Supplanting Gravity with Centrifugal Force for Sieving and Processing Regolith under Micro-Gravity

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Work supported by NASA SBIR Phase-1 NNX11CE32P

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Why size-segregate regolith?

Improve reliability of ISRU processing systems

- Remove size populations that foul seals
- Reduce mean particle size to improve system throughput of chemical processing systems

Construction applications

- Size graded regolith would have different uses for different construction jobs: berms, road beds, habitat cover, etc...

Manufacturing applications using regolith

- Sintering, additive manufacturing, etc… improved results with well defined particle size

Low gravity has a negative impact on granular flow

- μ-g granular flows will act like a more cohesive flow compared to 1-g
- Larger openings required in low-g gravity driven flow
- Vibrational sieving does not function as well in low-g

Table 3: Summary of sieve runs in lunar-g trajectories

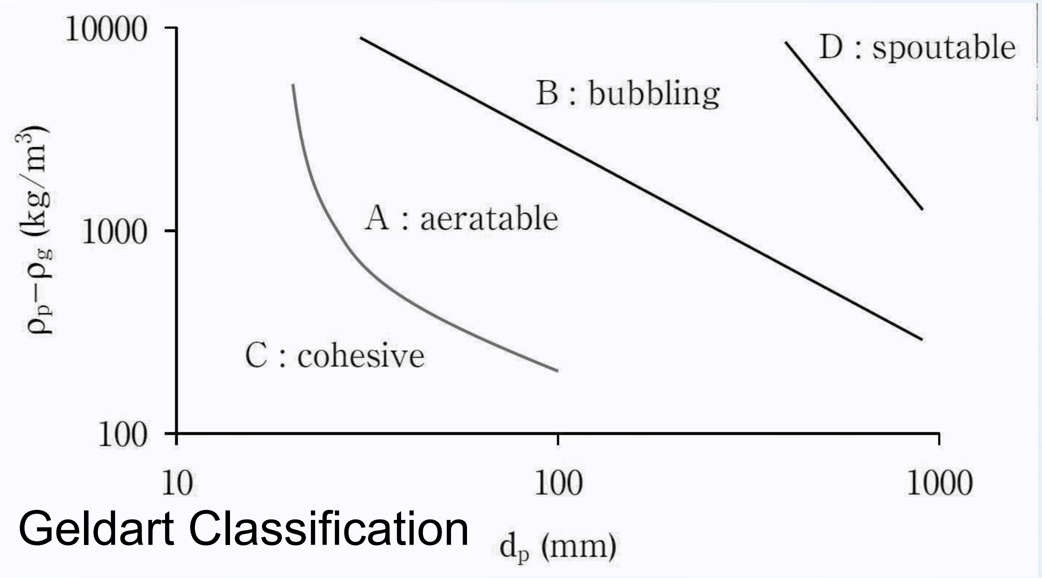
Sieve ID	Simulant	Mesh size	Initial mass	Passed mass	% Passing
1	JSC1-a	75 μm	100 g	7.5 g	7.5
2	LHT	150 μm	100 g	4.1 g	4.1
3	LHT	500 μm	199.1 g	85.4 g	42.9
4	LHT	75 μm	100.1 g	2.7 g	2.7
5	LHT	150 μm	100 g	3.7 g	3.7
6	LHT	500 μm	200 g	61.3 g	30.7
7	LHT	75 μm	100 g	0.1 g	0.1
8	JSC1-a	150 μm	100.1 g	15.3 g	15.3

Townsen et al. (2010)
40th Aerospace Mechanisms Symposium
NASA/CP-2010-216272

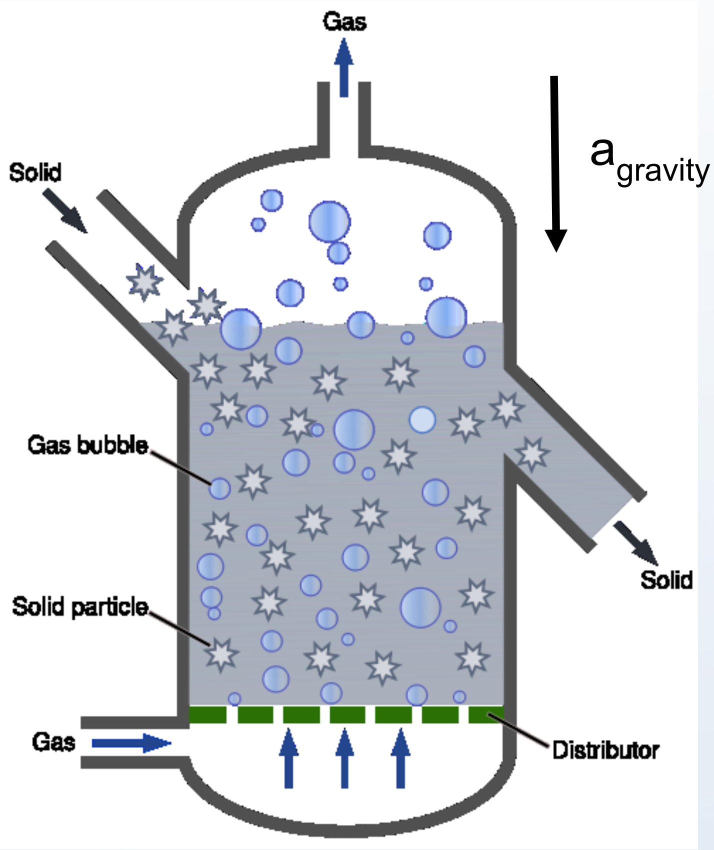
Ramé et al. (2010) “Flowing and Sifting Lunar Soil Simulant in Lunar Gravity” (Zero-G flights Aug 13-14, 2009,Final Report, GRC)

Fluidized Bed flow becomes more cohesive in μ-g

- Williams (2006) showed that in reduced gravity the Geldart classification moved toward Class C, cohesive.
- Qian (2004) showed that centrifugal motion improved fluidization. Moving from Class C to A then B with increasing centrifugal force.

