AN APPROACH TO DUST HANDLING AND MITIGATION FOR LUNAR HABITATS. J. N. Rasera[1], L. E. Salinas Faran[1], A. K. Pukkella, C. J. Wisentaner[1], C. A. Bright[1], I. Bhamani[1], S. O. Starr[1], J. J. Cilliers[1], and K. Hadler[2], [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 advancement of lunar exploration and habitation underscores the critical need for sophisticated technologies to effectively manage lunar dust, a significant challenge that adversely affects astronaut health and the durability of equipment. The fine, abrasive nature of lunar regolith, coupled with its tendency to adhere electrostatically to surfaces, demands the development of innovative strategies for dust handling and mitigation within lunar habitats. This work presents a strategy that concentrates on enhancing the treatment of dust-laden airstreams.

Dust Handling and Filtration: Despite the implementation of preventative measures to control dust ingress, addressing the treatment of dusty airstreams within lunar habitats remains a critical concern for maintaining optimal air quality and safeguarding the health of occupants. The limitations of High Efficiency Particulate Air (HEPA) filters, particularly when confronted with high concentrations of lunar dust, highlight a significant challenge in this context. HEPA filters are the gold-standard for filtration efficiency in, and are designed to capture >99.97% of particulates 0.3 micrometres and larger [1]. However, the unique properties of lunar dust—including its fine particle size, sharp angular nature, and the potential for electrostatic adhesion—pose a risk of rapid filter clogging, thereby reducing filtration efficiency and operational lifespan.

Given that air filtration is critical for astronaut life support, HEPA filters are likely to be manufactured on Earth to maintain and ensure their stringent filtration standards. Due to the logistical and economic constraints associated with transporting replacement filters from Earth, extending the functional duration of these filters becomes paramount, and underscores the importance of optimising their use and lifespan.

In response to the limitations of HEPA filters in lunar habitats, two methods to pre-treat dust-laden airstreams have been considered: pre-filters produced *in-situ*, and air cyclones. Both techniques are intended to serve as a first line of defence, preventing the bulk of larger particles from reaching the HEPA filters. By removing a significant portion of the dust load upfront, pre-treatment of the airstream could substantially extend the operational lifespan of HEPA filters.

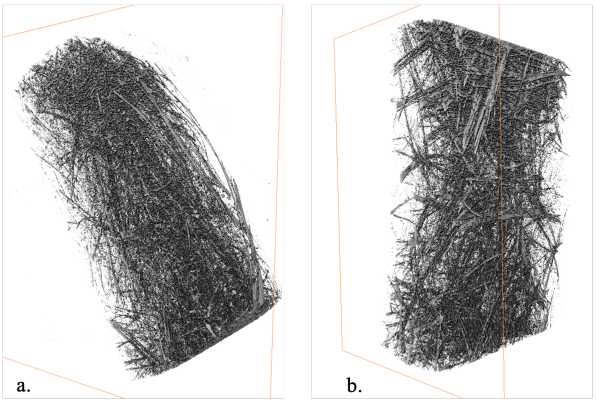

Figure 1 – Micro-CT cross sections of (a.) commercially available needlefelted basalt fibres and (b.) the proprietary Moonfibre material produced by FibreCoat from lunar regolith simulant.

Pre-filters could be fabricated from materials available *in-situ* or from recycled materials, offering a sustainable solution to resource utilisation in lunar environments. Woven and needlefelted filters produced from basalt fibres, as well as recycled, repurposed, and organically-derived filters have been tested. Micro computed tomography (micro-CT) scans of the filter materials are used to determine the size of the particles captured by the pre-filters, as well as to characterise their penetration depth into the filter. An example of this is found in Figure 1.

The filtration efficiency versus pressure drop for the basalt fiber filters is found Figure 2, and for the recycled, repurposed, and organic materials in Figure 3.

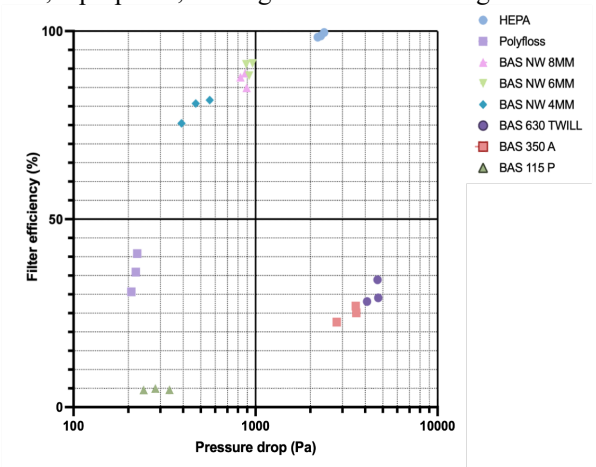

Figure 2 – Filtration efficiency versus pressure drop for basalt fibre-based pre-filters.

