Inertial Centrifugal-Based Pre-filter for Spacecraft Life Support Systems

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Whitwam, R. (2019, September 24). NASA Hires Lockheed Martin to Build up to 12 Orion Spacecraft

Background

- Lunar dust has potential to cause serious health hazards for astronauts
- Future missions will be longer than ever before
- Dust contamination levels in a lander could potentially he high
- Particles remain airborne in microgravity





Jenner, L. (2019, November 5). NASA's Coating Technology Could Help Resolve Lunar Dust Challenge.

NASA photo AS11-40-5877

Lunar Regolith

- Regolith- A layer of loose, heterogeneous superficial deposits covering solid rock
- Result of bombardment of micrometeorites melting and breaking up soil
- Adhesion and surface charge properties can cause dust to collect on surfaces, fabrics (space suits), and gaps and cavities (seals, bearings)
  - Dust on space suits could be carried into the main cabin, which has happened on past missions
- Lunar dust may cut through vacuum seal if accumulated
- Grain size distribution
  - 90% < 1mm
  - 50% < 100µm
  - 10% < 10 µm



Jones, E. (2015, September 16). Using Munsell Color Charts to Classify Apollo Lunar Soil Core Samples.

Project Mission

- Remove bulk particulate matter out of air stream prior to HEPA filtration.
- Design a solution that is:

a) Lightweight

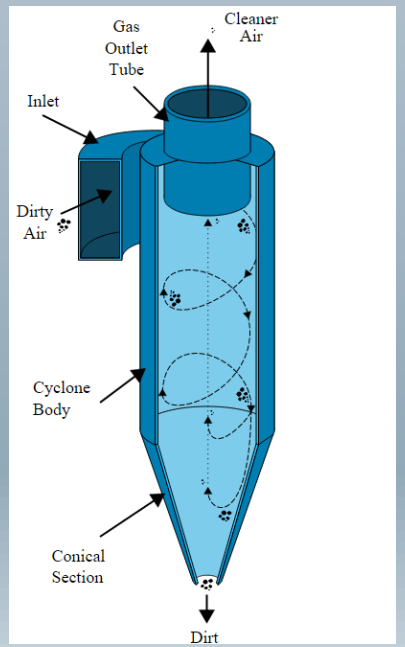
b) Regenerable
   a) Reusable

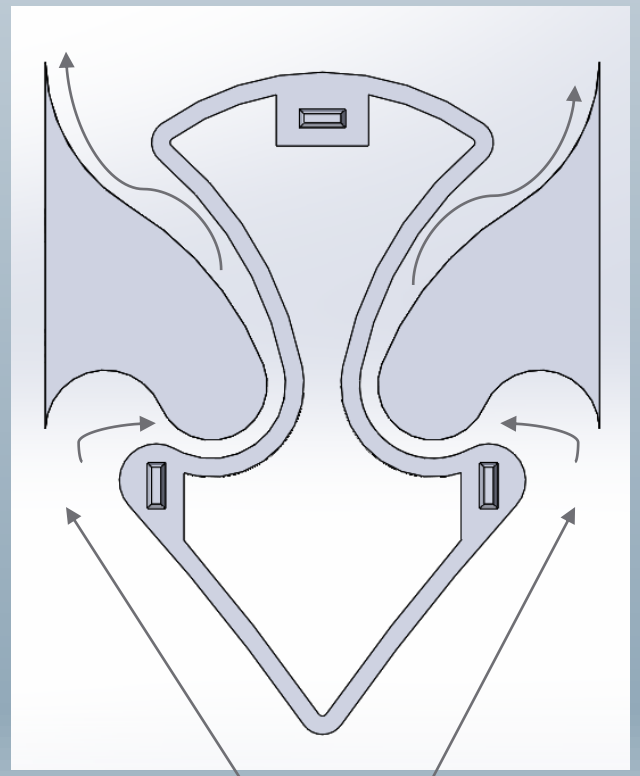
c) Efficient
   a) Effectively removes particles

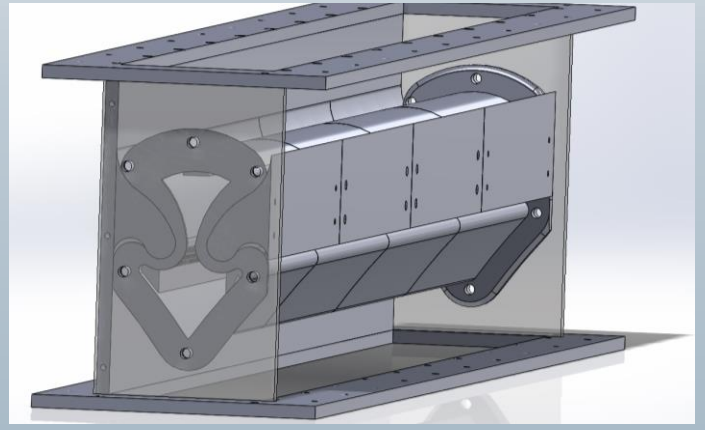
d) Low Power
   a) Minimal pressure drop

