AN OVERVIEW OF SRU RESEARCH AT IMPERIAL COLLEGE LONDON. J.N. Rasera[1], R.D. Cruise[1], Y. Yu[1], L. Malone[1], K. Ikeya[1], V. Schein[1], L. Salinas-Faran[1], S.O. Starr[1], K. Hadler[1,2], and J.J. Cilliers[1], [1]Imperial College London, Exhibition Road, London, SW7 2AZ, United Kingdom, j.rasera@imperial.ac.uk [2]European Space Resources Innovation Centre (ESRIC), Luxembourg Institute of Science and Technology (LIST), Maison d'Innovation, 5, avenue des Hauts-Forneaux, Esch-sur-Alzette, L-4362, Luxembourg.

Introduction: The separation of lunar regolith by size and particle type presents challenges for space resource utilisation due to the high fraction of fine particles, the variety of components, and the unique environmental constraints of the Moon [1, 2]. Dry particle classification and mineral enrichment technologies are needed to address these challenges, but current approaches used on Earth, such as water-based separation processes, are not suitable for lunar resources [2]. To overcome these challenges, research efforts have focused on understanding and optimising tribocharging (contact charging) and electrostatic separation processes for use in vacuum conditions [3, 4].

At Imperial College London, the Space and Terrestrial Resource group has been actively working towards developing dry particle classification and mineral enrichment technologies, as well as developing novel lunar mining optimisation strategies.

Research Overview: The favourable conditions for electrostatic separation of lunar regolith under vacuum include a lack of charge dissipation mechanisms that exist at standard atmospheric conditions, making it possible to concentrate specific mineral components such as ilmenite [4].

Our investigations have focused on understanding the fundamental physical processes that underlie particle contact charging, which is essential for mineral conveyance and classification under vacuum conditions. Through extensive simulations and experimental campaigns, we have explored the tribocharging of particles of different size and material type, and have optimised the design of electrostatic separation processes to be used with lunar regolith.

A novel application of the discrete element method (DEM) has been developed for designing and optimising tribochargers to control the contact charging of particles. This approach, initially validated under terrestrial conditions, looks to maximise the relative proportioparticle-wall contacts has been modified to study a theoretical lunar tribocharger. A comparison of seven tribocharger baffle designs is found in Figure 1.

Furthermore, the effect of pressure on triboelectric charge saturation has been investigated. Findings indicatae that particles can be discharged almost completely, and prevented from gaining charge, when maintained in a low pressure environment (Figure 2). These results have potential applications for dust mitigation and powder transport systems.

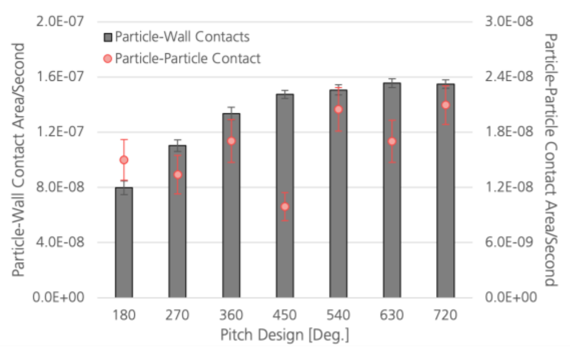

Figure 1 - Comparison of lunar tribocharger designs. The 450° pitch angle design demonstrated the best performance.

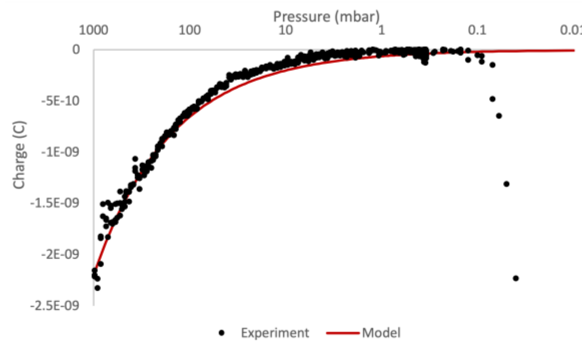

Figure 2 - Particle charge versus atmospheric pressure. Particles were found to gain little, if any, charge at reduced pressures.

Electrostatic particle conveyance methods have been studied for particle transport and size classification. The theory for single particle motion in an electrostatic traveling wave field has been explored through simulation and experimentation. The dielectrophoresis force has been identified as a key contributor to the effect of particles moving in the opposite direction to the travelling wave, in close proximity to the electrode surface. Additionally, experimental work has demonstrated the separation of particles with varying sizes based on their unique moving characteristics, such as their direction of motion.

