# THE BRAZIL NUT EFFECT (BNE) FOR PARTICLE SIZE CLASSIFICATION IN ISRU.

J. N. Rasera[1] and L. E. Salinas Faran[1], [1]Imperial College London, Exhibition Road, London, SW7 2AZ, United Kingdom, j.rasera@imperial.ac.uk

**Introduction:** The advancement of lunar habitation and exploration activities necessitates the development of effective techniques for the preparation of regolith feedstock with uniform size and mineralogical composition. Such uniformity is crucial for the efficient and reliable production of oxygen or metals, serving as a cornerstone for In Situ Resource Utilisation (ISRU) strategies on the Moon [1]. Previous investigations have posited that the exclusion of particle sizes greater than 1 mm and finer than 90 µm could significantly improve the efficacy of material handling, mineral enrichment, and oxygen production methodologies [1].

Despite the recognised importance of this requirement, a thorough examination of the current literature reveals a significant shortfall in research dedicated to mineral beneficiation, pmarticularly in the realm of size classification using dry methods [2].

Historically, terrestrial mining operations have relied on size classification techniques that utilise process fluids such as water or air to facilitate separations [2]. However, the unique conditions of the lunar surface, marked by a hard vacuum and extreme temperature variances, preclude the use of fluid-driven classification systems. This constraint highlights the necessity for alternative, dry classification methods.

The Brazil Nut Effect (BNE) is a phenomenon where larger particles ascend in a granular mixture when vibrated; it is named from the observation that Brazil nuts tend to rise to the top when a container of mixed nuts is shaken [3]. The BNE, well-documented in terrestrial settings, presents an intriguing mechanism for particle size segregation without the need for external fluids, making it a strong candidate for investigation within the context of ISRU.

**Previous Work:** Initial investigations into the suitability of the BNE for size segregation of lunar regolith were conducted using Apollo regolith sample A15601 and simulants JSC-1, LMS-1, and TUBS-M [4]. This study revealed variable segregation performances across the different materials tested (Figure 1). Notably, A15601 and LMS-1 samples demonstrated the formation of three distinct layers – coarse, fine, and unmixed. The JSC-1 sample exhibited the clearest segregation into coarse and fine layers. The TUBS-M sample displayed no noticeable segregation.

These results indicated that a combination of the particle size distributions, vibration characterisics, and the geometry of the container all contributed to the formation of three distinct layers within the LMS-1 and A15601 samples. As fine particles descended, they formed a uniform, monodisperse layer in the middle of the vial. The high surface-to-volume ratio of the fine particles amplified interparticle forces, culminating in the creation of a 'locked' middle layer [4]. Even at higher vibrational frequencies, the vibrational characteristics were insufficient to mobilise the locked layer. As a result, the fines impeded the upward movement of coarser particles fromt the unmixed layer.

This variability in segregation behaviour underscores the complexity of applying the BNE to lunar regolith and simulants, necessitating a deeper exploration of the underlying factors influencing segregation outcomes.

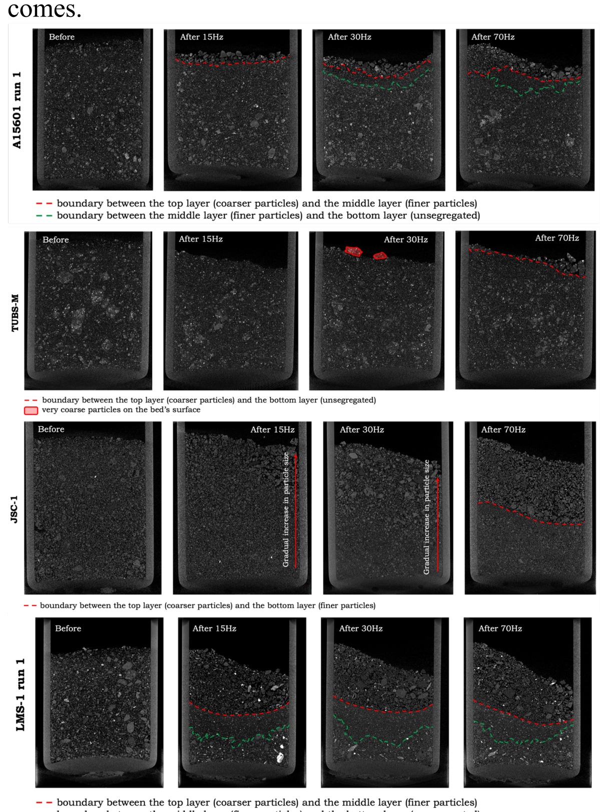


*Figure 1 - Cross-sectional slices of micro-CT scans for each sample [4].*

**Experimental Approach:** This purpose of this work is to investigate the complex dynamics governing the BNE, with a particular focus on the influence of container geometry, particle size distribution, and environmental conditions on segregation patterns.