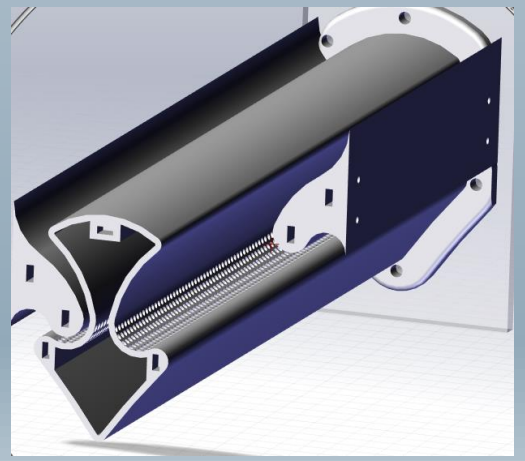
Proposed Solution: Inertial Air Filter

- Separates more massive particles from air stream
- Channels and redirects flow
- Perforated inner curve
- Central collection chamber



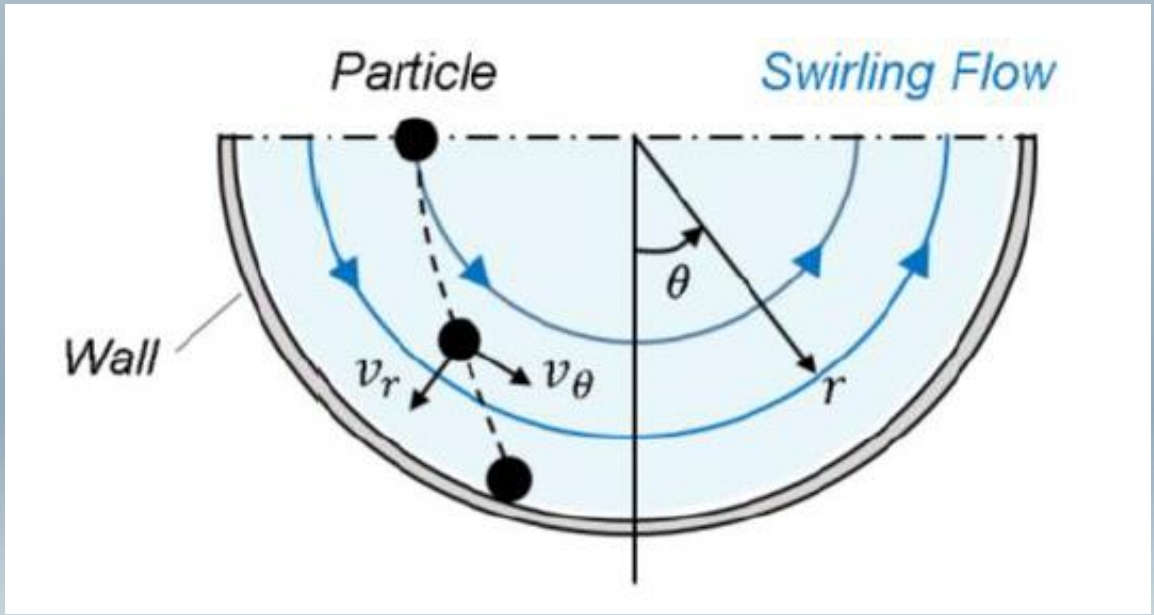






How it works

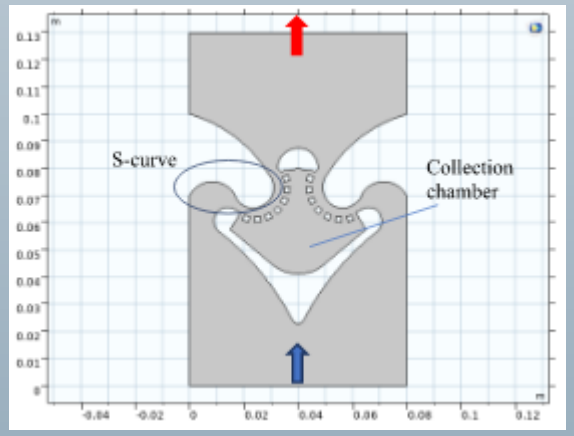
- Acceleration of flow
- Quick redirection of flow
- Inertial properties of more massive particles will resist radial acceleration of particles, instead they will continue to move more tangentially.
- Centrifugal forces cause particles to accelerate away from the center of rotation



