RASC-AL Capstone Project

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1 Design Construction and Justification

1.1 Background

In this technical Proposal, we present the use of a dust mitigation system for use on Mars. The system consists of an external, lightweight structure that connects to the airlock, and uses an Electrostatic Precipitator (EP) to remove the majority of the particles in the air.

An EP is constructed with a high-voltage source that connects to various parallel plates, and a charged mesh. First, a particle travels through the mesh, which is charged negatively, and picks up a negative charge. Afterwards, the charged particle travels between the plates, which are alternating in voltage in order to induce an electric field between two adjacent plates, and ideally the particle lands on the plate due to the relative positive charge. A visual representation is shown in Figure 1.

For the construction of the EP, there are some major assumptions and constraints to satisfy for our design to function under Martian conditions. The primary assumption is that both the pressure outside and inside the design are the same, at Martian atmospheric pressure (6-7 mbar). This allows the structure to be designed so that it only supports the weights of the fans, the EP, and the tent.

The technical constraints are as follows: (1) The air must be moving at a speed high enough that it disperses the particles through the chamber continuously, (2) The voltage must be high enough to allow the particles to be captured by the plates as they pass between them, and (3) the plates must be far enough apart so that there is no arcing between them.

1.2 EP Equations

To investigate the first two constraints, we pose the worst-case scenario for the EP: a massive, fast-moving particle with the charge of a single electron that starts its trajectory between the plates from close to the grounded plate. This imposes a relationship for the distance between the plates, the width of the plates, the voltage differential between the plates, and the initial velocity of the particle.

$$E = \frac{\Delta V}{d}, F_{plates} = q_p E \rightarrow F_{plates} = m_p a_p = \frac{q_p \Delta V}{d} \rightarrow a_p = \frac{q_p \Delta V}{m_p d} \quad (1)$$

First, the force acting on the particle from the plates can be determined from the electric field created by the voltage differential, as shown above. This allows us to find the acceleration acting on the particle from the electric field alone. m_p and q_p are mass of the particle and charge of the particle respectively.

$$\Delta x = v_0 t + 0.5at^2 \rightarrow t = \frac{w}{v_0}, d = 0.5a_p t^2 = \frac{q_p \Delta V w^2}{2m_p d v_0^2} \rightarrow \Delta V = \frac{2m_p d^2 v_0^2}{q_e w^2} \quad (2)$$

Using kinematics, the above relationship can be found using d, the distance between plates, v_0, the initial velocity of the particle, and ΔV, the voltage difference between plates. q_p is exchanged for the charge of an electron in the last equation and w is the width of the plates. The above relation assumes that v_0 is adjusted appropriately so that the particles remain within the length of the plates during flight.

The range of particle sizes carried in the Martian atmosphere are between 1-4 micrometers. The density of Martian particles were found to be approximately 800-1800 kg/m^3 [Gro+21]. Using the assumption that most particles can be modeled as spheres, the heaviest particle possible is $6.0318578949 \times 10^{-14}$. Substituting this, g_M and q_e into the equation, we get the following, which gives an approximation of the minimum voltage required to capture the particle before it leaves the EP.

$$\Delta V_{min} = (7.41 \times 10^4)(\frac{v_0 d}{w})^2 \quad (3)$$

To satisfy the third constraint and set an upper bound on the voltage, we use Paschen's Law, which gives the breakdown voltage between two electrodes in a gas as a function of pressure and gap length. The breakdown voltage describes the voltage necessary to start a discharge arc across an insulator; in this case, it is specifically for gases.