Different container geometries with the same quantity of material will produce different magnitudes of interparticle forces. Reducing these forces, particularly amongst fine particle fractions, should facilitate more efficient segregation. Through systematic variation of container dimensions and particle size distributions, the experimental campain aims to reveal the relationship between the container geometry and the properties of the sample that achieves comprehensive segregation.

This experimental setup will also be used to evaluate the performance differences between wide and narrow particle size distributions. Additionally, the role of ultrafine particles and the degree of polydispersity on segregation efficiency will be explored. Integrating controlled amounts of ultrafine particles into the mixtures will enable the study of the mechanisms leading to the formation and of stratified layers.

A significant for this study compared to our previous work is the performance of experiments under atmospheric pressure and low vacuum conditions. This approach is instrumental in assessing the impact of aerodynamic and electrostatic forces on particle movement and segregation in the BNE. This will provide insight into how the absence of an atmosphere influences the BNE and, by extension, the feasibility of employing this phenomenon for dry particle size classification in ISRU.

**Characterisation Methodology:** To accurately characterise the segregation patterns and particle size distributions post-segregation, micro X-ray computed tomography (micro-CT) is employed. This non-invasive imaging technique provided high-resolution, three-dimensional views of the internal structure of the granular mixtures, facilitating a detailed analysis of the particle size distribution as a function of height within the container.

The acquired datasets are segmented into three primary components: the container, the particles, and the voids between particles, using a combination of Matlab and Avizo software. This segmentation enables the quantitative analysis of the components. The Otsu algorithm is applied for the separation of the container from the particles and voids, and the Maximum Entropy algorithm is used for background differentiation [5,6].

To reduce the effects of the container walls on the analysis, a cylindrical core is extracted from the centre of each column (Figure 2). This core is then broken down into subdomains. The particle size distribution for each subdomain is then determined. A successful classification experiment using the BNE is characterised by coarser particles in the upper subdomains, and finer particles in the lower ones.

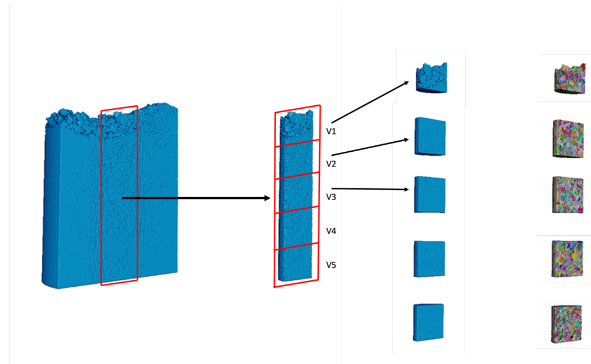


*Figure 2 - Subdivision of granular column for individual particle size distribution analysis. Here, a central column is selected to minimise the influence of any wall effects [4].*

**Conclusions and Future Directions:** As ISRU continues to gain momentum, the development of innovative approaches to resource processing, such as the BNE, will play a pivotal role in enabling sustainable human presence and exploration activities on the lunar surface and beyond.

This study offers insight into the practical application of the BNE for particle size classification in lunar ISRU contexts. The experimental and characterisation approaches employed here will provide the key data required to enable the design and development of a demonstration payload for *in-situ* size classification of regolith on the lunar surface.

**References:** [1] Cilliers, J.J., *et al.* (2020) *Planet. Space Sci.,* 180, 104749. [2] Rasera, J. N., *et al.* (2020) *Planet. Space Sci.,* 186, 104879. [3] Shinbrot, T. (2004) *Nature*, 429.6990, 352-353. [4] Rasera, J.N., *et al.* (2024) *Under Review.* [5] Otsu (1979) *IEEE Trans. Syst. Man. Cybern.*, 9 62-66. [6] Skilling and Bryan (1984) *Mon. Not. R. Astron. Soc.,* 211, 111.