Review on influence of radiating and aerodynamic shock at hypersonic vehicle

Balaji R[1*], J V Muruga Lal Jeyan[2], Vijay Kumar singh[3]

[1*]Research scholar, Department of Aerospace Engineering, SME, Lovely Professional University, Punjab, India
[2] Professor, Department of Aerospace Engineering, SME, Lovely Professional University, Punjab, India
[3]Professor, Head, SME, Lovely Professional University, Punjab, India

balaaero07@gmail.com

Abstract. Hypersonic vehicles are going to play a huge role in the upcoming years. As the vehicle has to attain the hypervelocity flow front at the leading edge of the vehicle, need to be strong enough to withstand the effect of the shock wave and radiating waves. Aerodynamic design and the velocity range decide the aerodynamic heating rate of the vehicles. It is known whenever the flow field and the radiation are coupling one another that make the shock layer region complex to analyse. In general inside the developed shock layer, heat flux variation is maximum that enhance the heat transfer. Technically in practice the ability to alter the heat transfer rate of the outer skull depends on the aerodynamically design. To achieve and maintain the hypervelocity region minimizing and or sustaining the aerodynamic heating is necessary. To achieve that regression study on those mentioned three parameter is mandatory. In this review, design and cooling method of different types of hypersonic vehicles taken, and the possible ways to reduce the intensity of shock waves are discussed.

1. Introduction

In the hypersonic region, gas dynamics plays an important role. There is a certain flow characteristic occurs at hypersonic velocities that is Shock Layer, Entropy Layer, Aerodynamic heating, and Low Density. In this region, C_p and C_v values are no more constants due to the discontinuity of the flow. As the Mach number increases strong shock wave formation occur on the body. It starts moving closer to the body resulting in a high rise in the stagnation temperature and other stagnation flow conditions such as pressure and density. It is also important to study the flow behaviour on the downstream of the shockwave as flow properties behave very differently in the downstream of the shockwave in compare to the upstream of the shockwave. The aerodynamic effects can be simulated in the software to validate the result and to visualize the hypersonic flow over the body. In structure, blunt bodies are the perfect shape to any hypersonic craft. Blunt shape nose has mostly used the nose of the re-entry vehicle. As the larger surface leads to a decrease in the temperature and also leads to form a shockwave far from the body of the hypersonic craft. To design the blunt nose cone for any hypersonic craft, studies related to the field of aerodynamics and structures needed. Blunt nose cone structure provides the strength to nose to sustain the high temperature during hypersonic speed. The structural part also covers the study of the material required for the outer parts of the vehicle along with the heat

transfer field. As most of the metals and higher aluminium alloys have melting points around 2000 K, the stagnation temperature can easily rise to melting temperature of the most metal and higher aluminium alloys. So it is important to study the structural and fabrication part for the design of hypersonic craft along with aerodynamics.
Many kinds of research are going on in the field of hypersonic region. In-depth studies in field of aerodynamics and structure are on-going presently. Below is the brief report of various research articles publish in recent years in the field of hypersonic design and heating.

2. Design of Hypervelocity objects:

Hypervelocity vehicles have a discontinuity in the flow region. The in-efficient design has a compliancy of creating high drag co-efficient which leads to high aerodynamic heat flux variation over the surface to the surroundings where the radiation is coupling with the flow field.
The study AMRITA MALLICK[1] done shows the problems what re-entry vehicle faces in the earth ATM and the formation of shock layer in the frontal cone section and comparative methods to avoid the Aerodynamic heating over the vehicle and methods of cooling to avoid the aerodynamic heating over the re-entry vehicle

- It says that the frontal area will have chance to reduce the shock formation
- Foam insulation production system caries the betterment effect in Aerodynamic heating

