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A2_2 Water on the Moon: an energy comparison

Samantha Rolfe, Mark Wilson, Ry Evill, Christopher Johnson

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH.

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Abstract
This paper discusses the implication of the LCROSS mission finding water-ice in a permanently shadowed crater on the Moon. If water-ice is discovered, through looking at a simple model of the crater, this paper looks at how useful the water-ice would be to future long-term missions by comparing the amount of energy needed to raise the ice from the surface of the Moon to transporting water from Earth. Assuming water-ice is present - even in the general case where the mission length and crew number is unspecified - to send sufficient water from Earth a factor of 10^8 J person^{-1} day^{-1} is required when compared to mining the ice.

Introduction
On 9th October 2009 the LCROSS mission consisting of a probe called Centaur and the Shepherding Spacecraft were impacted on the lunar surface in an attempt to discover the presence of water ice in a permanently shadowed crater [1]. This mission was initiated on the basis that hydrogen had been detected on the Moon by the Lunar Prospector mission a decade ago [2]. The crafts crashed into the surface only days ago, but early results have been returned. If hydrogen on the lunar surface is in the form of water ice, the information collected by the Shepherding Spacecraft should reveal this.

Discussion
An implication of finding water-ice is that the cost of a mission to the Moon would be reduced as little or no water would have to be transported there for use during a mission, or in the future – on a Lunar Base. However, this would entirely depend on how much water-ice was found and how easy it would be to claim the water-ice from the surface. The water-ice would need to be mined from the surface, and may only exist as a small percentage within a soil sample. Taking a simple model of the crater, where a layer of regolith covers pure water-ice, we look to compare the energy budget of mining the water-ice to raising enough water from Earth to the Moon to support a long-term mission.

Daily water consumption aboard the International Space Station (ISS) for bathing is about four litres per person and it is recommended that one to two litres per day should be consumed to prevent dehydration [3,4]; this gives an extreme usage, y, of seven litres and with current technology the water reclamation efficiency, ε, is 80-90%[1] [5]. The mass of water required is dependant upon the number of people, n, and the length of the mission, t. In terms of the above variables, the mass, m, of water to be raised is

$$m = \varepsilon y n t. \tag{1}$$

On the surface of the Moon, we assume that the regolith is to a depth of 0.4 m based on observations and conclusion from the Lunar Prospector [6], with a density, ρ_r, of 2000 kgm^{-3}. Under the regolith there is pure water-ice of depth, x, to 1 m, with a density, ρ_w, of 934 kgm^{-3}. The area to be mined, A, – assuming a perfect cuboid, so not taking into account any possible curvature – is

[1] In our calculations an efficiency of 80% is used.

$$A = \frac{m}{\rho_w x} = 6 \times 10^{-3}\ nt\ m^2, \tag{2}$$

where m is given by (1). In order to raise this from the surface of the Moon by total depth, d, (1.4m in this model) it is possible to find the energy needed using

$$W = Fd = m_t a d, \tag{3}$$

where W is the work done, F is the force, m_t is the total mass of ice and regolith to be raised and a is the acceleration due to gravity, which, in the case of the Moon is $g/6$. Therefore, an energy budget of 23.8 J $person^{-1}$ day^{-1} is required.

To work out the energy needed to raise enough water to the Moon we integrate over the distance to the Moon[2], h, and account for the gravitational pull of the Moon:

$$U(r) = \left(-\int_{R_E}^{h} -\frac{GM_E m}{r^2} dr\right) - \left(-\int_{R_M}^{h} -\frac{GM_M m}{r^2} dr\right), \tag{4}$$

where R_E is the Earth's radius, R_M is the Moon's radius, G is the gravitational constant, M_E is the mass of the Earth, M_M is the mass of the Moon and m is the mass of the water to raised. Therefore, an energy budget of 3.29 x 10^8 J $person^{-1}$ day^{-1} is required. This result shows that mining the water-ice on the Moon would incur a smaller energy budget by a factor of 10^8 J $person^{-1}$ day^{-1}.

Taking the example of a six month mission and a five-person crew, would mean that with current efficiency, a total of 5110 litres would need to be provided. This gives an energy budget of 3.15 x 10^{11} J to raise the water from Earth. On the Moon an area of 5.47 m^2 would need to be mined. This would be an expenditure of 21.7 x 10^3 J. If the mining equipment were already in place, it is possible to see that the difference in energy saving and therefore in cost, would be enormous.

In conclusion, the implications of LCROSS finding water-ice on the Moon is highly significant for the future – it may well spell the beginning or end of long-term missions to the Moon depending on the outcome of the results. However, we have not taken into account the many factors that could cause mining the water-ice to be problematic, or even of the mass of the craft needed to carry water from Earth to the Moon. If the results come back positive, then further research into this area can be conducted.

References

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[3] http://science.nasa.gov/headlines/y2000/ast02nov_1.htm
[4] http://www.cks.nhs.uk/patient_information_leaflet/dehydration#
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[6] Feldman et al., Science, 281, 1496, 1998
[7] http://www.nineplanets.org/luna.html

[2] We have taken h to be the surface-to-surface distance, worked using a Moon-Earth distance of 384,400 km [7].