Particle Loading Tests on HEPA Flat Sheet Media at Sub-Ambient Pressures Using a Lunar Dust Simulant

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Background

Environmental Control and Life Support System (ECLSS) architectures in the Human Landing System (HLS) and the Gateway Habitat and Logistics Outpost (HALO) will use HEPA filters to control lunar dust contamination

Scenario: Lunar dust first enters the HLS which then docks with the Gateway -

- Crew and equipment will generate airborne lunar dust particles through the vestibule and hatch
- HALO Inter-module Ventilation (IMV) filters will process initial dust, and the Cabin Air filters will remove remaining dust to meet air revitalization requirements.

Implications

- There exists a significant gap in knowledge regarding the capability to control and contain the transfer of lunar dust onto the Gateway, and this is a program risk.
- Air filtration is the first line of defense in this effort, and its success will prevent extensive contamination of the Gateway habitable volume

Background

The Artemis program needs to perform evaluations and testing to determine the extent of the issue and determine the best means of managing dust intrusion

<u>Approach</u>

- **Testing of HEPA and other high efficiency filter media using lunar simulants and expected cabin pressures**
  - NASA GRC has unique testing facilities tailored for simulated lunar dust filtration testing
  - A multi-phased approach to test/evaluation from flat sheet filter media to full size pleated elements is adopted (flat sheet media testing is the focus of this presentation)
  - Results will inform the HALO and HLS contractors in their filtration system designs

- **Test objectives:**
  - pressure drop vs loading
  - filter efficiency vs loading

Filter media dust loading

Current knowledge and gaps

References

- Estimates of lunar dust transfer into lander cabin
  - 50 g/EVA/crewmember (Dust Mitigation Stakeholders Working Group)
  - The lunar dust will become airborne in the cabin

- ISS
  - ISS Bacterial Filter Elements (BFE's) loading capacity 32 g. (maximum allowed, Perry, NASA/TM—2005–213846)
  - Surface loading 0.69 mg/cm^2 (~4.7 m^2 total surface area, calculated)
- Industry
  - 4.2 - 28 mg/cm^2 @ up to 5 kPa pressure drop (McCormack et al., 1978)
  - Linear increases in pressure drop up 2.2 mg/cm^2 for up to 2 kPa pressure drop (Novack et al., 1992)

Implications/Questions

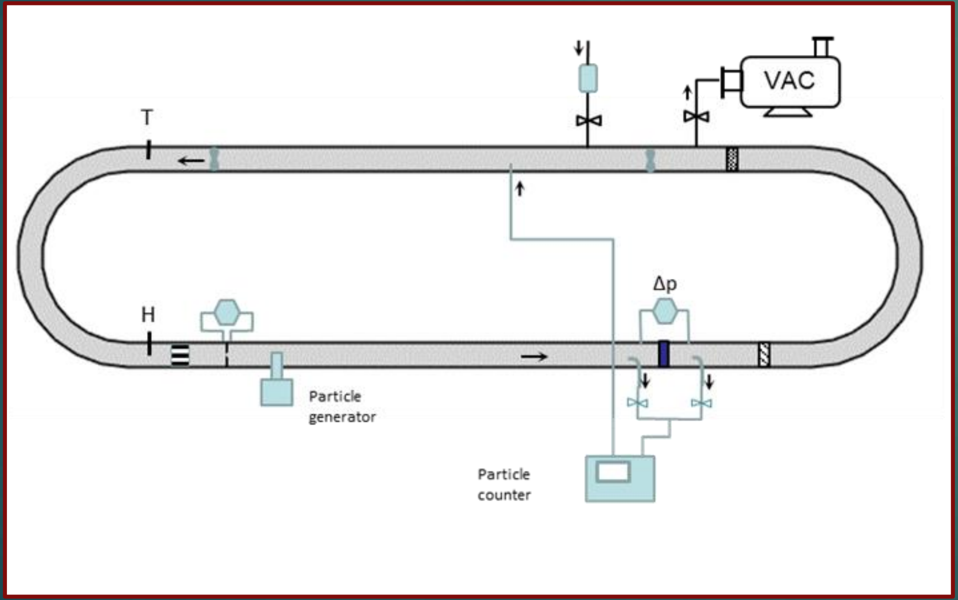
- What are the effects of lunar dust properties on filter media?
- Will Reduced gravity and microgravity result in larger suspended particle loads?
- Scarce data on HEPA media performance at reduced pressures.
- Lunar dust loading may exceed capacity of HEPA filters
- Are studies needed to inform maintenance strategy for cleaning filters and spares?

