An Overview of the Activities of the von Karman Institute for the Aerothermodynamic Analysis of the Intermediate eXperimental Vehicle (IXV)

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Abstract
An overview of the activities performed by the von Karman Institute for the analysis of the aerothermodynamics of the Intermediate eXperimental Vehicle is presented. The efforts include the analysis of the aerothermodynamic flowfield environment around the IXV by both experimental and numerical means. Experiments are performed in the Mach 14 Longshot facility for this purpose. Numerical investigations include both rarefied and continuum regime. The thermal protection systems and the gas-surface-interactions are studied numerically and experimentally in the VKI Plasmatron facility. Experimental results obtained in the Plasmatron wind tunnel at the von Karman Institute for Fluid Dynamics also serve for the purpose of developing CATalycity in-flight Experiment (CATE)

1. Introduction

The Intermediate eXperimental Vehicle (IXV) is a flight test project managed by the European Space Agency and it aims at studying the atmospheric re-entry of a lifting body. According to the European Space Agency, the critical technologies of interest in IXV project are 1) guidance, navigation and flight control through a combination of jets and aerodynamic flaps 2) thermal protection and hot-structures solutions and 3) advanced instrumentation for aerodynamics and aerothermodynamics.

The von Karman Institute for Fluid Dynamics is one of the many European research institutions that work on the development and aerothermodynamic analysis of the IXV. This paper summarizes the results of experimental and numerical campaigns devoted to characterization of the Intermediate eXperimental Vehicle. The investigations performed by the von Karman Institute include the overall aerodynamic and aerothermodynamic behavior of the vehicle itself, the detailed analysis and qualification of the thermal protection systems and the development of an on-board materials catalytic behavior experiment “CATalycity in-flight Experiment (CATE)”,

2 Aerothermodynamic Characterisation of the Vehicle at Longshot Facility

Longshot facility of the von Karman Institute is a free piston hypersonic wind tunnel with a contoured nozzle that can be run at Mach 14. The test duration is in the order of 25 milliseconds and the test gas in Nitrogen. A scaled down IXV model is tested in the Longshot facility. Various tests are being performed to study the effects of Reynolds number, flap deflection angle, angle of attack, side slip angle, forced transition, etc… The test model is equipped by 36 coaxial thermocouples and 9 Kulite pressure transducers.