$$V_B = \frac{Bpd}{ln(Apd) - ln(ln(1 + \frac{1}{\gamma_{se}}))} \tag{4}$$

Constants A and B are dependent on the gas, p is pressure, d is distance between the plates, and γ_{se} is the secondary electron-emission coefficient. For Mars' atmosphere, primarily composed of CO2, we find that A can be approximated as 20.0 $cm^{-1}Torr^{-1}$ and B as 466 $Vcm^{-1}Torr^{-1}$ for the range 500 to 1000 $Vcm^{-1}Torr^{-1}$ for E/p [SK00], [Cob41]. Few papers discuss γ_{se} for Aluminum and CO2, but it was shown to range between 1.5 and 3 for eV from 3 to 2000 [Bag+00]. Using these values, we can find a theoretical relationship between the voltage of the plates and the distance between the plates. However, in practice, it is best to find the values A, B, and γ_{se} experimentally for the desired E/p range.

$$V_B = (\frac{2097d}{ln(90d) - ln(ln(1 + \frac{1}{3}))}, \frac{2097d}{ln(90d) - ln(ln(1 + \frac{1}{1.5}))}) \tag{5}$$

This allows us to set an upper bound for the voltage between the EP's charged plates, which is the lower bound of these two values. Converting to mm from cm for d, we get the following equation.

$$\Delta V_{max} = \frac{209.7d}{ln(9d) + 1.25} \tag{6}$$

Another considerations is for the fans that are blowing air towards the EP. Since there are no equations that dictate the dependence of airflow velocity on distance from the fan outlet, this is best found experimentally, and adjusted accordingly so that it does not influence particles that are at the entrance of the EP's charged plates. This is further complicated by the low atmospheric pressure on Mars, which would drastically reduce the airflow for each fan, and also the initial velocity of the particle.

However, given these equations, we can come up with an theoretical framework for the ideal voltage. Given some fixed d, we could plot values of v_0 (m/s) and w (mm) against $\Delta V_{max} - \Delta V_{min}$, where positive values represent regions where it is possible to run the EP while satisfying the three constraints. Some examples are included in Figure 3, which are plotted for fixed d at d = 40mm and d = 60mm.

$$\Delta V_{max} - \Delta V_{min} = \frac{209.7d}{ln(9d) + 1.25} - (7.41 * 10^4)v_0^2(\frac{d}{w})^2 \tag{7}$$

1.3 Structure Equations

To calculate the total mass of the outer structure, the volumes of several components must be calculated. The body is made up of hollow cylinders, cones, and triangular prisms. All of the cement components will be 3D printed and the floor will be made of aluminum and transported by the rocket.

$$V_{cylinder} = \pi(R^2 - r^2)h - \frac{1}{2\pi}(R^2 - r^2)h \tag{8}$$

$$V_{cone} = \frac{1}{3}\pi(R^2 - r^2)h \tag{9}$$

$$V_{airlock} = \frac{1}{2}(LWH - lwh) \tag{10}$$

$$V_{door} = \frac{1}{\pi}(R^2 - r^2)h \tag{11}$$

$$V_{floor} = .1\pi r^2 h \tag{12}$$

$$m = V_{total}\rho = (V_{cylinder} + V_{cone} + V_{airlock} + V_{door})\rho_{cement} + V_{floor}\rho_{al} \tag{13}$$

