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CFD Analysis of the Effect of Material Properties of Nose Cone on the Heat Flux and Thermal Field during Re-entry of Space Vehicle

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Abstract— **Safe re-entry of the spacecraft is one of the biggest challenges for the space engineers. Overheating of the surface of space craft is the major concern. A space vehicle re-entering to the atmosphere must pass through Earth's dense fluid medium at extremely high speeds. It results in the generation of shock wave in front of the re-entering space vehicle. As the shock waves slams into the air molecules in front of the re-entering space vehicle, they go from cool, dormant state to an excited state, acquiring heat energy, which transfers to the metal object in contact. This results in the generation of very high temperatures i.e. up to 30000C. Surviving this temperature is impossible for convectional metals. So, composite materials are used in most parts of thermal protection system of a space vehicle. In this present work, CFD analysis using SolidWorks Flow Simulation software is made on the surface contour of the nose cone for three different materials. Heat flux and temperature generated on the surface of nose cone is compared among the three materials. Heat flux obtained from the CFD analysis is used to calculate the temperature that is transferred inside the crew cabin. From the analysis we can conclude that, Reinforced Carbon-Carbon is best suitable for nose cone of space vehicle.**

Keywords: **Space vehicle, Re-entry, Shock waves, Composite materials.**

I. INTRODUCTION

During re-entry of a space vehicle, the temperature generated on the surface of nose cone will be maximum [1]. So the selection of the material for the nose cone is most important for safe re-entry. Metals have a lot of advantages over ceramics. They can handle impacts much better, but the drawback is metals are heavier than other materials and can't tolerate high temperatures as well as ceramics. To take maximum advantage of material properties, in Thermal Protection Systems (TPS) of a re-entry vehicle combination of metallic and ceramic parts are employed [2]. A composite material is composed of reinforcement embedded in a matrix. The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than individual materials [3-4].CFD is a science that predicts and analyzes the system involving fluid flow, heat transfer and associated phenomena by means of computer based solver. Flow simulation of Re-entry vehicle requires a thorough understanding of all physical phenomena and variations that happens in the flow field to evaluate its aerodynamic and aero-thermodynamic performance. This requires a number of wind tunnel and flight tests which are costly and time consuming. CFD can be used as an efficient tool which mimics the real situation and significantly reduces the number of wind tunnel and flight tests and gives accurate results [5-7].The objective of the present work is to analyze the heat flux and temperature generated on surface of the nose cone and transferred into the crew cabin for three different materials. Heat flux obtained from the CFD analysis is used to calculate the temperature that is transferred inside the crew cabin. The model considered for this study is a spherically blunt nose cone with half cone angle of 600 and nose bluntness ratio of 0.25. Three materials used are Reinforced Carbon-Carbon, C/SiC and Al/SiC. Focus is made on the effect of material properties on the aero-thermodynamic characteristics of nose cone. Surface temperature and heat flux is calculated by SolidWorks Flow Simulation software for three different materials. The effect of material properties on the heat flux and thermal field variation on the surface of the space vehicle is analyzed and reported. The complete analysis is made assuming steady state heat conduction across the thickness of the nose cone.

II. MODEL GEOMETRY

Spherically blunt cone geometry is considered for the present study. Fig. 1 represents the 2-D model which is axi-symmetric. Table1 represents dimensions of the nose cone model.

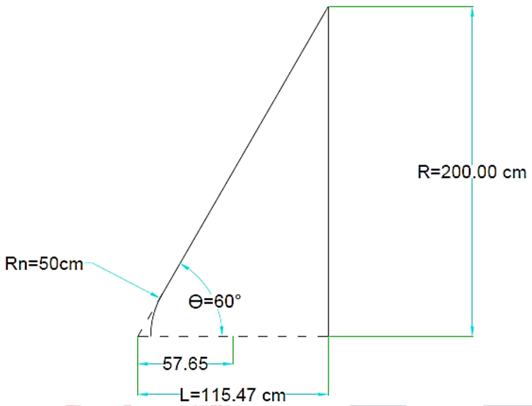

Fig1: 2-d model

Table 1: Dimension of Nose Cone

Half cone angle (Θ)	60^0
Nose bluntness ratio (Rn/R)	0.25
Nose radius (Rn)	50 cm
Base radius (R)	200 cm
Thickness (dx)	5.08 cm
Length (L)	115.47 cm

III. MATERIAL SELECTION

The materials used in thermal protection system should possess high strength, high Young's modulus, low thermal conductivity, higher temperature capability, greater thermal shock resistance, more durability, and high melting temperatures.

