Thermal Soak Analysis of SPRITE Probe

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A concept called SPRITE (**S**mall **P**robe **R**eentry **I**nvestigation for **T**PS **E**ngineering) has been developed at NASA Ames Research Center to facilitate arc-jet testing of a fully instrumented prototype probe at flight scale [1]. Besides demonstrating the feasibility of testing a flight-scale model and the capability of an on-board data acquisition system, another objective for this project was to investigate the capability of simulations tools to predict thermal environments around the probe/test article and its interior. The present paper summarizes results of thermal analyses that were performed during the early design phase for the SPRITE project to provide input to the design team, as well as post-test analyses to obtain the temperature histories of the probe, substructure and payload and compare them against measured data. The results reported here have been obtained using a commercial finite element (FE) solver MSC.Marc [2], which supports fully transient, non-linear, coupled thermal/mechanical FE analyses. In the test design phase, several conduction and re-radiation based thermal analyses were performed for variations in design parameters. The requisite surface heat-flux distributions (used as boundary conditions for the 2D axi-symmetric FE model) were obtained using DPLR [3] for arc-heated flow fields. These results helped guide the test and design teams in – (1) selecting the material for the substructure and container box for the data acquisition system, (2) determining the exposure time for arc-jet test article, and (3) determining thermal pathways for suitably placing thermocouples in the test article. For post-test predictions of temperature histories for the probe and internal payload during the cool down process, the fidelity of the modeling was improved through the integration of a materials response code, TITAN [4], in the analyses. The temperature maps obtained from TITAN were imposed on the finite element model at the end of the heat pulse. Doing so ensured that ablation and pyrolysis during the exposure were included in the analysis. The cooling process and heat transfer from the forebody and aft TPS to the substructure and payload were then analyzed using the MARC solver. Furthermore, the heat generated by the battery (installed to power the internal data acquisition system) was also included in the model. The temperature histories predicted by the FE model were in good agreement with data obtained from thermocouples placed on the battery and metal container. The finite element analyses were able to predict the time and magnitude of the peak heat in the aluminum box and the battery within ± 5 $^{\circ}$C. This approach will be further advanced to develop thermal soak models for Multi mission earth entry vehicles.

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References

[1] Howard, Austin R., Prabhu, Dinesh, K., Venkatapathy, Ethiraj, and Arnold, James, O.: "Small Probes as Flight Test Beds for Thermal Protection Materials" Proceedings of the 7th International Planetary Probe Workshop, Barcelona, Spain, 2009.

[2] "Multidimensional Testing of Thermal Protection Materials in the Arcjet Test Facility", **Parul Agrawal**, Donald T. Ellerby, Mathew R. Switzer,Thomas H. Squire, proceedings, 10th AIAA/ASME Joint Thermophysics and Heat Transfer Conference Chicago, Illinois, June 28- July1 2010.

[3] Prabhu, D. K., Saunders, D. A., Oishi, T., Skokova, K. A., Santos, J., Fu, J., Terrazas-Salinas, I., Carballo, J. E., Jr., and Driver, D. M., "CFD Analysis Framework for Arc-Heated Flowfields, I: Stagnation Testing in Arc-jets at NASA ARC," AIAA Paper 2009-2081, AIAA Thermophysics Conference, San Antonio, TX, June 2009.

[4] Chen, Y.-K., and Milos, F.S., "Two-Dimensional Implicit Thermal Response and Ablation Program for Charring," *Journal of Spacecraft and Rockets*, Vol. 38, No. 4, July-August 2001, pp. 473-481.