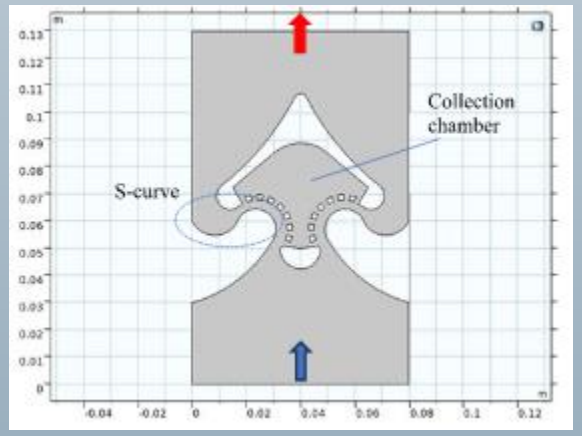
Disotell, Kevin J., (2019, August 8), Vortex- Based Inertial Particle Separation for Gas Cleaning

Possible Geometric Designs

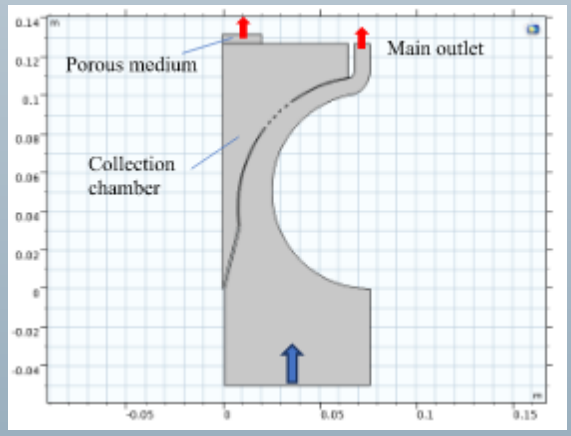
Symmetric Model



Inverted Symmetric Model



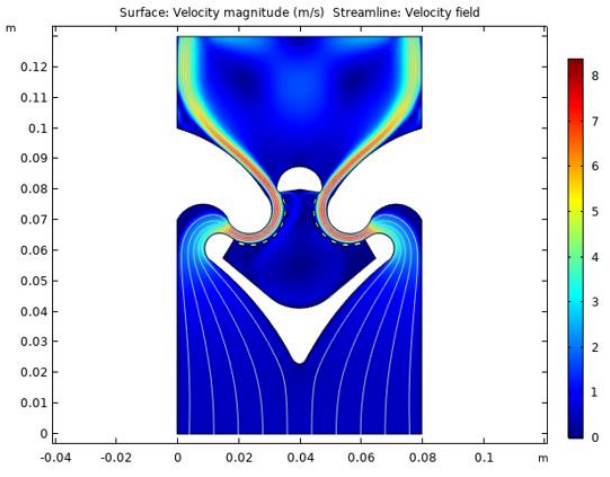
Asymmetric Model



CFD Testing – Velocity

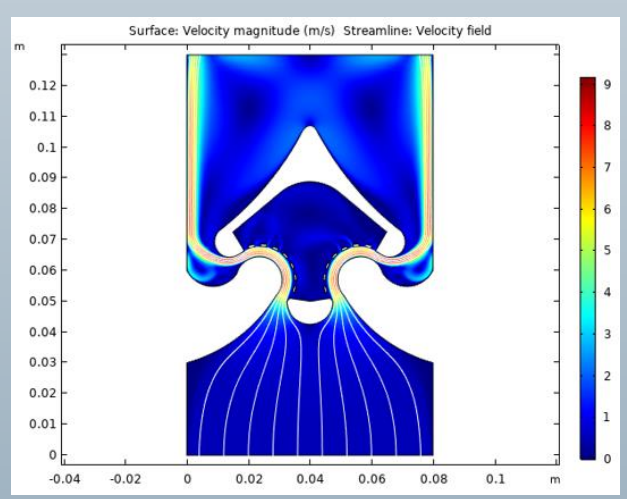
(Computational Fluid Dynamics)

Symmetric Model



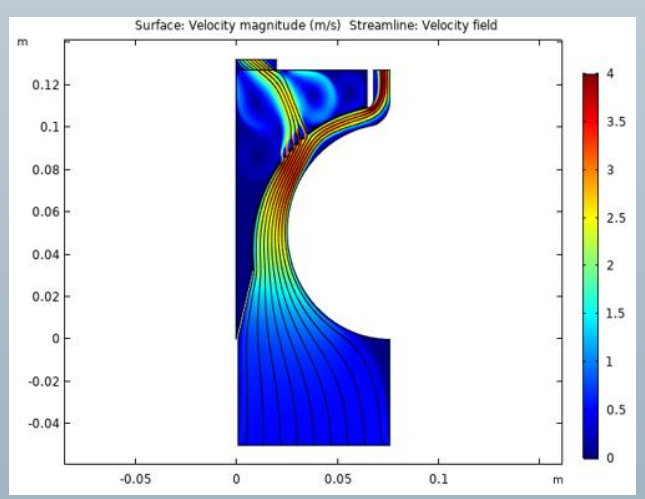
- Max velocity : 8 m/s
- Max Centripetal Acceleration: 7000 m/s^2