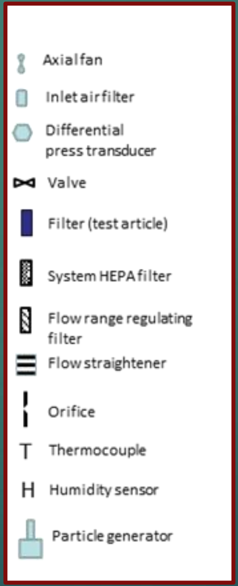
GRC Filtration Flow Loop

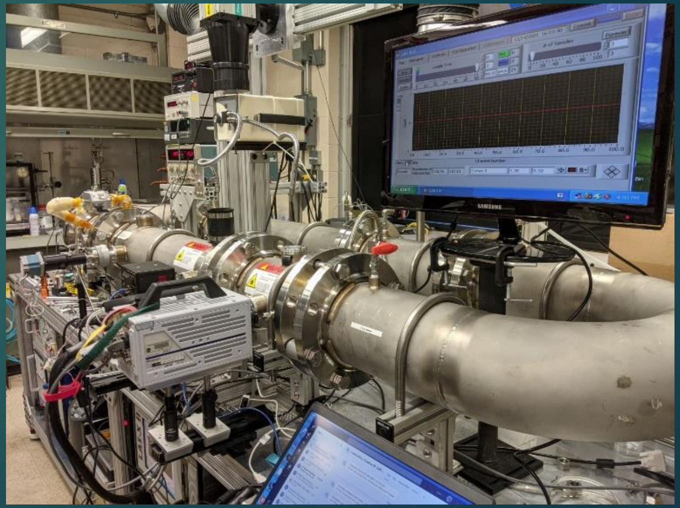
GRC Filtration Flow Loop

Measurements with test media
- Delta pressure
- Particle counts upstream and downstream
- Accurate mass accumulated on sample

Capabilities include
- Constant air pressure from .056 MPa to .101 MPa (Can also go to single Torr values, e.g. Martian atmospheric pressure)
- Flow velocities of 0 – 0.5 m/s (no load), flat sheet test velocity is 3 to 10 cm/s (depending on media type)
- 15.2 cm (6 inch) internal diameter can adapted to various sizes of filter-cross-sections.







Materials and Methods

Material/Method	Description	Range/Spec/Comment
Simulant	JSC-1af	Orbitec
Filter grade	HEPA	H&V HB media (99.985 % efficiency at 0.3 micron DOP)
Dust Feeder	Custom in-situ particle generator	Solid powders (any size)
Mass	Microbalance for collected dust	0.1 mg increments
Particle sizer and counts/concentration	Particle Measurement Systems LAS-XII (100 channel optical particle counter)	particle size distribution from 90 nm to 7.5 µm
Flow rate	Lambda Square Oripac orifice with MKS 0.1 inch H2O MKS transducer	Beta ratio 0.283 (0.2 also available). Calibrated by Rick Munns Co. (3rd party lab)
Differential pressure	MKS capacitance based	0.1 in H2O (orifice) 5 inch H2O (filter pressure drop)
Humidity	Honeywell (HIH-4000)	0 – 100% RH
Temperature	Type K	Ambient temperature (20º to 30º C)
Data acquisition	NI 6323 (16 bit)	For system pressure, pressure drop, temp, RH
Flow visualization	Photron High Speed camera, Halogen Fiber Optic light source	Photron 1024 PCI

Materials and Methods

General test conditions shown

- Temperature is not controlled, but typically 22 – 26 ^{o}C.
- Relative humidity will only be measured and not controlled
- Percent oxygen content will remain constant during all test pressures

