

The Effect of Martian Dust on Radiator Performance

by D. Keith Hollingsworth, Larry C. Witte, and Ashley Higgins

ABSTRACT—Thermal radiators are a critical element for lunar or Martian habitation missions. Experiments by University of Houston and NASA investigators have demonstrated a dramatic degradation in radiator emittance attributed to the accumulation of a Martian dust simulant. The ISSO mini-grant funded the development of an automated facility that will lower operational costs for future tests.

DUST IS EXPECTED TO BE A MAJOR contributor to the local environmental conditions at the Martian surface and may also be a substantial problem for long-term equipment on the lunar surface. The ISSO Mini-grant afforded researchers funding intended to enhance an existing University of Houston/NASA Johnson Space Center effort to measure the radiative emittance of thermal radiator coatings laden with simulated Martian dust. This larger project—“The Mars Radiator Characterization Experimental Program”—received NASA funding in 2002-2004 and produced measurements of the reduction in effective radiative emittance as (simulated) Martian dust accumulates on surfaces coated with high-emittance materials. This work was motivated by the expectation that radiators will be a critical element in the thermal control system for future robotic and human exploration missions to Mars. Radiator performance depends on the radiating surface area, the emittance and absorptance of the radiator surface, the temperature of the radiator, the effective sky temperature surrounding the radiator, solar radiation, and atmospheric irradiation levels. Radiative properties of the surface are affected by dust accumulation and surface oxidation.

Project goals

During the original NASA project (Hollingsworth et. al., 2004 and 2006), an apparatus was developed to measure the radiative emittance of test coupons in the JSC Energy Systems Vacuum Chamber. The chamber produced a range of sky temperatures typical of Martian conditions. The Martian dust “simulant” used by NASA is Carbondale red clay. Eight radiator coupons were constructed so that two examples of each of three candidate radiator coatings and a control surface could be tested at each dust loading. The coupon design included active guard heating that prevented heat loss from all surfaces other

than the test surface of the coupon. The system included an apparatus that deposited dust uniformly on multiple coupons *in situ* in the vacuum chamber. (An invention disclosure has been filed through NASA-JSC and UH.) Experiments were completed for seven temperature operating conditions under vacuum (10-6 torr). The effect of dust loading was dramatic: high-emittance surfaces see an approximately 50 percent reduction in emissive power as the surface emittance drops toward that of the dust simulant. The highest dust loading produced a thickness of roughly 100 microns.



D. Keith Hollingsworth

The weakest element of the system was the manual temperature control used to adjust the 16 heaters necessary to establish the eight coupons at steady-state conditions. Under the control of an experienced operator, the system would require more than three hours to stabilize at single set of conditions. An automatic controller would allow a significant reduction in the time required for a single run.

The ISSO mini-grant funded a conversion of this system to automatic control. The idea is that the measured temperature and heater voltage would be used to compute an estimated set point for each heater. That set point would be communicated to the heater power supply electronically so that manual adjustment via potentiometers of the heater power would be replaced by transistor-gated control of the heater power. Both the main

and guard heaters were automatically controlled so that the coupon arrives at the set point temperature with essentially a zero temperature difference within the structure of the coupon.

Results

Each test coupon was driven by two heaters: a main heater that provides the measured power to the radiator surface and a guard heater that is set to maintain the remainder of the coupon surface at the same temperature as the surface. Temperatures of the test surface and of the surrounding structure were measured by resistance temperature devices (RTDs). The temperature of the vacuum chamber walls was controlled by a separate system operated by NASA staff.

For all eight coupons there were a total of 16 RTDs to monitor and 16 heaters to adjust. An IoTech Daqbook data acquisition system collected the temperature and power data while sixteen precision DC power supplies provided manually-controlled current to the heaters. Data from the IoTech were recorded on a laptop computer. The operator observed the 16 RTD readings and adjusted the power supplies to arrive at the target temperature.

To implement automatic control, four IoTech digital-to-analog boards and associated power conditioning equipment were added to the data acquisition system. The power supply for the coupon heaters was modified so that either transistor control or potentiometer-control (manual operation) could be selected by a switch.