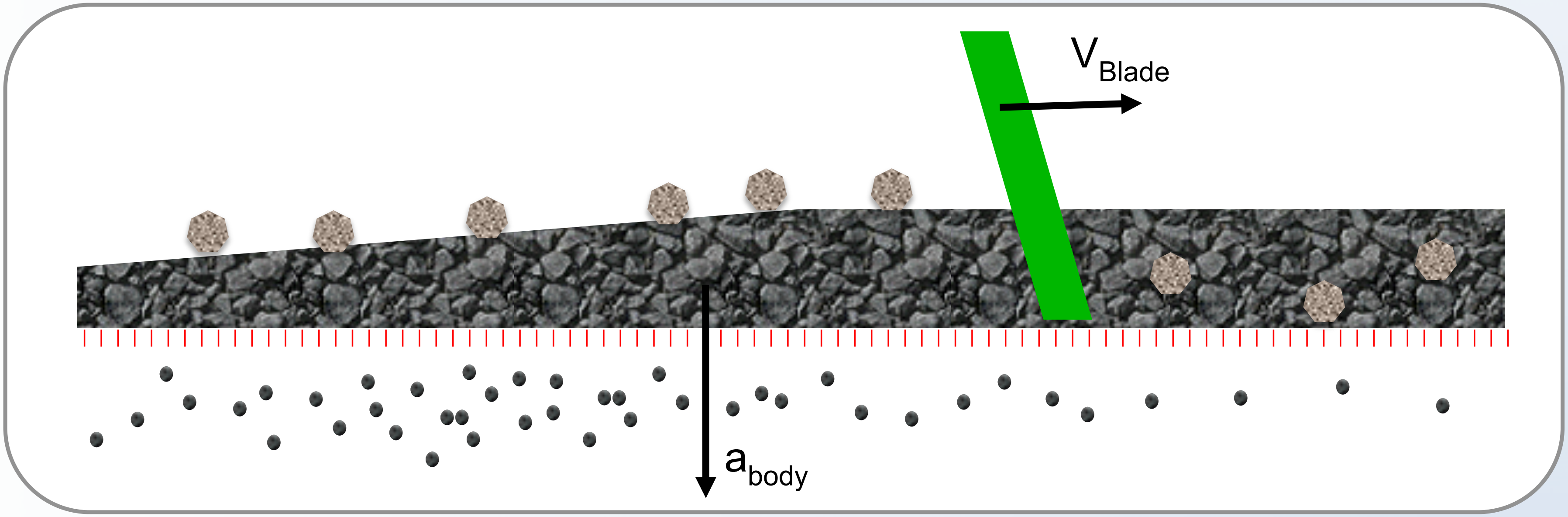


Geldart Classification



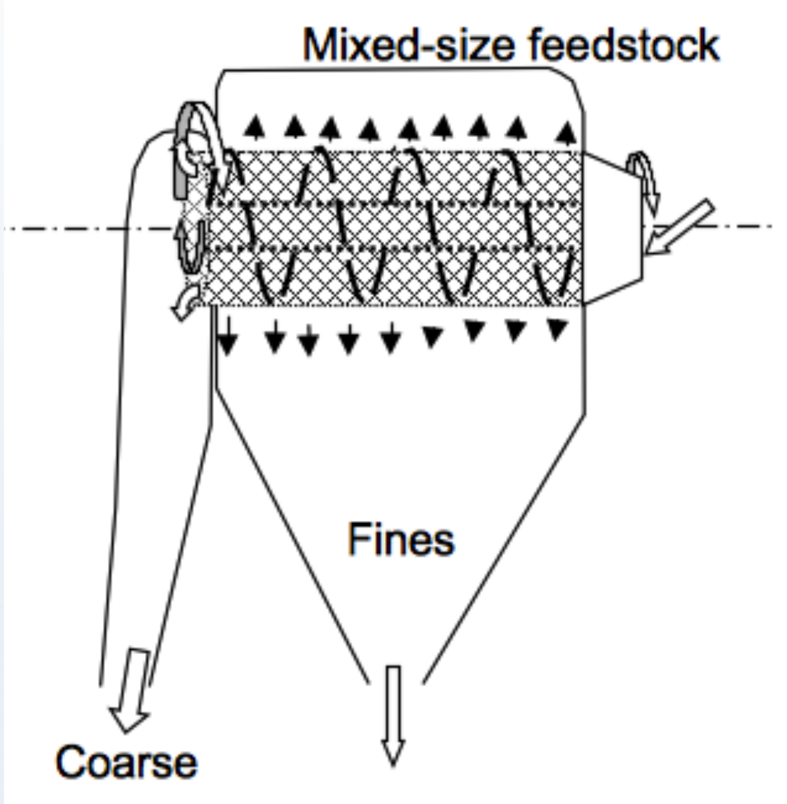
Centrifugal Sieve Concept

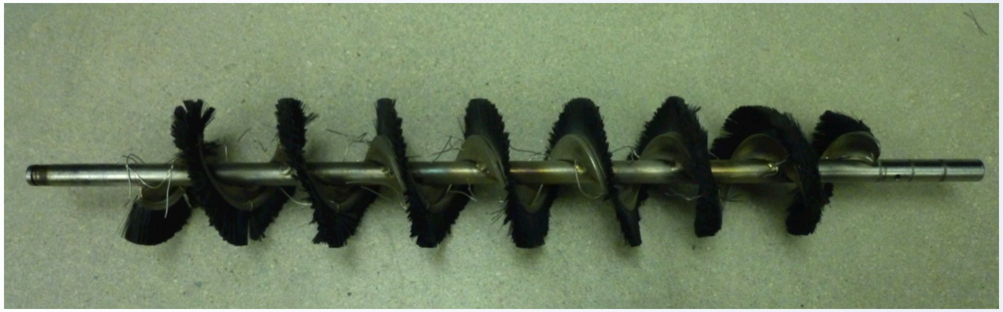
- Centrifugal “force” drives particle flow
  - Gravity independent
- Shearing flow is induced by vibration or a moving blade
  - Larger particles naturally rise to the top in dry granular shear flow
  - Smaller particles fall downward



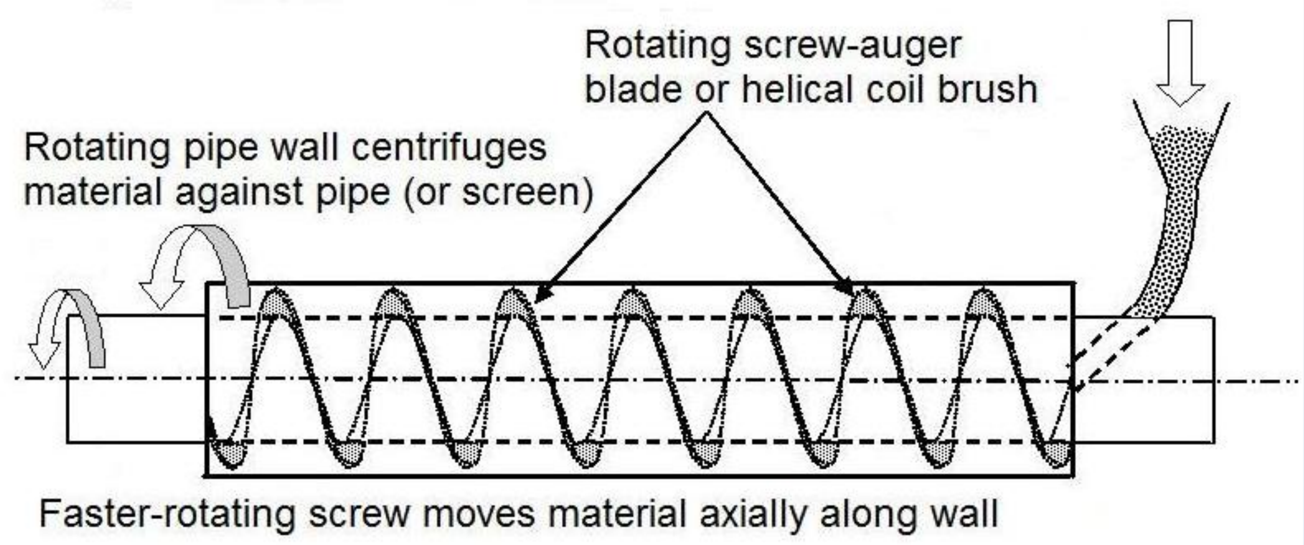
Cylindrical screen and helical blade