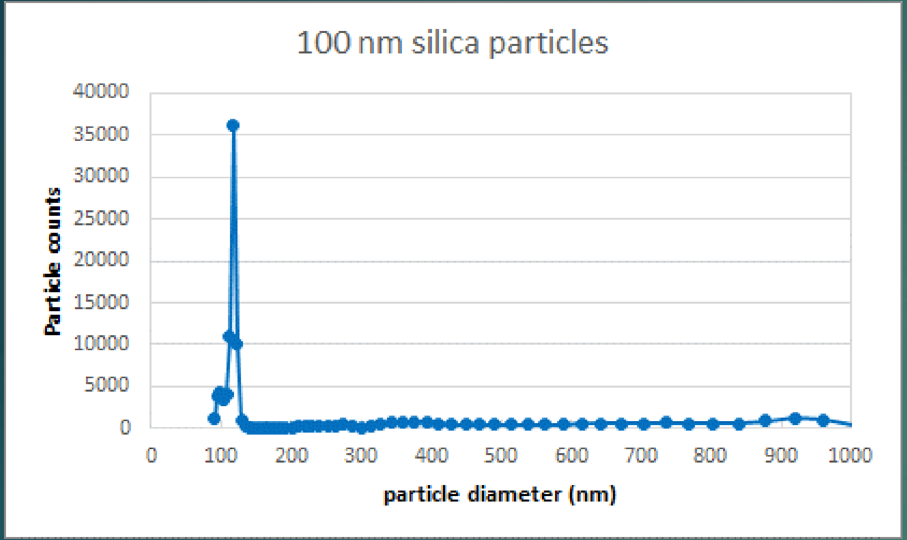
Test parameters

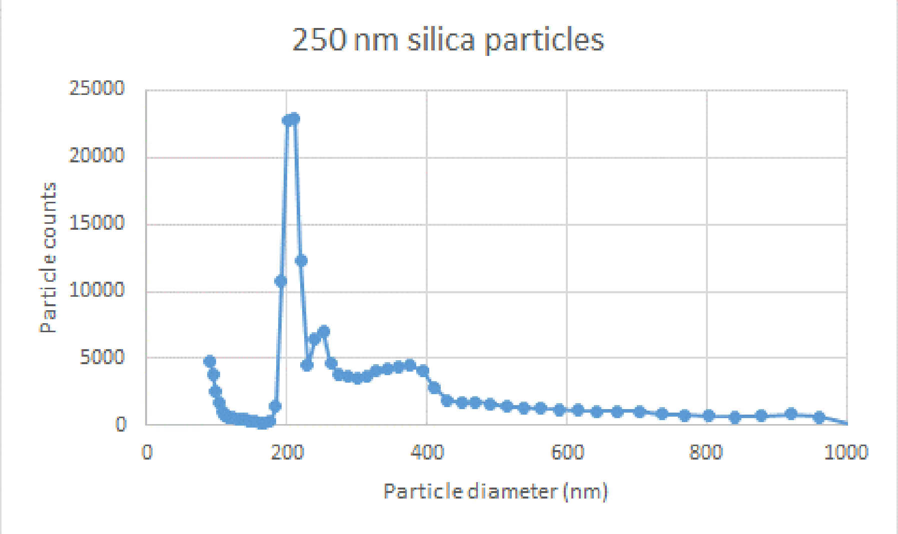
parameter	Value/setting	Units	Comments
Average Filter Face velocity	5.3, 7	cm/s	Based on nominal and 50% above the nominal flow rates
Operating Pressure	0.0565, 0.703, 0.101 (8.2, 10.2, 14.7)	Mpa (psia)	
Temperature	22-26 (72-79)	^{o}C (^{o}F)	
RH	22-40	%	Only measured
Dust Feed rate	variable	g/cm^3	Device setting
Sampling rate	10	Hz	Δp, Q, temp, RH

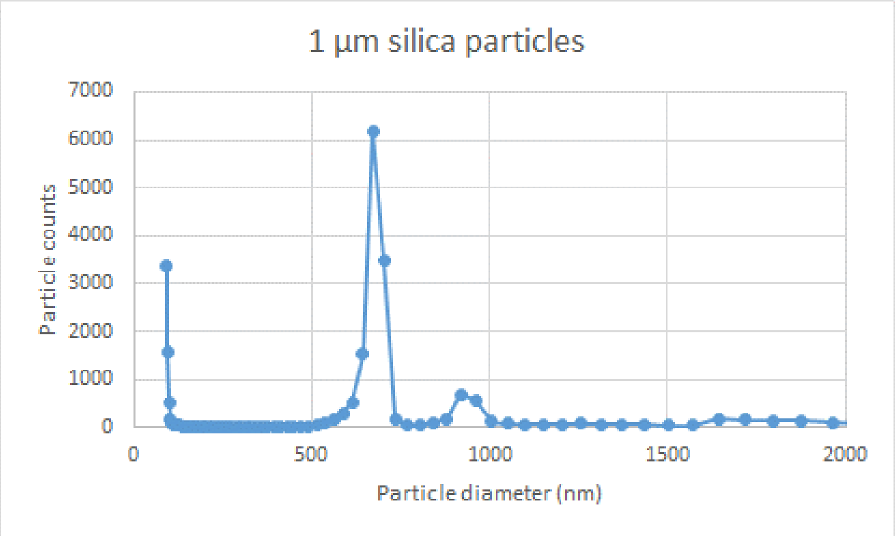
Simulant and characterization using a particle spectrometer

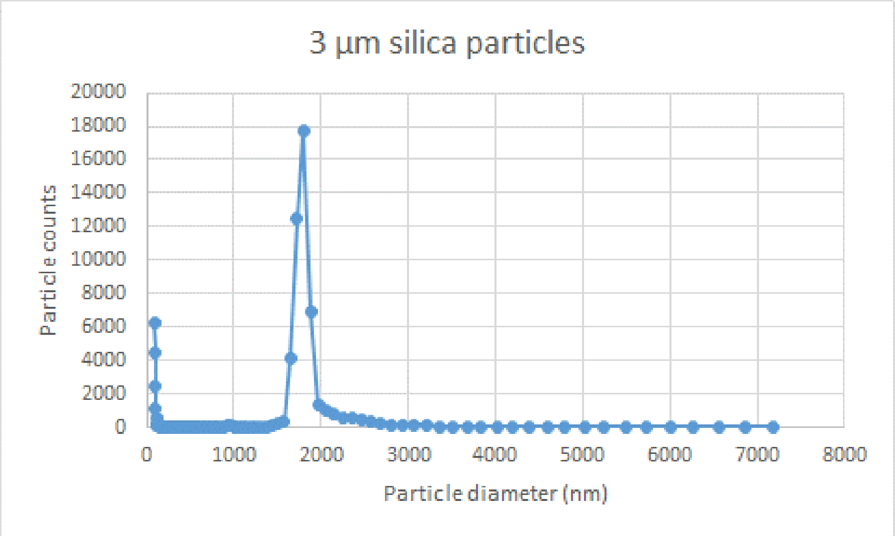
JSC-1AF particle size comparison to silica standard particles