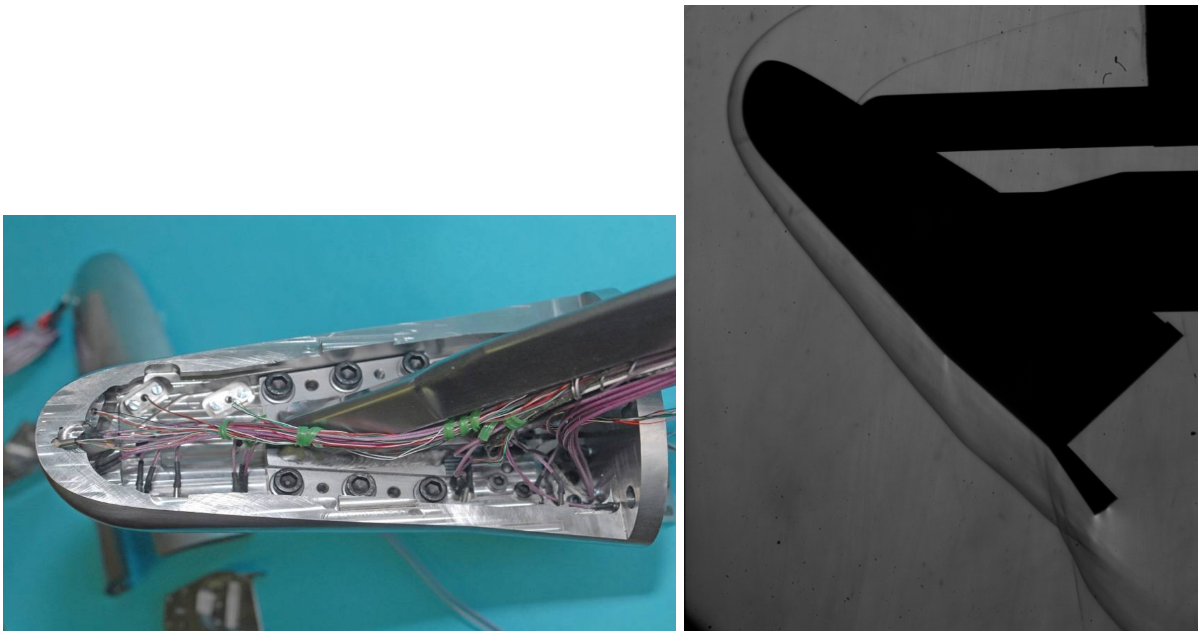

Figure 1: The instrumented IXV model (left) and a Schlieren image taken during the test (right).

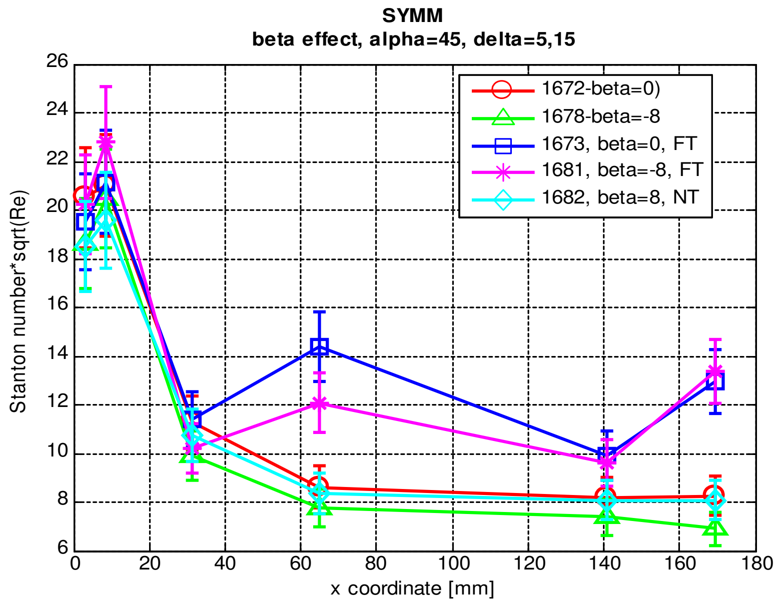

Figure 2: Variation of the non-dimensional heat flux (Stanton number) along the symmetry plane of the IXV

3 Testing and Qualification of the Thermal Protection Systems

The thermal protection materials that are going to be used on the IXV are being tested at the VKI Plasmatron facility, which is an inductively coupled plasma generator. The Plasmatron facility is the most powerful of its kind (1.2 MW) on Earth and it is a very suitable facility to study the aerodynamic heating in the vicinity of the stagnation point. Pressure, heat flux and emission spectroscopy measurements are performed to characterize the freestream conditions. Non-intrusive temperature measurements by infrared thermography are performed to measure the front surface temperature of the thermal protection materials that are exposed to plasma flow. Through post-processing of the measurement data, it is possible to detect the emissivity and catalycity of the test materials as a function of temperature and pressure.