- Helical blade rotates slightly faster than the cylindrical screen
  - Transport coarse material to outlet
  - Induces shear
  - Fines collected after passing through screen





Rotating-wall conveyor



A rotating-wall, or centrifuging-pipe screw conveyor
→ similar to an ordinary screw-conveyor

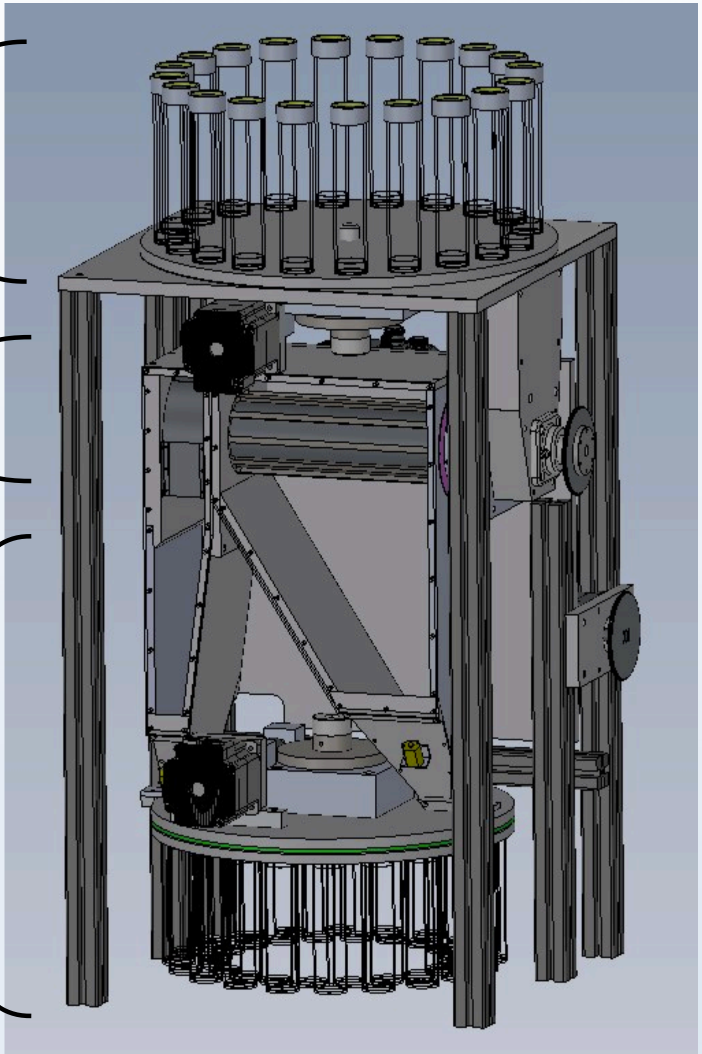
except the material is centrifuged to the pipe-wall where the screw moves it axially
→ transport nearly independent of gravity-level