Measured distributions from LAS-XII OPC instrument



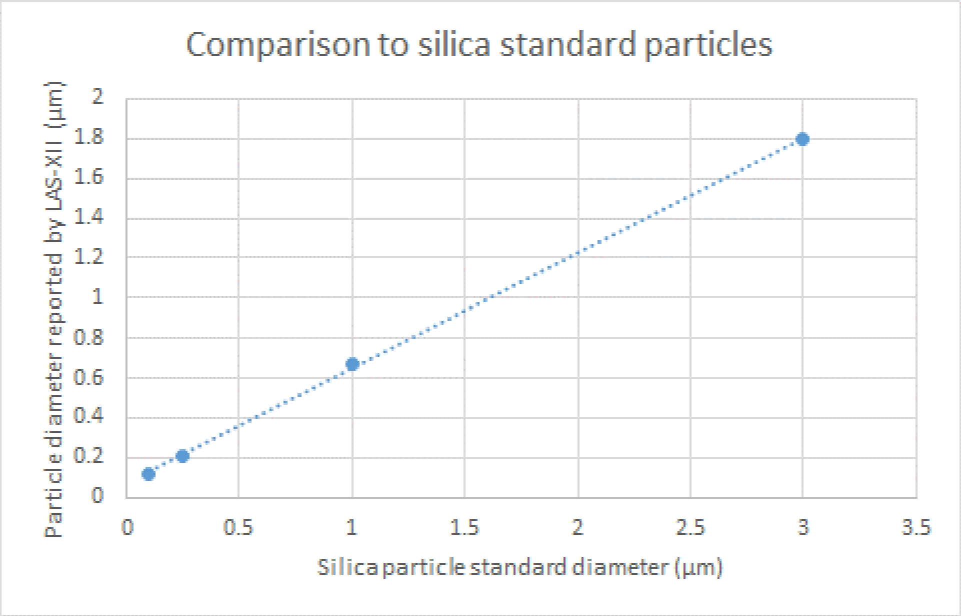






JSC-1AF/Silica standard particle comparison

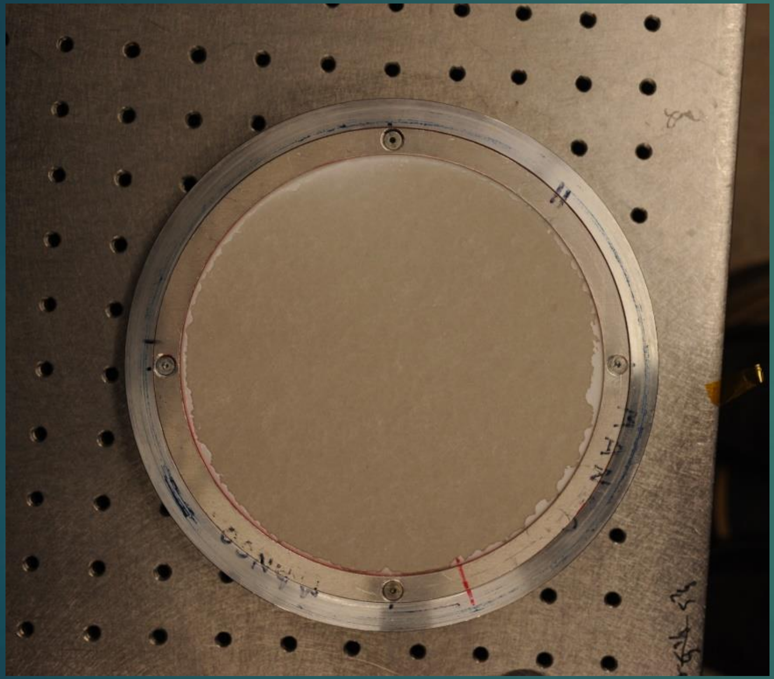
Silica standard particle size	LAS-XII reported
0.1	0.118
0.25	0.21
1	0.672
3	1.796



