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Coupled Field Analysis of Space Capsule

Thermostructure Analysis

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***Abstract*— The detail engineering design of a re-entering space- vehicle heat shield requires the coordinated efforts . The predominant difficulty lies in the definition of thermal-mechanical properties of the heat-shielding material which encounters wide range of temperature conditions during its environmental life cycle. The conventional space capsules use liners and foam bricks as insulators to resist the temperature of aerodynamic heating.**

These conventional liners and foam bricks can be replaced with insulating material which has good structural properties. This paper presents the coupled field analysis of conventional space capsule using Zirconium Diboride (ZrB_2) and Hafnium Diboride (HfB_2) as insulating material. The coupled field analysis is carried out using finite element analysis software ANSYS. The analysis resulted that insulating material absorbs the temperatures before reaching the CFRP structure.

Keywords* — *Space Capsule ; Coupled field analysis; ANSYS; CATIAV5.

I. INTRODUCTION

Space capsules are the compartments designed to support humans during their journey through space. The space capsule must also protect astronauts from the cold and radiation of space. Space capsules are well-suited to high-temperature and dynamic loading reentries. The space capsule must be strong enough to slow down quickly, must endure extremely high or low temperatures, and must survive the landing. Capsules are well insulated and contain systems to adjust the internal temperature. To design and build a space capsule that will survive re-entry through the Earth's atmosphere one should have the knowledge of the forces of gravity and acceleration along with test design trials. The space capsule experiences two biggest forces namely gravity and drag. Capsules reenter aft-end first with the occupants lying down, as this is the optimum position for the human body to withstand the decelerative g-force. 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. Planets with atmospheres will create friction (and heat) with the spacecraft, which will slow re-entry down a small amount. Typically during a planetary reentry, 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[1].

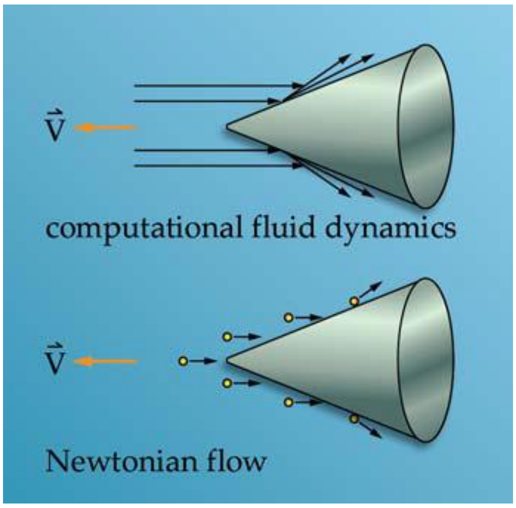

Figure 1: Computational Fluid Dynamics (CFD) Versus Newtonian Flow

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 [2]. The flexible bottom structure of a space capsule is the heat-shield that may be made of sandwiched composites [3]. The qualities of Hafnium Diboride (HfB2) (melting temperature of 3250°C) and Zirconium Diboride (ZrB2) (melting temperature of 3246°C) [1].

II. METHODOLOGY

The blunt nose profile is taken as the shape of space capsule and different materials are applied on the surface. The top 4 layers of the surface are applied with Hafnium Diboride (HfB2) and Zirconium Diboride (ZrB2) alternately and base material is taken as carbon epoxy. The material properties of these composites are shown in the table 1.

S .NO	Material Property	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: Material Properties

III. FINITE ELEMENT MODELLING AND ANALYSIS

A. Design

The Space Capsule is modeled using CATIA V5 software to get a profile shape. The spline model is created and is imported to ANSYS into a new co-ordinate system (11-cordinate system) created using the three KP (key points) and is meshed.

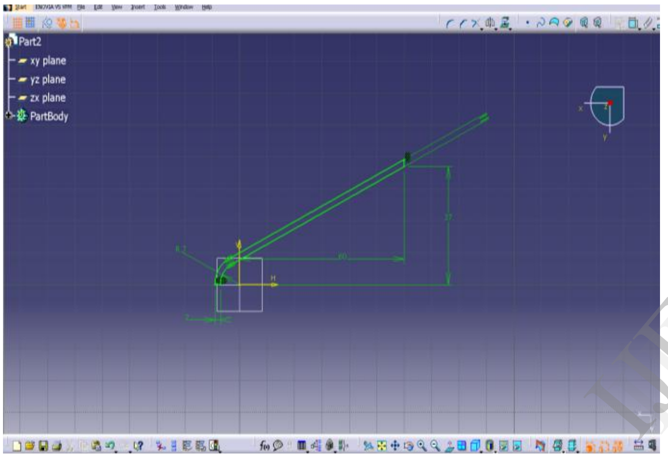

Figure -2: Profile Shape.

B. Analysis

The thermal and static analysis is done on the space capsule by applying composites. The thermal analysis is done by applying temperature of 2798 k on top layers and temperature 305k on base material. The results obtained in the thermal analysis are applied for the space capsule in structural analysis.