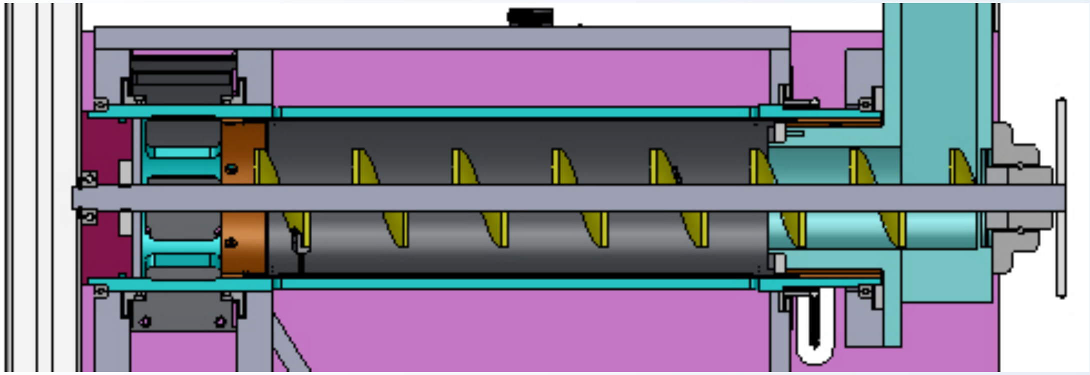
2 inch diameter cylinder at 300 rpm (2.5 g), Feeder Cone 45° incline, Fine sand 200-600 micron diameter

Equivalent to ~40 kg/hr

Micro-g flight apparatus

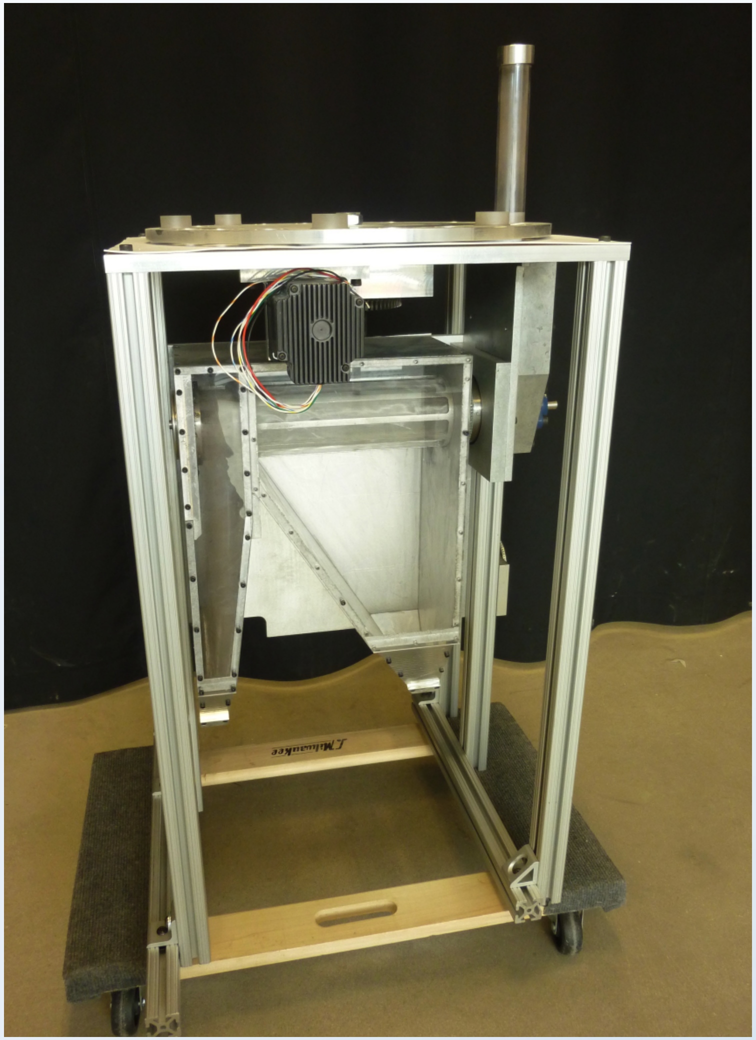
- Sample delivery carousel
  - 20 sample delivery tubes
  - delivery during high-g
- Centrifugal Sieve
  - 3 inch diameter sieve screen
  - 9 inch active length
  - sieving/transfer during micro-g
- Sample collection carousel
  - 20 Fines collection tubes
  - 20 Overs collection tubes
  - collection during high-g



