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Calibration of TACOT Material Database and PATO Through Bayesian Inference and Surrogate Modeling

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ABSTRACT

On August 6, 2012 the Mars Science Lab (MSL) vehicle entered the atmosphere of Mars following its launch on November 26, 2011. During its hypersonic entry through the planetary atmosphere, the heatshield of the vehicle that was composed of individual Phenolic Impregnated Carbon Ablator (PICA) tiles protected it from the excessive heat generated by the surrounding flow field. The design of the heatshield included a full range of instrumentation designed to capture among others material temperature history throughout the atmospheric entry phase. The availability of these data allow for calibration and uncertainty quantification to be undertaken on existing material response computational frameworks such as NASA's Porous Material Analysis Toolbox (PATO) and the TACOT material database [Meurisse et. al.]. The present study will be carried out through Bayesian inference [Tarantola] and is aimed at improving the ability of the framework to predict future flight performance and to be able to accurately capture prediction uncertainty. Because Bayesian inference methodology can incur heavy computational costs due to the reliance on sampling algorithms, polynomial chaos surrogate model is used here to approximate the response of the original model [Blatman].

The calibration data set in the present analysis consists of material temperature history profiles from the 3 deepest thermocouples (TCs) located inside of MISP-4 plug on the vehicle heat shield.

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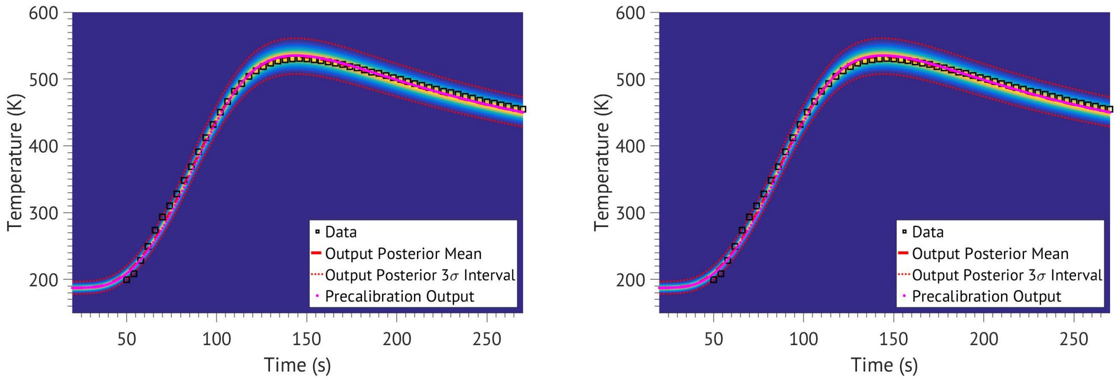

Figure 1: *Output distribution from the forward propagation of posterior distributions for TC2 (left) and TC3 (right)*

The uncertain parameter space consists of temperature dependent thermal conductivity parameters of virgin and char states of the PICA ablator. In addition, uncertainty due to modeling and data error sources will be quantified per thermocouple basis. It is important to note that the material model was calibrated using a deterministic method prior to the present study.

Bayesian inference was carried out by sampling posterior distributions using a Markov Chain Monte Carlo (MCMC) sampling scheme. For the MSL scenario being studied, the intercept parameters for the virgin and char thermal conductivity parameters exhibit the largest influence over output. Differences, although minuscule, are also present between the Maximum A Posteriori (MAP) and pre-calibrated parameter values, and their respective posterior distributions exhibit moderate uncertainty. Following, quantified uncertainty due to parametric, modeling, and data error sources were forward propagated through the model which yielded probabilistic calibrated output in Figure 1. The MAP calibrated outputs in general exhibit minor improvements in overall agreement with the majority of the thermocouples with the exception of the third thermocouple under study. Above all else, the total uncertainty due to parametric, modeling, and data error sources has been captured in the calibrated output across all thermocouple locations. These uncertainty bounds have the potential of reducing safety factors in future vehicle designs.

References

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