Aero-thermal Mapping of Passive Thermal Protection System for Reusable Hypersonic Vehicle

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Doctor of Philosophy

By

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Dedicated

To my wife, Neetu and Son Archit.

To my parents, Sh. Jaikumar and Smt. Saroj Devi.

To my sisters, Pravesh and Durgesh.

To my Brother, Dinesh.

Declaration by the Research Scholar

I hereby declare that the entire work embodied in this Thesis is the result of investigations carried out by me in the School of Engineering, Indian Institute of Technology Mandi, under the supervision of Prof. S. P. Mahulikar and Dr. P. Anil Kishan (Internal Co-guide), and that it has not been submitted elsewhere for any degree or diploma. In keeping with the general practice, due acknowledgements have been made wherever the work described is based on finding of other investigators.

Place: I.I.T. Mandi (HP)

Date: 05 Oct. 2017

Sachin Kumar

THESIS CERTIFICATE

This is to certify that the thesis titled "**Aero-thermal Mapping of Passive Thermal Protection System for Reusable Hypersonic Vehicle**" submitted by **Sachin Kumar**, to the Indian Institute of Technology Mandi for the award of the degree of Doctor of Philosophy, is a bona fide record of the research work done by him under our supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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Date: 05 Oct. 2017	Date: 05 Oct. 2017

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Abstract

The aero-thermal analysis of hypersonic vehicles is of fundamental interest for designing its Thermal Protection System (TPS). In recent years' interest has grown in air-breathing Reusable Hypersonic vehicles (RHVs) due to their potential applications in low cost space and time critical military missions. However, the increased drag and convective heating associated with flow at hypersonic speeds have a significant impact on the design of vehicles. Therefore, research on RHV programs is ongoing at several places across the globe. Together with optimum TPS design study, techniques for simultaneous control aerodynamic flow field have been researched for a long time, which can be classified into Active (requiring a dedicated power source) and Passive methods (simple modifications in the geometry). In the present study, passive method is considered to modify the flow field in order to reduce the drag and heat transfer to the body. Thereafter, it is necessary to design a suitable TPS that takes the advantage of material properties to serve as a heat shield for the inner structure. The selection of an appropriate TPS is mainly depending upon the accuracy of the aero-thermal environment prediction. It is necessary to estimate the aero-heating characteristics of hypersonic vehicles in order to ensure their survivability to a high degree of certainty, without over-designing. On the basis of nature of protection provided, the TPS materials can be classified as ablative and insulative. The ablative materials mainly used for the stagnation region and insulative TPS protect the inner structure of the hypersonic vehicles. In this study, a one-dimensional heat transfer model is used to design a light weight passive TPS for RHV. Since uncertainties are more in these studies: inverse analysis is used to overcome those uncertainties. From these studies, it is clear that a light weight passive TPS for RHV can be designed accurately. The present investigations can be summarized as follows:

The influence of sweep-back angle variations on heat flux and wall temperature of swept leading edge hypersonic vehicle is analyzed through the CFD simulation. The main purpose of this work is to propose the aero-thermal concepts for configuration design of swept leading edge hypersonic vehicle. Results obtained from these computational analyses reveal the existence of *temperature and drag-minimized sweepback*, and most importantly, the *thermally benign sharp SBLE effect*. Thereafter, on the basis of these concepts, two hypothesized lifting body shape hypersonic vehicles are designed. In order to analyze the aero-thermal characteristics of these two lifting body configurations, a CFD simulation has been carried out at Mach number ($M_\infty = 7$), $H = 35$ km altitude with zero angle of attack.

The present study also established a methodology aiming to design a light weight passive TPS for RHVs. This problem is completed in two steps, in the first step, best candidate TPS materials are selected based on their thermal properties. Thereafter, one-dimensional heat transfer analysis is performed by using an explicit finite difference scheme. In the second step, the geometrical dimensions are determined for different combinations of the selected materials, and these dimensions are optimized for the design of light weight passive thermal protection system. The best combination of material employs SIRCA, Saffil and Glass-wool for the first, second and third layer, respectively.

In view of necessity of accurate prediction of surface heat flux, an inverse heat transfer approach has been established for prediction of surface heat flux. Analytical one-dimensional heat conduction models are used for determining the surface heating from the knowledge of recorded temperature history using thermocouples. In this study, an inverse heat conduction analysis based on Lavenberg-Marquardt method is applied to reconstruct the aero-thermal heating and thermal protection material response of a Reusable Hypersonic Vehicle (RHV) from the knowledge of temperature measurements taken within the Thermal

Protection System (TPS). In addition to reconstruction of TPS material response, a light weight passive TPS for RHV based on these predictions is designed. The influence of measurement errors upon the accuracy of the inverse results is also investigated. Finally, results show that the Lavenberg-Marquardt is an effective technique to design a light weight passive TPS for RHV by using inverse approach.

Keywords: Aero-thermal, Reusable Hypersonic Vehicle, Thermal Protection System, Inverse analysis

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