Vibration-based lunar dust removal logbook

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Entry 1 - 11/03/2025

- Today was the first day of planning for our science fair project. As a team, we discussed our goal of creating an innovative project that addresses a real-world problem rather than simply demonstrating an existing concept.

- We conducted preliminary online research to explore current issues and emerging technologies. As we evaluated different ideas, we considered factors such as originality, feasibility, available resources, and the ability to produce measurable results. The most promising concepts were recorded in a separate document for further comparison.

- By the end of our discussion, we had developed a shortlist of potential project ideas. In our next meeting, we will analyze these options more carefully and determine which project is both impactful and realistic to complete within the given timeline.

Entry 2 - 11/08/2025

- We decided to conduct further research on potential project ideas. After exploring a wide range of possibilities, we narrowed our focus to a few concepts rooted in innovation.

- As the discussion progressed, we began to gravitate toward space-related projects. Given that space represents the next frontier of technological advancement and that space activity is rapidly increasing, we felt a space-focused project would be highly relevant.

- Some of the ideas we considered included a closed-loop oxygen system, growing plants in microgravity, and an app to detect orbital debris. However, after researching these options in more detail, we realized that they might not be the most feasible for our science fair project and decided to revisit the drawing board.

Entry 3 - 11/12/2025

- While conducting further research on space innovation, I came across the Artemis mission on NASA's website. Learning that Artemis II aims to send humans back to the Moon, we realized that a lunar-based project with potential applications for the mission would be both relevant and feasible.

- This discovery prompted us to explore specific challenges faced during lunar missions, which led us to an article discussing the problems caused by lunar dust during the Apollo missions. The article explained that lunar dust is extremely sharp and abrasive, capable of damaging critical equipment and surfaces that are essential for lunar operations. It also highlighted how lunar dust can cling to surfaces due to its electrostatic properties, creating long-term issues for astronauts and machinery.

- After reviewing this information, we had a group discussion about potential ways to address this challenge.

- We considered different methods for removing lunar dust and thought about how vibrations, coatings, or electrostatic solutions could be tested in a controlled environment.

- Through this discussion, we agreed that our project this year will focus on developing practical methods to remove lunar dust from various surfaces. By tackling a real problem faced in lunar exploration, we hope our project will not only demonstrate scientific principles but also contribute ideas that could support future missions like Artemis II.

Entry 4 - 11/21/2025

- To begin our project, we first needed to identify specific parameters to ensure that our design could be applicable to lunar conditions. After conducting initial research, we established a set of criteria and constraints to guide the development of our project.

Criteria:

- **Effectively remove lunar dust from surfaces** – The primary goal of our project is to ensure that lunar dust, which is abrasive and can damage equipment, can be safely and efficiently removed.

- **Minimize energy consumption** – Energy is limited in lunar environments, so our design must operate efficiently to be practical for real missions.

- **Operate reliably** – Any system used on the Moon must work consistently, as failures could jeopardize mission equipment or astronaut safety.

- **Use inexpensive, easily accessible materials** – For the purposes of our prototype, materials should be affordable and readily available while still demonstrating the concept.

Constraints:

- **Maintain a small and accessible design** – Lunar modules have limited space, so our system must be compact and easy to integrate.

- **Function in low-gravity conditions** – The Moon's gravity is only about one-sixth of Earth's, so our design must account for how dust behaves differently in this environment.

- **Avoid damaging critical equipment** – The method we use must not harm any surfaces or instruments, as lunar equipment is delicate and costly.

- **Be easy to assemble and disassemble** – For testing and potential future use, the system should be straightforward to set up, adjust, and remove as needed.

- By carefully defining these criteria and constraints, we aim to create a design that is not only scientifically sound but also practical, feasible, and aligned with the real challenges faced in lunar exploration.

Entry 5 - 11/22/2025

- After identifying our criteria and constraints, our next step was to brainstorm feasible solutions to address the lunar dust problem. Through background research, we explored several methods currently being used or proposed by institutions for dust removal, including:

- **Pressurized liquid nitrogen** – Uses bursts of extremely cold gas to blow dust off surfaces; effective but bulky and hard to control in small spaces.

- **Electrodynamic dust shields** – Apply electric fields to repel dust particles; reliable for flat surfaces but less effective on irregular or complex equipment.

