# Uniform Dust Deposition System for Dust Tolerance Studies

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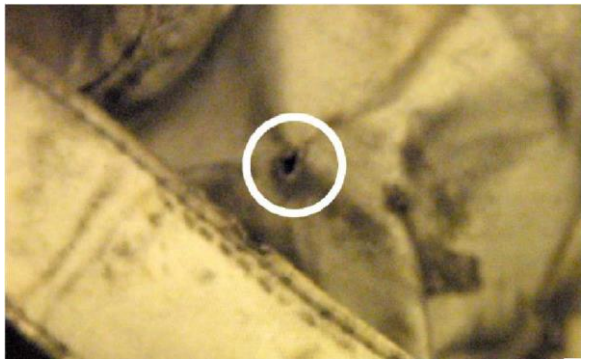
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# Background: The Need for Dust Testing

- Future missions to the Moon will require mechanisms and materials to effectively and reliably operate in the presence of lunar regolith.
- NASA has identified the risks associated with lunar dust exposure as a top concern.
- The abrasive and electrostatic properties of lunar dust can:
  - Obscure optical and thermal radiation equipment.
  - Create extreme wear.
  - Disrupt mechanisms and rotary systems.
  - Compromise critical seals.
- Common methods of dust application are often limited to sprinkling it on targets by hand or with a spoon in an uncontrolled manner.
  - Amount of simulant applied with these methods is not measured, uniform, or repeatable.



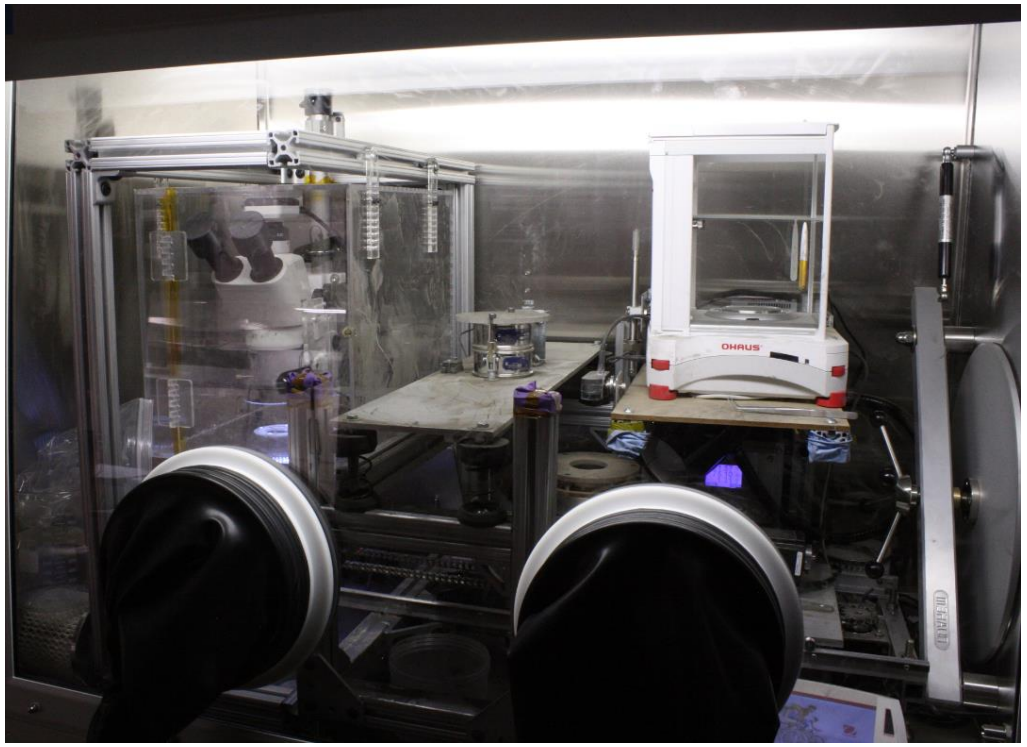
*Apollo 17 pressure garment assembly showing a hole worn through the outer layer above the boot.*



*A7L spacesuit worn on the lunar surface by Apollo 12 LMP Alan Bean.*

# New Dust Deposition System

- NASA GRC has developed the Uniform Dust Deposition System (UDDS) to repeatably deposit a known amount of lunar dust simulant per unit area.
  - Modular design to make system configurable to changing applications.
  - System is in a dry-air glovebox to permit testing at <1% RH.
  - Made of vacuum compatible components.
- Techniques were also developed for preparing, depositing, and characterizing dust simulant.