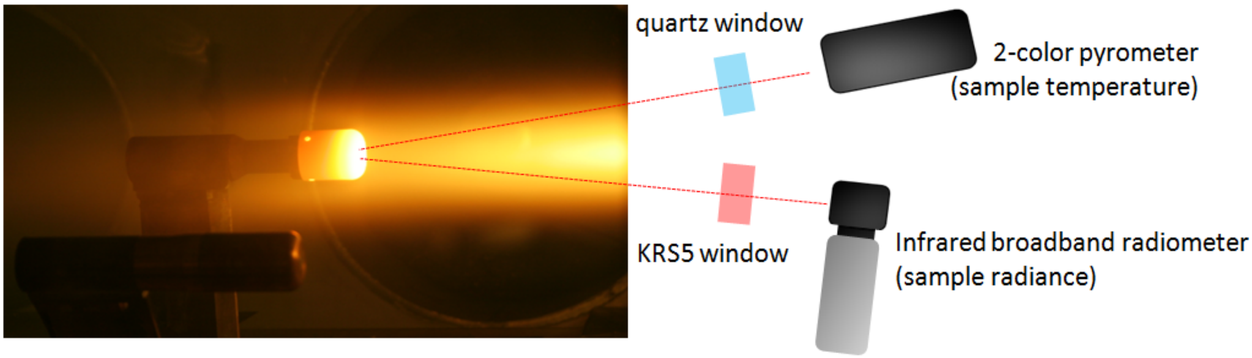

Figure 3: Experimental set-up for the non-intrusive optical measurement of surface temperature

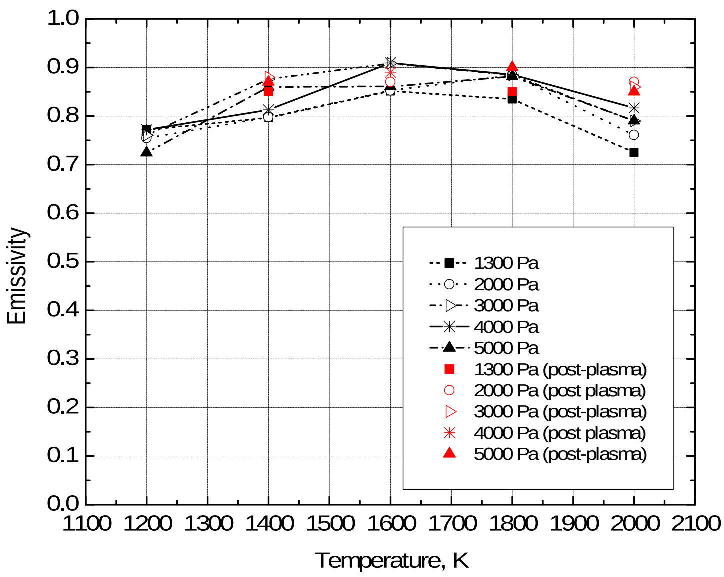

Figure 2: Summary of in-situ emissivity measurements and comparison with post-plasma room temperature measurements.

4 Numerical Simulations

The aerodynamic and aerothermodynamic environment of the IXV are calculated numerically both in rarefied and continuum regimes. Direct Simulation Monte Carlo (DSMC) methodology is used for the calculations in the rarefied regime. DSMC method is a particle simulation based on the Kinetic Theory of Gases. It uses simulated molecules, each possessing a position and velocity just like real molecules, to represent a large number of real molecules. The flowfield is partitioned into cells, and each cell is further subdivided into subcells to compute collisions & to obtain macroscopic variables. The simulation evolves by marching in discrete time steps. VKI employs the RGDAS code for this purpose. For DSMC computations, VKI has been following various steps, such as getting used to and developing tools to incorporate RGDAS into the VKI's computing cluster environment; validation runs on Apollo capsule; determining the lowest altitude possible before approaching the continuous regime, etc. Currently VKI is able to simulate down to 90km, and further improvements are expected. VKI is also able to perform combined simulation of external flow around the vehicle with the booster turned on. The plume can be considered continuous while the external flow is rarified.

