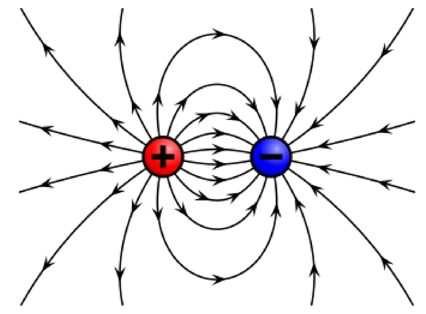
A BREAKTHROUGH IN LOW VOLTAGE REGOLITH MITIGATION

BACKGROUND

Dust may seem like a minor inconvenience, but through the lens of space exploration, it's a major challenge. On Mars, dust is sharper and clingier than on Earth, and it can interfere with Mars rovers' solar panels, gears, and electrical components, rendering them useless and stranded 140 million miles away from Earth.

Let's Talk Science. (2025) *A small pile of Martian regolith simulant JSC MARS-1A* (Image). Let's Talk Science. https://letstalkscience.ca/educational-resources/backgrounders/soil-on-mars

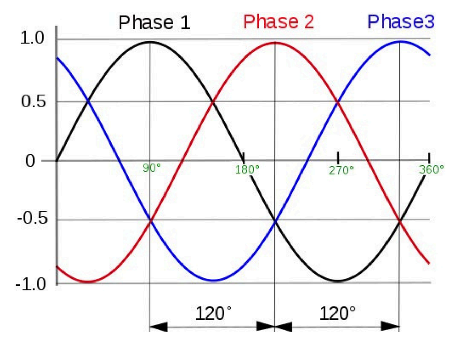
Electric fields create forces of attraction and repulsion between charges. Those fields can also interact with things that have no charge. This allows for the phenomenon known as polarization to occur. Polarization is when a particle's protons and electrons are pulled away from each other and barely separate, which forms small poles on a particle.



Geek3. (2025) *Illustration of the electric field surrounding a positive (red) and a negative (blue) charge* (Image). Wikipedia. https://en.wikipedia.org/wiki/Electric_field

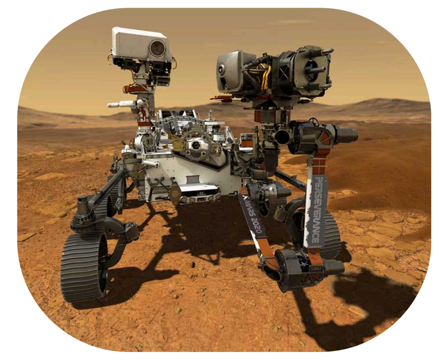
The basic goal of an Electrodynamic Dust Shield (EDS) system is to accomplish two things: lift dust vertically and move dust horizontally, like a force field. In order to run an EDS, it is necessary to code a single-board microcontroller, or an Arduino, to ensure the EDS runs in a three-phase pattern.

NASA's high-voltage EDS systems have a very high success rate in repelling dust off of model Mars rovers tested on Earth and easily overcome the surface forces, such as friction. I wanted to see if I could make an EDS and test its ability to repel Martian regolith in the Martian environment and in Earth's environment, but do it with very little voltage, so as to maximize the efficiency of the EDS. That is more difficult to accomplish with lower voltages because the force of friction is harder to overcome with low voltage, so an angled surface allows the downward force of gravity to partially overcome friction and help clear the dust.



Energy Relief. (2025) *Three-Phase System* (Image). Energy Relief. https://energyrelief.co.za/3-phase-power/

The Martian atmosphere is a semi-vacuum with a pressure of just 6 millibars, only about .6% of Earth's pressure at sea level. This is very different from Earth's air pressure. The lack of air on Mars makes it so there is less intercession from water molecules, making the electric field more effective.



Mars 2020 Perserverance. (2020) *Rover Name Plate on Mars* (Image). NASA. https://science.nasa.gov/mission/mars-2020-perseverance/

This project is concerned with removing dust from Mars rovers, specifically through a low-voltage solution to reduce safety risks.

PURPOSE

The general purpose of the project was to find a solution to the problem of dust sticking to machinery and people. In specific, the purposes were to:

- Evaluate if low voltages between 0-50 volts can create an electric field that polarizes Martian regolith particles and levitates and moves them horizontally in a simulated Martian environment and in Earth's atmosphere when the regolith is dropped onto a the surface of a 3-phase electrodynamic dust shield (EDS), which is set to an incline.
- Find how the amount of voltage applied to the low-voltage 3-phase EDS affects the percentage of Martian regolith mass that is repelled from the EDS surface in a simulated Martian environment and in Earth's atmosphere.

