UQOP 2019
Uncertainty Quantification & Optimization Conference
18-20 March, Paris, France

Robust Calibration of the Catalytic Properties of Thermal Protection Materials: Application to Plasma Wind Tunnel Experiments

Anabel del Val*

Aeronautics and Aerospace Department, von Karman Institute for Fluid Dynamics, Belgium
Centre de Mathémathiques Appliquées (CMAP), École Polytechnique, France
ana.isabel.del.val.benitez@vki.ac.be

Olivier Le Maître†

LIMSI, CNRS, Université Paris Saclay, France
olm@limsi.fr

Olivier Chazot‡ and Thierry Magin§

Aeronautics and Aerospace Department, von Karman Institute for Fluid Dynamics, Belgium
chazot@vki.ac.be, magin@vki.ac.be

Pietro Congedo¶

INRIA Saclay Île-de-France, École Polytechnique, France
pietro.congedo@inria.fr

Keywords: Uncertainty Quantification, Bayesian Inference, Plasma Flows, Catalysis

ABSTRACT

Historically, experiments have been the main source of knowledge since the dawn of scientific pursuit. The invention of computers lead to a raise in computational methods that are widely used in modern engineering to reduce time and costs during the design phase of a complex system, often as an alternative to experiments when our confidence in the models is very high. Another use for computational methods is the capability of solving complex equations which otherwise would remain unsolved or would require a considerable amount of human resources

*PhD Candidate, VKI, Chaussée de Waterloo 72, 1640 Rhode-St Genèse, Belgium
†Senior Researcher, CNRS, Université Paris Saclay, Bt 508, rue John von Neumann, Campus Universitaire, 91405 Orsay, France
‡Professor, VKI, Chaussée de Waterloo 72, 1640 Rhode-St Genèse, Belgium
§Associate Professor, VKI, Chaussée de Waterloo 72, 1640 Rhode-St Genèse, Belgium
¶Research Scientist, INRIA, 1 rue Estienne d'Orves, 91120 Palaiseau, France

[Golemba, 1994]. Since the beginnings of the computational era, experiments and simulations have been used alongside one another to uncover deep physical laws and to understand nature. As our knowledge of the world is never perfect and so far we cannot account for all its different multi-scale details, uncertainties must play a role in the understanding process.

The study of the aerothermal environment surrounding a vehicle during atmospheric entry is extremely complex, as such, experiments and models are put to the test to avoid critical mission failure. In this context, the reliability of our predictions as well as the quality of our models must be assessed. The von Karman Institute (VKI) uses a state-of-the-art Inductively-Coupled Plasma (ICP) torch [Bottin *et al.*, 1999] to collect relevant data to study flow-material interaction phenomena for relevant spacecraft reentry conditions. Depending on the material to be characterized, different testing techniques can be used to assess different aspects of their performance. We focus our interest in reusable materials for which the heat load is partially re-radiated back to the atmosphere. One of the key factors in choosing them is the specified reaction recombination efficiency which measures how much of a chemical species is recombined at the wall compared to its net difussion flux to the wall. The characterization of these surface properties is done in an indirect manner by using several measurement techniques and numerical rebuilding. Uncertainties affecting each part of the rebuilding process must be accounted for, from the measurement errors, to the methodology used to measure, to the model used to perform the rebuilding.

In this work, we address the answer to the following questions: Can the estimation of the recombination efficiency parameter be improved through different experimental methodologies? When doing so, can the Bayesian framework be extended to include new parameters and give accurate posteriors? Is the calibration useful in other testing conditions?

State-of-the-art uncertainty quantification techniques are applied to catalytic thermal protection system characterization using plasma wind tunnel experiments [Viladegut, 2017]. Different testing methodologies are discussed based on their resulting posterior distributions allowing for recommendations regarding the testing. To assess whether or not the calibration of the recombination efficiency parameter can be extrapolated to other testing conditions, a hypothesis testing analysis is also included. The computation of the Bayes factor relates the comparison between two different marginal likelihoods or evidences attached to two alternative hypotheses. The results from this analysis determine the suitability of one hypothesis or the other opening up the discussion about model selection and the influence of the experimental conditions for optimal testing.

From this work, conclusions indicate that a more complex testing methodology must be put in place to obtain more accurate posterior distributions for the recombination efficiency parameter. Choosing two materials of very different catalytic behavior (fully catalytic versus non-catalytic) and having the catalytic behavior of the material we want to characterize somewhere in the middle, gives us a much better estimation of the parameter of interest. Using the calibrated parameter for different testing conditions proves problematic as indicated by the Bayes factor, inviting us to rethink the rebuilding methodology.

In general, this contribution offers a deeper insight to the experiments performed in this domain and how to improve our model upon experimental evidence.

References

[Golemba, 1994] Golemba, B. (1994). Human Computers: The Women in Aeronautical Research. NASA Langley Archives, 1994.

[Bottin *et al.*, 1999] Bottin, B., Chazot, O., Carbonaro M., Van der Haegen V. and Paris S. (1999). The VKI Plasmatron Characteristics and Performance. *Measurement Techniques for High Temperature and Plasma Flows*, RTO-EN 8, pp. 6-1, 6-24.

[Viladegut, 2017] Viladegut A. (2017). Assessment of Gas-Surface Interaction Modelling for Lifting Body Re-Entry Flight Design. PhD thesis VKI/UPC, 2017.