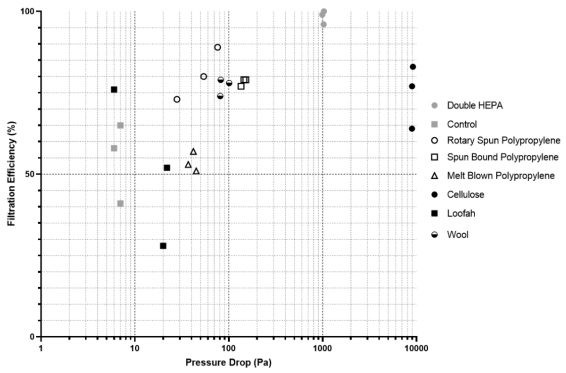

Figure 3 - Filtration efficiency versus pressure drop for recycled, repurposed, and organic pre-filters.

Air cyclones provide an additional mechanical separation method that relies on the centrifugal forces to segregate dust particles from the airstream based on size and density [2]. This technique effectively reduces the particulate load on subsequent filtration stages, further safeguarding the HEPA filters from premature loading and degradation. This study combines experimental investigations and CFD simulations.

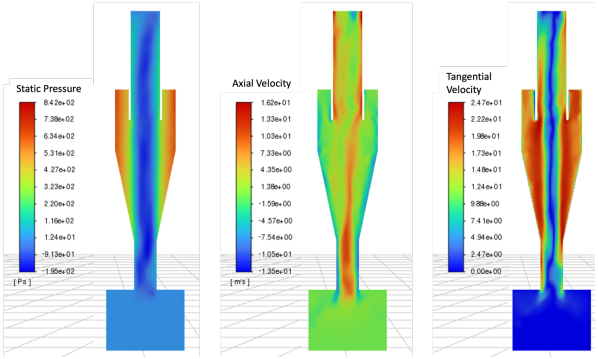

Figure 4 - CFD outputs showing the static pressure, axial velocity, and tangential velocity of the air flow profile within the cyclone.

In the CFD study, a 50 mm cyclone is simulated with a 200 LPM inlet flow rate (Figure 4). Turbulence is modeled using the Reynolds Stress Model. Air density is assumed to be 1.225 kg/m³, and the particle density of LMS-1D is 2920 kg/m³. After the convergence of the flow profile, particle behavior is tracked using Lagrangian particle tracking. LMS-1D particles with a size distribution of 0.1-10 µm, are released at the inlet. The underflow bin is modeled with a trap, and dust outlet is an escape boundary. The Separation efficiency (Figure 5) is the ratio of particles trapped to those released. The cut-size is observed to be around 0.9 µm. This implies that the coarsest particles would be captured by the cyclone.

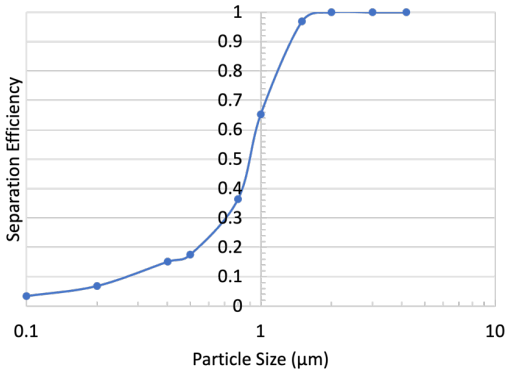

Figure 5 - Separation efficiency versus particle size for the 50 mm cyclone. The cut size is observed to be 0.9 µm.

The results of the experimental campaign will be compared with transient particle tracking simulations to improve the accuracy of the simulations. Furthermore, the performance of the cyclone will be compared directly to the best performing filter materials tested in previous campaigns.

Conclusions: The approach presented here for dust handling and mitigation in lunar habitats provides an avenue towards addressing the limitations of HEPA filters. By employing pre-filtration techniques to dusty airstreams, it will be possible to extend the life of critical components in a lunar habitat life support system.

References: [1] Environmental Protection Agency, (2024) https://tinyurl.com/mpmjjeec. [2] Pukkella, A. K., *et al*. (2024). *Pow. Tech*., 433, 119217.