- **Handheld static ionizer tools** – Generate static electricity to attract and remove dust; limited in reach and efficiency, especially over large areas.

- **Electrostatic dust lifts** – Use charged plates or brushes to lift dust from surfaces; can be effective but risk damaging delicate equipment.

- While each of these methods has potential, we found that none fully meet our criteria and constraints. Many are difficult to operate while wearing bulky space suits, some are only moderately effective, and others could damage sensitive lunar equipment.

- After analyzing these limitations, we determined that a vibration-based cleaning system would be the most feasible solution for our project. This system would use a piezoelectric device to generate precise vibrations, which can lift lunar dust off surfaces. Lunar dust particles are extremely fine and have low mass, so even small vibrations can overcome the forces holding them in place, such as weak adhesion or electrostatic attraction. This approach allows for efficient dust removal while minimizing energy use and avoiding damage to critical equipment, making it well-suited to the conditions of a lunar environment.

Entry 6 - 11/27/2025

- Now that we have decided on the method we will use, the next step is to create a research question and hypothesis for our project. Since our goal is to determine how effective a vibration-based solution is compared to pre-existing dust removal methods, we carefully considered how to frame our investigation.

- **Research Question:**
  - *How does a vibration-based frequency affect the detachment of lunar regolith compared to pre-existing methods?*

- We chose this question because it not only evaluates the effectiveness of our solution but also allows us to measure how it performs relative to other techniques currently being explored or used in lunar exploration. By making this comparison, we can determine whether a vibration-based system offers a practical advantage in terms of efficiency, safety, and minimal impact on sensitive equipment.

- **Hypothesis:**
    - *If varying frequencies are applied to dislodge lunar regolith from different surfaces, then the regolith will be removed efficiently. This is because when a surface vibrates with an acceleration greater than the gravitational or adhesion forces acting on the dust particles, the particles will lift off. Additionally, using vibrations reduces the risk of damage to the surface compared to manual or mechanical removal methods.*

- This hypothesis aligns closely with our project criteria, emphasizing **effective dust removal**, **low energy use**, and **safety for sensitive equipment**. By testing it, we can quantify the efficiency of vibration-based dust removal and assess whether it could provide a viable, low-risk alternative to existing methods, which is a key consideration for supporting future lunar missions such as Artemis II.

Entry 7 - 11/30/2025

- Today, we developed a set of guiding questions to direct our background research. These questions will provide us with solid foundational knowledge and scientific evidence to support our experimental design. We intentionally created questions across multiple subject areas to ensure we fully understand the physics, engineering, environmental factors, and design considerations related to our project.

Physics and Engineering

- Is there a resonant frequency at which lunar regolith detaches most efficiently from a surface?

- How do vibrations overcome electrostatic forces compared to mechanical adhesion forces?

Materials and Surface Science

- How does surface texture or coating influence the effectiveness of vibration-based dust removal?
- Would vibrations work better on rigid surfaces (such as solar panels) or flexible surfaces (such as spacesuit fabric), and why?
- How does repeated vibration affect long-term material fatigue on lunar equipment?

Future Applications and Ethical Considerations

- Could vibration-based dust removal be scaled for larger lunar bases or long-duration missions?
- What risks might vibrations pose to sensitive instruments or scientific measurements?
- Should dust removal systems prioritize efficiency, durability, or astronaut safety, and why?
- These research questions will serve as structured guidelines to ensure we gather comprehensive and relevant information before moving forward. By addressing multiple perspectives—scientific, engineering, and ethical—we aim to build a strong theoretical foundation that will support both our experimental design and final conclusions.

Entry 8 - 12/01/2025-12/10/2025

- Over the next twelve days, we focused on thoroughly researching and answering the background questions we had developed. This process allowed us to build a strong foundational understanding of the physics, engineering principles, material science, and environmental conditions relevant to our vibration-based lunar dust removal system. We gathered information from credible scientific sources and analyzed how each topic connected back to our project design.

