Y	.090811	.076791
Displacement -Z	.069094	.091868
Stress -X	1760.38	1348.18
Stress -Y	1394.64	1255.22
Stress -Z	1801.28	1313.52
Von-Mises stress	2038.33	16142.12

Table 3: Table showing the values obtained in the analysis

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V. CONCLUSION

The desertation work concludes that nose cone thermal and structural analysis where we can observe the deformed+ un deformed shape values are minimum and the body temperature varied from the outer surface to the inner surface of the nose cone i.e., maximum to the minimum, but when we compare to the Von Mises stresses the failure rate is maximum in order to reduce it the thickness of the outer surface of the space cone can be increased. The materials used for this nose cone are the Carbon epoxy, Hafnium diboride and Zirconium diboride when we compare all these materials the Carbon epoxy material can sustain the thermal protection system located in the inner surfaces of the CFRP. It can also be concluded that the stress and displacement is more when applied with gravity than the stresses without gravity.

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