Trajectory and Atmospheric Reconstruction for Entry Vehicles

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Abstract

Reconstruction of the hypersonic entry of planetary capsules has mainly focused on engineering trajectories (position/velocity). However, development of sophisticated on-board experiments and demand for in-situ atmospheric profiles by the climate modeling community, require accurate atmospheric conditions.

Keywords: trajectory, atmosphere, reconstruction, FADS, flow characterization, uncertainty quantification.

1. Introduction

Reconstruction of the hypersonic entry of planetary capsules has mainly focused on the engineering trajectory (position, velocity). The interpretation of accurate on-board experiments (e.g. EXPERT) and a demand for in-situ atmospheric profiles by the planetary climate modeling community, require accurate reconstruction of also the atmospheric conditions. Currently, this is typically limited to +/-15% [ref 1]. Atmospheric profiles from hypersonic entry are especially interesting on planets where in-situ measurements are scarce, such as Mars [ref 2].

Figure 1 is a simplified representation of the reconstruction process. The set of available measurements almost always includes accelerometers; sometimes also gyroscopes, nose surface pressures (for use in a Flush Air Data System) and Doppler shifts in the radio link signal are included. Additional information going into the reconstruction can include an aerodynamic database built from CFD simulations or wind tunnel experiments, a planetary gravity model and even uncertainty estimates of the above (including the measurements). This additional information

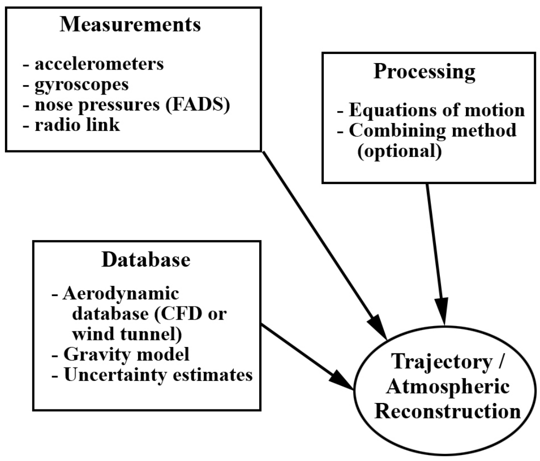

Figure 1: Simplified reconstruction process

is listed under the catch-all term 'database' indicating prior knowledge. A sophisticated, accurate database is preferable to a very simple set of assumptions. Finally, the processing consists of the integration of equations of motion and optionally some method to combine multiple measurements. These range from simple comparative calculations to stochastical Kalman filters that produce weighted averages based on uncertainty estimates in the database. Such a filter also produces uncertainty estimates on the results.

2. Approach

We will investigate several of the above elements to determine which are crucial to the atmospheric reconstruction effort. Resulting atmospheric profiles can be compared to each other and climate models. Available datasets include ARD on Earth, Phoenix, Pathfinder, MER on Mars and Huygens on Titan. NASA's Mars Science Laboratory (MSL) will land in August 2012. MSL is the best equipped Mars entry vehicle to date, including nose pressures for FADS and heat flux measurements.

Currently, we use the Phoenix dataset as a test case for estimating atmospheric reconstruction accuracy and sensitivity to measurements and database elements. The result will be a versatile reconstruction code including simple uncertainty quantification (UQ) analysis. We can incorporate existing work such as the VKI 6-DOF trajectory code, the Royal Observatory's radio Doppler code and a publically available Inertial Measurement Unit reconstruction code [1].

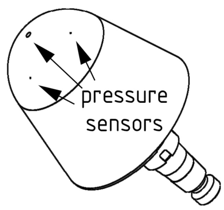

Figure 2: FADS sensors on wind tunnel probe

MSL will be the first opportunity to use a FADS system on Mars for separating aerodynamic and atmospheric uncertainties. Reconstruction code using the pressure measurements has been developed at NASA Langley [2]. At VKI we are currently building the basic FADS expertise, as well as investigating the incorporation of state-of-the-art UQ methods and heat flux measurements to improve FADS accuracy. In broad strokes, this consists of CFD simulations with associated UQ, carried out by the team of T. Magin, and wind tunnel testing (Figure 2) with associated flow characterization by the team of O. Chazot, including the PhD candidate. Specifically, we are developing a static pressure probe (Figure 3) to more accurately determine the Longshot flow conditions.

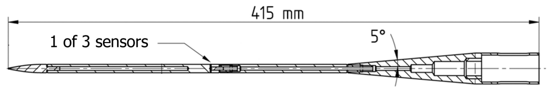

Figure 3: Nagamatsu hypersonic static pressure probe

We will use the Phoenix dataset and the reconstruction tool to produce synthetic datasets for a hypothetical FADS system, and similarly for the MSL dataset when it becomes available in August 2012. The objective is to identify design and processing features that constrain or benefit the accurate calculation of atmospheric profiles such as the free stream density. Inverse problem UQ and wind tunnel results should quantify the state-of-the-art accuracy and point out methodologies for improvement.

3. Conclusion

Reconstruction of atmospheric conditions (i.e. static pressure and density) during hypersonic entry has received little attention compared to reconstruction of the basic trajectory. More accurate atmospheric conditions have direct applications to lifting-entry vehicle control, interpretation of in-flight experiments and climate modeling (especially on non-Earth planets such as Mars). Our aim is to improve that accuracy with a comprehensive approach including CFD, wind tunnel testing, UQ tools and various processing techniques depending on the available sensor information.

Acknowledgments

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References

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