HYPOTHESIS

- The device would produce an electromagnetic field that repels Martian regolith due to the 3-phase system creating a non-uniform field that polarizes the dust and then pushes it away from the surface in a single direction by the sequential voltage pulses of the phases.
- Increasing the voltage by 2 volts in each trial would lead to a higher clearing factor, about 0.3% per 2 volts of increase, based on previous studies that found higher voltages lead to more regolith being repelled.

DATA

Table 1: Summarized Data

Group	Mean Clearing Factor	Standard Deviation in Clearing Factor	Sample Size
Earth, EDS off	48.43%	13.39%	20
Earth, EDS on	72.58%	6.48%	76
Martian, EDS off	60.97%	2.31%	5
Martian, EDS on	71.85%	5.95%	5

Graph made by student on https://www.mycompiler.io/new/r in 2025 using R (R Core team, 2021) and the package ggplot2 (H. Wickham, 2016).

Table 2: Compared Data

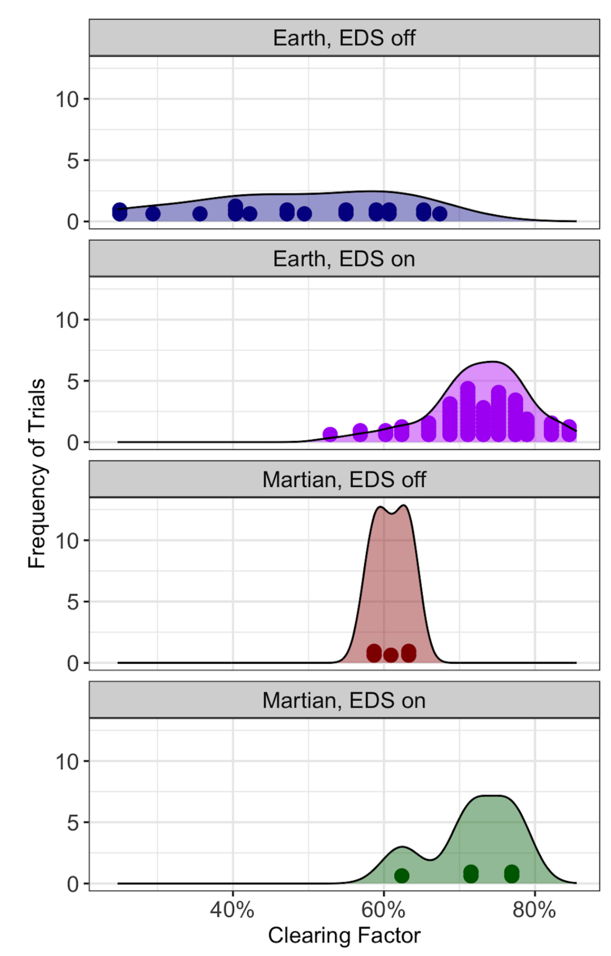
Group 1	Group 2	Difference in Mean Clearing Factor	Overall Standard Deviation	Overall Degrees of Freedom	t-value	p-value
Earth, EDS on	Earth, EDS off	24.15%	3.09%	21.39	7.83	0.00000012
Martian, EDS off	Earth, EDS off	12.54%	3.17%	22.3	3.96	0.00066822
Earth, EDS on	Martian, EDS on	0.73%	2.76%	4.65	0.26	0.80493457
Martian, EDS on	Martian, EDS off	10.88%	2.86%	5.18	3.81	0.01250772

Graph made by student on https://www.mycompiler.io/new/r in 2025 using R (R Core team, 2021) and the package ggplot2 (H. Wickham, 2016).

- The p-value shows the likelihood that the data points that were collected were completely random.
- A low p-value means that there is a low chance that the data was caused by randomness, which means that the two groups have a legitimate difference between their clearing factors.