Inverted Symmetric Model



- Max velocity : 9 m/s
- Max Centripetal Acceleration: 8000 m/s^2

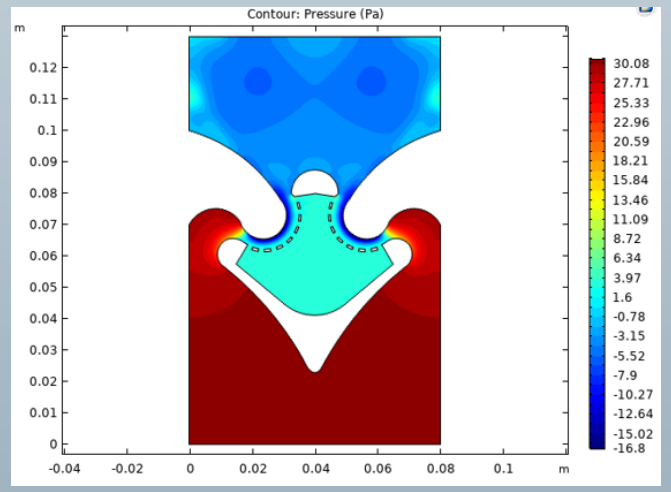
Asymmetric Model



- Max velocity : 4 m/s
- Max Centripetal Acceleration: 320 m/s^2

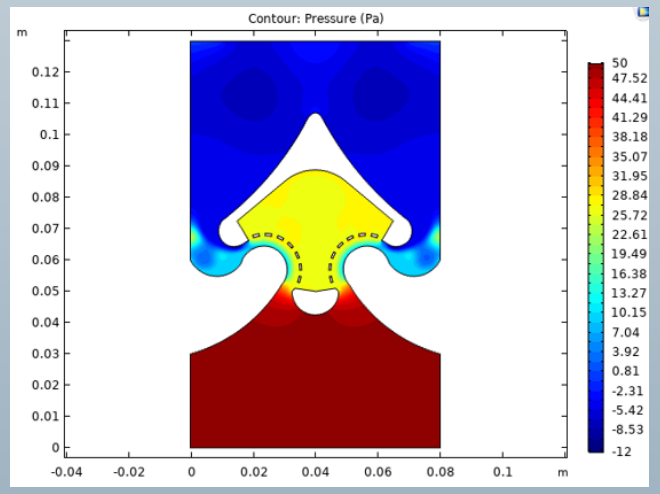
CFD Testing – Contour Pressure

Symmetric Model



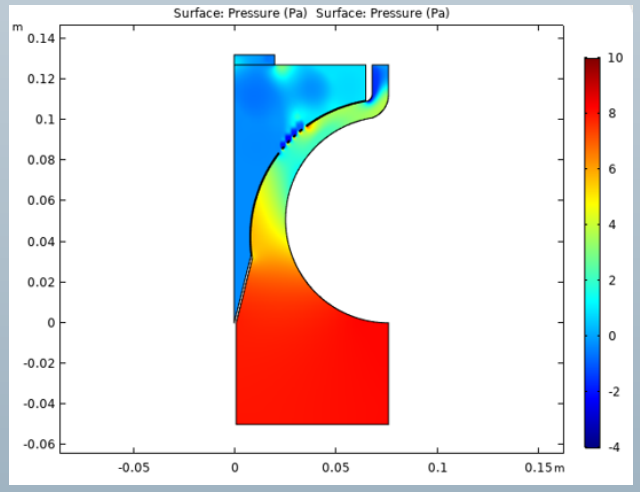
- Max Pressure: 30.08 Pa

Inverted Symmetric Model



