INFLUENCE OF LUNAR ROVER ON LUNAR SURFACE TEMPERATURE

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ABSTRACT

The lunar regolith is a very poor thermal conductor. As a result, the temperature of the surface can fluctuate quickly as the environment changes. For terrestrial applications it is common to assume that the planet's surface is fixed at an appropriate temperature. The properties of the lunar regolith indicate that this approach may not be valid for a lunar rover which will experience a varying radiative environment resulting from the presence of the rover itself.

This paper demonstrates the implementation of a published lunar regolith model in Simcenter Space Systems Thermal and investigates the influence of a simplified lunar rover on the surface temperature and the impact of these changes on rover thermal performance.

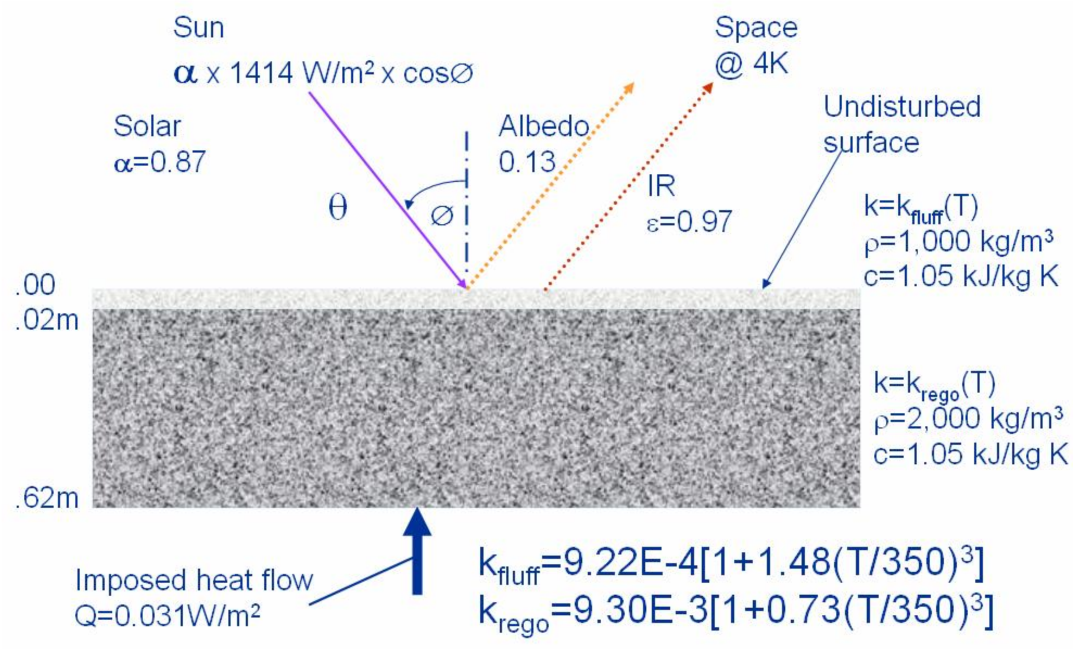
INTRODUCTION

Maya HTT Ltd. And Canadensys Aerospace Corp. have collaborated on a number of projects related to lunar rover thermal design and analysis. In the early projects the lunar surface was assumed to be at a constant temperature, based on the latitude assigned to the mission. For later projects a detailed thermal model of the lunar surface was used, based on the work presented by Christie et al[1]. This paper presents the results of an investigation into the benefits and costs of the improved lunar surface model.

LUNAR SURFACE MATHEMATICAL MODEL

The lunar surface model contained two distinct materials, lunar fluff and lunar regolith. The lunar fluff is a layer of dust that covers the lunar surface that is assumed to be 20mm thick. Below the fluff layer is the regolith. The regolith was modeled to a depth of 600mm. The materials used for both layers were given temperature dependent thermal conductivities. Specific heat and density were constant. The values used are given in Figure 1. Additionally, the geothermal processes of the moon are represented by a heat flux of 0.031 Wm^{-2}, applied to the bottom of the regolith.

Christie et al[1] compared the results of analyses performed with this model against lunar data. For this paper, the initial results will be compared with those presented for the results of the analysis in the original paper.