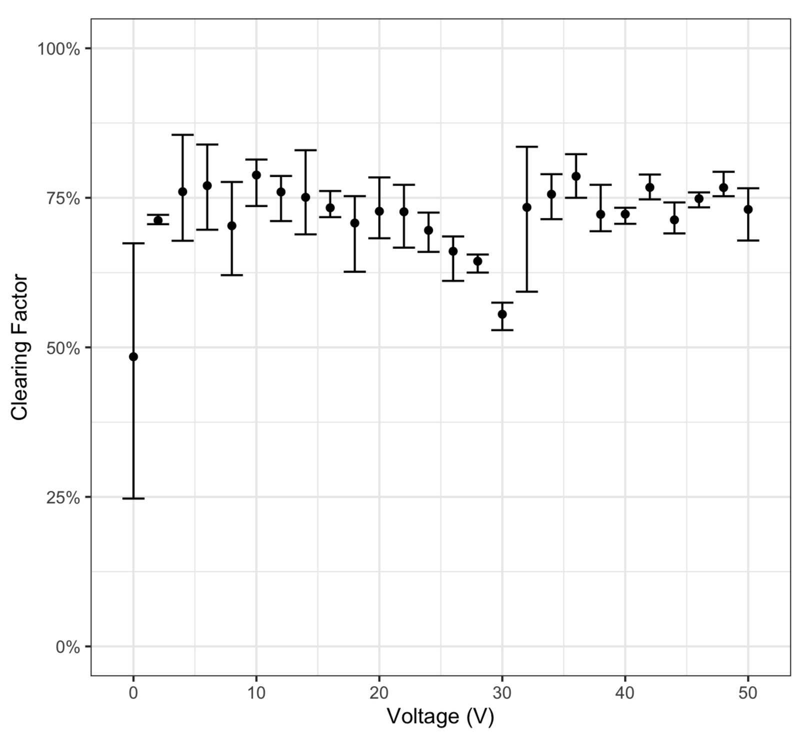
DATA ANALYSIS

Graph 1: Comparing Distribution of Clearing Factor



Graph made by student on https://www.mycompiler.io/new/r in 2025 using R (R Core team, 2021) and the package ggplot2 (H. Wickham, 2016).

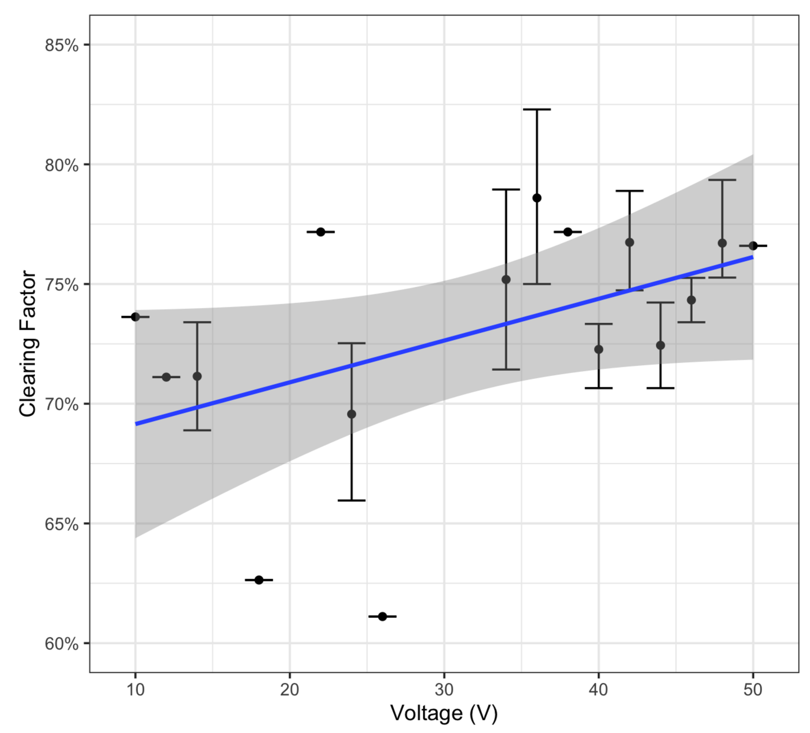
Graph 2: Clearing Factor vs Voltage on Earth



Graph made by student on https://www.mycompiler.io/new/r in 2025 using R (R Core team, 2021) and the package ggplot2 (H. Wickham, 2016).

Points show average clearing factor for the 3 trials done at each voltage. Bars show the minimum and maximum at each voltage.

Graph 3: Clearing Factor vs Voltage on Earth for Initial Masses (0.9 g or More)



Graph made by student on https://www.mycompiler.io/new/r in 2025 using R (R Core team, 2021) and the package ggplot2 (H. Wickham, 2016).

Blue line shows that the average clearing factor increases as the voltage increases.