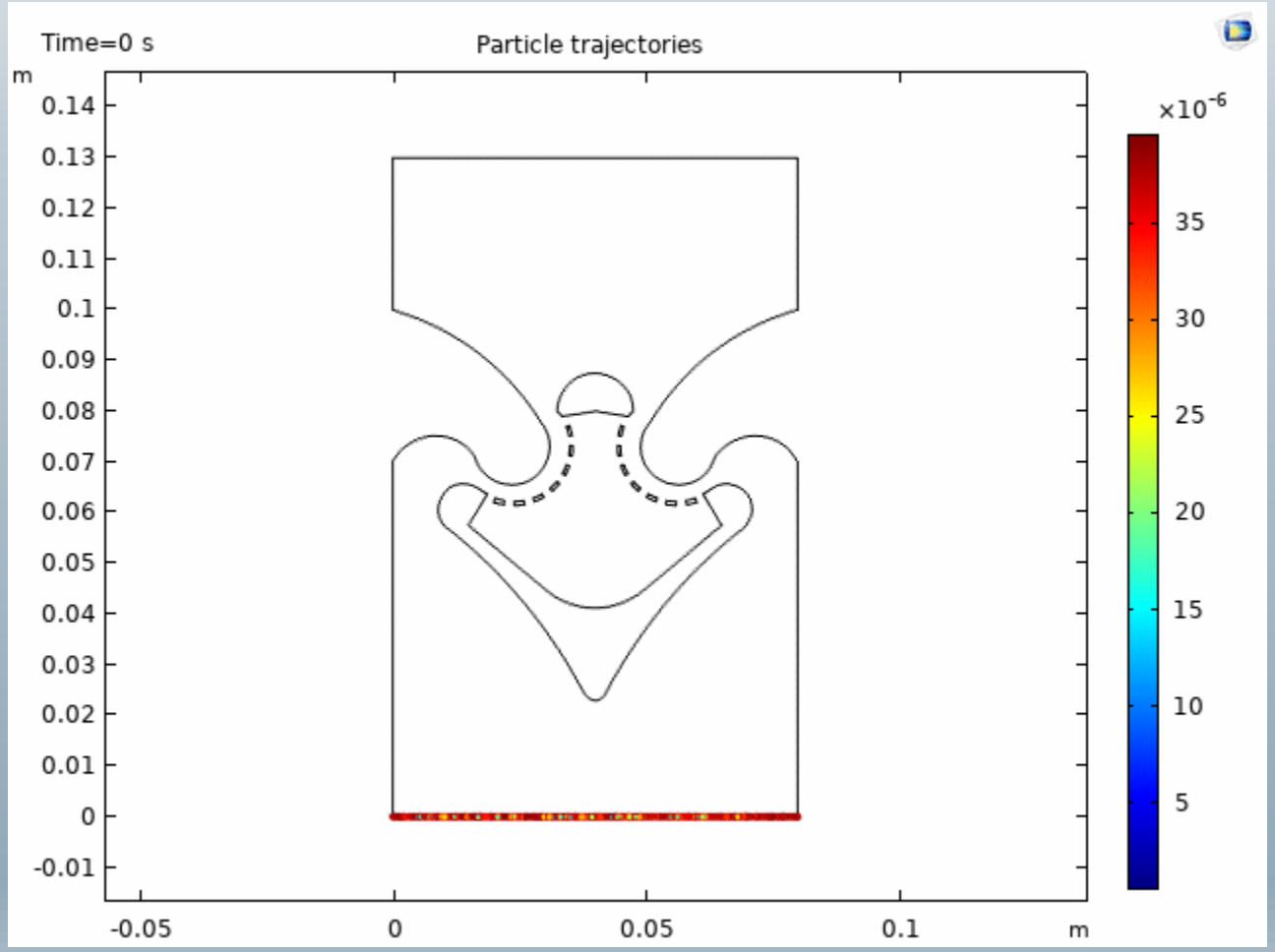
- Max Pressure: 50.0 Pa

Asymmetric Model



- Max Pressure: 10.0 Pa

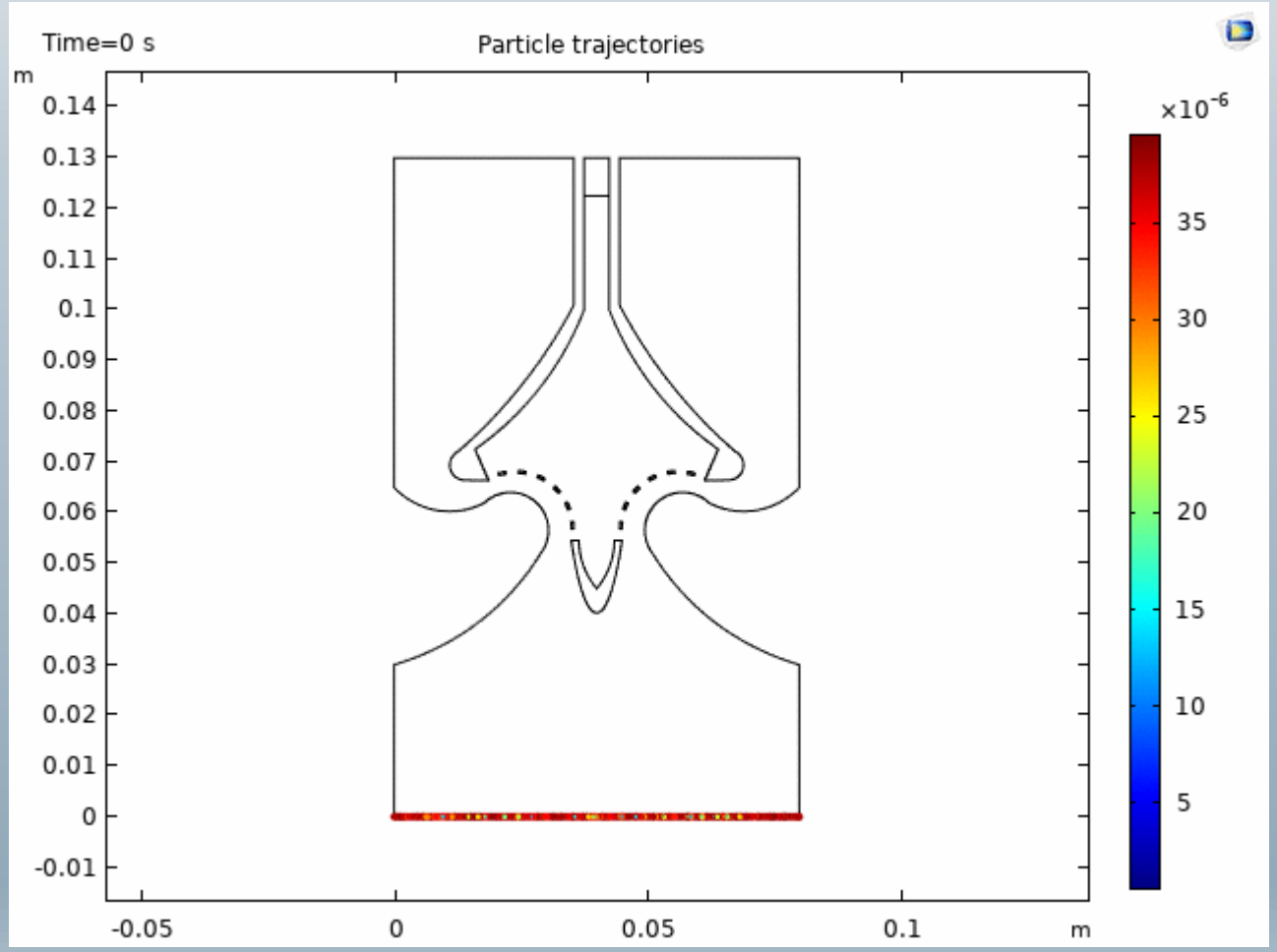
CFD Testing – Particle Tracing



Symmetric model

- Buildup can be seen in the first corner prior to reaching collection site
- Larger particles leave collection chamber due to non-stick surface conditions
- Opposite from desired results with given surface conditions