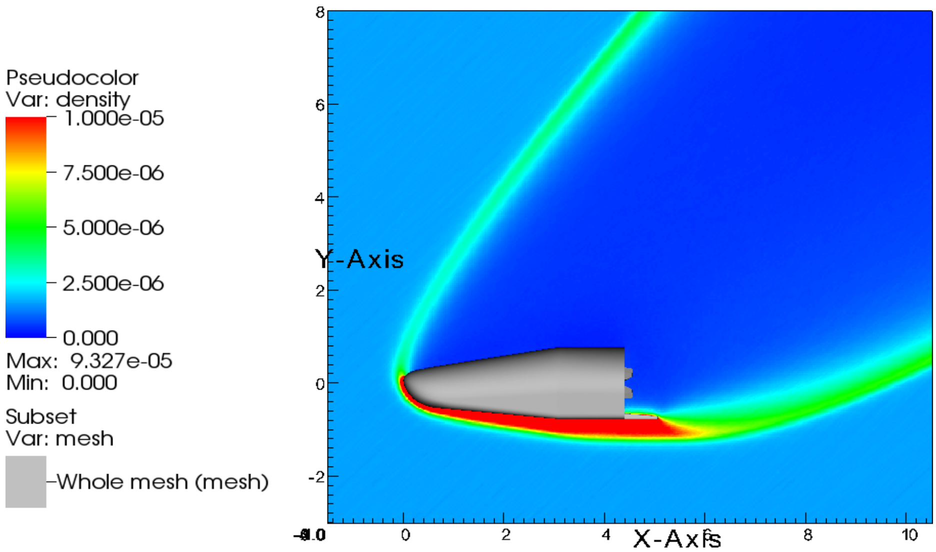

Figure 5: Typical DSMC results: Density variation around IXV

CFD++ computations are performed to compute the aerothermodynamic environment in continuum regime. These computations have the objectives of 1) Analysing the effect of the Reaction Control System on the Yaw moment, 2) Comparing different trajectory points, 3) Studying the effect of the jet plume on the back flow and shock configuration and 4) Analysing the thermal loads. The Mach number is changed between 3 and 20. Different catalytic boundary conditions are implemented, and these results are compared with the results of perfect gas assumption runs.