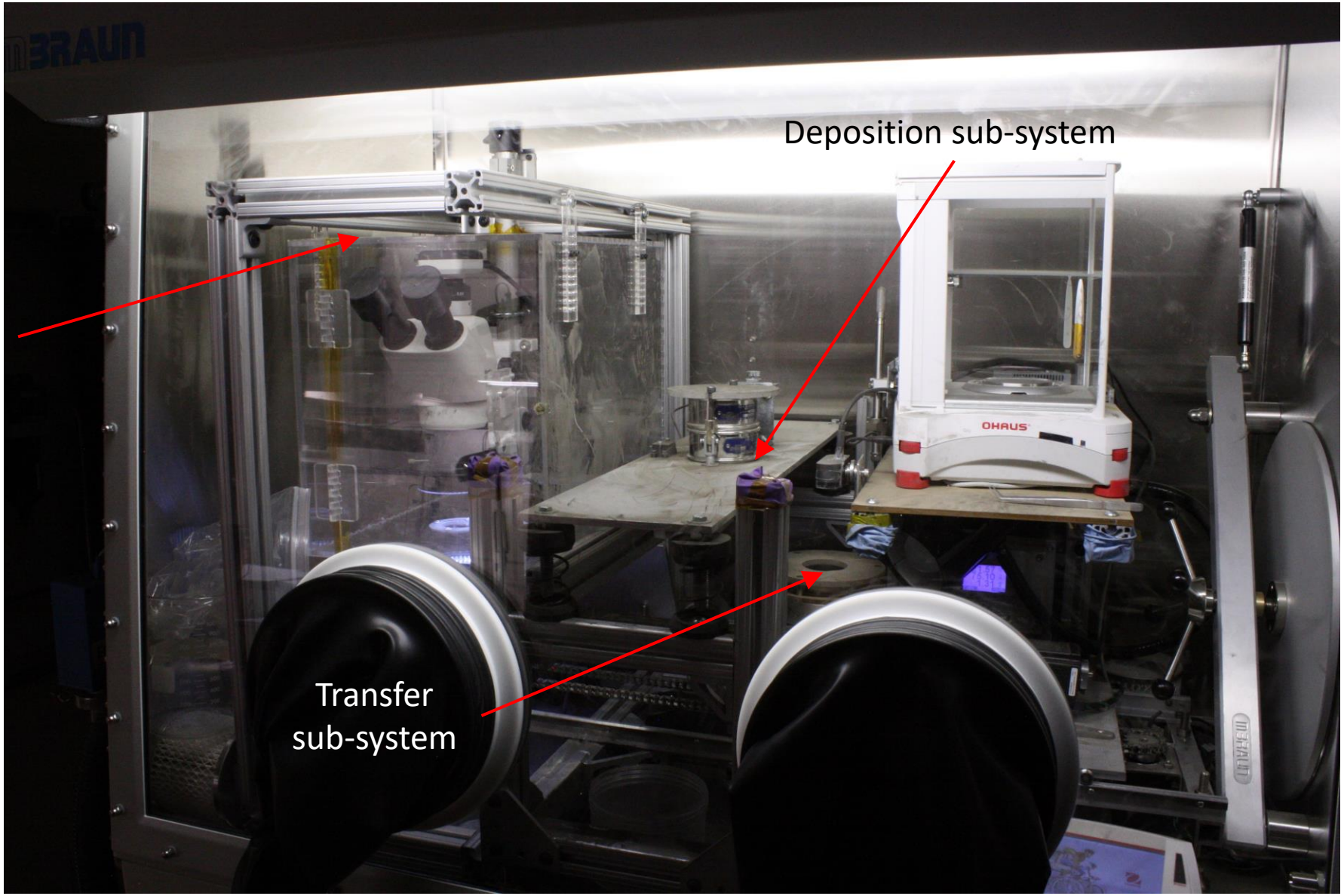

*All-up System Inside Glove Box*

# System Requirements

- The main goal was to produce a reliable, repeatable, and safe technique for depositing dust on target surfaces.
- Accuracy and uniformity of the deposition were two critical design requirements.
- In-depth overview of system requirements and features in NASA/TM-2021-0024128.

| Requirement | Specification |
|---|---|
| Deposition Level Accuracy | ±1.5 mg/cm$^2$ |
| Deposition Uniformity | <20% Coefficient of Variation of percent of area covered |
| Deposition Surface Size | 60 cm diameter (24 in. diameter) |
| Test Article Height | 15 cm height (6 in. height) |
| Atmosphere | < 1% RH |
| Vacuum (Compatibility) | $10^{-6}$ Torr |
| Exposure Control | Glove box |
| Deposition Test Time | < 30 minutes |
| Simulant Size Fraction | 20 µm – 1000 µm |
| Image Resolution | 10 µm |
| Temperatures | Room Temperature (evolvable with heaters and cold plates) |