Physics and Engineering

- Is there a resonant frequency at which lunar regolith detaches most efficiently from a surface?
  Well, there probably is such a resonant frequency as to remove the lunar regolith most effectively, but this is not something constant for the whole universe. On the contrary, the most effective frequency would depend on the type of lunar dust itself, on the type of surface material, etc.
- Mechanical resonance is the tendency of a mechanical system to respond to a higher amplitude when the frequency of the oscillations match the natural vibration frequency more than any other frequency. The formula for the natural frequency is this:
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$$F_0 = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

Fundamental Frequency (F_0), Stiffness (k), Mass (m)

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- F is the natural frequency, k is the spring constant, which is the stiffness of the surface, and m is the mass of the surface. The spring constant tells you how much force is needed in order to cause a certain amount of movement. Factors like how it bends and compression affect the measurement, for example, a thin flexible surface has a low spring constant while a stiff metal plate has a high spring constant. It can be measured by $k=(2\pi f)2m$ which is an equation to measure it using vibrations, it is derived from Hooke's law.
- The particles detach when the vibration produce enough acceleration to overcome gravity and adhesion forces, it is represented in this formula:
- **$a=(2\pi f)^2A$**
- Where "a" is the maximum acceleration, a "A" is the vibration amplitude. Looking at the equation we can see that when the vibration amplitude increases, then the acceleration increases significantly. Since it is squared, small changes in the frequency will make the biggest difference in dust removal. Amplitude is the maximum distance the surface will move from its equilibrium position.
- When the vibration speed equals the natural frequency of either the surface, the dust layer, or the interface between surface and dust, the phenomenon of resonance takes place. In that situation, even minute vibrations can generate large motion. In lunar regolith, efficient removal can be facilitated by vibrations that can cause the dust particles to momentarily lift away from the surface by overcoming friction, cohesion, and electrostatic forces. Thin layers of fine dust might be more effectively removed by high-frequency vibrations, potentially ultrasonic, while larger layers might be more readily stripped at lower frequencies with larger amplitudes. Furthermore, it may occur that the surface itself has its resonant frequency. If a solar panel, plate, and membrane vibrate at their resonant frequency, it enhances surface vibrations that can efficiently remove dust with less energy input. Nevertheless, it may occur that conditions on the lunar surface can alter these effects due to low gravity, a vacuum, as well as pronounced electrostatic charging. It is anticipated that frequency tuning will emerge as the most effective method by experimenting and tuning different vibration frequencies to optimize dust removal.

- How do vibrations overcome electrostatic forces compared to mechanical adhesion forces?
- Electrostatic forces and mechanical adhesion forces are two major reasons why small particles, like dust, adhere or stick to surfaces. Electrostatic forces, as their name implies, relate to electric charge. When two objects have opposite electric charge, they attract each other, a fact described by Coulomb's Law. Mechanical adhesion forces result from the physical contact of surfaces. Even the smoothest surface has microscopic roughness. When a dust particle comes into physical contact with a surface, there are a number of microscopic "points of contact." At these points of contact, intermolecular forces, which are Van der Waals forces, act between molecules.
- The dust particles are attracted to the surface because of two main forces: mechanical adhesion and electrostatic forces. The mechanical adhesion consists of van der Waals forces and microscopic surface interlocking, which occurs because of the roughness of the surface. The forces are effective at very short distances and are determined by the closeness of the dust particle to the surface. Electrostatic forces, on the other hand, are relevant in dry conditions, such as on the surface of the Moon. The electrostatic forces are effective at slightly longer distances and are usually greater than the mechanical adhesion. If the surface on which the dust particle rests is vibrating, it means that the surface is accelerating. The inertial force on the dust particle on the surface is given by:

- Fvibration=ma

- Where "m" is mass and "a" is the acceleration of the vibrations.

- Vibrations are able to break the mechanical adhesion because they cause the surface on which the dust particle rests to move up and down very fast. The dust particle, however, resists the movement because of inertia. When the inertia becomes larger than the adhesive force, the microscopic points of contact are broken. The repeated action of the surface moving up and down breaks the adhesive forces, causing the dust particle to be detached from the surface. The adhesive forces are generally weaker, and that is why they are the first to be broken.

- Electroelectric forces are slightly more difficult to remove, but are done when the mass and acceleration overpower the vibration.

Materials and Surface Science

- How does surface texture or coating influence the effectiveness of vibration-based dust removal?