A custom-written software controller in the laptop generated

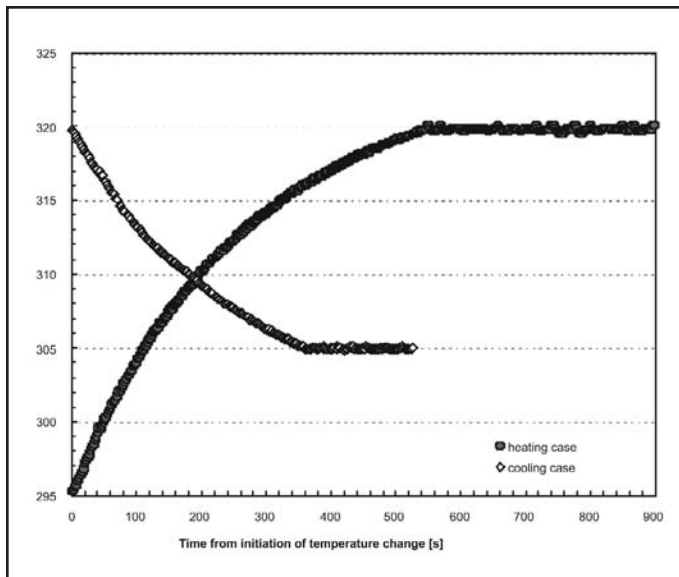


Figure 1. Heating of one coupon from room temperature to 320 K, cooling from 320 K to 305 K. For the heating case the 95% confidence uncertainty at steady state is ± 0.25 K. For the cooling case, the uncertainty during steady operation is ± 0.13 K.

appropriate heater settings which were then converted to analog voltages by the D-to-A boards. Those voltages drove power transistors which generated a current sufficient to drive the heaters at the desired power. The resulting heater voltages, along with the coupon and guard temperatures, were read by the data acquisition system and the process repeated. A proportional integral (PI) control strategy was implemented in the same VisualBasic code that handles the data acquisition.

To demonstrate the automatic control system, scientists had one coupon exercised in room air in the laboratory. Operation of the system in room air is a more severe test of the control system than its operation in high vacuum. For the heating case shown in Fig. 1, the coupon is initially at room temperature and the system given a target of 320 K. The coupon temperature traversed the 25 K difference in roughly 9 minutes and was steady at an average of 319.8 K with a 95 percent (two-sigma) single-sample variation of ± 0.25 K. This uncertainty is 1.0 percent of the difference between the target and ambient temperatures and is on the order of the uncertainty produced by the measurement system. For the cooling example, the coupon was initially at 320 K and cooled by natural convection under automatic control to a target temperature of 305 K. The cooling process occurred over 6 minutes and the system achieves a steady state at 305.0 ± 0.13 K. This uncertainty is 1.3 percent of the mean rise above ambient. In vacuum, the heat transfer rate from the coupons would be much lower and the transients longer; however, response faster than the 2-3 hours per point typical of manual operation is expected.

Automatic control proved to be a successful and worthwhile addition to the system. A new proposal for continued work featuring the strong potential of cost-savings produced by the improved system was submitted to both the NASA Johnson Space Center Director's Discretionary Fund (\$200,000) and to the NASA Constellation/Exploration Program. The timing of

these follow-on efforts coincided with the redirection of NASA's efforts away from a mission to Mars for which dust storms were an obvious problem and toward a lunar mission where the problems posed by dust require a new evaluation. Efforts to date for renewed funding have not been successful.

Publications

- D. K. Hollingsworth, L. C. Witte, J. Hinke, and K. Hurlbert. "The Effect of Martian Dust on Radiator Performance," *Proc. ASME Summer Heat Transfer/Fluids Engineering Division Joint Conference: ASME HT-FED04-56577*, 2004.
- D. K. Hollingsworth, L. C. Witte, J. Hinke, and K. Hurlbert. "Reduction in the Emittance of Thermal Radiator Coatings Caused by the Accumulation of Simulated Martian Dust," *Applied Thermal Engineering* 26 (2006): 2383-92.

Presentations

- D. K. Hollingsworth. "The Effect of Martian Dust on Radiator Performance," NASA Contamination and Coatings Workshop, Aug. 3-4, 2005.
- D. K. Hollingsworth, L. C. Witte, and J. Hinke. "The Effect of Martian Dust on Thermal Radiators," National Teleconference Meeting of the NASA Advanced Life Support Group, Johnson Space Center, Aug. 12, 2004.
- D. K. Hollingsworth, L. C. Witte, J. Hinke, and K. Hurlbert. "The Effect of Martian Dust on Thermal Radiators," Poster HLS46, Habitation 2004, National Conference, Orlando, FL, Jan. 4-7, 2004.

Proposals

- Project Managers: George Tuan, Katy Hurlbert; UH Investigators: D. Keith Hollingsworth, Larry C. Witte. "Dust Impact of Radiator Test Stand," NASA Johnson Space Center Director's Discretionary Fund, NASA JSC, Nov. 2005. FY 2006 and 2007. \$200,000. (Status: *Not funded* by JSC CDDE.)
- Project Managers: George Tuan, Katy Hurlbert; UH Investigators: D. Keith Hollingsworth, Larry C. Witte. "Dust Impact of Radiator Test Stand," NASA Constellation/Exploration Program, Level 2. (Status: *Not funded*.)



CREED—Inside the UH Cullen College of Engineering Building, the Engineers' Creed reads, "As a professional engineer, I dedicate my professional knowledge and skill to the advancement and betterment of human welfare."