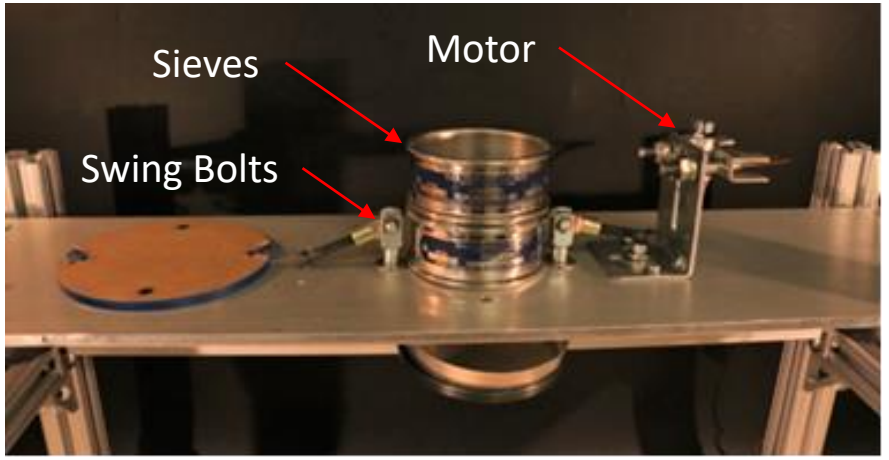
# System: Overview



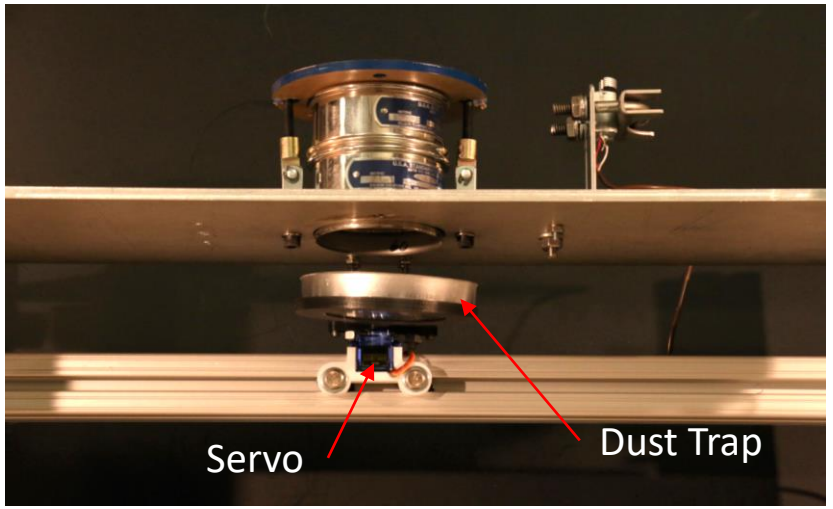
# System Design: Deposition Sub-System

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- Vibration plate holding standard 3” sieves.
- Isolated from system with spring mounts.
- Excited by an eccentric mass motor.
- Dust trap swings out of the way once steady state vibration is achieved.



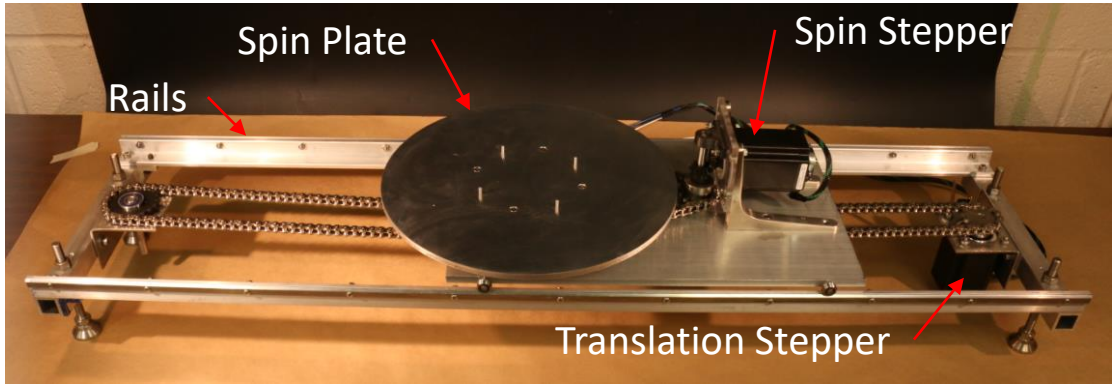

*Vibration Plate Top View*




*Dust Trap*

# System Design: Transfer Sub-System

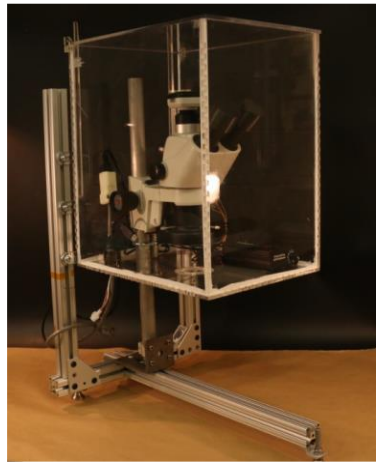
- Accurately positions target surface in a repeatable fashion.
- Uses chain drives for system durability and use in dirty environment.
- Uses NEMA 23 stepper motors on the rotation and translation stages for automation.
- Spin Plate has positioning pins for repeatable alignment of target surfaces.