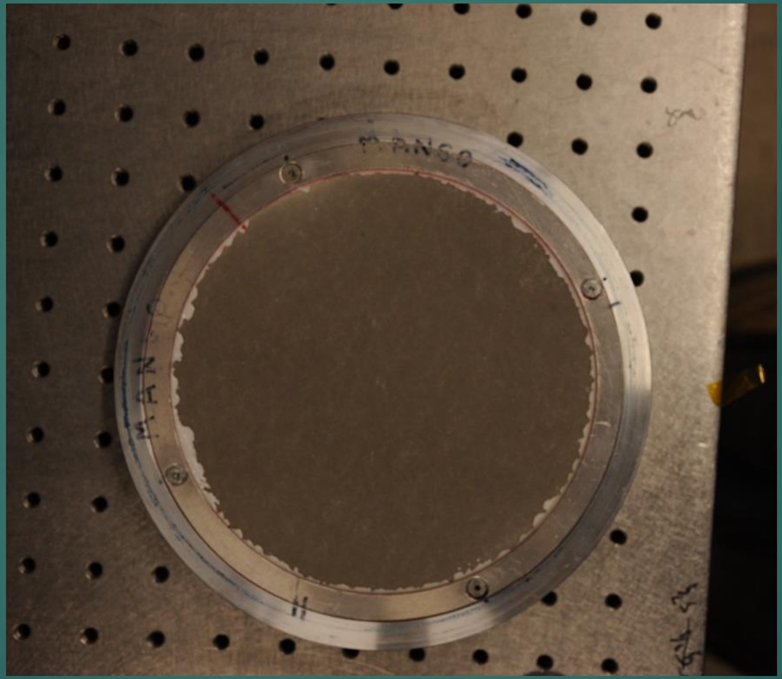
Flow and Dust Loading Tests

Pictures of dust loading on filter media

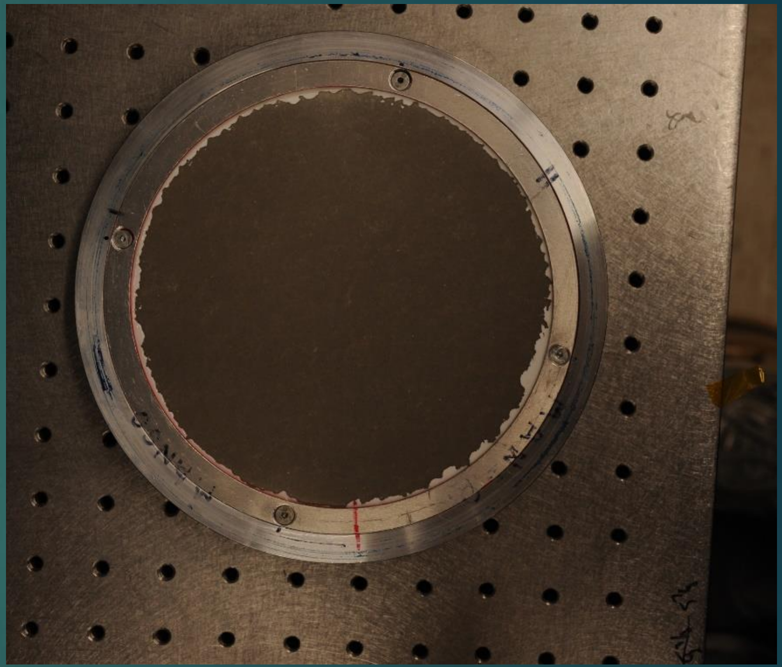
0.552 mg/cm^2



0.804 mg/cm^2

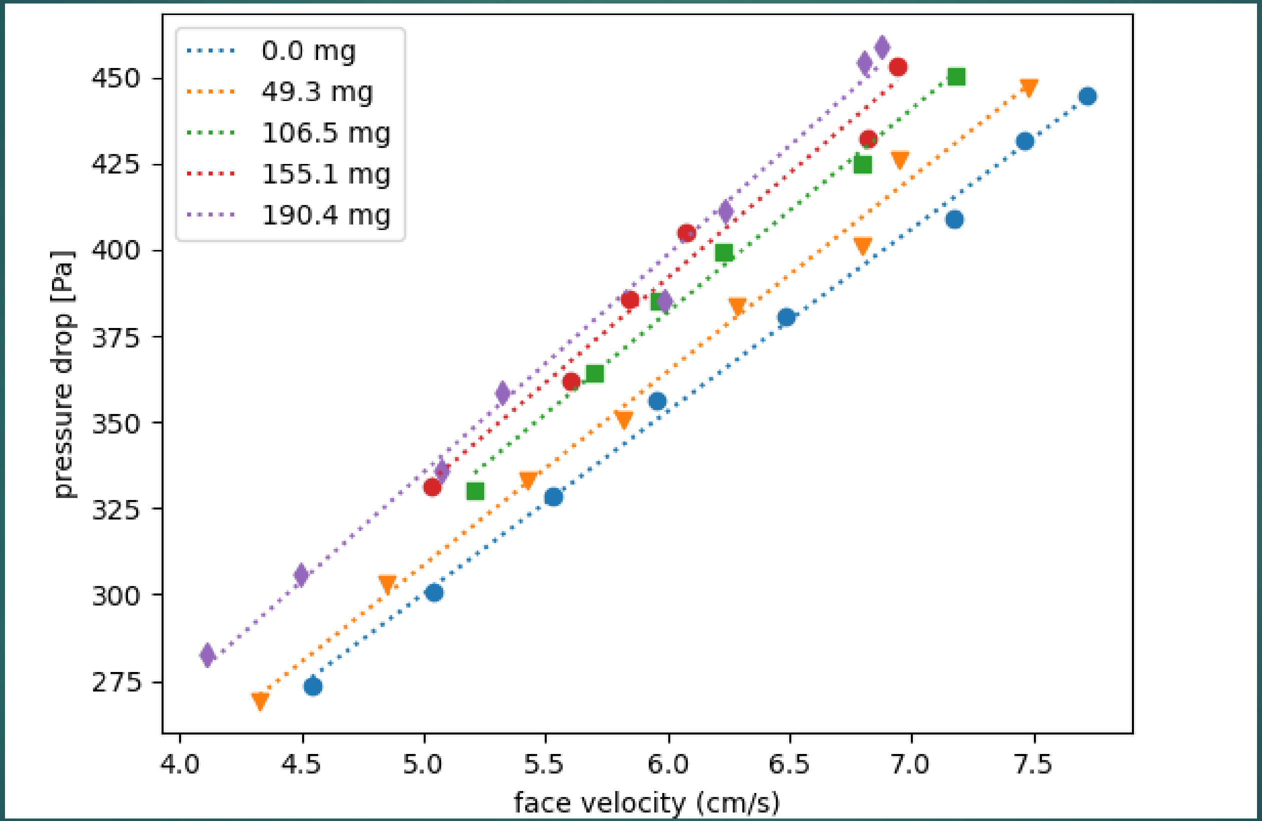


0.988 mg/cm^2



