Lunar Dust Mitigation System For a Lunar Habitat

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ABSTRACT

- Our design goal is to develop a reliable and efficient lunar dust mitigation system that prevents harmful lunar dust, "regolith", from entering the living quarters of a lunar habitat.
- The system will use a four-funnel airflow design to pull dust particles downward through a filtration system of our design before recirculating clean air back into the airlock.
- A scaled prototype will demonstrate the effectiveness of this process by removing dust from astronauts and their equipment. The final design aims to achieve at least 90% dust removal while remaining safe, compact, energy-efficient, and compatible with existing lunar habitat systems.

Project Background

- During lunar habitat entry and egress, lunar dust poses a critical threat due to its highly abrasive nature and electrostatic charge, which can quickly interfere with aerospace equipment and compromise astronaut health.
- Developed for space agencies, habitat engineers, and active lunar crews, an effective dust mitigation system must prioritize crew safety by shielding lungs, eyes, skin and interior life-support environments from harmful regolith exposure.



Figure 1. Lunar Regolith Simulant [1]

Objectives

- Mitigate 90% of the lunar regolith that enters the airlock chamber.
- Remain power efficient and compatible with existing lunar habitat power systems and conditions.
- The safety of the astronauts within the chamber is upheld while the mitigation system is active.

RESULTS & DISCUSSION

Module A – The Box

Prototype Box Volume:

- $V_{Prototype} = 1.5ft\ x\ 1.5ft\ x\ 1.5ft = 3.375ft^3$
- $Ma = \frac{V}{a} = .0015\ (< .3)$ => Incompressible Modelling
- $h_f = \frac{V^2}{2g}\left(\frac{fl}{d} + \sum K\right) = .3374\ ft$
- $h_{pump} = \frac{\Delta P}{\rho g} + \Delta z + h_f + h_{cyc} + h_{HEPA} = 1247\ ft$
- $P_{pump\ required} = Q * \rho * g * h_{pump} = 4.85\ W$

Analysis started from a given pressure difference of 1inHg and 40 air changes per hour. Where Ma is the mach number, *V* is air velocity (ft/s), *a* is the speed of sound in air (ft/s), *hf* is the head loss due to piping (ft), *g* is the acceleration of gravity at the surface of earth (ft/s^2), *l* is the total length of the piping, from the two farthest hoppers (ft), *d* is the diameter of the pipe (ft), *K* is a minor frictional head loss, *ΔP* is the required pressure differential (psi), *ρ* is the mass density of air (slugs/ft^3), *Δz* is the change in elevation of the system (ft), *h* values are the head loss due to their respective subscripts (ft), and *Q* is volume flow rate (ft^3/s). [2]

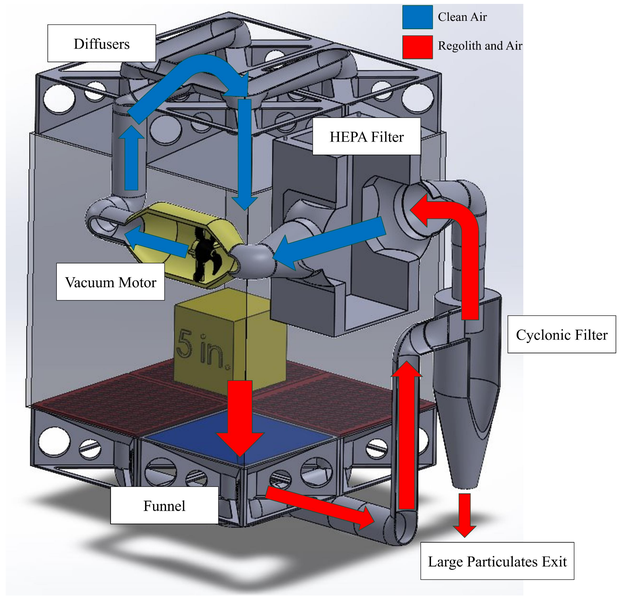


Figure 2. Prototype Assembly (note cube for scale)

Module B – The Collector

- A reverse-flow tangential entry cyclone separator modeled after the Stairmand Reference intakes regolith and air. At the base, heavy particles drop out into a container, this then causes a smaller, upward vortex to form. This carries the lighter regolith and air upwards to the outlet and towards Module C.

