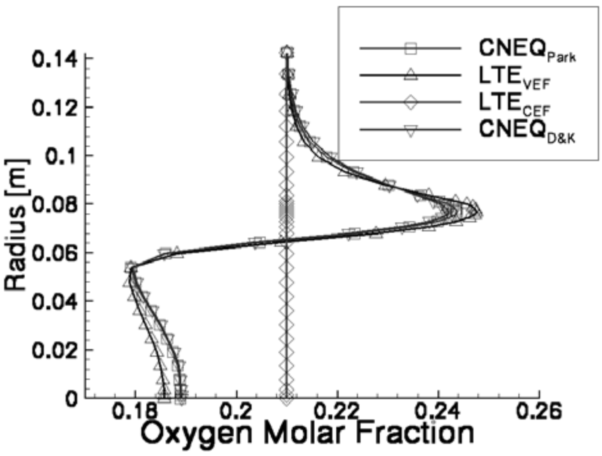
# NUMERICAL SIMULATION OF NON-EQUILIBRIUM PLASMA FLOWS

**Marco Panesi**, Italy
Supervisors: O. Chazot & P. Rini

In order to protect space vehicles from the high thermal loads during the atmospheric re-entry, suitable heat shields must be provided The design of the thermal protection systems (TPS) requires the knowledge, as accurately as possible, of the catalytic properties of the TPS materials, because of their strong influence on the heat flux. For this purpose a methodology based on heat transfer and pitot pressure measurements on one hand, and numerical simulation of the flow in the testing facility and in the boundary layer around the probe on the other hand, has been developed by research scientists at the Institute of Problem in Mechanics in Moscow.

The goal of this research project is to assess two main hypotheses of the methodology, concerning the degree of non equilibrium and demixing at the boundary layer edge, that develop around the sample (used in the experiments). To achieve this goal three different mathematical formulations have been used: an extended chemical non-equilibrium formalism including finite-rate chemistry and two forms of equation valid in the limit of local thermo-chemical equilibrium: the LTE-VEF formulation, that takes into account the demixing of chemical elements and the LTE-CEF formulation, where the molar fraction of element is supposed to be constant. Moreover two models for the simulation under chemical non-equilibrium have been used: Park and Dunn-Kang. This was done in order to assess the dependency of the results from the model chosen. Simulations at various operating pressures indicate that the model dependency is strongly reduced at higher pressures and is relevant at lower pressures. As the operating pressure increased, chemistry becomes faster and the non-equilibrium results correctly approach the results obtained assuming local thermo-chemical equilibrium, supporting the validity of the proposed local equilibrium formulation. Significant demixing of oxygen and nitrogen elements occurs, regardless of the degree of non-equilibrium in the plasma. Finally, from this investigation we conclude that CNEQ and demixing effects should therefore be taken into account when processing the results of tests of thermal protection materials for (re-)entry spacecraft in inductively coupled plasma wind tunnels.



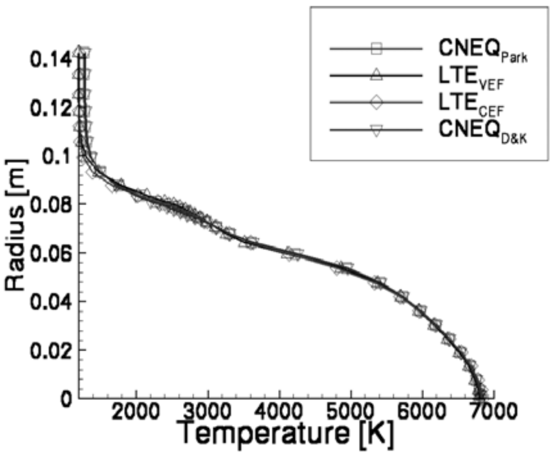




*Figure 1: The pictures above show how at high pressure the LTE-VEF is consistent with the CNEQ formulation, since the radial temperature profiles and oxygen molar fraction plots are basically overlapped. The operative pressure is 30000 Pa.*