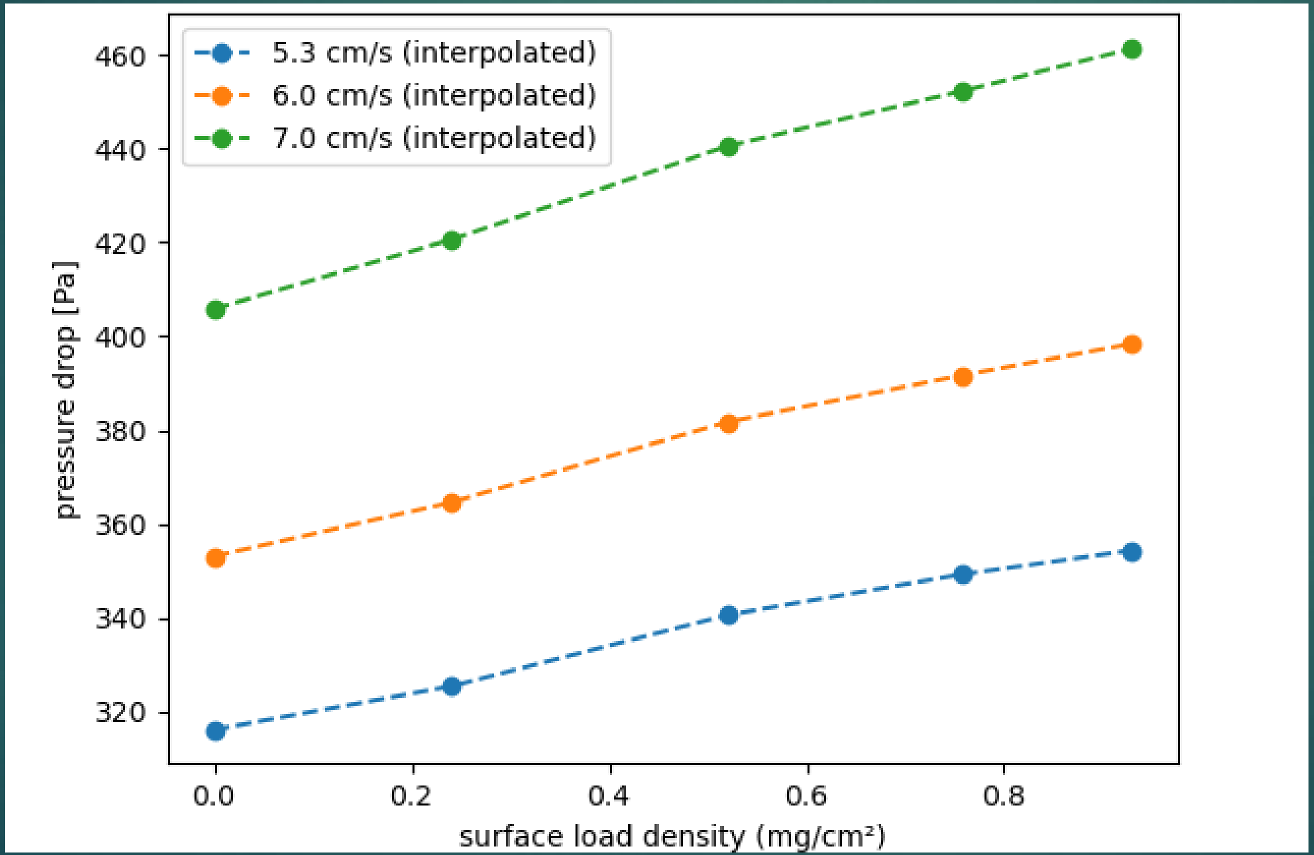
Filter sample was removed from flow loop every 5 or 6 hours to measure the amount of dust on media.
Filter sample was inverted and reinstalled for continued loading to produce more uniform loading.