The author discusses the process and they didn’t find the method to identify the heat flux variation value.
In the other end boundary layer control which helps us to increase the Drag co-efficient and leads to aerodynamic heating of the object. Some modification in the design which increases the drag co-efficient with less amount of aerodynamic heating rate will produce the highly efficient design. Sai Nandyala [2] shows that Research shows that Hypersonic Inflatable Aerodynamic Decelerator or HIAD method is one of the best methods to avoid aerodynamic heating over the surface of the Re-entry vehicle. Based on the Inflatable Re-entry Vehicle Experiments the researcher tries to analyses the thermal and thermal structural analysis over the surface of the re-entry vehicle and tries to study the heat flow behaviour over the surface

- Kevlar as an outer layer will give the maximum amount of strength
- Kapton outer layer gives more effect on the pressure and temperature concern

The author doesn’t discuss the heat flux starting and transformation boundary region over the surface of the re-entry vehicle.

2.1. *Aero spikes design:*

Spikes are the unavoidable design in supersonic vehicles to increase the boundary layer. The same technics were used in Re-entry vehicles [3], the leading edge surface with spikes on blunt bodies show a great impact on the reduction of drag as well as heat flux. The spike changes the location of the shockwave in such a way that the peak pressure is experienced at a small area at the tip of spike without jet injection drag reduction in a single hemispherical spike is more than single conical spike due to contact surface. The peak pressure and drag co-efficient are slightly less for single spike re-entry vehicles with jet injection. Twin conical spike with jet gives the best result in terms of reduction of heat flux as compared to co-efficient of drag.

- Single conical spike with jet has a great reduction in the coefficient of drag
- Twin conical spike has a great reduction in heat flux to free-stream conditions.

In the Reduction of aero-heating by introducing a spike at a frontal region of the nose. Slender spike [4] design reduces the drag but it creates more in aerodynamic heating. Slender spike design reduces the drag but more in aerodynamic heating. Blunt spike design produces more drag, but they are choosing able as aero heating is concerned. To avoid stronger shocks and also for reducing the temperature, spikes are placed at a frontal portion of the nose region. In the blunt spikes, the shock wave scattered along the length and decreases temperature. Due to spikes, there is a heat reduction at nose blunt spikes that are comparatively preferable over slender ones.

2.2. *Blunt body design:*

Blunt bodies generally generate detached shock wave which tends to slow down the aerodynamic heating over the object. With the thermal protection system in the line, the vehicle payload will not be affected by heat. The large heat shield products the payload. As per the study [5] large effective radius of the blunt-body acts to mitigate the effects of convective heat transfer. Due to turbulent flow on re-entry vehicle, we will get high re-entry velocities and non-zero angle of attack lifting trajectories. Turbulent flow led to high re-entry hypersonic aero heating. Rarefied flow helps to predict the stagnation point heat flux. To alter the heat flux radiation in the flow filed genetic algorithm method used. During the comparative study [6] on Single objective genetic algorithm, single objective single run genetic algorithm and Multi-objective genetic algorithm applied to two multi-module funs-Ackley and bump functions. The study carried to minimize the mission cost which is equal to minimize the heat absorbed, structural mass to maximize drag co-efficient. In this they had shown an assortment of a trajectory for inveterate depends on payload and confidence co-efficient. Re-entry form high-speed conditions required a blunt high-drag body. If the body is blunt shock wave is detached ahead of the body. In this, the bow shock wave is normal to the stagnation streamline and convert the supersonic flow forward of the shock to the low subsonic speed at the high static temperature downstream of the shock. Apart from altering the flow filed delaying the vehicles landing velocity using maneuvering helps us to avoid the high aerodynamic heating of the blunt-body.

To delay the blunt bodies' velocity and generate high lift using spinning Magnus effect is one of the standard techniques to delay. That ablation [7] can alter the value of the dynamic stability of non-spinning or slow spinning slender re-entry vehicle. The spinning objects produce more time lags comparing to the non-spinning one. Due to the spinning of the re-entry vehicle as per the Magnus effect side force will be generated on the object. The side force is useful to produce the dynamic lags of the re-entry cone that's used to reduce the unwanted detonation and the destination should be on the decided place. He didn't explain the variation on the heat flux based on the lift generation.