PHOTOGRAPHS

Pictured is the power supply being turned up to 10V and the code being run for the Arduino. *Photo taken by guardian or student.*

Pictured is the regolith being scooped in preparation for experimentation on the EDS with the box set on the scale. *Photo taken by guardian or student.*

Pictured is the dropping of regolith onto the EDS in Earth's atmosphere. *Photo taken by guardian or student.*

Pictured is the dropping of regolith onto the EDS in a simulated Martian atmosphere. *Photo taken by guardian or student.*

METHODS

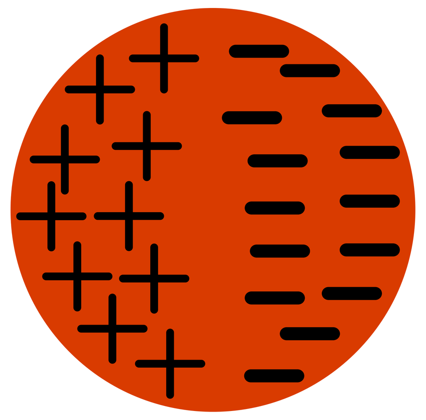
1. Fixed an old vacuum box using spackle, foam strips, and screws to make it as airtight as possible.
2. Connected vacuum pump to valve on the box to remove the atmosphere.
3. Glued three wires through combs to make evenly spaced rows on plexiglass.
4. Connected wires and a 50-volt power supply to breadboard.
5. Each wire had a resistor to prevent a short circuit and MOSFET that activated and deactivated at set times, turning the EDS phase on and off repeatedly.
6. Connected MOSFETs to Arduino, and coded it to turn on/off each MOSFET and time the pulses of electricity to polarize and move the dust particles.
7. Angled the plexiglass so dust would partially slide down when EDS is off.
8. Measured & weighed a tablespoon of Martian regolith simulant in each trial.
9. Dropped dust onto plexiglass in controlled motion, at a set height.
10. Placed box to collect the dust at the bottom of the EDS.
11. Weighed dust mass after experimentation to measure amount that was cleared.
12. Repeated each trial multiple times, with and without the power supply on, from 0 to 50 volts.
13. Repeated experiment in Earth's atmosphere and also in the vacuum chamber to simulate a Martian atmosphere.

CONCLUSION

- Both in and out of a Martian-simulated atmosphere, the EDS works extremely well.
- The average clearing factor of my EDS was nearly identical in both atmospheres with voltage on, about 72%.
- Even low voltages, such as 2 volts, were successful in clearing dust, while the results were far less consistent with the EDS turned off and had a much lower mean clearing factor, 48% on Earth and 61% in the simulated Martian atmosphere.
- There is a correlation between the amount of voltage used and the amount of dust that was cleared. When the voltage went up, so did the amount of dust that was cleared.
- Both hypotheses were accepted for these reasons.

DISCUSSION

- Lower voltages can clear a significant amount of dust in both environments.
- A low-voltage electric field can polarize dust particles, and the 3 phase EDS system can help move the polarized dust off the EDS surface by turning on the electrodes at different times and attracting the dust to the electrodes in sequence.
- Higher voltages can increase the amount of dust that is repelled by the EDS, although this was only observed after filtering the data points to trials with at least 0.9 grams of initial mass. This may be due to the stronger field creating more force on the dust particles to overcome the surface forces like friction and adhesion that resist movement.
- The clearing factor dropped at about 24 to 30 volts, possibly due to the initial mass being smaller in those trials. More mass is easier to repel if dust is layered on top of itself and there are fewer surface forces such as friction.
- The horizontal force may have been weak since it requires the phases to be in perfect synchronism. If that were the case, then more dust was cleared because of a slight upwards force from the electrodes, allowing gravity to pull the particles down the plexiglass. Any voltage large enough to overcome these surface forces will negate the main source of resistance to the dust's movement.



Pictured above is a polarized particle created by student

NEXT STEPS

In future testing, this project could be expanded upon by:

1. Testing with the same amount of dust on every trial. This would eliminate any uncertainty that more voltage helps clear more dust.

2. Gathering more data points. More data could reinforce findings and maybe highlight some things that weren't as apparent with less data points.

3. Testing more kinds of voltage pulses. Different lengths of voltage pulses could improve results. The EDS could also incorporate different amounts of voltage in each pulse or cycle. A 2 phase system could also be tested due to the fact that it would work similarly to a 3 phase system, but with more simplicity.