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Aerothermodynamic Analysis of a Generic Reentry Capsule with Hypersonic Inflatable Aerodynamic Decelerator

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***Abstract*—** In this work, a Hypersonic Inflatable Aerodynamic Decelerator (HIAD) concept is studied from the aerothermodynamics point of view using computational fluid dynamics. Using a commercial CFD software for solving Navier-Stokes equations, the heat flux of and the aerodynamic forces acting on the reentry vehicle with and without inflatable aerodynamic decelerator are calculated. Results has shown considerable effect of inflatable aerodynamic decelerator on the aerothermodynamic parameters of reentry capsule.

***Keywords*—** Aerothermodynamics, Hypersonic Aerodynamics, Inflatable Aerodynamic Decelerator, Reentry Capsule.

I. Introduction

IN space missions, spacecraft landing on planets with high speed has always been one of the major concerns of designers. Numerous system studies in the past fifty years demonstrate the benefit of developing a new decelerator technology capable of operating at higher Mach numbers and higher dynamic pressures than existing decelerators allow. One of the most these technologies is Inflatable Aerodynamic Decelerator (IAD) [1]. This technology is based on drag augmentation so that the IAD will reduce speed by increasing drag force. The limitations of current parachute technology and the benefits afforded by the use of IADs have renewed research efforts into IAD systems. Some recent design, analysis, and testing work has been performed on IADs in the recent years, but significant testing and analysis remains to mature this technology to a Technology Readiness Level (TRL) that would enable its use on a flight mission. In particular, the aerodynamic performance of relevant IAD designs would need to be characterized throughout their operating envelope. Detailed regarding physical integration of the IAD and entry vehicle, including load paths and attachment methods, would also need to be studied. The European Space Agency and the Russian Federation designed the Inflatable Reentry and Descent Technology (IRDT) concept to return payload to Earth from the International Space Station. The IRDT's first flight test was in November of 1996; this test was unsuccessful due to a launch failure [2].

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The second flight was in February 2000; this flight was partially successful. After completing six orbits, the vehicle entered the Earth's atmosphere; however, a tear in the inflatable heat shield occurred during descent and caused an impact velocity that was higher than planned. Works of [3] and [4] are preliminary studies on the conceptual design of IADs.

II. Analysis method

Currently, accurate prediction of the aerothermodynamic behavior of hypersonic inflatable decelerators is still an interesting topic for the researchers. On the other hand, computational analysis of IADs will become increasingly important throughout their development cycle. Modern ground test facilities are able to test full-scale decelerator articles at appropriate structural loading conditions or test subscale articles in appropriate flow conditions; however, these facilities cannot satisfy both requirements simultaneously. The preliminary thermal design of hypersonic vehicles requires precisely and reliably predicting the convective heating over the blunt nose of the vehicle, since aerodynamic heating is a function of V_∞^3, its consideration in hypersonic flights is more important than aerodynamic forces. Therefore in high speeds the first concern is the large amount of heat production on the surface of vehicle which highly increases the shell temperature. Aerothermodynamic behavior of a reentry vehicle can be obtained by numerically solving the Navier-Stokes (NS) equations [5], or one of their various subsets such as the parabolized Navier-Stokes (PNS) equations [6] and viscous shock layer (VSL) equations [7-8] for the flow field surrounding the vehicle. In the present work, an IAD concept is studied from the aerothermodynamics point of view using computational fluid dynamics. Using a commercial CFD software for solving Navier-Stokes (NS) equations, the heat flux of and the aerodynamic forces acting on the inflatable aerodynamic decelerator are calculated.

III. Results and discussion

A commercial CFD code is used for the flow field solution and symmetry, where applicable, is considered for the computational cost reduction. Results are obtained for a generic reentry capsule with and without deployed hypersonic IAD (Fig. 1). It is observed that using the hypersonic IAD will improve the aerodynamic drag (nearly twice) and heat load on the spacecraft dramatically. Mach number and temperature contours on the hypersonic inflatable aerodynamic decelerator' surface are shown in Figs. 2 and 3. Flow conditions are $M_\infty = 7.93$, $P_\infty = 1750$ N/m^2 and T_∞=1055.5 K. Wall temperature is assumed constant equal to 555.5 K. Also, from heat flux distribution analyses, it is concluded that increasing the IAD's radius will reduce the heat flux on the hypersonic inflatable aerodynamic decelerator surface.