- The surface texture and coating drastically change how effective vibrations can be at removing lunar regolith. Surface texture can affect how effective vibrations are for multiple reasons. A rough surface has a greater surface area compared to a smooth surface, meaning rougher surfaces collect a greater amount of lunar regolith compared to smoother surfaces. A rougher surface also has an increased amount of grooves, ridges, and edges for regolith to get trapped. When vibration is applied to a rough surface, the dust particle has less room to move around and dislodge due to limited space, leading to vibrations being less efficient compared to a smooth surface, which dust can easily slide or lift off much quicker.
- Surface coatings can reduce how strongly the lunar dust sticks to the surface in the first place. Some coatings are designed to be dust-repellent or anti-static, which lowers the electrical attraction between the dust and the surface. Lunar dust becomes electrically charged, so if a coating reduces this charge, vibrations don't need to be as strong to remove the dust. Other coatings are harder and more durable, which prevents dust from embedding into the surface over time.
- Overall, smooth surfaces and dust-resistant coatings make vibration-based dust removal much more effective because they reduce adhesion between the lunar dust and equipment. This allows vibrations to safely remove dust with less energy, while also lowering the risk of damage to instruments or structures.

- Would vibrations work better on rigid surfaces (such as solar panels) or flexible surfaces (such as spacesuit fabric), and why?

- Vibrations would generally work better on rigid surfaces, like solar panels, than on flexible surfaces, like spacesuit fabric.
- Rigid surfaces respond to vibrations in a more predictable way. When a solid surface vibrates, the motion is transferred evenly across the material, which helps shake loose lunar dust particles. Solar panels are smooth and stiff, so dust has fewer places to get trapped. When vibrations are applied, the dust can break free more easily and fall or be shaken off.
- Flexible surfaces, such as spacesuit fabric, absorb vibrations instead of transmitting them effectively. The fabric bends and flexes, which reduces how much energy reaches the dust particles. Lunar dust can also become embedded in the tiny fibers of the fabric, making it much harder to remove using vibrations alone. Because of this, vibrations are less effective at cleaning flexible materials.

- Overall, vibrations are more effective on rigid, smooth surfaces because they efficiently transfer energy to the dust particles, while flexible surfaces tend to absorb the vibrations and trap dust more easily.

- How does repeated vibration affect long-term material fatigue on lunar equipment?

- Repeated vibration can cause **long-term material fatigue** in lunar equipment, which means materials slowly wear out over time. Even if the vibrations are small, they can still stress the material again and again. This repeated stress can cause tiny cracks to form inside the material.
- Over time, these small cracks can grow bigger and weaken the equipment. Eventually, parts could break or fail, which is a big problem on the Moon because equipment is very hard to repair. For example, bolts and screws could slowly loosen, joints might start to crack, and electronic parts could shift or become damaged from constant shaking.
- The Moon already has extreme temperature changes between day and night, which puts extra stress on materials. When vibration is added on top of that, the damage can happen faster. Because of this, engineers need to control how much vibration equipment experiences and use strong materials that can handle repeated movement. This helps lunar equipment last longer and stay safe to use.

Future Applications and Ethical Considerations

- Could vibration-based dust removal be scaled for larger lunar bases or long-duration missions?
- Yes, vibration-based dust removal could be scaled up for large lunar bases and long-term missions, but it would need to be designed carefully. For bigger lunar bases, vibration systems could be built into areas like airlocks, spacesuit cleaning stations, landing pads, and the outside of buildings. These systems could use gentle vibrations to shake lunar dust off surfaces before it spreads inside the base.
- For long-term missions, this type of system would be helpful because it can be reused many times and doesn't need a lot of replacement materials. It could also work automatically, which would save time for astronauts. The vibrations could be limited to specific areas, such as where astronauts enter or where equipment is stored, so dust is removed without affecting the entire base.
- However, there are some challenges. If the vibrations are too strong, they could disturb sensitive scientific instruments or loosen parts of equipment. They could also be uncomfortable for astronauts if not properly controlled. To prevent this, engineers would need to carefully control how strong the vibrations are and use materials that absorb or reduce vibration.
- Overall, with the right design and safety measures, vibration-based dust removal could be a practical solution for large lunar bases and long-term missions.

- What risks might vibrations pose to sensitive instruments or scientific measurements?