Thermal conductivity are given in $Wm^{-1}K^{-1}$

Figure 1. Lunar surface representation and properties (from 1).

The mesh used for the lunar surface model is the same as presented in the original paper. There is a single layer of solid elements to represent the fluff layer and four layers of solid elements to represent the regolith. The regolith layers have increasing thickness with increasing depth. The thicknesses are: 60mm, 80mm, 160mm and 320mm to give the total of 620mm.

The model was validated by modelling a section of the lunar surface at the equator and running a transient analysis through a number of lunar days until the temperatures are repeatable. The temperatures were then compared with those given by Christie et al[1] and found to give good agreement.

INVESTIGATION

To investigate the interaction between the lunar surface and a rover, a lunar rover is required. The analysis uses a simple, small, lunar rover. The rover body is simple rectangular block, 150mm×300mm×500mm. There is a wheel at each corner with an outer diameter of 200mm. The effects determined for this small rover should be scalable to a larger vehicle.

All six surfaces of the rover body are treated as radiators and assigned the surface properties of a typical white paint, α= 0.23, ε=0.88. The temperature of each surface is fixed at 35ºC and the analysis determines the heat required to maintain that temperature. This equates to the heat load that the radiator can handle. 35ºC allows for a 20ºC temperature drop from typical electronics at their maximum operating temperature and the radiator.

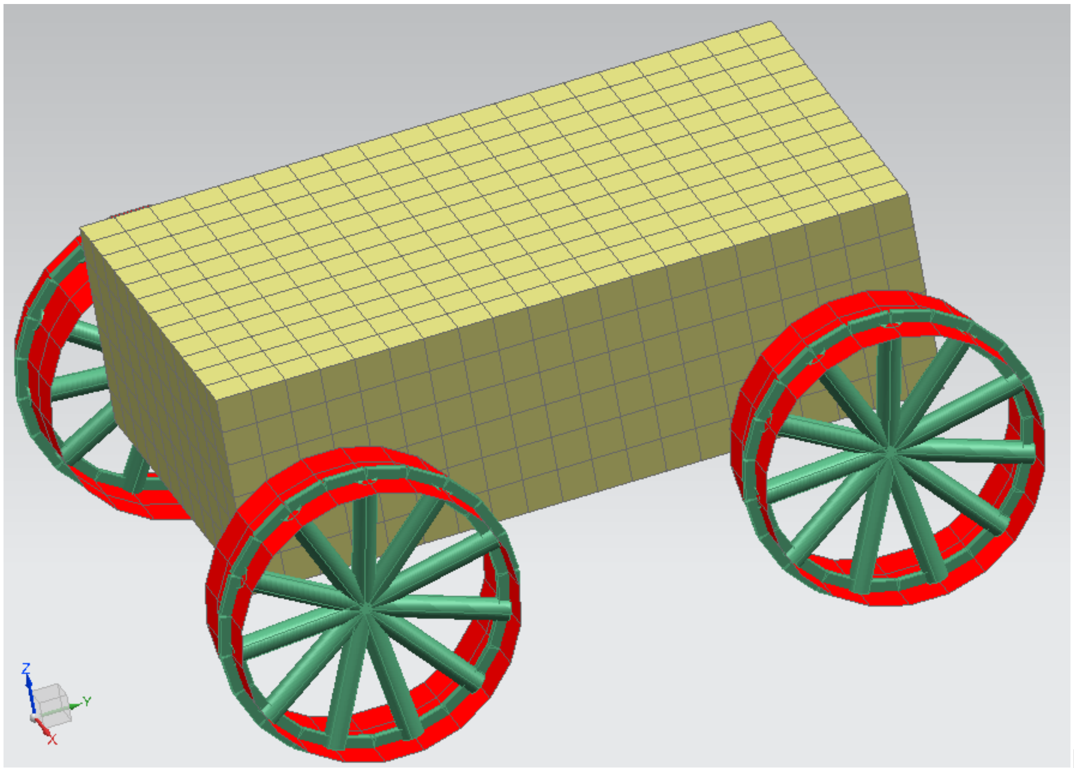


Figure 2
Thermal model of simple rover.

