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## A3_6 Could it really be cheese?


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**Abstract**

This paper investigated the material properties of the Moon in the film "Wallace and Gromit: A Grand Day Out". We conclude that it is possible for the Moon to be comprised of cheese, demonstrated by a kinetic friction coefficient of 0.260 which is comparable to what is expected.


### Introduction

In the ending sequence of "A Grand Day Out," the robot seen in the movie is skiing over two hills on the surface of the Moon. The film poses the possibility of the Moon being made of cheese, and so we investigated the frictional properties of the Moon to comment on that likelihood.

### Theory

To make measurements of quantities such as the height of a hill, we measured its height in pixels and compared it against Wallace, who we assumed had a height of approximately 1.70m (and if Wallace was not in the same scene then the robot would be used). As the robot travels down the first hill, the gravitational potential energy will be converted into kinetic energy and then back into gravitational potential as it rises up the second hill. On a friction-less surface, the robot would be able to travel to the same height from which it descended, but in the movie, we see it is only able to reach the top of a second smaller hill. We also assumed that there is zero air resistance due to the Moon having an extremely thin atmosphere, which means any total losses of energy will be due to friction:

$$E_{fr} = \Delta E_g = m_r g \Delta h \qquad (1)$$

Where $E_{fr}$ is the work done by the frictional force, $\Delta E_g$ is the total change in gravitational potential energy, $m_r$ is the mass of the robot, $g$ is the surface gravity on the Moon, and $\Delta h$ is the difference in height between the two hills.

We constructed an equation for the work done by the frictional force in terms of the sliding friction coefficient:

$$E_{fr} = \int_0^L \vec{F}_{fr} \cdot \vec{dl} \ = \int_0^L \mu_{fr} F_N \, dl \qquad (2)$$

Where $\mu_{fr}$ is the sliding friction coefficient between the robot's skis and the Moon surface, $dl$ is an infinitesimally small section of the robot's path length, $F_N$ is the normal force and is equal to $m_r gcos(\theta)$, where $\theta$ is the angle between $\vec{g}$ and $\vec{dl}$, and $L$ is the total path length.

Since $\theta$ will vary as $\vec{dl}$ changes direction, we will approximate the path to be as shown in Figure 1. We can then simplify the work done by friction to be:

$$\int_0^L F_N\, dl \;= m_r g(L_{flat} + cos(\theta_1)L_1 + cos(\theta_2)L_2) \tag{3}$$

Where $L_{flat}$, $L_1$, $L_2$, $\theta_1$, $\theta_2$ are all defined in Figure 1.

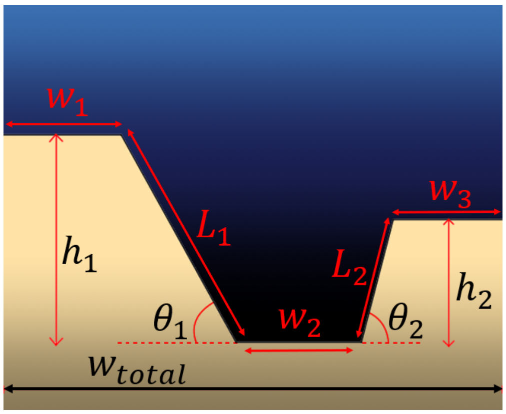


Figure 1: A simplified model of the Moon hills, where $L_{flat} = w_1 + w_2 + w_3$.

Combining Eq. 3 and Eq. 1 gives an expression for the sliding friction coefficient:

$$\mu_{fr} = \frac{h_1 - h_2}{(L_{flat} + cos(\theta_1)L_1 + cos(\theta_2)L_2)} \tag{4}$$

## Results

Using the pixel measurements we approximated $\theta_1$ to be 1.19 radians and $\theta_2$ to be 1.26 radians. Similarly, we found $h_1$ to be 5.07 m, $h_2$ to be 3.04 m and $w_{total}$ to be 7.56 m. Using geometry and trigonometry, $L_{flat}$ was found to be 4.54 m, $L_1$ to be 5.46 m, and $L_2$ to be 3.20 m. Using these values with Eq.4, we find the coefficient of friction $\mu_{fr} = 0.260$.

## Conclusion

The skis from the movie are made of scrap metal from Wallace's spaceship. We will therefore assume that the skis are made out of steel, as this would be a material that Wallace could feasibly acquire. To justify whether the calculated coefficient of friction is realistic, we shall make the following assumptions:

1. The Moon's location is cold enough to freeze the cheese.
2. Since cheese is comprised heavily of water [2], it will form microscopic patches of ice on its surface.
3. These patches will result in a frictional coefficient similar to pure ice, but greater due to the rough non-icy areas.

Given that the coefficient of friction for steel-ice interactions at sub-zero temperatures is approximately 0.100 [1], our value of 0.260 is reasonable given the assumptions. It is therefore possible for the Moon in "A Grand Day Out" to be made of cheese, especially if it is a high water-content cheese.

## Discussion

The major issue with the conclusion of this paper was the assumption of a patchy icy surface. This is a necessary assumption made from the logic that ice tends to form crystals when frozen inside food products, however there are no studies into whether it forms microscopic smooth surfaces. To further research the possibility of this Moon being cheese, it would therefore be necessary to investigate the frictional properties of different cheeses (with respect to steel) and examine their water content. Another problem to consider is that the Moon is situated in a vacuum which would induce the out-gassing of water from the cheese. Therefore our conclusion is only valid at the Moon's poles where ice can exist [3], but whether Wallace landed there is unknown.

## References


[1] `https://iopscience.iop.org/article/10.1088/0031-9120/43/4/006/pdf` [Accessed 09 November 2022]

[2] `https://culturecheesemag.com/cheese-iq/ask-the-expert-are-soft-cheeses-fatty/` [Accessed 09 November 2022]

[3] `https://www.nasa.gov/feature/ames/ice-confirmed-at-the-Moon-s-poles` [Accessed 09 November 2022]