The author [8] uses a Mamdani fuzzy PD controller has reliability and robustness for control re-entry vehicles with sudden guests in the approach and landing phase. The longitudinal controller (PD Fuzzy) was developed intended for the approach and landing phase of re-entry vehicle. In approach and landing phase, the re-entry path angle at touch down is so small altitude error which causes large touch downrange error. The scholar shows the angel and the landing phase of the re-entry but the descending heat flux effects will not be discussed in the research articles.

Introduction of undulation [9] improved the aero-thermodynamic characteristics reduction of heat flux observed. An increase in boundary layer thickness causes decrease in kinetic energy and increase in high temperature on the surface. Undulation varying in both amplitude and wavelength, if pitching moment is clockwise then it's called as stabilizing moment, at the same time if pitching moment is zero then it's called as monostability of a re-entry vehicle if the pitching moment is anti-clockwise then de-stabilizing. As amplitude and wavelength vary mono-stability and L/D ratio is varying increasing. High heat flux observed in the capsule shoulder region due to undulations less heat flux due to an increase in the frontal area. Introduction of undulations lead to a net decrease in heat flux value.

Shiva Prasad [10] study shows that FIRE II and OREX vehicle Maneuvering effect will be discussed and the small change in the angle effectively affects the Aerodynamics heating property of the re-entry. Due to change of the angle, the flow will get affected and it comes to Non-equilibrium condition

- No need of guidance and control precautions Ballistic probes
- Low ballistic factor means large reference area, high drag coefficient, and low mass

2.3. *Aerodynamic Heating and Cooling:*

A vehicle while approaching the hypervelocity range due to high aerodynamic drag heat will be generated over the surface of the objects due to shock waves. Within the entropy, layer flow will be coupled with radiation. Due to the coupling of flow conductive heat transfer will happen over the surface. To reduce the effect of coupling of radiation with flow field Thermal protection has been used for a decade. While the blunt-body reaches the hypervelocity surface of the material gets eroded and ablative cooling is possible over the surface of the blunt-body. Due to erosion shape of the blunt-body has been changes and the aero dynamical property changes widely. The casting [11] which protects spacecraft during re-entry. High fidelity simulations of re-entry vehicle responses to critical nuclear environments. Nose tip contains c-c (carbon-carbon) composites with tungsten composite for stability during shape change, when the lead re-entry detonates the ensuring blast wave propagates outward and can interact with trailing re-entry. The main role of re-entry vehicle in the area of nuclear environment survivability, to maintain accurate element aspect ratio, number of elements around circumference also increased. All material modes enhanced the effects of plastic material flow associated with yielding. The effects of yielding not mentioned.

To experience less amount of effect in the blunt-body material selection need to be a virtual role. The selected material need to withstand the high temperature and it should be less in weight. Ceramic matrix [12] composites are passive hot structures (they can operate at elevated temperature retaining acceptable mechanical properties). The author used that composites space shuttle wing leading edge panel made with titanium honeycomb structure. Ceramics are very brittle behaviour after fibre reinforcement increases the strength and damage tolerance give ductile behaviour. Saffill one of the ceramic will protection from high temperatures. Promasil is to protect the internal structure from high heat fluxes. If we are ceramics in leading-edge a reduction in weight.

The testing methodology of the vehicle also an influencing phenomenon. The flow region discontinues so that properties change rapidly in the flow field. The researchers [13] show the Monte Carlo technique was one the best method to analyse the uncertainties in the predicted heat flux. The heat flux gradient value has been found for different locations and different times been shorted out. In order to find the Aerodynamic heating over the surface of the re-entry vehicle the heat shield emissivity and insulator thermal conductivity selected and the simulation is carried out

- The thermal production system is one of the important phenomenon to consider while designing
- Multidisciplinary analysis one of the suitable method for re-entry vehicle

The Analysis made in different uncertainties manner, not a gradual analysis has been taken place.