Stationary Rover

The transient nature of lunar surface temperatures suggests that it may not be possible to perform a steady state analysis without fixing the lunar surface temperature as the regolith is never in steady state thermal equilibrium because of the daily solar cycle. However, the lunar surface is always very close to steady state equilibrium. This was confirmed by performing a steady state analysis at latitude 75º, midday conditions and comparing the results with those from a transient analysis that includes the daily temperature cycle. The surface temperatures were found to be within 1ºC for the two cases. The lower level layers showed considerable discrepancy, but the lunar rover only interacts with the surface and getting correct surface temperatures is the only requirement for rover design.

The temperatures predicted for the lower layers can be improved by fixing the temperature of the bottom layer, which is essentially at a constant temperature anyway. This temperature can be obtained from the literature or determined from a transient analysis.

To investigate the influence of lunar surface temperature on a rover, a steady state model was run for midday conditions with fixed, uniform, lunar surface temperature and another solution was run where the software calculated the lunar surface temperature.

The fixed temperature used was the lunar surface temperature, far from the rover, in the calculated model. The rover and lunar surface temperatures for the calculated case are shown in Figure 3. The lunar surface is cold in the shadow of the rover and warmer in the region on the sun side and under the rover. The overall temperature range of the surface is from -167ºC to 67ºC.

Table 1 Heat Dissipation of Radiators at 35ºC Using Two Surface Temperature Models (+ve = heat out)

		Heat Load (W)		Flux (Wm^{-2})		
Face	Area (m^2)	Fixed	Variable	Fixed	Variable	Fixed/Variable
Top	0.15	55.3	55.3	368.5	368.5	1.00
+X	0.075	20.6	19.0	274.8	253.2	1.09
-X	0.075	20.6	19.0	274.8	253.5	1.08
-Y	0.045	-0.1	-1.9	-2.3	-42.5	0.05
+Y	0.045	14.4	16.5	319.8	367.3	0.87
Bottom	0.15	25.5	4.2	170.1	27.9	6.11

As expected, there is no change in the dissipation of the top radiator. For the side radiators (X+, X-) the fixed temperature case gives dissipations 9% greater than for the case with surface temperatures explicitly calculated. This is presumably due to local heating of the lunar surface to the side of the rover. This cannot be seen in Figure 3 because of the wide temperature range. Interrogating the model shows that that the lunar surface immediately to the side of the rover reaches a temperature of 21ºC compared to a far-field temperature of -1ºC.

The Y- side of the model is the sun side and so has the lowest dissipation needed to maintain the required rover body temperature. In fact, it is negative for both cases indicating that the panel would run hotter than the assigned 35ºC with zero dissipation. As expected, the worst of the two cases is the case with calculated lunar surface temperatures. The Y+ side is the reverse with the fixed temperature case having the lower dissipation. The calculated lunar surface temperature in the shadow of the rover is as low as -167ºC. This low temperature region increases the dissipation of the Y+ side from 14.4W to 16.5W with the variable surface temperature model, a significant change.

The bottom surface dissipation is grossly overestimated by the fixed surface temperature model. The radiator itself heats up the lunar surface under the rover reducing radiator dissipation. If a rover design includes a bottom mounted radiator, thermal modeling should include a variable temperature lunar surface.