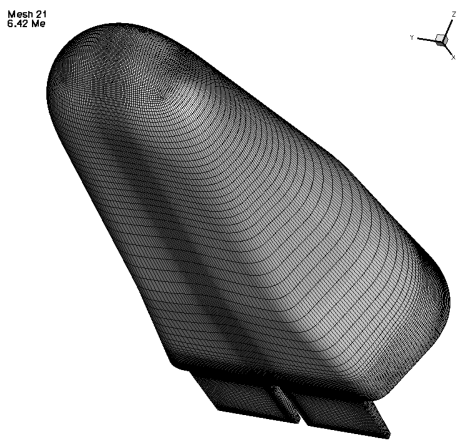

Figure 6: Surface mesh of the IXV

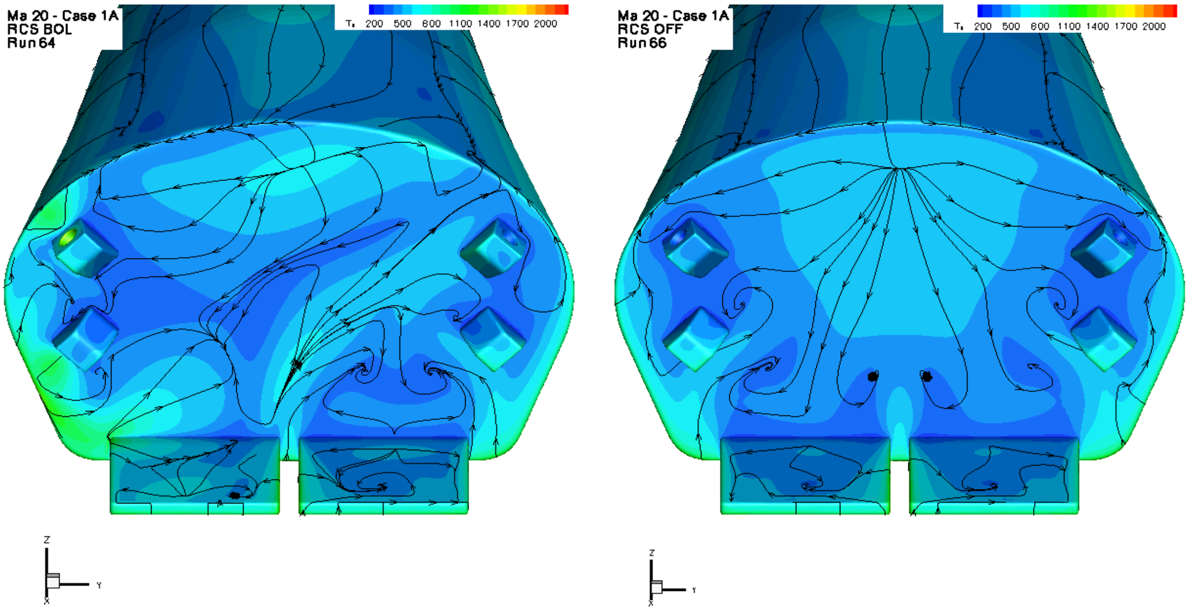

Figure 7: Back flow wall stream-traces over Temperature contours

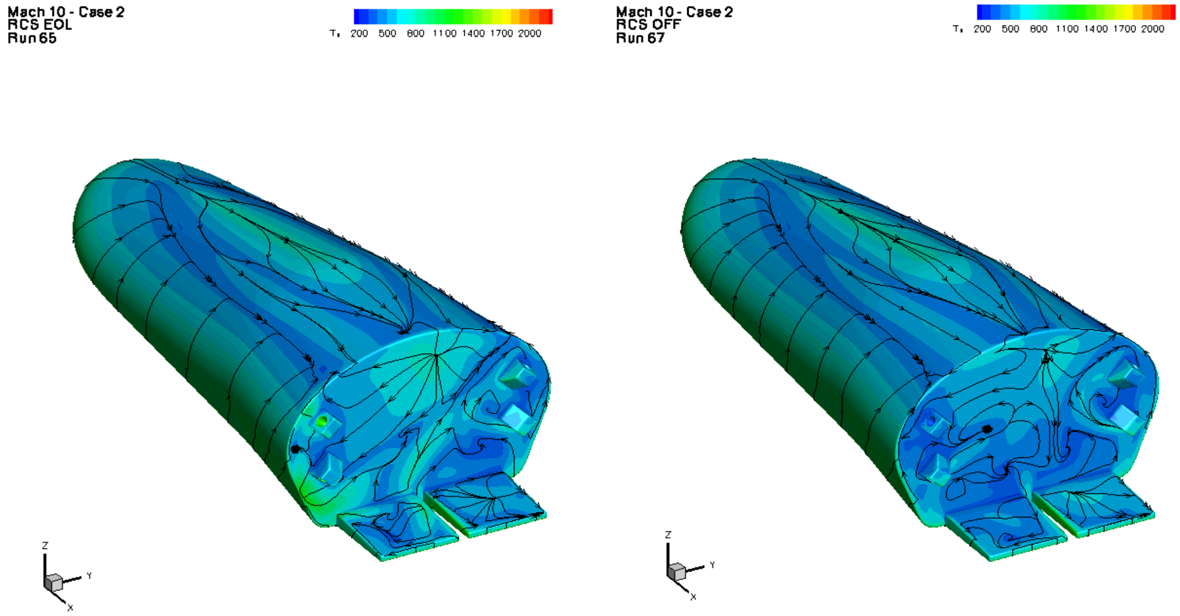

Figure 8: Temperature contours and wall stream traces on vehicle leeside

5 CATalycity in-flight Experiment (CATE)

CATalycity in-flight Experiment (CATE) is an in-flight experiment proposed and developed by VKI. It serves for the purpose of understanding the complex phenomena occurring in a reactive flowfield environment when the reactive flow interacts with more than one solid boundary with different catalytic properties. The interactions between the reactive flow and the thermal protection material are highly influenced by the catalytic properties of the material itself. As a result, the heat flux experienced by the vehicle can be increased significantly due to the additional chemical reactions occurring near the wall. The gas-surface interaction becomes even more complex when there is more than one material involved. The CATE experiment aims to create such an environment with patches of highly catalytic and low catalytic coatings/materials on the windward side of the vehicle. For the development and qualification of the CATE payload, numerical and experimental studies are being performed. The experimental studies focus on both stagnation-point and off-stagnation-point configurations. The main assumption behind the off-stagnation testing is that the heat-flux due to dissociated hypersonic boundary layer over a surface could be simulated in a subsonic plasma facility by matching the chemical time of the flow. It is believed that understanding these complex gas-surface interaction phenomena will help the researchers to build safer vehicles with fewer resources.

