Off-Stagnation Point Testing in Plasma Facility

Abstract

Reentry space vehicles face extreme conditions of heat flux when interacting with the atmosphere at hypersonic velocities. The bow shock in front of the spacecraft can rise the gas temperature until dissociation of gas molecules takes place. Thus, the hypersonic boundary layer becomes a gas mixture in which diffusion of species is a major concern. Eventually, part of the energy stored during the dissociation process at the shock could be released by recombination of atoms into molecules when reaching the wall of the vehicle. This energy transfer is one of the main components of the heat flux balance at the wall and its duplication in ground facility is an important requirement.

Stagnation point is considered one of the most critical regions in terms of heat flux due to the high static enthalpy of the flow under these conditions. However, some critical phenomena in terms of heat flux can also occur at off-stagnation point such as jumps in catalytic properties of the wall or flap deflection. The present work assesses the implementation of a testing methodology able to reproduce in plasma facility the off-stagnation boundary layer over a flat plate model.

The off-stagnation point methodology considered here states that if outer edge static enthalpy, density, chemical reactions, the ratio x/U_δ and the Damköhler number based on this ratio are respected for two different velocities, the boundary layer will be the same and hence the heat flux will be reproduced. Such statement is confirmed with CFD computations over a flat plate under uniform freestream conditions. Heat flux distributions for two different Mach numbers converge when plotted along x/U_δ.

The potential of this methodology relies on the fact that a similar distribution of heat flux at off-stagnation point can be obtained in a reduced scale model, overcoming one of the current limitations of plasma facilities. The present work focuses on the implementation and the assessment of this methodology at the VKI Plasmatron facility.

A CFD analysis over a finite flat plate configuration is carried out in order to study further limitations of the methodology when applied in the Plasmatron, which is far from an ideal case. The geometry used in computations intends to reproduce the flat plate probe used during the testing campaign afterwards. First, the methodology is applied over the described configuration. Then, the effect of static pressure in the test chamber over the heat flux distribution is considered. Finally, both velocity and enthalpy jet profiles coming from the plasma torch are introduced as inlet boundary conditions. Conclusions of this analysis are discussed toward the practical application of the off-stagnation point testing methodology.

The validation campaign in the VKI Plasmatron facility is carried out in two main steps. The first one is the calibration of the Plasma facility in terms of mass flow, static enthalpy and heat flux at stagnation point in order to characterize the incoming flow conditions during the tests on the flat plate model. The second one is the heat flux measurement itself over the flat plate probe under two different velocities. The results are analyzed and allowed to assess the testing methodology for the duplication of the boundary layer condition on scaled models.