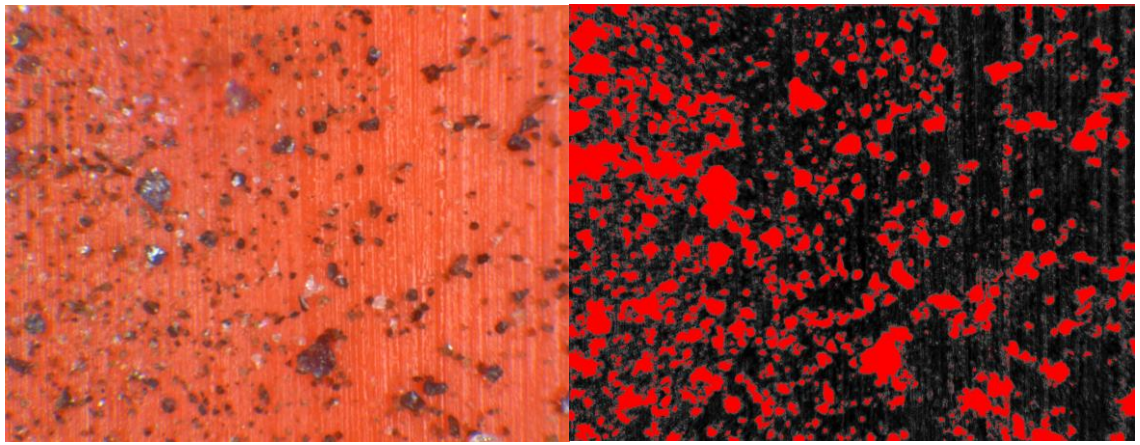

*Transfer Sub-System Outside the Glovebox*

# System Design: Imaging Sub-System

- Inspects target surface and captures micrographs at various locations while it is still inside the dry-air environment of the glove box.
- Uses commercially available stereo microscope (Motic SMZ-171) and camera (Motic Moticam 10).
- Capable of magnification in the 7.5X – 100X range.
- Custom enclosure and stand built for protection from dust with quartz disc under the microscope objective for optical clarity.
- Stepper motor attached to the microscope focus drive to enable z-stepping capability.
- A Z-stack image was taken at the target surface and processed using ImageJ software.

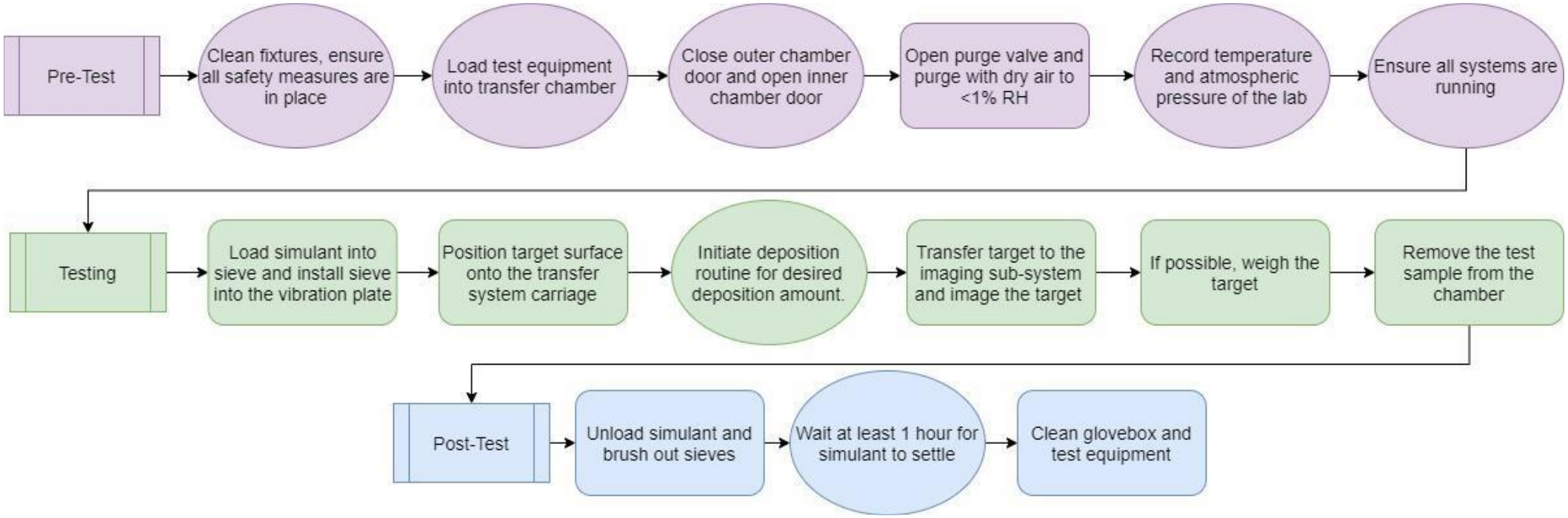


*Imaging Sub-System Outside the Glovebox*



*JSC-1A simulant on silicone rubber at 50X Magnification. Left: Focused Image, Right: Segmented Image.*

# Testing Procedure




- Simulant used in testing is desiccated, rolled, and batched into individual test-sized bins before testing. See NASA-STD-1008 and NASA/TM-2021-0024128 for more details.