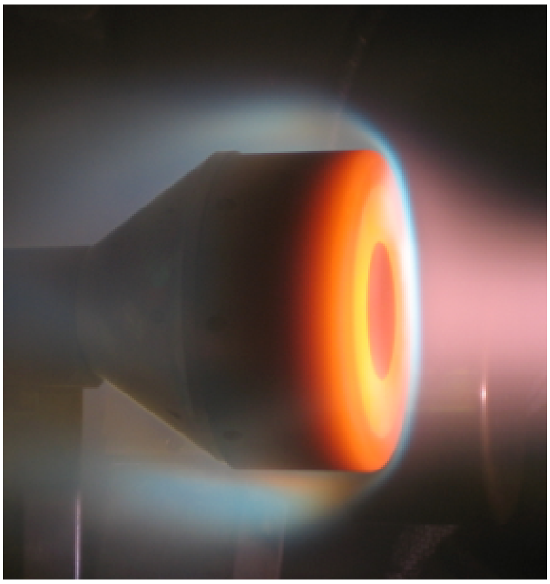

Figure 9: Stagnation-point testing of materials with different catalytic properties

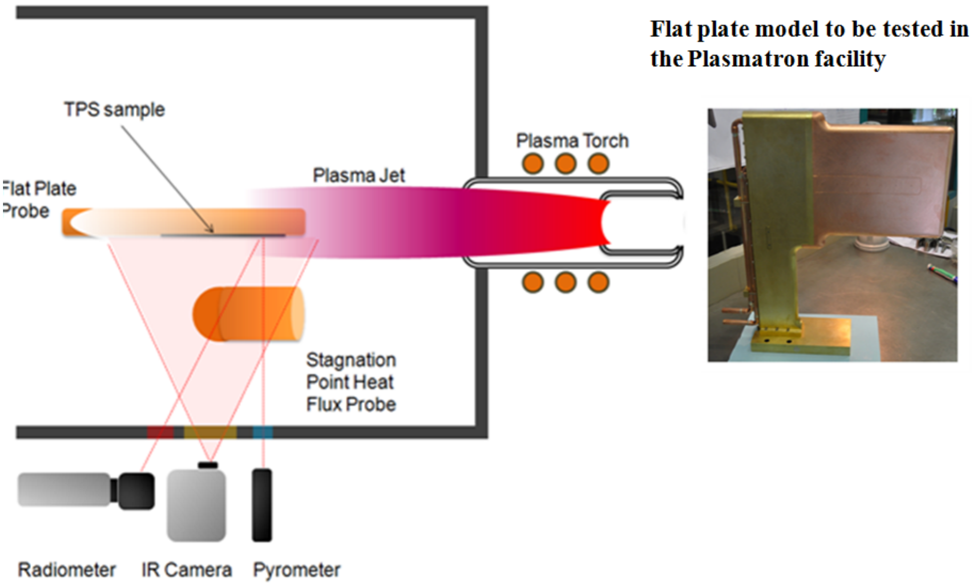

Figure 8: Off-stagnation point testing configuration

5 Conclusions

IXV project is being studied along with the Aerodynamics and Aerothermodynamics database development at VKI with CFD computations and hypersonic ground testing facilities. The duplication of flight conditions has been addressed in Plasma wind tunnel under dissociated flow conditions for the characterization of TPS. Similar efforts have been performed in the Longshot facility to understand the flowfield – vehicle interaction at various conditions. Numerical tools, both in rarefied and continuum regimes, have been used for the validation and a better understanding of the experimental data. Finally, developments have been initiated for the modeling issue concerning Gas-Surface-Interaction and the ground testing for off-stagnation point conditions. This also serves for the purpose of developing the CATalycity in-flight Experiment (CATE).