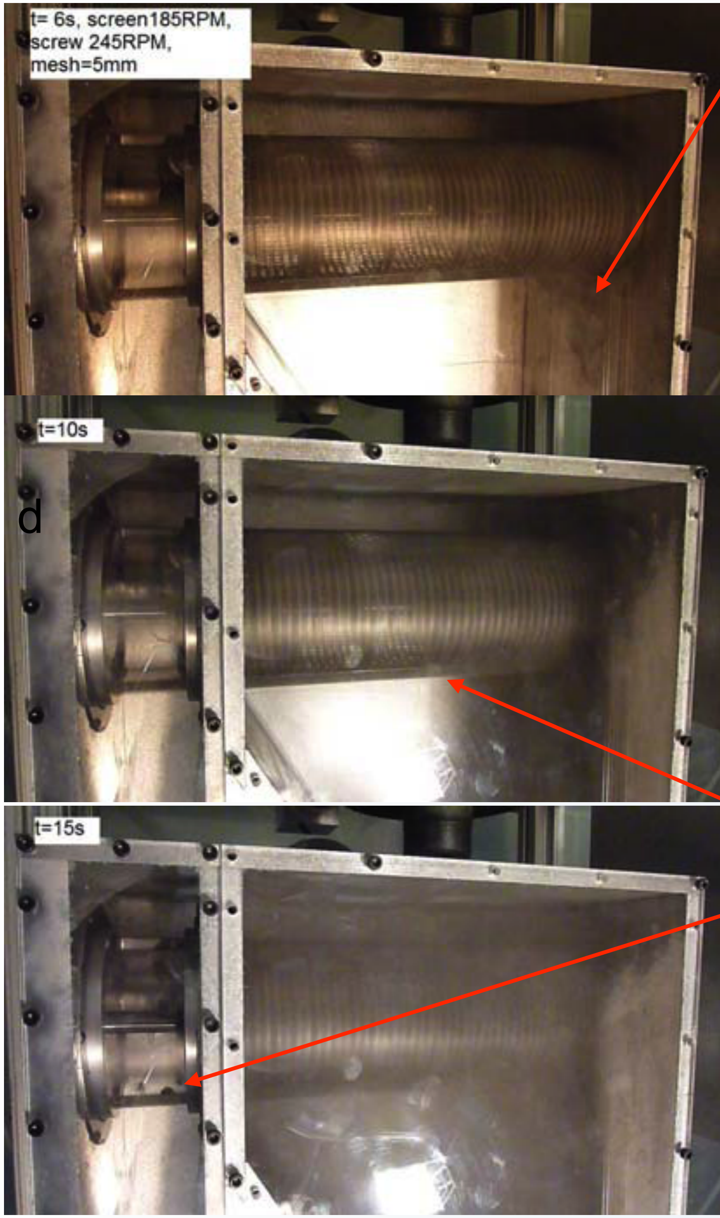


Built and tested in 1-g

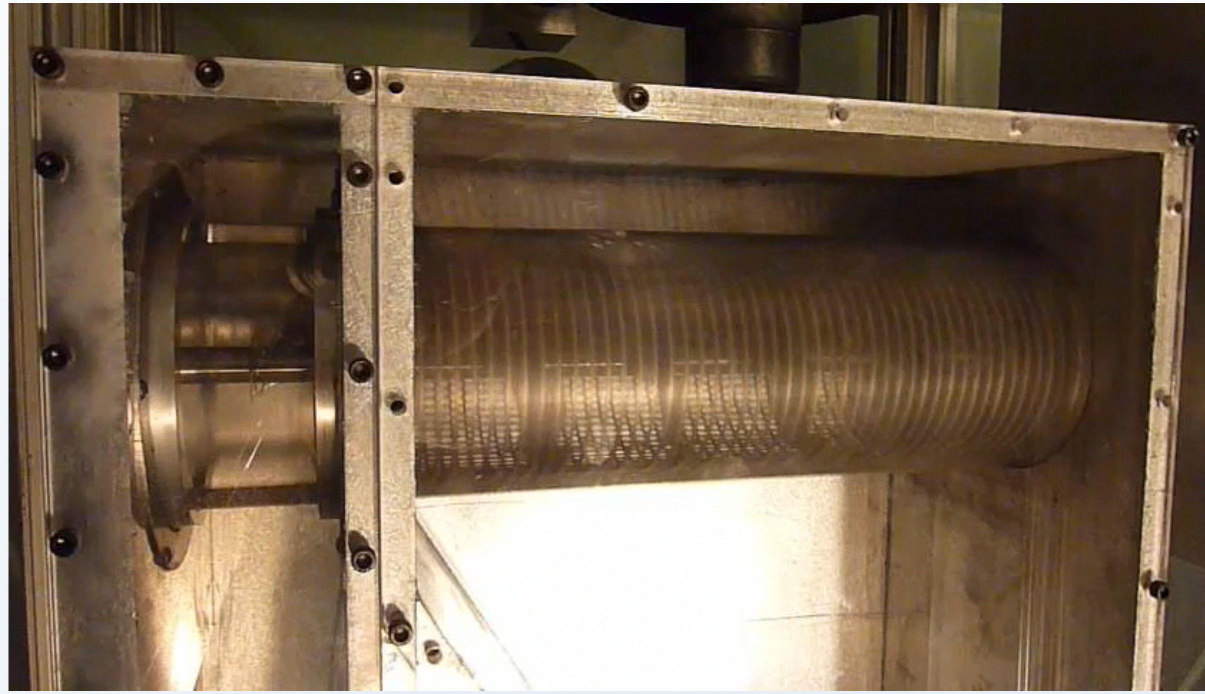
- ~85% built in phase 1. Collection carousel not built
- Tested sieving and dispensing in 1g with 4.6 mm and 100 µm screens.
- Tested from 1.5 to $3g_o$ (185 to 270 rpm, blade +60rpm)



