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Advanced Thermal Control Technologies for Mars Rovers and Landers

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ABSTRACT

The long term survival of Mars landers and rovers depends critically on the thermal control of their batteries, electronics and the science equipment. The ambient atmospheric temperatures on Mars range from +10 °C during the day, to as low as –90 °C at night. Various passive thermal control techniques have been used in past Mars missions to keep the temperatures of the electronics, science equipment, and batteries in landers and rovers within their acceptable limits. Of all the equipment used on the Mars 03/05 Athena rover, the Lithium-Ion secondary battery is the most temperature sensitive. Batteries can age prematurely at elevated temperatures (above 40 °C) and electrolytes can freeze at low temperature (below –30 °C). The temperature limits of the Athena rover electronics and science is –40 to +40 °C, whereas the Raman spectrometer optical assembly CCD operating limit is –20 to -40 °C.

Novel thermal control technologies developed for the future Mars missions for keeping their equipment temperatures within their allowable limits will be described in the paper. The thermal design relies on several new thermal control technologies such as phase change material (PCM) thermal storage, variable conductance loop heat pipe (LHP), heat switch, and high performance lightweight thermal insulation. To keep the battery temperatures above the lower limit, the system uses the PCM thermal storage module to store heat and a loop heat pipe (LHP) to transfer heat between a set of Radioisotope Heater Units (RHUs) and the battery. To keep the battery temperature below the upper limit, a thermal control valve in the LHP opens to redirect the working fluid to an external radiator where excess heat is dumped to the atmosphere. The PCM thermal storage module was designed and fabricated using dodecane paraffin wax (melting point, –10.5 °C) as the phase change material. This design also incorporates a lightweight aluminum jacket and carbon fibers interspersed within the PCM to provide thermal and structural reinforcement to the module. A miniature variable conductance loop heat pipe was designed and fabricated. A thermal control valve integrated in the LHP provides the variable conductance.

A new type of lightweight thermal insulation for the Martian environment has been developed and evaluated. In this insulation, the ambient (10 torr) carbon dioxide of Mars is used as the insulating medium with a multilayer insulation enclosure separated by Mylar stand-offs. This thermal insulation is lighter, cheaper, and much faster to fabricate and install on Mars landers and rovers and their payloads than the insulation used in the past Mars missions. The thermal insulation used on the past Mars landers and rovers have been based on fiberglass batt material, aerogel, and Eccofoam. While the performance level of the new insulation is similar to the traditional insulation, the new insulation is 60% lighter, 75% cheaper, and 60% faster to fabricate and install on the payload. After a thorough analytical and experimental evaluation, it has been chosen to be used on the Payload Electronics Box, Pancam, and mini-TES instrument of Mars '01 lander.

One of the advantages of using carbon dioxide is that the thermal conductivity of the gas is very close to aerogel and batt material. Aerogel insulation requires an enclosure to provide structural support; no such structural support is needed for the carbon dioxide. A much larger mass of fiberglass batt material is needed to achieve a thermal performance equivalent to carbon dioxide. Additionally, the convective heat transfer between the inner and outer walls of the insulation containing the gas is small wall gaps up to 8 cm. The total thickness of the new insulation used for the Mars '01 lander is less than 5 cm.

The results from an experimental simulation of the Mars '03/'05 rover thermal performance in the Martian environment will also be presented in the paper. Tests are currently being performed for various internal configurations of the PCM and LHP arrangements including worst case hot and cold cases. Based on the results of these tests, the Mars '03/'05 rover thermal design development will be finalized. Many lessons are being learned during the development and implementation of these thermal technologies for Mars rover battery thermal control. Recommendations for the design and operation of loop heat pipe and phase change material thermal energy storage systems for future space missions will be described in the paper.

The paper will also include the experimental results from the evaluation of the lightweight thermal insulation for the Martian environment. The lessons learned in the design and application of this insulation for Mars '01 lander payload will also be presented.