# System Verification Testing: Approach

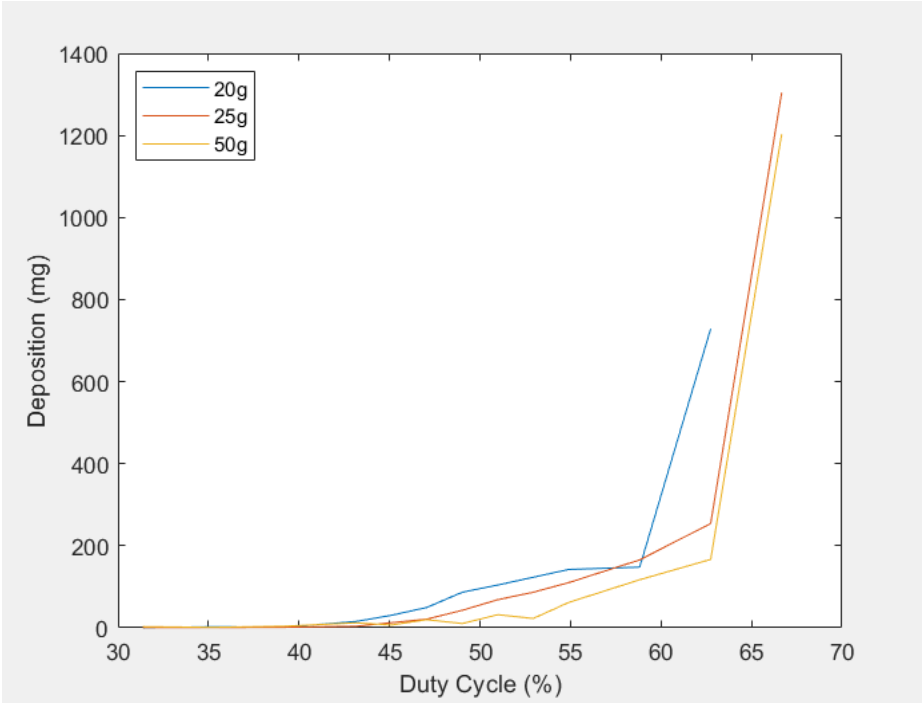
- Objectives:
  - Find harmonic frequencies of vibration system.
  - Determine ideal mass of simulant to load into sieves.
- Overview:
  - Three simulant masses used in testing: 20 g, 25 g, 50 g.
  - Target surface was an aluminum tray with a 5 cm diameter area masked off for deposition.
  - A new sample of simulant (JSC-1A <250 µm particle size distribution (PSD)) was deposited for 10 seconds for every test.
- Test results were ~~are~~ dependent on specific motor and supplied voltage.
- Simulant mass deposited was measured at several duty cycle targets.
  - The duty cycle was defined as the pulse width sent to the DC motor given the maximum motor operating voltage.
  - Increased by 2.5% intervals.



*Fixture for Verification Testing: Tray and Mask with 5 cm Diameter Opening.*

# System Verification Testing: Results

- Harmonic phenomena observed for each simulant mass case.
  - Excitation frequency that resulted in system harmonic frequency between 59% and 63% duty cycle for all three cases.
- Selected 53% duty cycle for future testing since all three mass case deposition curves displayed a moderate linear slope in the region before the harmonic phenomenon was observed.
- A simulant mass of 25g was selected for future testing.
  - Measurable deposition.
  - Widest linear correlation observed.




*Deposited Mass (mg) vs. Motor Duty Cycle (%) [10 second depositions]*
*for Various Sieve Simulant Masses*

# System Validation Testing: Approach

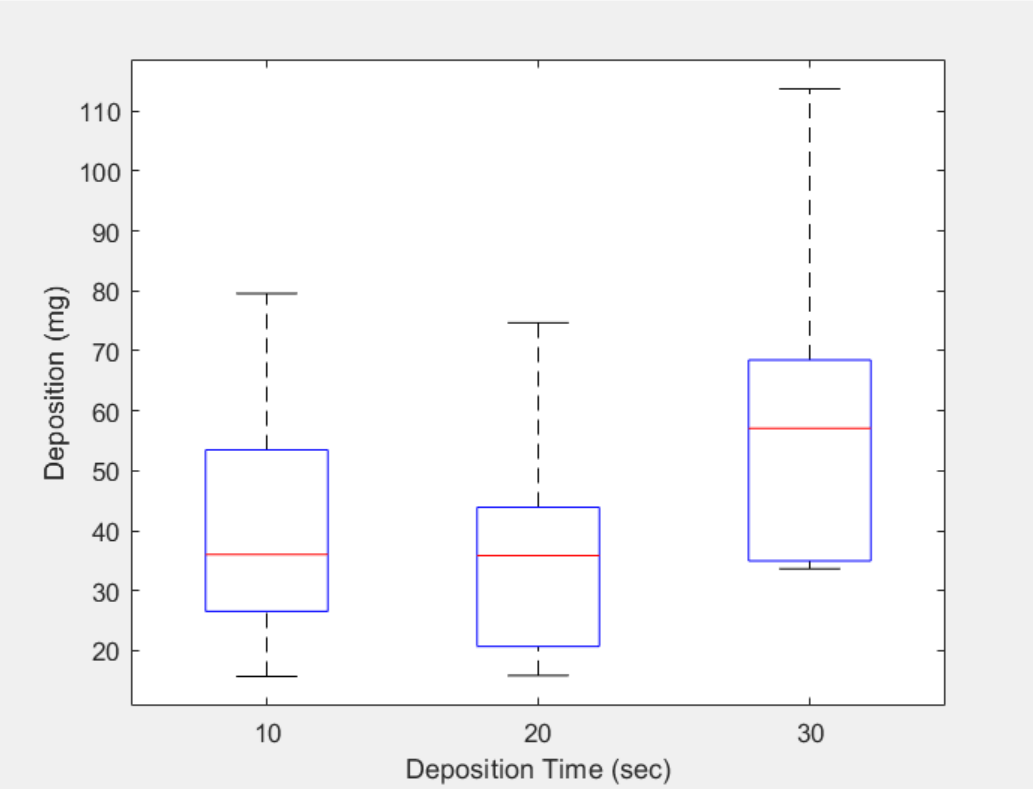
- Objectives:
  - Quantify the accuracy and precision of the system by correlating deposition time to deposition mass.
  - Evaluate deposition uniformity.
  - Relate percent area coverage measured by imaging system to deposition mass.
- Overview:
  - A new sample of simulant (JSC-1A <250 µm PSD) was deposited for every test.
  - Target surface was an aluminum tray with a 5 cm diameter area masked off for deposition.