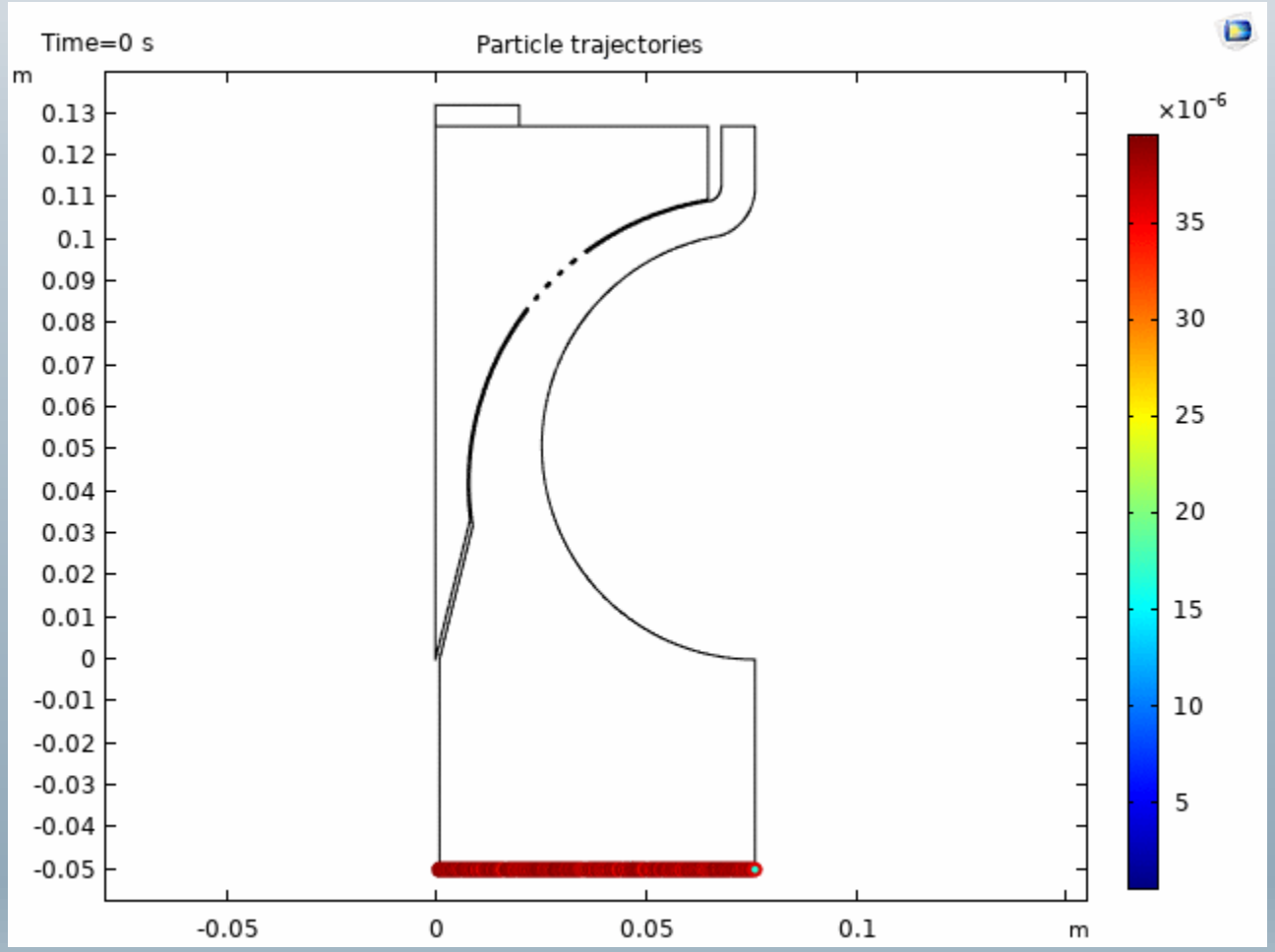
CFD Testing – Particle Tracing



Inverted symmetric model

- Effectively captures most particles between 5µm and 40µm
- Porous medium added to end of collection center to channel flow