IV. Conclusion

In this paper a commercial CFD software is used for solution of the flowfield around a reentry vehicle with hypersonic inflatable aerodynamic decelerator. Results are obtained for a generic reentry capsule with and without deployed hypersonic IAD. It is observed using the hypersonic IAD will improve the aerodynamic drag and heat load on the reentry capsule. Also, it is concluded that increasing the IAD's radius will reduce the heat flux on the HIAD' surface.

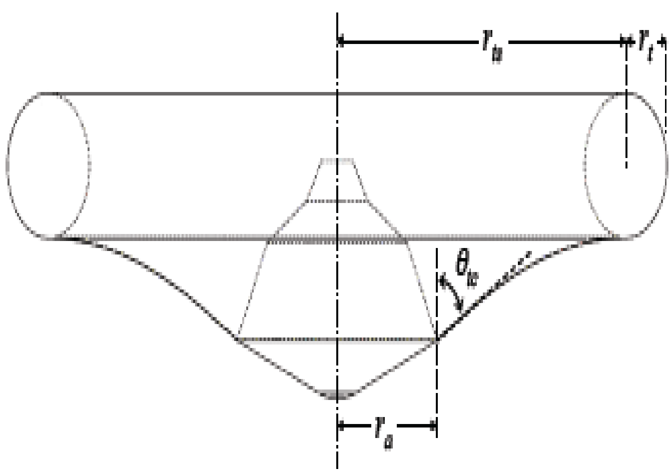


Fig. 1 Generic reentry capsule surrounded by its inflatable aerodynamic decelerator

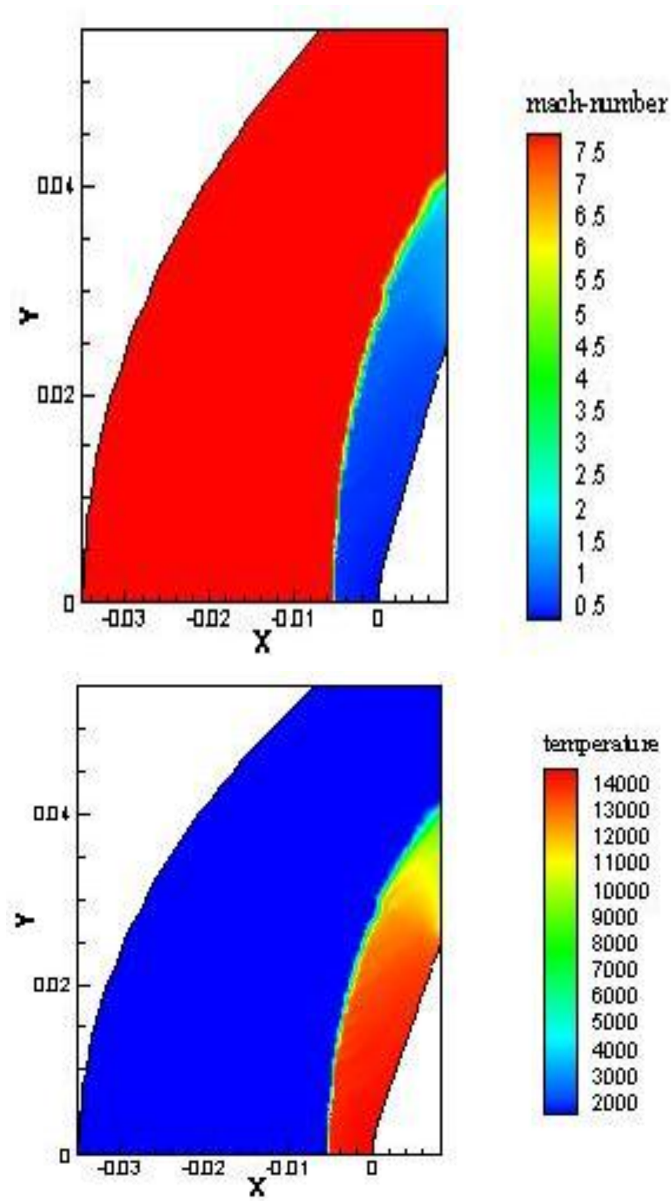
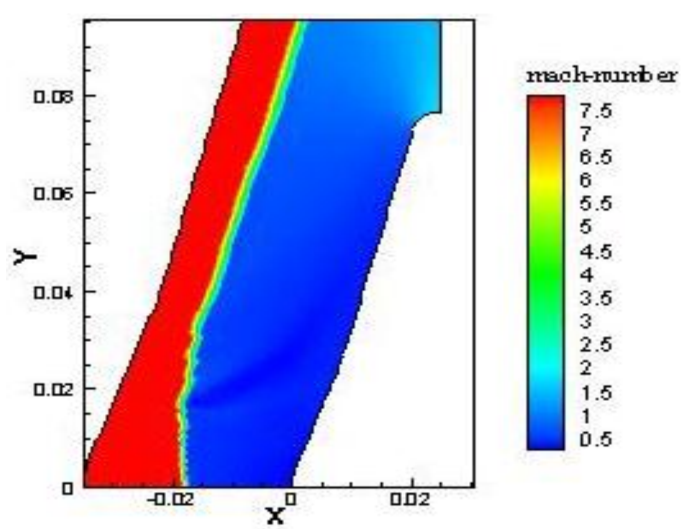