# System Validation Testing: Single Deposition Results

- First series of tests included single runs for deposition times of 10, 20, and 30 sec.
- Simulant mass deposited varied.

| Deposition Time (s) | Standard Deviation (mg) |
|---|---|
| 10 | 18 |
| 20 | 17 |
| 30 | 24 |

- Range of mass deposited overlapped for the different deposition times demonstrating a weak correlation of deposition time to mass deposited.



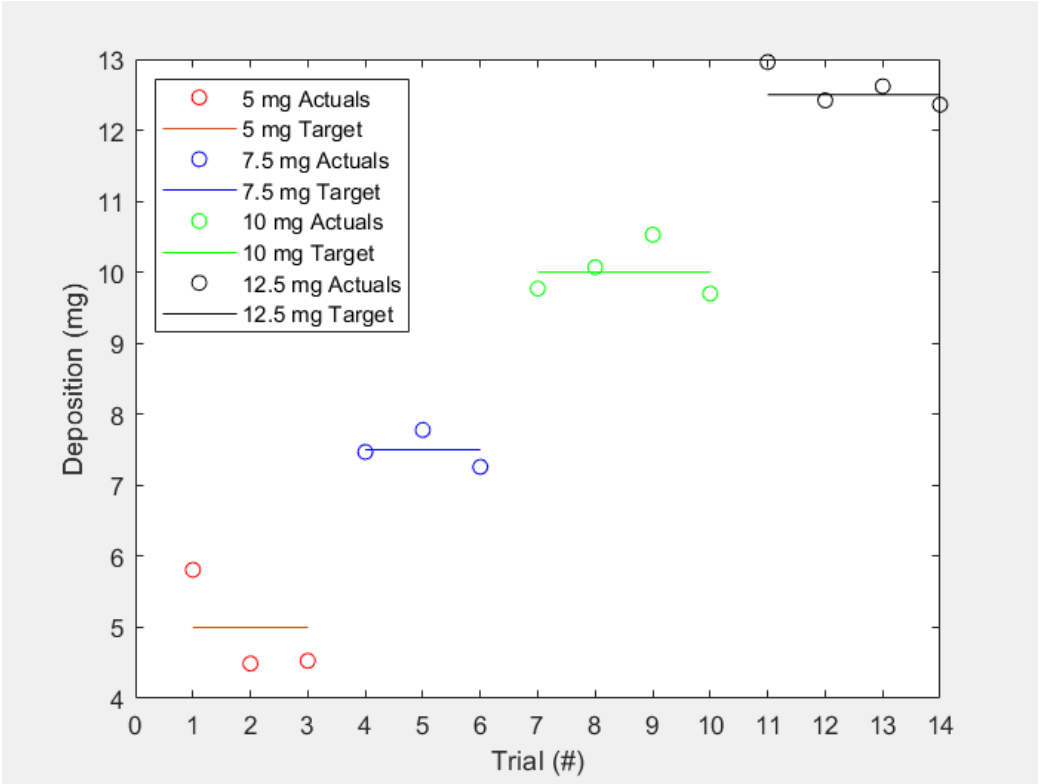

*Accuracy Testing: Box and Whisker Plot of Deposited Mass Trials for Three Deposition Times, Single Deposition Run*

# System Validation Testing: Multiple Deposition Results

- Second series of testing:
  - Multiple depositions were run to achieve a target deposition mass.
  - 3-4 repeat tests were performed at each target mass.
- Actual mass deposited for each test was close to the target mass.

| Target Mass (mg) | Standard Deviation (mg) |
|---|---|
| 5 | 0.613 |
| 7.5 | 0.213 |
| 10 | 0.327 |
| 12.5 | 0.234 |

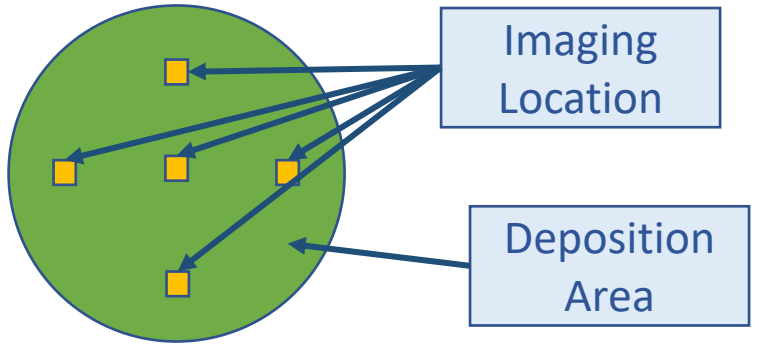
- This process will work well for small test articles that can be weighed on a mass scale but will be harder to implement for larger test articles.