The author [14] analyses the flow field with radioactive heat solver with open foam software. Particular software has been used to verify the entire re-entry vehicle, One dimensional and two dimensional slap method to been used to find out the variant in the flow field. or more accurate result angular integration scheme used The results obtained from the angular integration scheme were found to be in close agreement with the tangent slab results, indicating that the effect of curvature and radial gradients on stagnation line heating rates is not significant.

Ablation material decides the temperature gradient level in the flow field. The previews research [15] shows the different ablative cooling material to decrease the heat flux. Thermal production system product the space vehicle from aerodynamic heating. Thermo-physical properties like thermal diffusivity, thermal conductivity, and specific heat help to reduce the temperature. The kind of ceramics used to overcome the aerodynamic heating. Carbon/ phenolic composite material act as a very effective insulator in a wide range temperature. It shows the maximum changes in the heat flux value and the temperature gradient value also less comparing to other materials. But the research doesn't show the importance of the detachment of the shock wave on the leading cone of the re-entry vehicle.

In ablation [16] rate has been measured in spherical nose cap in terms of heat fluxes. As the altitude increases the heat flux rate decreases on the nose. The effect of leading-edge shape change leads to a reduction in heat flux predicted along the surface of the leading edge cone. Heat flux over the leading edge surface point is very high hence the material. The ultra-high temperature ceramic (zirconium di bonide) is capable of withstanding a maximum temperature and a good substitute for current thermal protection systems. The shape change due to ablation also changes the surface heat flux. Persistence roll resonance on re-entry vehicle can cause a catastrophic increase in vehicle angle of attack. The author proves that boundary equation effects trajectory parameters occurrence of persistence roll resonance, low static stability, and large ballistic co-efficient. Boundary equation used to predict whether or not persistence roll resonance will occur on a particular re-entry vehicle on a particular trajectory. The dynamic balance approach can correct for pure roll torques resultant small imperfections in the ablative material, low oblique shock angle vehicle experiences large deceleration during re-entry. The behaviour of Al2O3 shows the crack patterns of simulation.ZrB2 based ceramic used for effects of the temperature dependence of crack propagation

Some other ways to reduce the heat flux rate are possible. Nan Wua [17] did a study Transpiration cooling with Uniform Porosity layout and Gradient Porosity layout was carried out with Liquid/air coolant and cooling Air as a coolant. The Results shows that Gradient Porosity Layout with Liquid Air coolant gives more efficiency compared to another type. At low Mass flow rate condition both the coolant, behaviour remains the same, if the Mass flow rate is increased then the efficiency of the Liquid/ air coolant is high. Near to the leading edge, the porosity size is increased to do effective cooling

- It cools the entire surface of re-entry.
- It neglecting the heat flow into the specimen from the bottom and the top side.
- The MFR of the coolant is also a major reason.

Differentiate the frontal cone area and change the radius of curvature.

3. Conclusion

As per the review, the design and analysis of the cooling effect, which deals with the coupled flow in hypersonic vehicles it is crystal clear while increasing the velocity of the hypersonic vehicles boundary layer, started decreasing and a high tensed shock wave effect has been noted. This high-intensity shock layer results in huge heat flux generation between the shock layers. In order to reduce the heat flux boundary layer need to be at maximum level in frontal area of the hypersonic vehicles. So blunt bodies were the highly effective designs for hypersonic vehicles for a decade. But while analysing the coupled flow field over the vehicles increases the complacence, so analysing the flow before coupling with radiation gives the exact effect of the shock layer for the prescribed radius of curvature of blunt-body. So analyzing the flow without cooling and coupling with minimum and a maximum distance of the shock layer can explain us the heat generation in-between the stipulated region.

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