- Vibrations can pose serious risks to sensitive instruments and scientific measurements, especially in environments like the Moon where extremely precise measurements are critical. Even small or low-frequency vibrations can cause instruments to shift, tilt, or lose alignment, which can lead to inaccurate or inconsistent data. For example, high-resolution cameras and telescopes require extreme stability; vibrations can blur images or distort observations, making it difficult to study lunar surface features or distant celestial objects accurately.
- Scientific instruments such as spectrometers and chemical analyzers are also highly sensitive to motion. Vibrations can introduce electrical or mechanical noise into their readings, which may be misinterpreted as real data. This can compromise experiments that analyze the composition of lunar soil or detect trace elements. Similarly, seismometers, which are designed to measure very small ground movements, can mistakenly record vibrations from nearby machinery or astronaut activity as moonquakes, interfering with the accuracy of seismic data.
- Over long periods, repeated vibrations can loosen bolts, connectors, or wiring inside instruments, gradually reducing precision and causing calibration drift. For instance, robotic arms or drilling equipment used near scientific stations may generate continuous vibrations that accelerate wear on nearby sensors. In harsh lunar conditions, repair opportunities are limited, so vibration-induced damage could permanently disable important instruments. For these reasons, minimizing vibrations is essential to ensure reliable scientific measurements and the long-term success of lunar missions.

- Should dust removal systems prioritize efficiency, durability, or astronaut safety, and why?
- Dust removal systems used on the Moon should prioritize astronaut safety, as the health and well-being of astronauts are of the utmost importance. Our design aims to mitigate the dangers posed by lunar regolith, which can significantly threaten future Moon missions. Lunar regolith is extremely sharp, chemically reactive, and easily inhaled, making it hazardous to human health. When inhaled, its abrasive particles can damage delicate lung tissue and the respiratory system. Additionally, lunar dust contains silicates, which are also found near volcanic regions on Earth. Workers exposed to high concentrations of silicates, such as miners, often develop silicosis—a serious lung disease that causes inflammation, breathing difficulties, and permanent lung scarring. Scientists believe that prolonged exposure to lunar regolith, especially during long-term lunar missions, could lead to similar health complications for astronauts.
- Beyond its impact on human health, lunar regolith can also severely damage equipment and instruments. During the Apollo missions, astronauts reported that lunar dust clung to spacesuits, clogged joints, scratched visors, and interfered with mechanical systems. These issues increased wear on equipment and made basic operations more difficult. As

future missions plan for longer stays on the Moon, an effective dust mitigation system is essential to protect both astronauts and mission-critical technology.

- By completing this background research phase, we ensured that we have sufficient knowledge and evidence to confidently move forward with designing and testing our prototype. This step was essential in reducing potential design flaws and strengthening the scientific basis of our project.

Entry 9 - 12/14/2025

- After completing our background research, the next step was to identify the variables for our experiment. Since our primary objective is to measure the effectiveness of dust removal, we structured our variables to allow for clear and measurable results.

- The **controlled variables** will include the amount of lunar regolith simulant applied, the material of the surface plate, and the number of piezoelectric disks attached to the plate. Keeping these factors constant ensures that any observed changes in dust removal are due only to the variable being tested.

- The **independent variable** will be the frequency of the piezoelectric disk. The **dependent variable** will be the amount of dust removed from the surface plate after vibration is applied.

- With our variables clearly defined, we were able to refine our hypothesis:

- **Hypothesis:**
  If varying frequencies are applied to dislodge lunar regolith from different lunar surfaces, then the regolith will be removed efficiently. This is because when a surface vibrates with an acceleration greater than the gravitational and adhesion forces acting on a particle, detachment will occur. Additionally, vibration-based removal reduces the likelihood of surface damage compared to manual cleaning methods.

- Now that we have established both our variables and hypothesis, we have a solid experimental foundation. Our next step is to design a detailed procedure that aligns with our variables, supports our hypothesis, and satisfies our previously defined criteria and constraints.

Entry 10 - 12/20/2025

- After finalizing our variables and hypothesis, the next step was to create a materials list for constructing and testing our prototype. Since our vibrations will be produced using a piezoelectric disk, we identified the necessary electrical components required to generate and control those vibrations. The piezoelectric disk will be connected to a function generator to produce controlled frequencies. Additionally, we may use an amplifier if the function generator does not supply sufficient power to achieve the desired acceleration levels.