Velocity dependence
(Test results @ 0.056 Mpa)



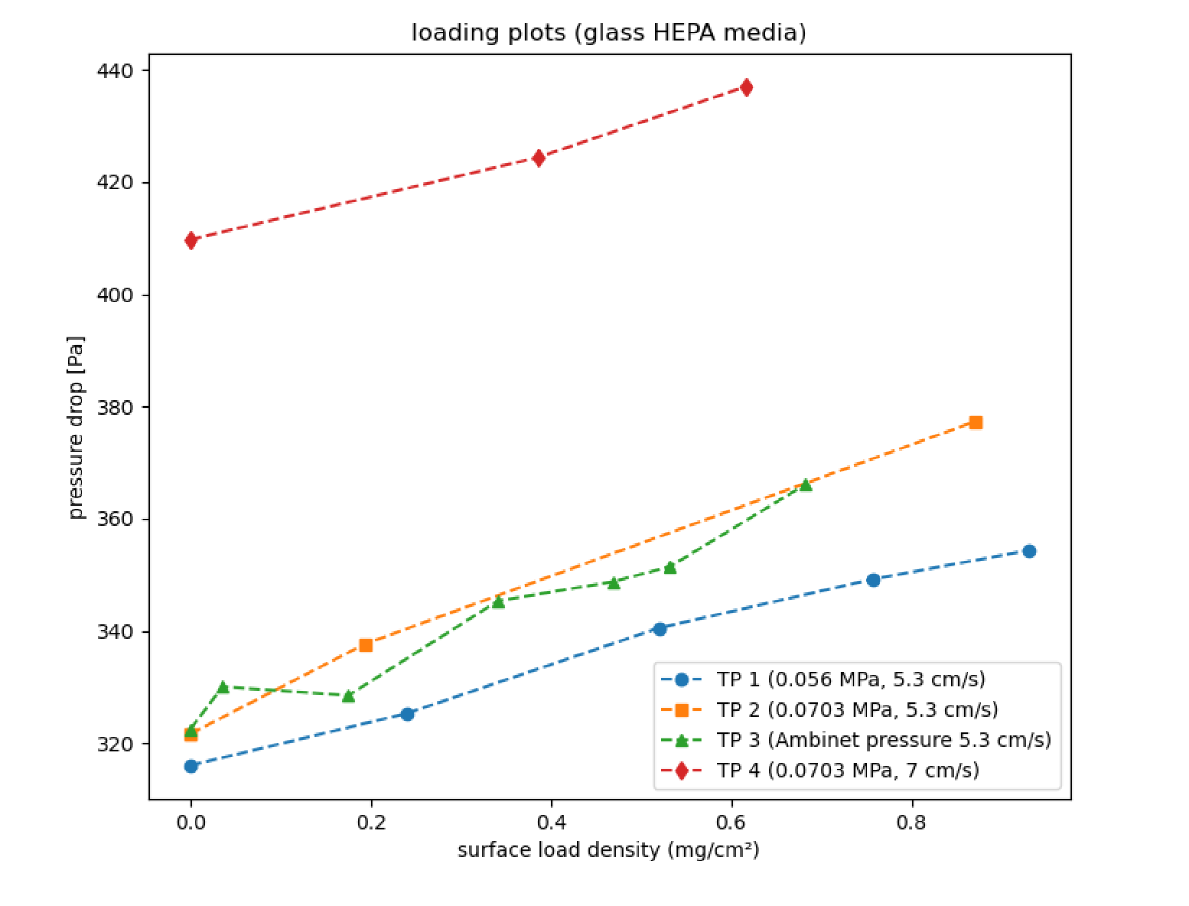
- Pressure drop increases linearly with face velocity
- Pressure drop curves shift upward with loading level

Media surface density loading curves (normalized by filter surface area) @ different velocities