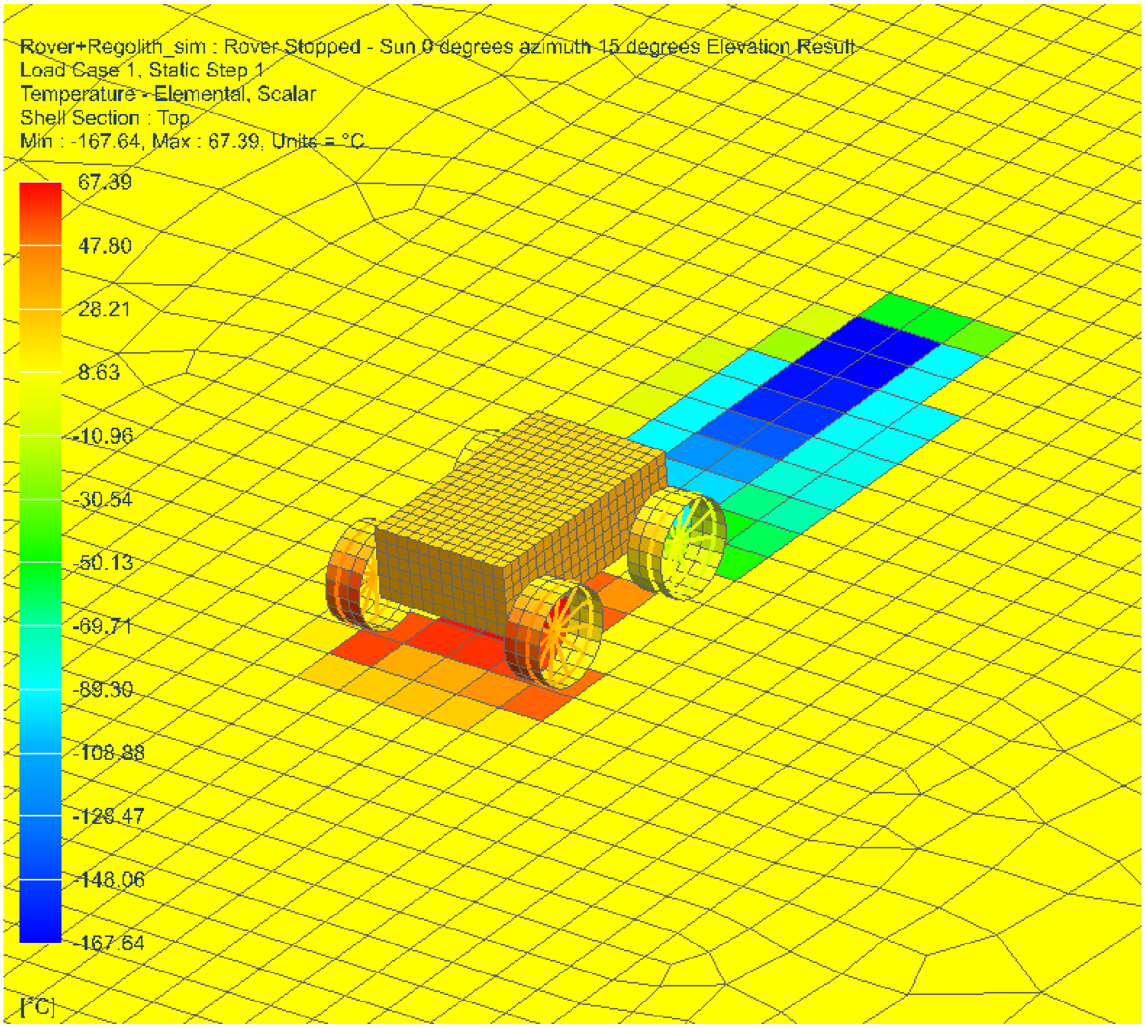


Figure 3 Rover and lunar surface temperature, midday, latitude 75º.

<u>Moving Rover</u>

Having established that the model gives good lunar surface temperatures, the next step is to determine the response time of the lunar surface to a step change in environmental inputs. This was achieved by running a transient analysis under lunar night conditions with lunar mid-day starting temperatures. Clearly, this step change cannot happen on a large scale but can happen locally due to shadowing by a moving rover.

The results of this analysis are shown in Figure 4. The lunar surface has an initial cooldown rate of 0.035 ºCs^{-1}.

