In-flight Experiment Design and Ground Testing of a Re-Entry CubeSat

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Abstract

Spacecraft, returning back to Earth, experience a very harsh environment during the re-entry. One of the major issues of the re-entry is the extreme aerodynamic heating and the exothermic chemical reactions due to the gas-surface interaction at hypersonic free stream velocities. There is a constant effort by the space agencies to increase the understanding of the re-entry flight dynamics to optimize the spacecraft design. The re-entry phenomena are investigated using three powerful tools with their advantages and inconveniences: flight tests, numerical simulations and ground testing. The most valuable among all is the real flight testing however they come with very high costs and they have to be designed with ground tests. Different from low speed aerodynamics, high enthalpy flows cannot be fully simulated on ground but only partial simulations are possible. The approach at VKI is the Local Heat Transfer Simulation (LHTS) which says that the stagnation region behind the shock can be simulated only if the total pressure and the boundary layer edge enthalpy and velocity gradient are reproduced.

The first part of this study is to develop methods the **Plasmatron flow characteristics** eventually to make sure the boundary layer edge and velocity gradient are kept. Two methods are initially proposed: free stream temperature measurement by emission spectroscopy and direct enthalpy measurement. Subsequently an **Aerothermodynamic Database** will be built and an envelope, where the mission trajectory will later be imposed, will be defined to develop Gas-Surface Interaction models for further design steps. The last step is then called **Flight Extrapolation** where the ground test conditions are pinpointed to the mission flight trajectory. The reference mission of this study is VKI's QARMAN (QubeSat for Aerothermodynamic Research and Measurements on Ablation) in the framework of QB50. Different from the rest of the QB50 satellites, the Re-Entry CubeSat is a double CubeSat, with an extra ablative thermal protection system (TPS) unit, resulting in the external dimensions of a triple CubeSat.

The major scientific return of QARMAN project is the contribution of flight data on an Earth re-entry trajectory by a very low cost mission compared to other similar missions such as ARD, EXPERT, IXV, etc. The re-entry conditions of QARMAN are representative of a real spacecraft re-entry (starting altitude of 120 km, V=7.5 km/s and $q \geq 2MW/m^2$). It is the first time that such a low-resource vehicle will be used for re-entry studies.

Several important issues at different phases of the re-entry flight are the starting points of the scientific questions that will be answered through the PhD study. The phenomena under consideration are: Aerothermodynamic environment, thermal protection system, gas-surface interaction (mainly ablation), telecommunications blackout, different stability regimes, turbulence effects, radiation, rarefied flow aerodynamics, atmospheric effects, stability, attitude control and controlled re-entry, disintegration, subsystem functionality and safety aspects. Using the ground testing methodology developed in the first part, it is aimed to investigate how those phenomena can be measured during the flight on such a constraining platform. The goal is propose eventually a flight qualified payload for in-flight experiment.