- Internal circulation helps prevent the escape of particles

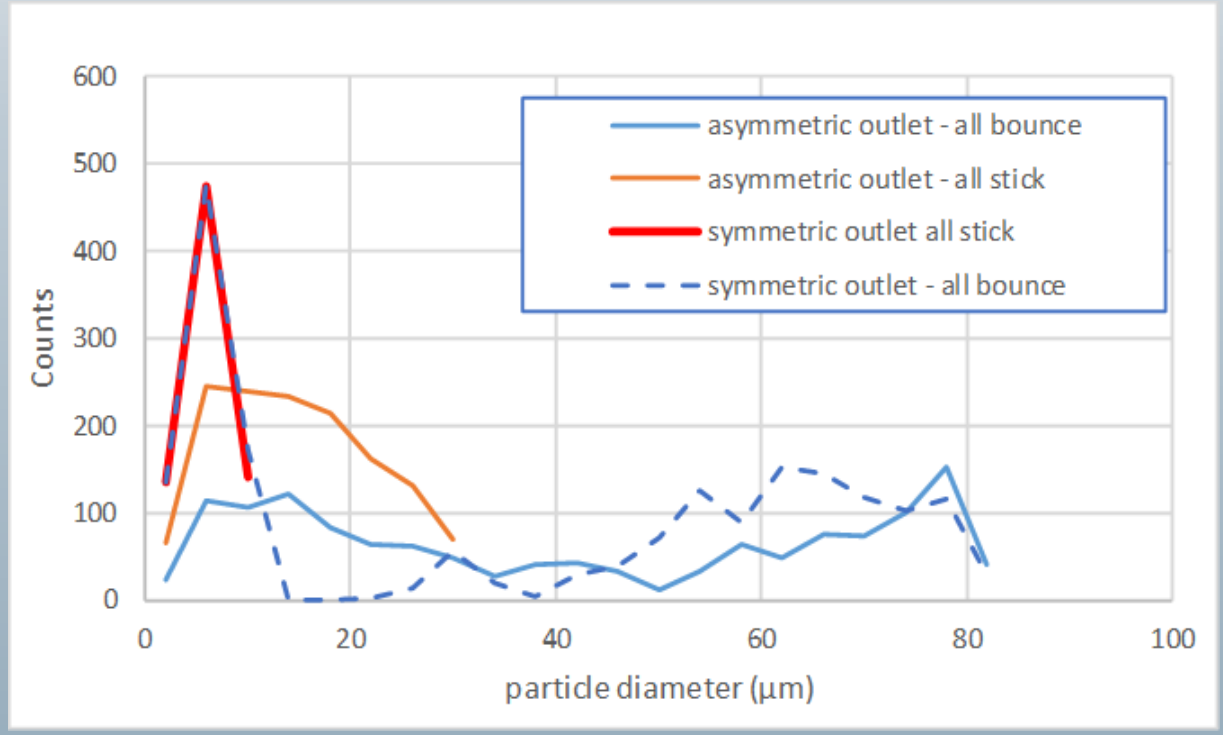
CFD Testing – Particle Tracing



Asymmetric model

- Collects majority of particles larger than 25μm
- Allows some particles of all sizes to pass through unfiltered