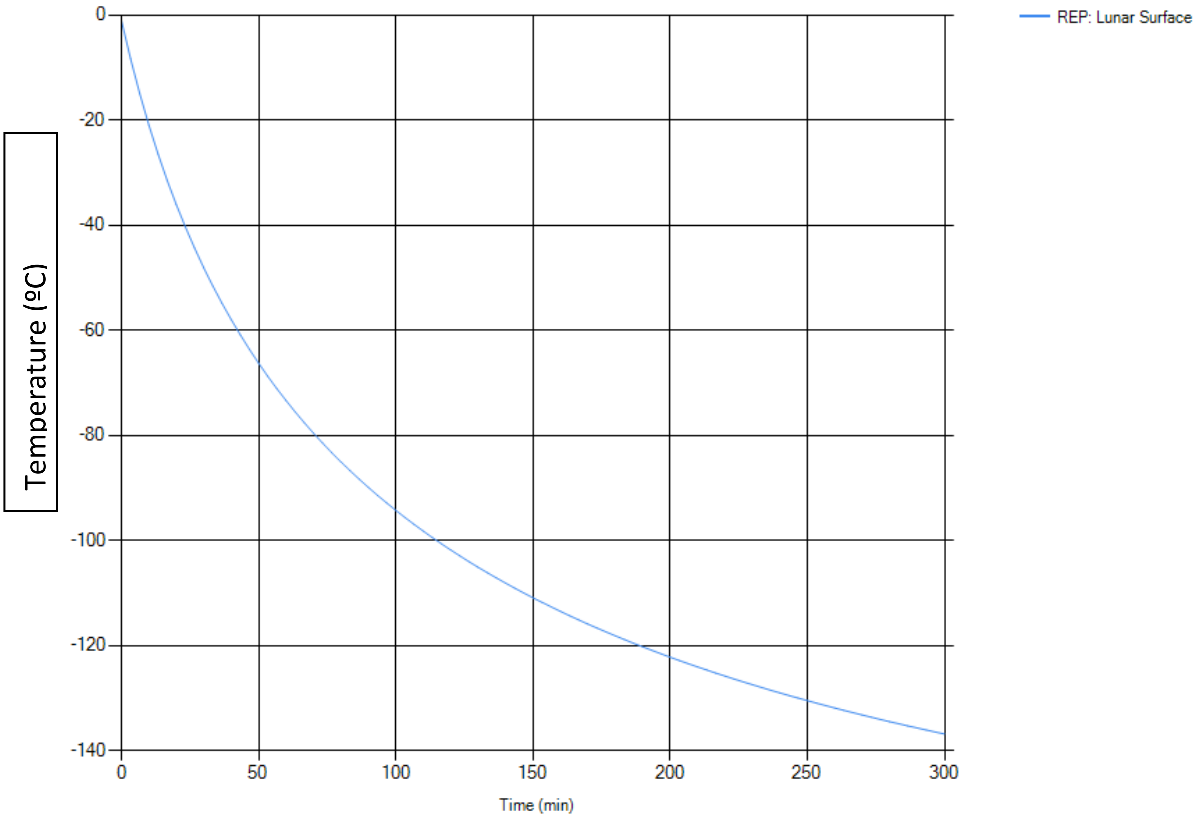


Figure 4 Lunar surface cool down.

If we know the length of a shadowed region and the speed of the rover it is possible to estimate the surface cooling due to the moving shadow of the rover. The results of these calculations are given in Table 2.

The temperature changes shown in Table 2 are generally small except for the longest shadow and the lowest speed. These low speeds are typical for a Martian rover, but lunar rovers can typically move significantly faster as they can be remotely controlled from the Earth without the considerable time delays inherent in communicating with Mars. For a manned rover, there is probably little point in a rover that is significantly slower than walking pace. The accuracy of the estimates given in Table 2 were verified by simulating the motion of the rover presented here traveling over the surface at a speed of 0.01 ms^{-1}. The resulting temperature profile is shown in Figure 5 which shows a temperature drop of 2.8ºC, the estimated temperature drop using the methodology of Table 2 is 3.2 ºC, indicating the estimates are reasonable.