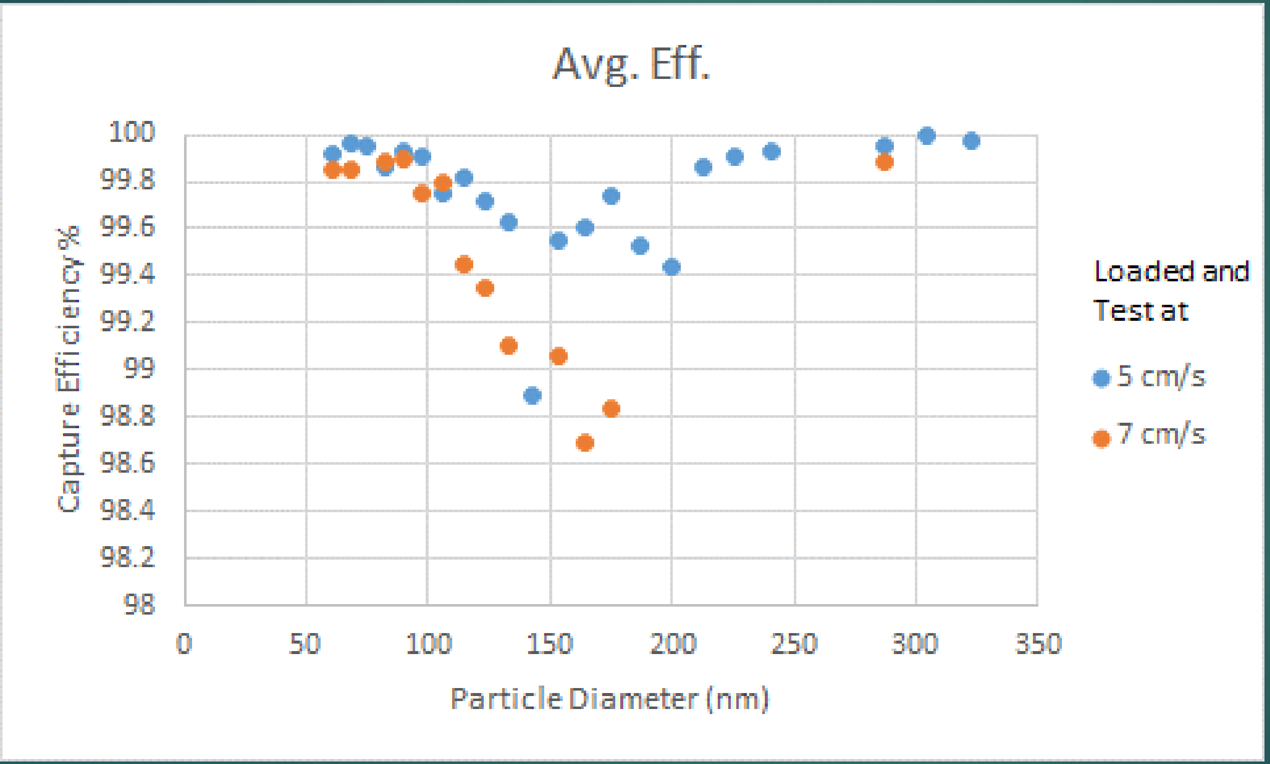
- Nearly linear increases in pressure drop with loading level for each velocity case
- Pressure drop curves shift upward and proportionally with velocity increases.

Loading curves
(three spacecraft pressures and two velocities)



- Nearly linear increases in Δp with loading level for each pressure case.
- Lower starting Δp and slope rise at the lowest pressure than the 0.0703 MPa and ambient pressure cases
- Significantly higher starting Δp in the higher velocity case.

Efficiency at end of loading (preliminary)



- Filter efficiency exhibits a characteristic minimum point (as seen with HEPA media) and shows the range of the most penetrating particle size (MPPS).
- A lower minimum efficiency was found at the higher velocity.

$$Efficiency = \left(1 - \frac{N_{downstream}}{N_{upstream}}\right) * 100$$

Summary

- Loading was reasonably uniform on the filter surface.
- Pressure drop increased linearly with dust loading.
- Modest increases in pressure drop (< 2x original Δp) were produced for significant mass loading (up to ~ 1.0 mg/cm^2 surface density load)
- Operating/Cabin pressure effects:
  - Rate of pressure drop increase was lower for the 0.0565 MPa than at the 0.0703 MPa than at 0.1003 MPa (ambient pressure) cases at the nominal flow rate of 5.3 cm/s.
  - The starting pressure drop was lower in the 0.0565 MPa case than the 0.0703 MPa and ambient pressure cases.
- Face velocity effects:
  - The starting pressure drop was significantly higher, in the 0.0703 MPa case, when the face velocity was increased to 7 cm/s for loading and testing.
  - Lower efficiencies were found when the face velocity was increased to 7 cm/s.
- This data can inform future ECLSS HEPA filter designs in the Artemis program.

Acknowledgements

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