Sieving >4.6mm from (JSC-1a + 5mm pebbles)



Fines begin to come through the screen



Fines exit further

Large fragments in the overs chute

Fines envelope the entire fines chute

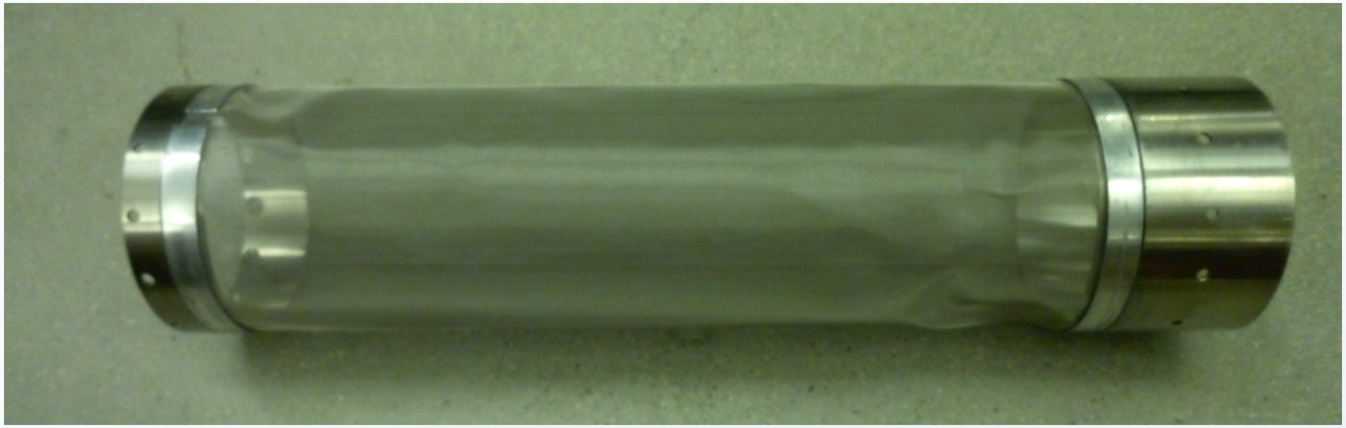
Input:
- 400g JSC1a
- + 40g >5mm, pre-screened