- We also require a lunar regolith simulant and a test surface plate to evaluate dust removal. A scale will be used to measure the mass of the simulant before and after testing to determine the amount of dust removed.

- Initially, we considered building a vacuum chamber to better simulate lunar conditions. However, after further research, we concluded that constructing a vacuum system would introduce excessive complexity, safety concerns, and feasibility challenges for this project. As a result, we decided to focus on accurately controlling measurable variables such as frequency and dust mass under standard laboratory conditions.

Material List:

- 50 mm piezoelectric disc
- Flat aluminum surface plate
- FG-200 DDS Function Generator
- ASHATA TPA3255 Digital Power Amplifier Board
- 47 Ω 5 W resistor
- BNC male to RCA male cable
- BNC to alligator wire connectors

- Lunar regolith simulant (cocoa powder)
- Weight scale
- 61 cm × 21 cm × 2 cm wooden plank (base)
- Jigsaw
- Wood glue
- Electric sander
- Tape
- Soldering iron
- Solder wire
- Spring clamps
- Pencil
- Protractor
- Ruler
- Safety glasses

- Once these materials are gathered, we will begin constructing the physical model and assembling the electrical components in preparation for testing. This stage marks the transition from research and planning to hands-on experiments.

- During preparation, we identified a potential limitation in our equipment. The scale available to us measures to the nearest tenth of a gram (0.1 g), which may introduce minor measurement uncertainty when calculating the amount of lunar regolith simulant removed. However, because we will use consistent dust quantities and perform multiple trials to ensure reliability, this limitation should not significantly impact the overall accuracy of our results.

Entry 11 - 12/24/2025

- Now that we have our list of materials, we now need to make our building procedure to build the physical model. We need a stand to hold the model, so we will be using scrap wood to construct a stand. Once the stand is created, the rest of the building will be a matter of connecting the piezoelectric disk to the function generator and directly attached onto the metal plate. With this basic idea in mind, we created our building procedure.

1. Assemble all materials required for building the demonstration, and wear safety goggles

2. Take 61cmX21cmX2cm wooden plank and use a pencil to draw a piece with a 12cm base, and on each side going up by 3cm, then inward again by 4.5 cm. For the 3cm gap in the middle, draw two 7cm lines going upward, then connect them at the top. This is the main side piece.

3. Repeat this process on another portion of the wooden plank

4. Now we need to draw the piece for the aluminum plate to rest on. This is just a simple rectangle shape that will later be glued onto the previously made shape. The rectangle is 12cmX3cm, draw two of them

5. To connect the 2 pieces, draw a rectangle piece that is 18cmX3cm onto the same wooden plank

6. To create a slope for the dust to glide off, there need to be two triangular-shaped pieces on the surface where the aluminum plate would rest, so the plate rests on the slope. It is a right triangle with a base of 12cm and a height of 4cm; the angle degree is 15 degrees, which is enough for the dust to glide off, but also ensures that gravity doesn't have a large role in the actual detachment of the dust

7. Once all of these pieces are drawn out on the wooden plank, use a jigsaw to cut the pieces out, ensuring that the cuts are right outside of the lines drawn

8. With all the cut-out pieces, use an electric sander to ensure the lines are straight and accurate.

9. To assemble the structure, use wood glue, and the center of the rest piece should be glued 3cm from the top of the main side piece, with the 2cm thick side being glued directly onto it. Do this for the other side plate as well

10. Glue the triangular piece on top of the rest of the piece, each one facing the same direction

11. Glue the back connection piece to the bottom of both the side pieces, connecting them

12. Now that the stand is complete, take the plastic piece and place it between both triangle pieces

13. Take the flat aluminum plate, and using thin double-sided tape, attach the 50mm piezoelectric disks side by side in the middle area of the aluminum plate

14. Place the aluminum plate on the slope, and place a piece of Styrofoam between the back of the plate and the plastic piece. This is to ensure that the sound is more contained.

Entry 12 - 12/24/2025

- We have now begun constructing the physical model for our experiment. Following our planned procedure, we successfully built the wooden stand designed to support the aluminum test plate at the specified angle. During construction, we ensured that all measurements were accurate and that the structure was stable enough to minimize unintended vibrations that could affect future testing.