$$\theta_{cone} = tan^{-1}(\frac{h}{R}) \tag{14}$$

$$\theta_{door} = tan^{-1}(\frac{h}{\frac{R}{2}}) \tag{15}$$

$$I = \frac{bh^3}{12} \tag{16}$$

$$M = Fx = g(\frac{1}{2\pi}(R^2 - r^2)h)\rho_{cement} \tag{17}$$

$$\sigma_{bending} = Mc/I \tag{18}$$

2 Appendix

2.1 A (Figures)

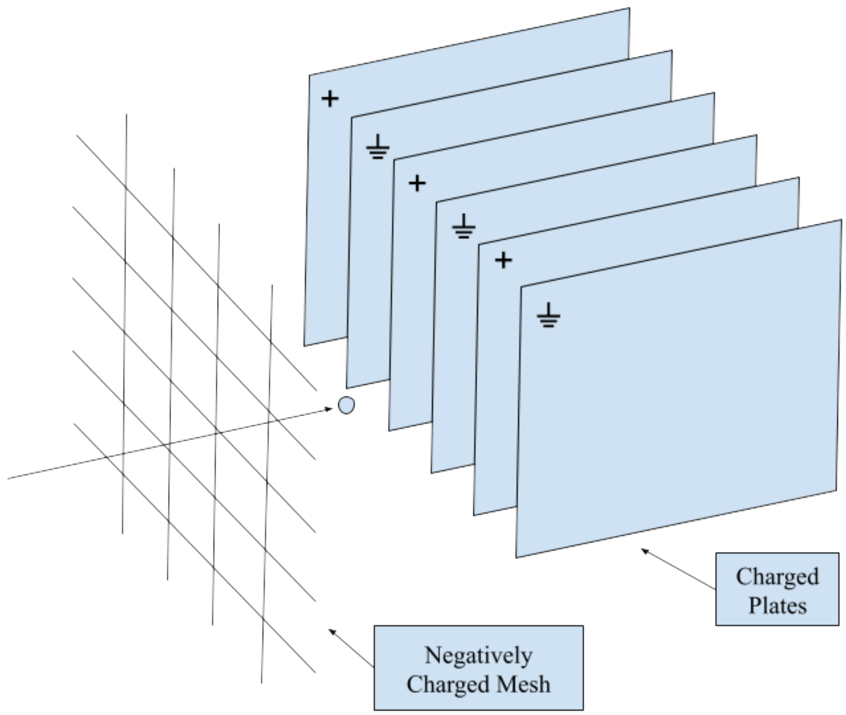

Figure 1: Visualization of Parallel Plate Electrostatic Precipitator

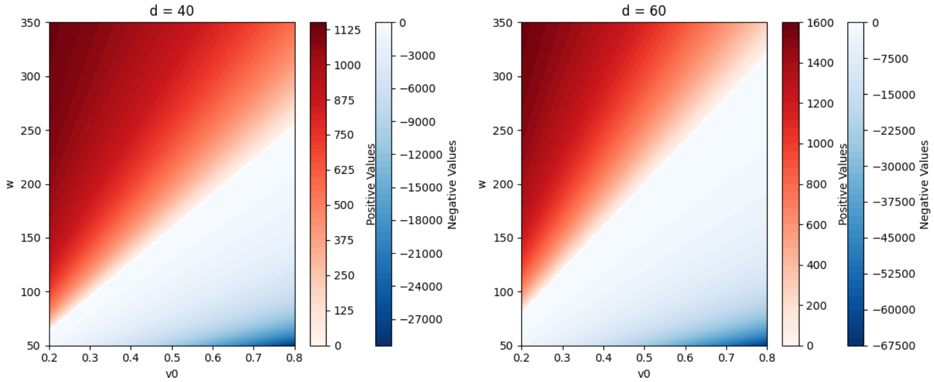

Figure 2: Valid Voltage Ranges for d = 40, d = 60 (mm)

2.2 B (Citations)

References

[Cob41] James Dillon Cobine. *Gaseous Conductors: Theory and Engineering Applications*. New York: McGraw-Hill, 1941.

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[SK00] H. Seiler and P. Kostler. "Secondary Electron Emission from Aluminum Surfaces". In: *Proceedings of the 7th European Particle Accelerator Conference (EPAC 2000)*. Available at `https://accelconf.web.cern.ch/e00/papers/THXF102.pdf`. 2000, pp. 256–258. URL: `https://accelconf.web.cern.ch/e00/papers/THXF102.pdf`.

[Gro+21] M. Grott et al. "Thermal Conductivity of the Martian Regolith at the InSight Landing Site from HP3 Active Heating Experiments". In: *Journal/Conference Name (if known)* (2021). Presented at [conference name if applicable]. URL: `https://doi.org/...`.