Output:
- Overs: 40g
- Fines: ~398g

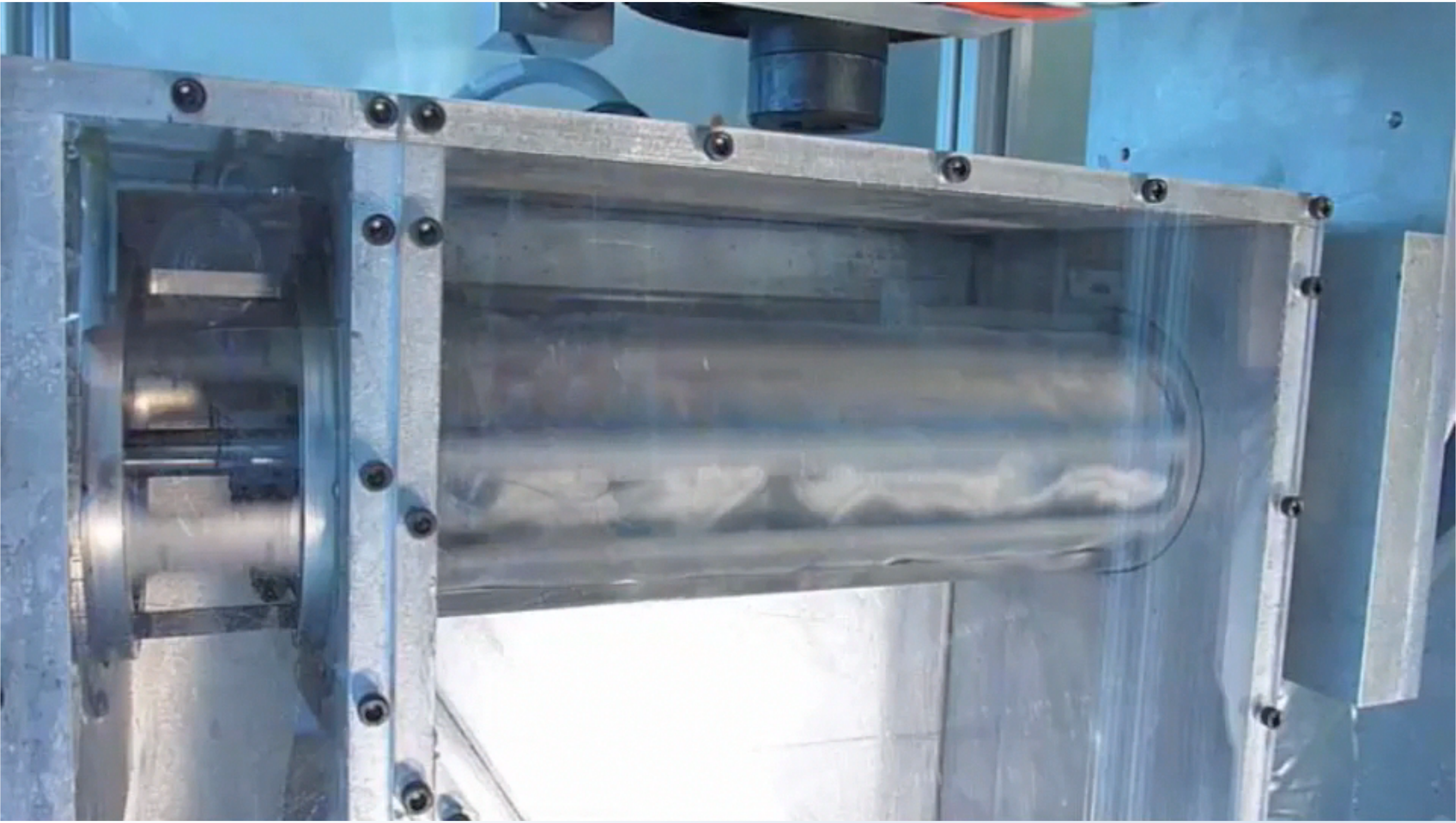
30 second test

Rate > 50 kg/hr

100 μm screen



100 µm screen with JSC-1a

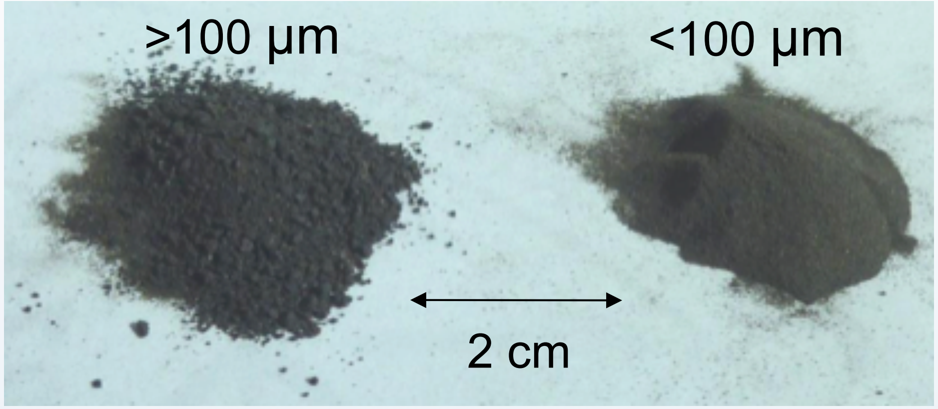


JSC-1a sieving

- Input: 400g JSC-1a
- Output:
  - Fines <100 μm 213 g (55%)
  - Overs >100 μm 175 g (45%)