Shepperd-Lapple Correlation:

- $\Delta P_{cyclone} = 16(\frac{a*b}{{D_e}^2})(\frac{\rho * {V_i}^2}{2})$ = 0.105 (psi)

Where $\Delta P_{cyclone}$ is the pressure drop across the cyclone (psi), a is the inlet height (ft), b is the inlet width (ft), D_e is the body diameter (ft), ρ is the air density $(slugs/ft\text{^}3)$, and V_i is the air inlet velocity (ft/s). [3]

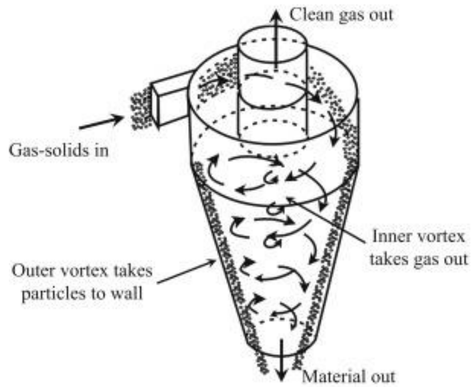


Figure 3. Cyclone separator diagram [4]

Module C – The Filter and Motor

Motor: A 235 CFM DC inline 4-inch blower motor was selected for its ability to output a large volumetric flowrate while utilizing only 48 watts under full load. Extraterrestrial habitats operate on a DC power system which allows this system to be easily integrated into a lunar habitat airlock. The speed is variable which allows for fine control of the flow rate and air velocity within the airlock.

- $ACH(max) = \frac{Q\ x\ (60\ mins\ )}{V} = \frac{235\ cfm\ x\ 60\ mins}{3.875ft^3} = 4{,}178\ Air\ Changes$
- $Air\ Change\ Time\ (min) = \frac{V}{Q} x\ 60 = 0.862\ seconds$

Filter: The filter stage will consist of a 3-stage inline layout (Pre-filter, Activated Carbon, and ePTFE HEPA)

- $\Delta P = \sum_{i=1}^{3}(a_i \cdot v + b_i \cdot v^2)$

Where ΔP is the total pressure drop across all 3 stages (psi), v is the face velocity (ft/s), and a_i and b_i are the viscous and inertial resistance coefficients for each stage [5].

- Efficiency: ≥ 99.97% capture for sub-micron lunar dust $(0.3\ \mu m)$
- Pressure Drop (ΔP): ~ 0.0435 psi (Clean) ~ 0.0653 psi (Loaded)
- Head Loss $(h_L = \frac{\Delta P}{\rho g})$: ~ 83.3 ft (Clean) ~ 125.0 ft (Loaded)



Figure 4. DC Inline 4-inch blower motor

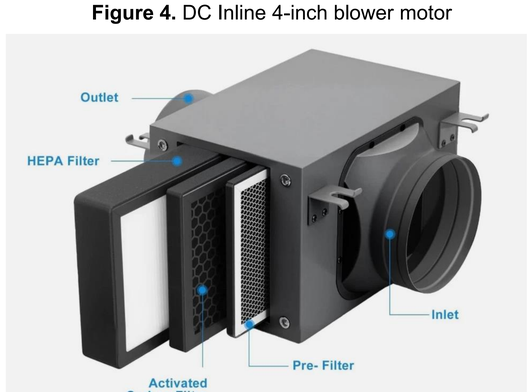


Figure 5. Filter staging box and configuration

FUTURE GOALS

- Develop the prototype model to verify calculations and assumptions.
- Perform tests with the prototype model to verify performance and make modifications to the design as needed.
- Develop a control system for the motor system to allow for variable stages of airflow (standby, low flow, high flow).
- Introduce more necessary redundancy to extend the lifetime and feasibility of the design.
- Develop a brush or vacuum attachment for Module A that assists with removing regolith from clothing.

CONCLUSIONS

- Our design removes large quantities of regolith from the airlock module in a short amount of time, while avoiding massive disturbance of the regolith within the chamber for the safety of those within it.
- Multiple stages of the system contribute to regolith filtering: beginning with the cyclone separator and magnetic pre-filter for larger particles, then a multi-stage HEPA filter apparatus for the smallest particles.
- Power requirements are minimal, the only component requiring power is a singular in-line vacuum motor.
- Human maintenance requirements are lessened where possible, however many components do require replacement often.

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References