The materials selected for this study are

- Reinforced Carbon-Carbon
- C/SiC (Carbon reinforcement and SiC matrix)
- Al/SiC (Al matrix and SiC reinforcement)

Table 2: Free stream conditions

M_∞	P_∞	T_∞
6	1atm	273.15K

IV. MESH GENERATION

The basic model is designed in Unigraphics (NX-CAD) and it is imported to SolidWorks Flow Simulation. In SolidWorks Flow Simulation mesh is generated automatically.

V. PRE-PROCESSOR

Density based solver is used along with steady external flow under steady state condition. Laminar and turbulent flow with high Mach number is considered. Axisymmetric geometry analysis is done by selecting the symmetry boundary condition as axis. The air is considered as ideal gas with density 0.000296 kg/m3. The boundary conditions given are; Aeroshell (Wall), inlet, outlet, top and symmetry. The Aeroshell wall condition is considered to be stationary with no-slip boundary layer and with surface roughness of 30µm. Isothermal condition is assumed over the wall at T = 273.15 K. Inlet, outlet and top are given pressure-far-field condition with pressure being 1atm and M = 6.

VI. RESULTS AND DISCUSSIONS

Table 3: Results of flow simulation

Material	Heat flux(W/m^2)	Outside TemperatureT_1 (K)	Inside Temperature T_2 (K)
Reinforced Carbon-	639090.249	3041.46	301.7

Carbon			3
C/SiC	873987.792	3047.99	933.77
Al/SiC	1965340.523	3019.12	2353.52

Inside temperature is calculated by using the heat flux equation

Heat flux = K(dT/dx) (1)

Where,

K= thermal conductivity (W/mK),

dT= T1-T2, dx= thickness (m)

Fig.2 to Fig.4 shows the temperature generated on surface of nose cone for three different materials. Fig.2 shows the nose cone with carbon-carbon composite which has developed a maximum temperature of 3041.46 K. Fig.3 shows the nose cone with C/SiC composite which has developed a maximum temperature of 3047.99 K. Fig.4 shows the nose cone with Al/SiC composite which has developed a maximum temperature of 3019.12 K.

Fig.5 to Fig.7 shows the graphs of heat flux generated on the surface of nose cone for three different materials. Fig.5 shows the nose cone with Carbon-Carbon composite which has developed an average heat flux of 639090.249 W/m2 .Fig.6 shows the nose cone with material C/SiC which has developed an average heat flux of 873987.792 W/m2 .Fig.7 shows the nose cone with material Al/SiC which has developed an average heat flux of 1965340.523W/m2.

From the equation 1 we can calculate the temperature transferred to the crew cabin. From the calculations the inside temperature obtained for the nose cone with material reinforced carbon-carbon is 301.73 K, for C/SiC is 933.77 K and for Al/SiC is 2353.52 K.

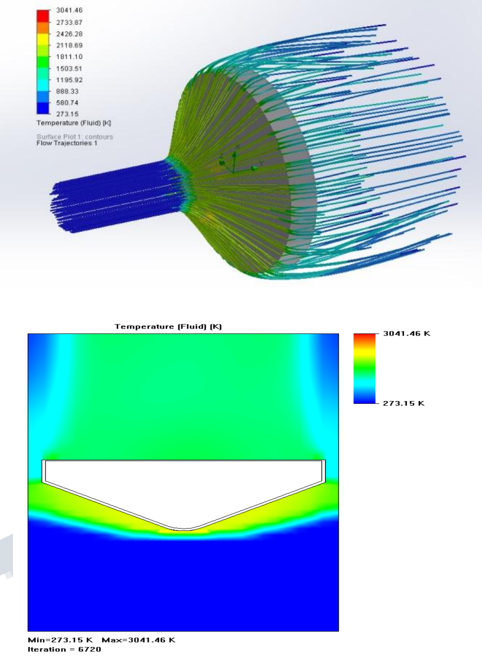

Fig 2: Temperature generated on the surface of nose cone with material Reinforced Carbon-Carbon.