Fig. 2 Temperature and Mach contours on the surface of reentry capsule without IAD



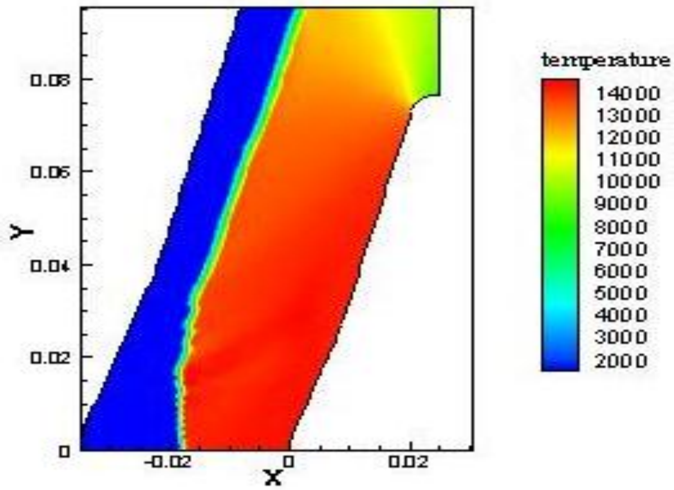


Fig. 3 Temperature and Mach contours on the surface of reentry capsule with IAD

REFERENCES

[1] Cruz, J.R., Lingard, J.S., "Aerodynamic Decelerators for Planetary Exploration: Past, Present, and Future," AIAA Guidance, Navigation, and Control Conference and Exhibit, AIAA 2006-6792, August 2006.

[2] Walther, S. et al., "New Space Application Opportunities based on the Inflatable Reentry & Descent Technology (IRDT)," AIAA/ICAS International Air and Space Symposium and Exposition: The Next 100 Years, AIAA 2003-2839, July 2003.

[3] Clark, I.G., "Aerodynamic Design, Analysis, and Validation of a Supersonic Inflatable Decelerator," Georgia Tech PhD Thesis, August 2009.

[4] Rohrschneider, R.R., Braun, R.D., "Survey of Ballute Technology for Aerocapture," Journal of Spacecraft and Rockets, Vol. 44, No. 1, January 2007.

[5] Shaw ST, Shan C and Qin N., "Development of a local MQ-DQ-based stencil adaptivemethod and its application to solve incompressible Navier-Stokes equations", Int JNumer Meth Fluids, Vol. 55, Issue 4, pp367 – 386, 2007.

[6] Birch T, Prince S, Ludlow D.K and Qin N., "The application of a parabolized Navier-Stokes solver to some hypersonic flow problems", AIAA 1753- 2001.

[7] Kuchi-Ishi S., "The development of a new viscous shock-layer code for computing hypersonic flow around blunted body and its applications", JAXA Research and Development Report, RR-05-001E, 2005.

[8] Thompson R. A., "Comparison of nonequilibrium viscous shock-layer solutions with shuttle heating measurements", Journal of Thermophysics and Heat Transfer, Vol.4, No. 2, PP. 162-169, 1990.