Particle Tracing - Results



Particle Tracing - Results

Geometry	Wall condition (Energy required to bounce) J	comment	partilce diameter μ	outlet (%)	corners (%)	collection chamber (%)	porous medium inlet (%)	walls (%)
symmetric	0.E+00		5 - 77	18.92	0	0.26		
symmetric	2.E-10		5 - 77	7.51	58.53	1		
symmetric	6.E-10	Max (all stick)	5 - 77	7.51	58.48	0.99		
symmetric inverted	2.E-10		5 - 77	10.29		31.62		
symmetric inverted	6.E-10	Max (all stick)	5 - 77	8.28		18.07		
asymmetric	0.E+00		5 - 77	32.09		59.78	59.51	0
asymmetric	1.E-11		5 - 77	26.44		58.69	36.2	13.58
asymmetric	3.E-11		5 - 77	23.45		45.64	23.76	17.33
asymmetric	5.E-11		5 - 77	18.7		40.48	19.67	24.93
asymmetric	8.E-11	Max (all stick)	5 - 77	13.61		25.75	14.79	43.77
asymmetric (no gravity)	0.E+00		5 - 77	29.35		55.58	55.46	1.41
asymmetric (no gravity)	8.E-11	Max (all stick)	5 - 77	13.34		26.05	14.09	44.38

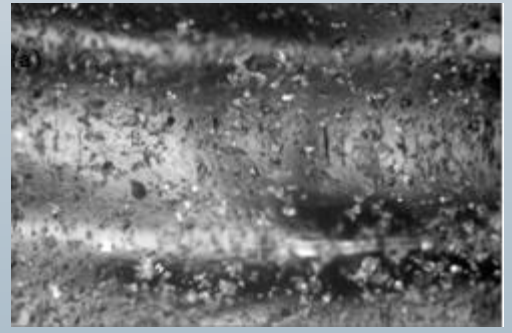
Surface Testing

- Material: Lunar Simulant (JSC-1aF)
- 3D printed coupons for anti-static coating testing
- Surface adhesion testing

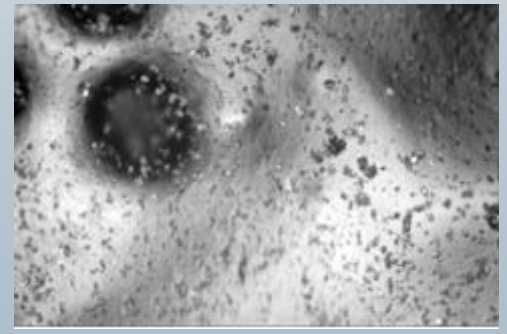


3D Printed Coupons and Lunar Simulant

Test 1: 1 layer glossy point vs 2 layers

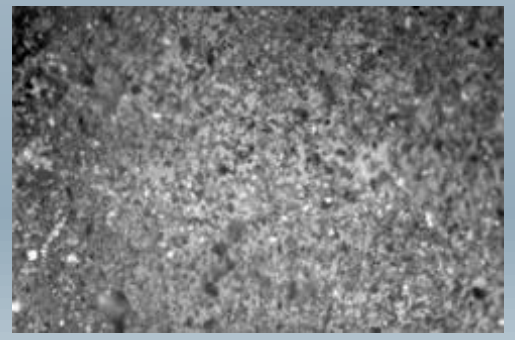


1 layer

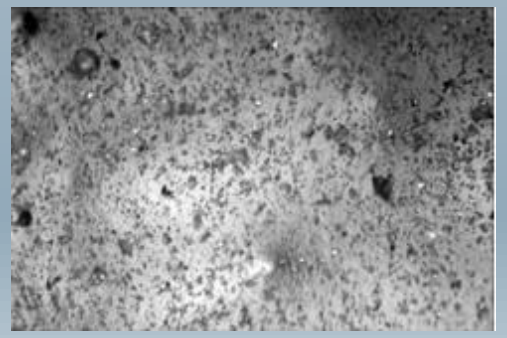


2 layers

Test 2: 2 layers glossy point vs 3 layers



2 layers



3 layers

Prototyping

- Material: Onyx
- Outer casing being manufactured
- 28 inches long X 3 Inches wide
- Perforated inner wall





Prototype for Asymmetric design still needed for physical testing!

Conclusions

- Further testing is required for application of inertial separation on future manned missions
- Computational Fluid Dynamics (CFD) and particle tracking provided a high degree of detail and performance characteristics on which to base a design for prototype and testing
- The tested models show promising results, and will continue into physical testing

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Future Work

- 3D printed prototyping of all viable designs
- Vacuum flow loop aerosol testing
- Exploring additional surface finishes and geometric designs
- Introducing field-induced (e.g. electrostatic) forces to improve particle separation

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