*Accuracy Testing: Deposited Mass Trials with Multiple Deposition Runs*

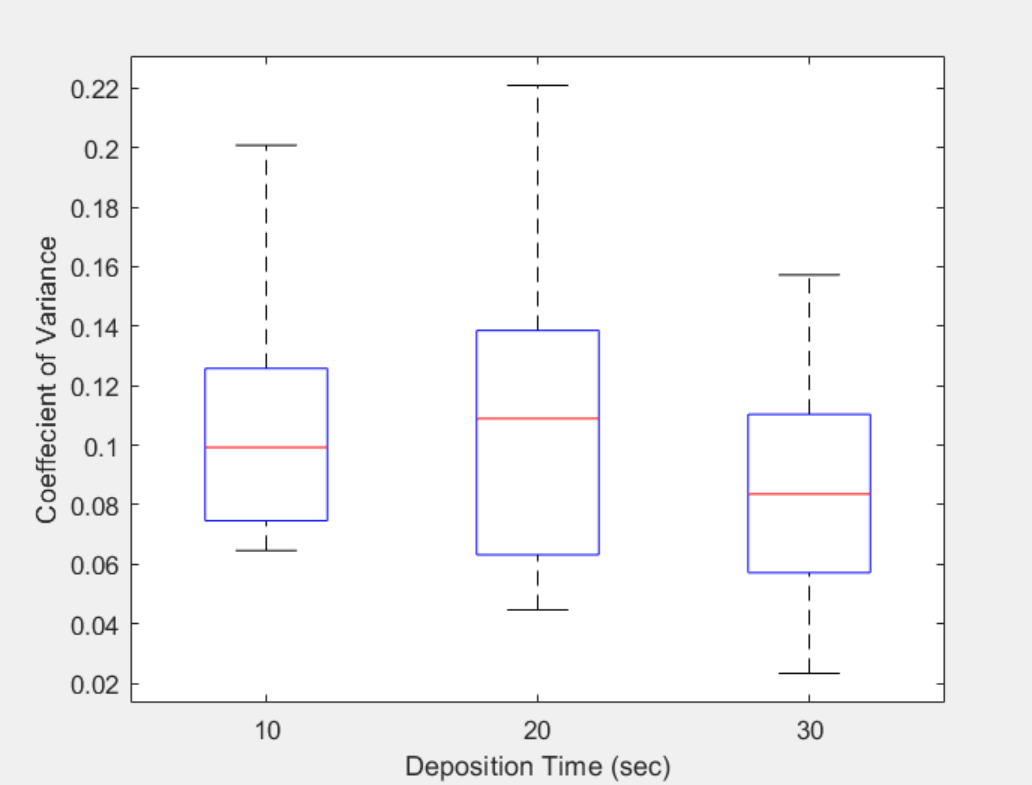
# System Validation Testing: Image Analysis Approach

- Third series of testing:
  - Using the imaging sub-system, an analysis technique was developed to characterize amount of dust on seal and obtain a correlation between percent coverage and actual mass of deposited simulant.
  - The goal was to develop an analysis technique that could work for targets of all sizes.
- ImageJ software was used to process the images.
- Approach:
  - Image stacks were taken at five locations.
  - 3-4 repeat tests were performed at each target mass.



# System Validation Testing: Image Analysis Results

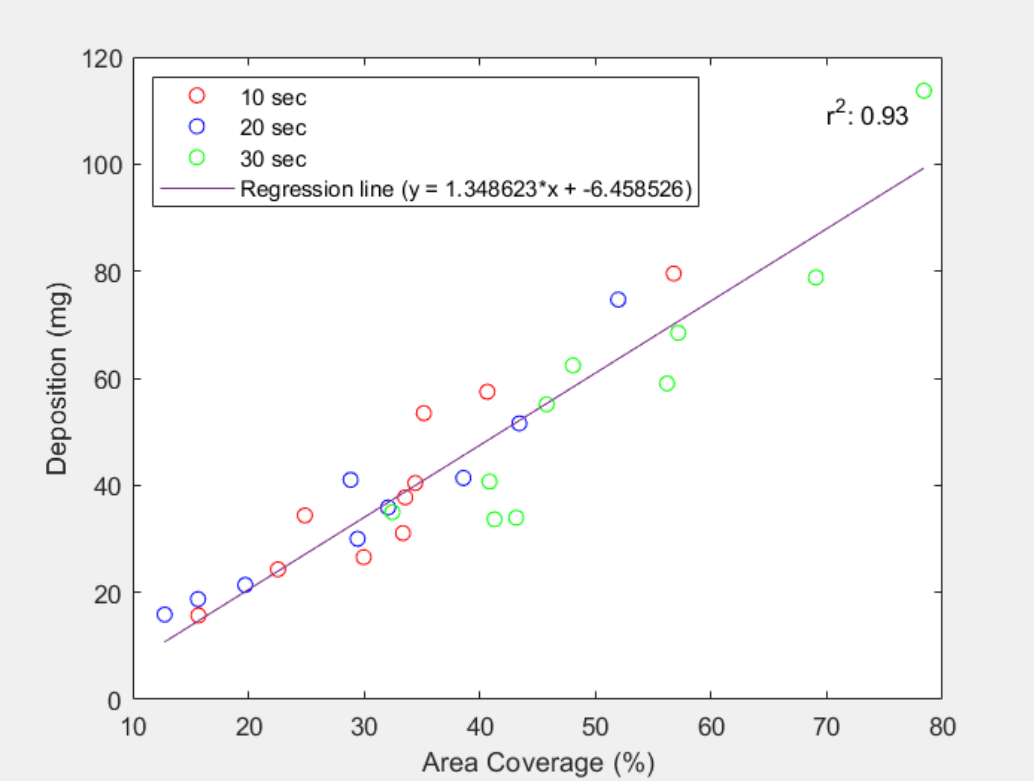
- Percent area coverage was calculated at each location for each test.
- The Coefficient of Variance (CV) of the percent coverages for each trial was used as a measure of uniformity.
- Low CVs indicate very uniform deposition throughout the trials independent of deposition time.