Table 2 Temperature Drop (ºC) due to Moving Rover Shadow

	Rover Speed (m/s)				
Shadow Length (m)	0.01	0.05	0.1	0.2	0.5
3.0	10.566	2.113	1.057	0.528	0.211
1.0	3.522	0.704	0.352	0.176	0.070
0.5	1.761	0.352	0.176	0.088	0.035

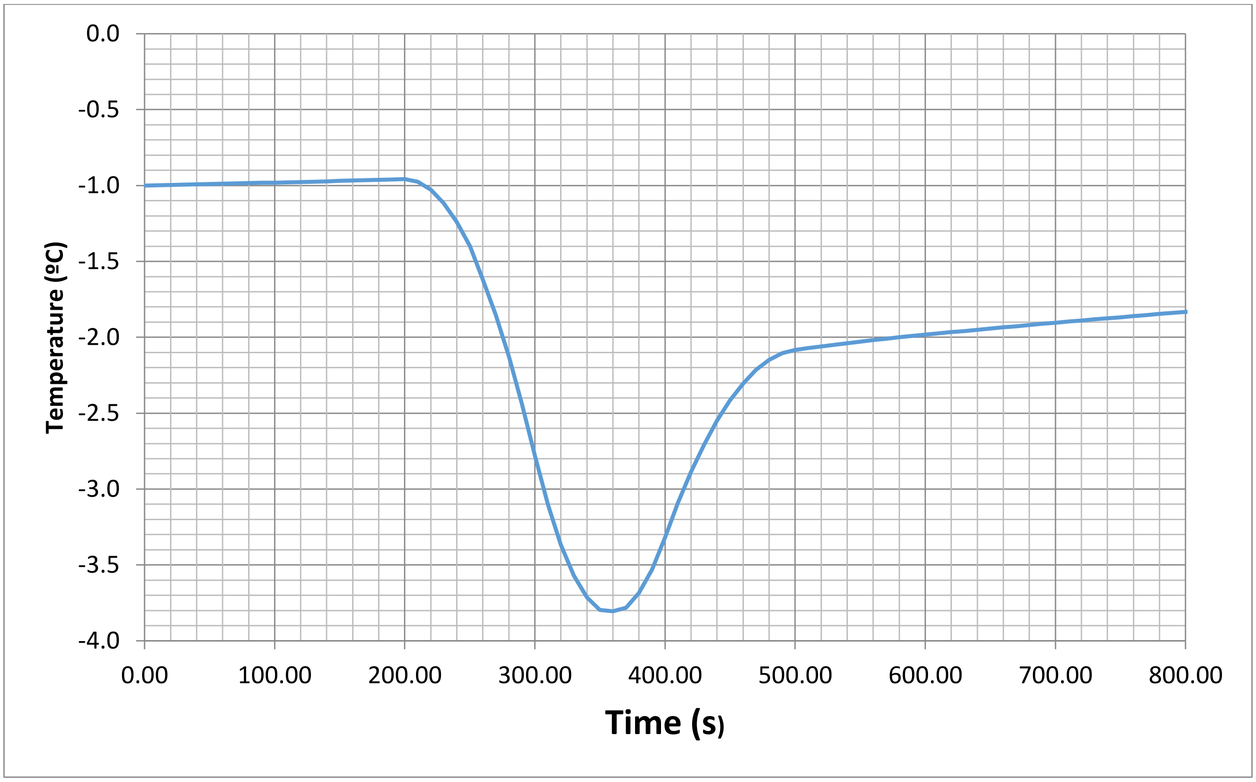


Figure 5 Variation of lunar surface temperature as rover passes over.

DISCUSSION

The work presented here uses an existing model of the lunar regolith and demonstrates how it can be leveraged to determine the interaction between the lunar surface and a lunar rover.

It has shown that assuming a fixed lunar surface temperature can lead to errors in the calculated heat dissipation capability of radiators. For the case considered here, fixing the lunar surface temperature caused the side radiator dissipation to be overestimated by 9% and the dissipation of the shadowed radiator to be underestimated by 13%. The performance of a radiator on the bottom surface of the rover was grossly overestimated.

The results also show that the temperature fluctuations caused by the shadow of a moving rover are unlikely to be significant. Except for the case of a large, slow moving rover, assuming a fixed lunar surface temperature is reasonable for analysis of a moving rover.

REFERENCES

1. R. J. Christie, D.W. Platch and M.M. Hasan. “A Transient Thermal Model and Analysis of the Lunar Surface and Regolith for Cryogenic Fluid Storage”, NASA/TM-2008-215300.