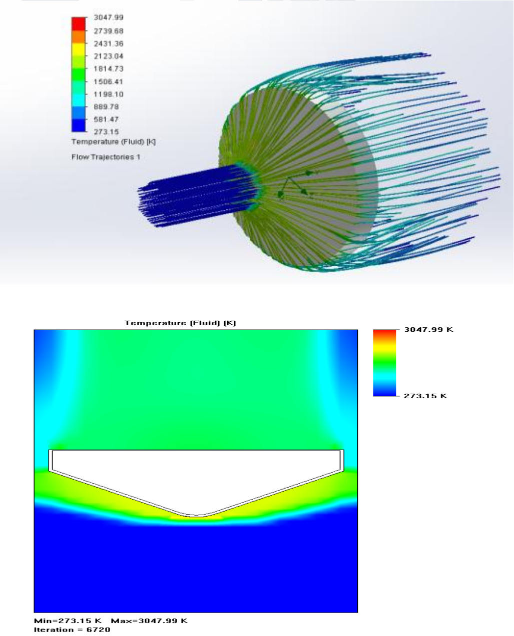

Fig 3: Temperature generated on the surface of nose cone with material C/SiC.

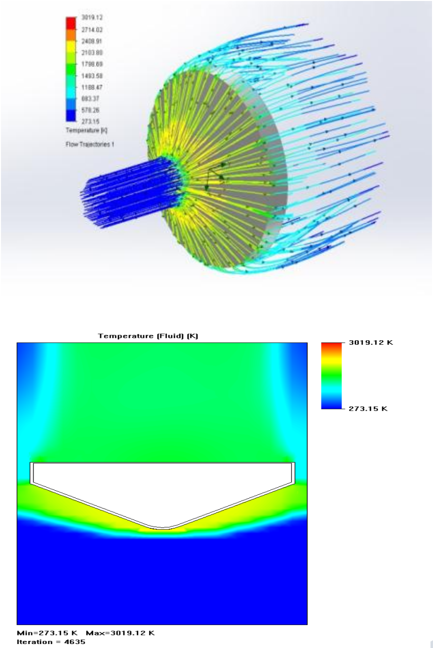

Fig 4: Temperature generated on the surface of nose cone with material Al/SiC

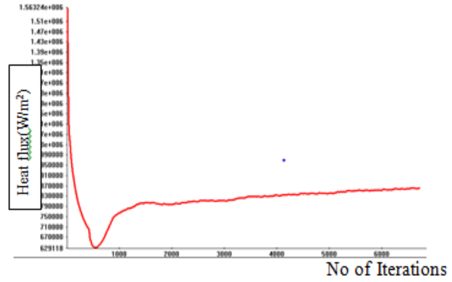

Fig 6: Heat flux generated on the surface of nose cone with material Reinforced Carbon-Carbon

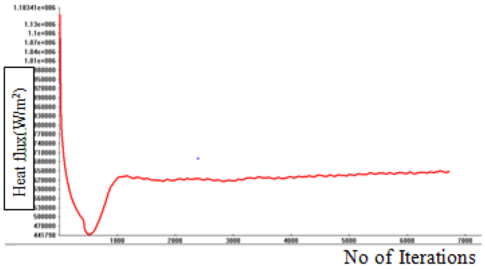

Fig 5: Heat flux generated on the surface of nose cone with material C/SiC

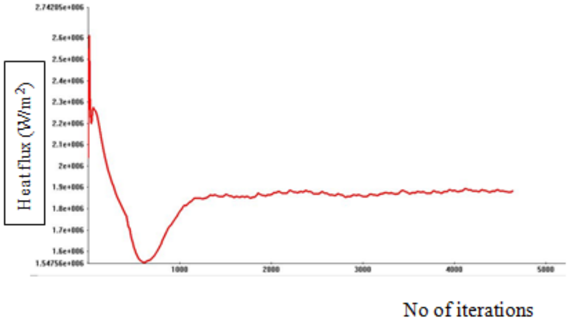

Fig 7: Heat flux generated on the surface of nose cone with material Al/SiC

The SolidWorks flow simulation results confirm that nose cone with material reinforced carbon-carbon transfer very less amount of heat inside the crew cabin during re-entry. The maximum temperature generated on its surface is 3041.46 K, which is below its melting point. So it can retain its properties. The temperature that is transferred inside the crew cabin is 301.73 K, where humans can survive which results in safe re-entry.

VII. CONCLUSION

In this present study, simulations are conducted on various materials of nose cone of a reentry vehicle using CFD software SolidWorks Flow Simulation for estimating the surface heat flux and temperature distribution across the thickness of three materials considered for the analysis. From the simulation results the following conclusions can be drawn.

- Material property has decided effect on heat generation, heat transfer and heat flux generation on the surface of the re-entry vehicle.

- Nose cone with carbon-carbon composite transfers very less amount of heat to the interior of the space craft.

- The crew within the space craft can survive inside the nose cone with material reinforced carbon-carbon composite.

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