*Box and Whisker Plot Showing Coefficients of Variance for Various Percent Coverage of Trials for Three Deposition Times*

# System Validation Testing: Image Analysis Results

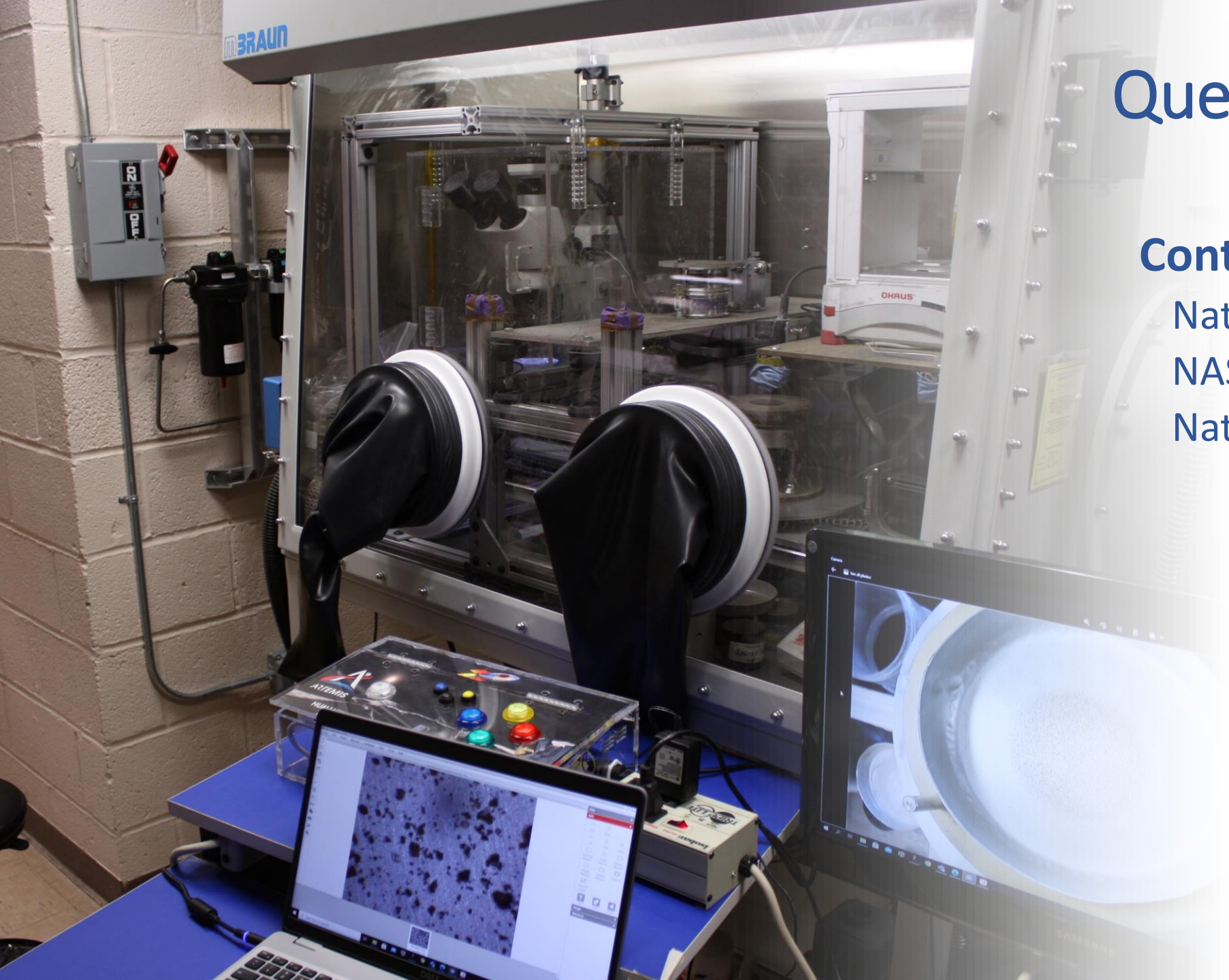
- Correlation of deposited mass to average percent coverage was shown to have a coefficient of determination ($R^2$ value) of 0.93.
- This demonstrated the ability to predict how much simulant was deposited on a surface using imaging alone to measure percent coverage (important capability for larger test articles).




*Imaging Precision Results, Mass vs. Percent Coverage*

# Conclusions and Forward Work

- The UDDS was developed at NASA GRC to provide repeatable, uniform, and automated deposition of simulants on surfaces of interest for dust mitigation testing.
- The system is capable of depositing simulants on test articles up to 60 cm in diameter and 15 cm high in a dry air environment with less than 1% RH while keeping users safe from aerosolized dust.
- Verification and validation testing of the system has shown that:
  - Image analysis can be used to accurately predict the amount of dust on a surface from images alone ($R^2 = 0.93$).
  - The coverage of dust on the surface has been shown to be uniform ($CV < 0.11$).
  - The current accuracy of the system for single deposition runs meets the system requirement that was defined but is less accurate than desired at 0.889 – 1.213 mg/cm$^2$.
    - Accuracy can be improved to 0.076 – 0.227 mg/cm$^2$ by performing multiple deposition runs to build up to a desired level of deposition where possible.
- Forward work:
  - Improve single run deposition accuracy.
  - Improve deposition time to deposited mass correlation.
  - Develop system inside a vacuum chamber.




# Questions?

## Contact Information

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