Recently, vibrational segregation, also knowna s the Brazil Nut Effect, to perform size separations on Apollo 15 regith (15601) was studied. The containers were scanned using micro-CT to characterise the sample behaviour. Bespoke image processing algorithms have been developed to describe qualitatively and quantitatively the sample separability and processability, allowing for optimisation and better design of the process. An example of this work is found in Figure 3.

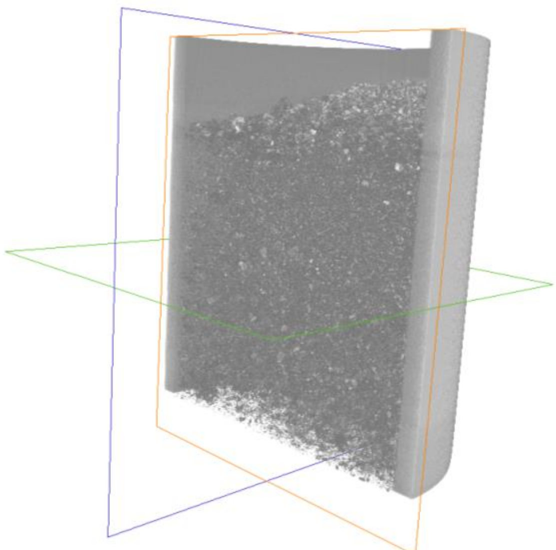

Figure 3 -3D rendering of a micro-CT scan of Apollo regolith sample 15601 after vibrational segregation at 70 Hz.

Additionally, new research is being conducted at Imperial in the fields of lunar mine design and optimisation.

Decision-making for the deployment of lunar ISRU plants is challenging due to the operational and environmental uncertainty. The explicit consideration of such uncertainty, and its effects on decision-making, has yet to be addressed fully. To produce oxygen on the moon, two types of architectures have been proposed: oxygen extraction from dry regolith or from polar ice. However, a novel hybrid lunar ISRU plant that can generate oxygen from both dry regolith and polar ice is now being considered. The aim of this work is to determine the expected performance and cost of each ISRU plant architecture through a Bayesian decision analysis and Monte Carlo simulations (Figure 4).

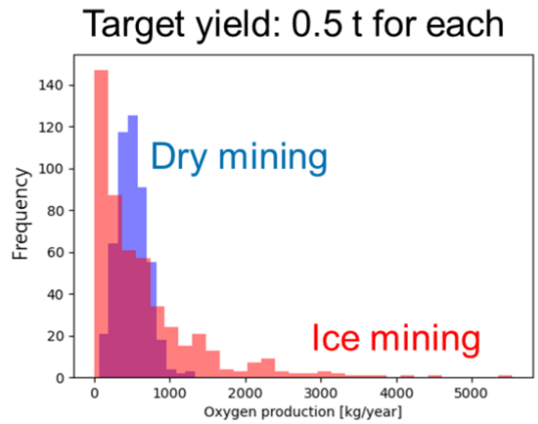

Figure 4 - Monte-Carlo simulations for both dry regolith mining and water ice mining for oxygen production with a target production rate of 0.5 kg oxygen per year show different distributions of the actual production rate.

Furthermore, a Comprehensive Lunar Mining Simulator (CLMS) has been developed in the Unity engine to simulate the management of a pilot lunar ISRU facility (Figure 5). It is being used to answer research questions on the role of human factors in enabling users to make decisions in complex and uncertain environments. Current work deals with expanding the scope of the CLMS to include decision support systems and VR capability.

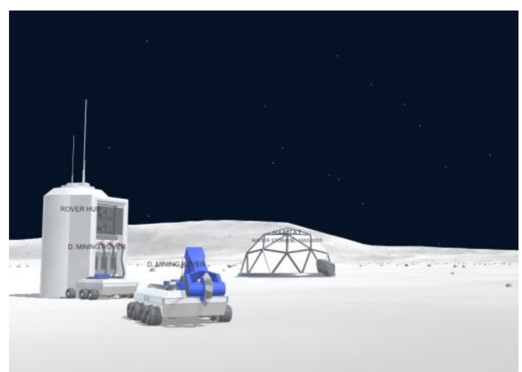

Figure 5 - A screen capture of the CLMS. Studies are currently underway, with volunteers playing through the CLMS and attempting to maximise their score.

References:

[1] J.J. Cilliers et al., 2020, PSS, 180, 104749. [2] J.N. Rasera et al., 2020, PSS, 186, 104879. [3] R.D. Cruise et al., 2022, J. Phys D, 55.18, 185306. [4] J. Toth et al., High-Vacuum Triboelectric Charging of Space Materials, 2022, NASA.