~30 second test

Rate > 50 kg/hr



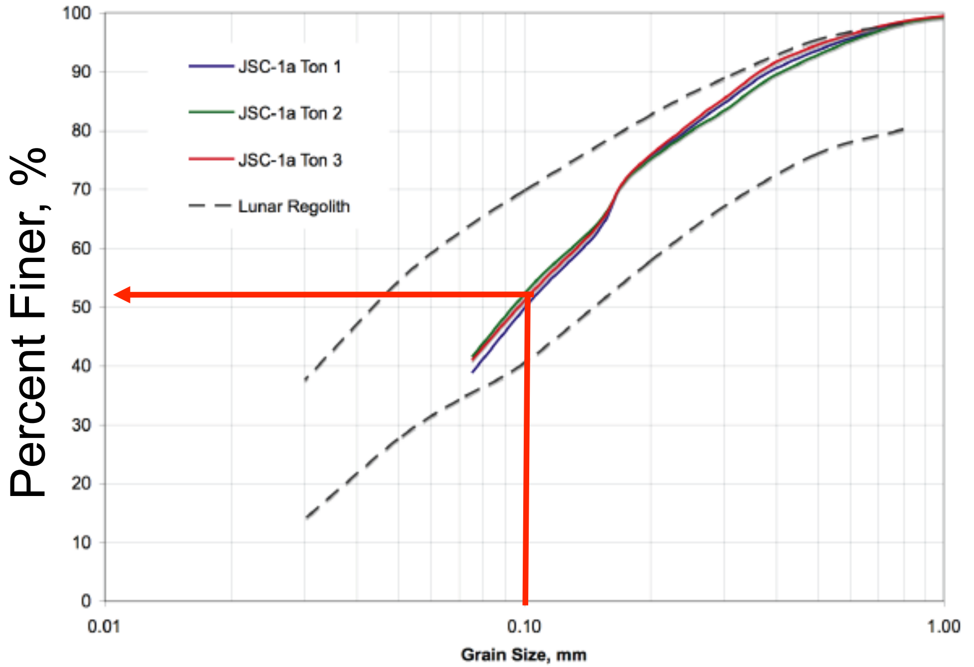
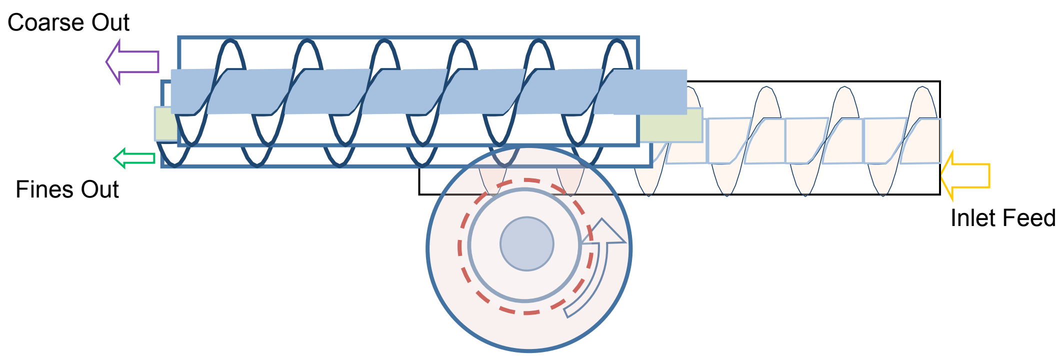
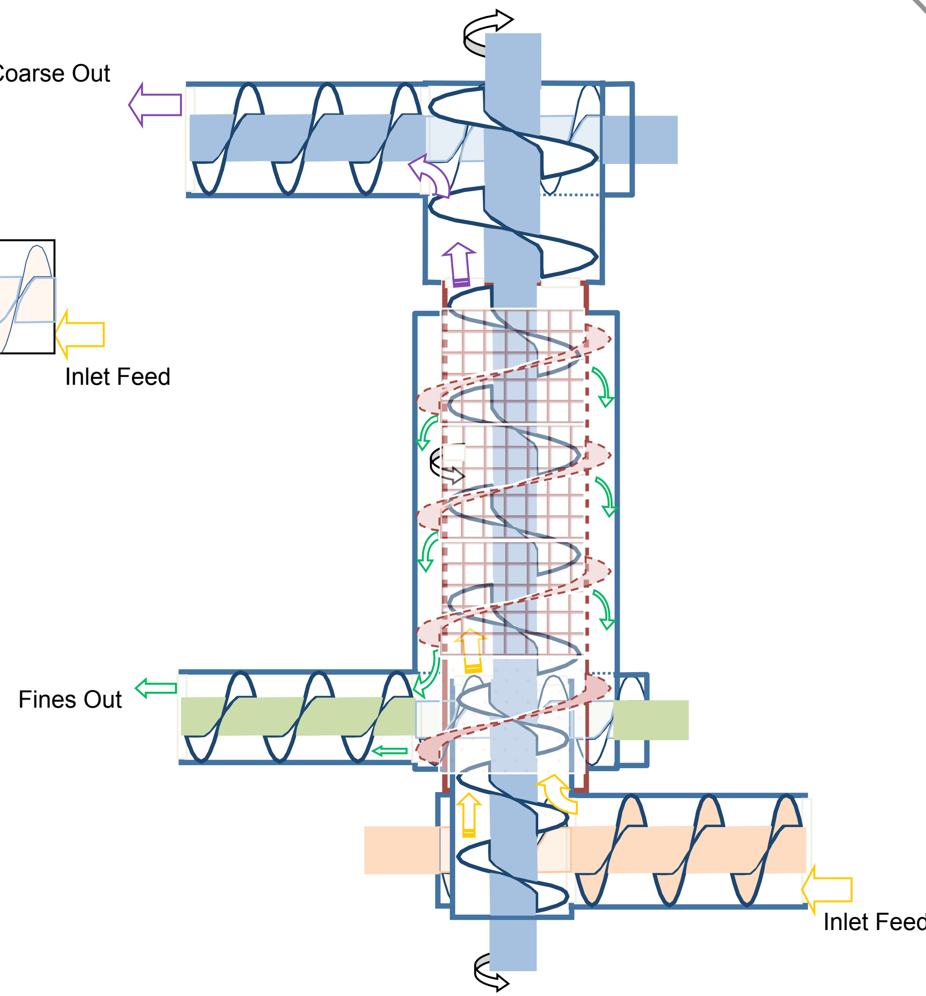


Figure 7. Grain size distribution of JSC-1A Tone 1, 2, and 3. Comparison with upper and lower bounds of lunar regolith (Carrier et al. 1973) is provided.

From Arslan, *et al.*, 2010

Micro-gravity capable centrifugal sieve





Inlet and outlets use screw conveyors

Fines transferred away from sieve by a compliant helical blade of opposite handiness

Next Steps for the Centrifugal Sieve

- Improve TRL
- Micro-g and vacuum tests
- Optimize operation
- Develop the fully micro-gravity-capable version

Conclusions

- Sieving technology is fundamental to many ISRU processes.
- Fine granular material behaves as a more cohesive material in low gravity and micro-gravity.
- Centrifugal sieve successfully separated >5 mm material from JSC-1A and size split JSC-1A at 100µm. Rate above 50 kg/hr.
- Good beneficiation method for rapid segregation of cohesive granular material less than 1 cm size. Particularly suited for when pneumatic systems are not feasible.
- Centrifugal systems should be used for many more applications, such as for material transport and fluidized bed processors.

Thanks for listening

Questions?