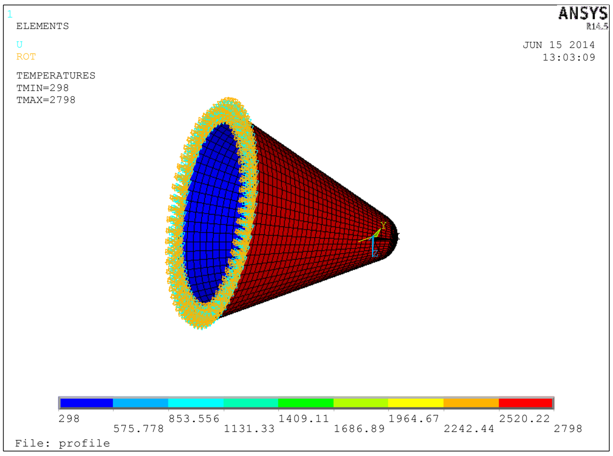

Figure-3: Applied Boundary Conditions

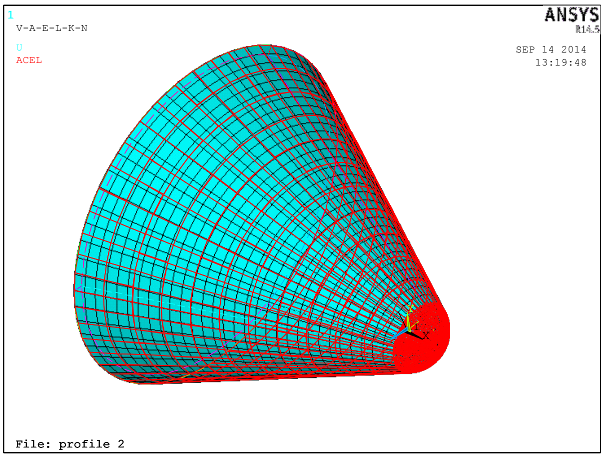

Figure-4: Applied Pressure with Gravity

IV. RESULTS AND DISCUSSION

The below figure shows the results of the nodal temperatures obtained from the thermal analysis of the space capsule. From the result obtained we can say that the temperature is getting decreased through the thickness which proves that the insulation material that we have selected is appropriate.

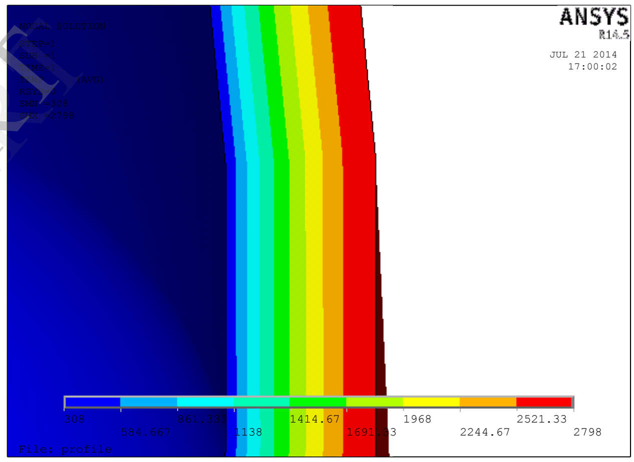

Figure-5: Nodal Temperature Results

The blunt nose cone is designed by 8 thermal protection layers applying Carbon Epoxy composite, Hafnium Diboride (HfB2) and Zirconium Diboride (ZrB2) composite materials with different angle orientations listed as below in the table 2.

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: Lay-Up Orientations

The thermal loads, gravity loads and pressure loads are applied stage wise to get the results in the static structural analyses which are listed in the table 3.

NAME	**WITH OUT GRAVITY**	**WITH GRAVITY**	**WITH GRAVITY & APPLIED PRESSURE**
Displacement Vector Sum	0.201375	0.213668	0.541876
Displacement-X	0.201313	0.213227	0.54057
Displacement – Y	0.076791	0.090811	0.18233
Displacement – Z	0.091868	0.069094	0.21131
Stress –X	1348.18	1760.38	8360.26
Stress –Y	1255.22	1394.64	9336.24
Stress –Z	1313.52	1801.28	7530.1
Shear stress-XY	557.94	585.546	5572.7
Shear stress-YZ	538.872	578.92	4478.06
Shear stress-XZ	663.773	429.993	5588.75
Von-mises stress	16142.12	2038.33	13782

Table-3 Comparison Between With Gravity, Without Gravity and Applied Pressure with Gravity

From the results shown in the above table the equivalent stresses acting on the space capsule are less when applied the gravity.

V. CONCLUSION

The coupled field analysis done on the space capsule resulted that the Hafnium Diboride (HfB2) and Zirconium Diboride (ZrB2) are acting as good insulating materials for the high temperatures and are absorbing the temperatures before reaching the CFRP material. So the problem of using conventional liners and foam bricks is avoided. This analysis also shows that the carbon epoxy material can sustain the thermal protection system located in the inner surfaces of the CFRP.

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