- However, we were unable to begin experimental trials today because some essential components—most importantly the function generator—are still missing. Without the function generator, we cannot produce the controlled frequencies required to power the piezoelectric disks and generate measurable vibrations.

Entry 13 - 01/03/2026

- The function generator has arrived, allowing us to begin initial testing of our system. Since the stand had already been constructed, we were able to quickly attach the piezoelectric disk to the aluminum plate and connect it to the function generator.

- We first conducted a preliminary test without using the amplifier. During this mock trial, we observed that the function generator alone did not produce sufficient voltage to generate vibrations strong enough to remove a significant amount of the lunar regolith simulant. Although vibrations were present, they lacked the necessary acceleration to meaningfully dislodge the dust.

- We then connected the amplifier to increase the output power. However, once the amplifier was attached, the system stopped functioning entirely. Despite spending considerable time troubleshooting—checking wiring connections, polarity, and component placement—we were unable to identify the cause of the issue during this session.

Entry 14 - 01/05/2026

- While we were diagnosing the issue with our setup, Anirudh contacted Roberto Moraes, a geotechnical engineer, for professional advice. When he responded, he provided valuable insight into how we should approach our experiment. His main point was that there is no single “average” frequency that removes lunar regolith most effectively, since individual dust particles have slightly different physical properties, which causes variation in their natural frequencies.

- He suggested that instead of focusing solely on resonance, we should examine how changes in peak acceleration affect dust detachment. By analyzing acceleration thresholds, we would be able to produce clearer, more measurable conclusions. Based on his feedback, we refined our experimental design while maintaining our original hypothesis structure.

Hypothesis

- If amplitude is held constant and the vibration frequency is increased is increased, thereby increasing peak acceleration according to $a_p = (2\pi f)^2 A$, then lunar regolith will detach once the peak acceleration generates an inertial force ($F = ma$) greater than the combined gravitational, electrostatic, and mechanical adhesion forces acting on the particles. Therefore, there will be a threshold peak acceleration which maximizes energy efficiency and effectiveness.

Variables

Independent Variable:

- The peak acceleration, changed by varying frequencies from the function generator

Dependent Variable:

- The threshold acceleration (Peak acceleration Vs. Percentage of dust removal)

Controlled Variables:

- Amplitude of the piezoelectric disk

- Aluminum plate
- Mass of dust (0.8g of coco powder)
- Thin layer of dust applied on plate
- Test duration
- Angle of the plate

Experimental Procedure

1. Connect the FG-200 DDS Function Generator to a power outlet.
2. Using the BNC-to-alligator clip wire, connect the function generator to the piezoelectric disks attached to the aluminum plate. The red alligator clips attach to the red wires on both disks, and the black clips attach to the black wires. If necessary, use wire strippers, and resolder any loose connections.
3. Prepare three metal plates, each with 0.8 g of coco powder.
4. Take one plate and evenly spread the powder across the aluminum plate. Place a white sheet of paper underneath the plate to collect dislodged dust.
5. Set the function generator to 500 Hz. Prepare a timer for 30 seconds.
6. Press “Run” on the function generator and start the timer simultaneously to ensure consistent testing duration.
7. When the timer ends, immediately stop the function generator.

8. Carefully collect the dust that fell onto the white paper and return it to a container on a zeroed weight scale to measure the amount removed.

9. Record the mass removed. Divide this value by 0.8 g and multiply by 100 to calculate the percentage of dust removed.

10. To determine peak acceleration, use the formula:

    $a_{\square} = (2\pi f)^2 A$

    Convert peak-to-peak displacement into amplitude by dividing by two. Convert millimeters to meters by dividing by 1000. Substitute values into the formula to calculate peak acceleration.

11. Repeat the process for the remaining two plates at the same frequency to ensure reliability.

12. Increase the frequency in 500 Hz increments up to 3500 Hz and repeat all trials.

- Now that our hypothesis, variables, and procedure are clearly defined, our final step is to ensure that the electrical system is fully functional so that we can begin formal testing and data collection.

Entry 14 - 01/05/2026

- Despite the continuous testing and troubleshooting, we could not figure out the issue with the electrical component to our model. Rather than give up, we decided to