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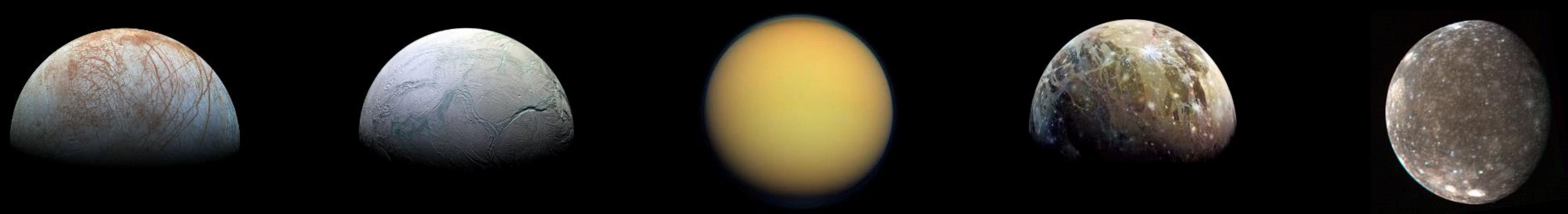
Boulder, Colorado

JOHNS HOPKINS APPLIED PHYSICS LABORATORY

HONEYBEE ROBOTICS Spacecraft Mechanisms Corporation

Pneumatic Sample Transport for Ocean Worlds



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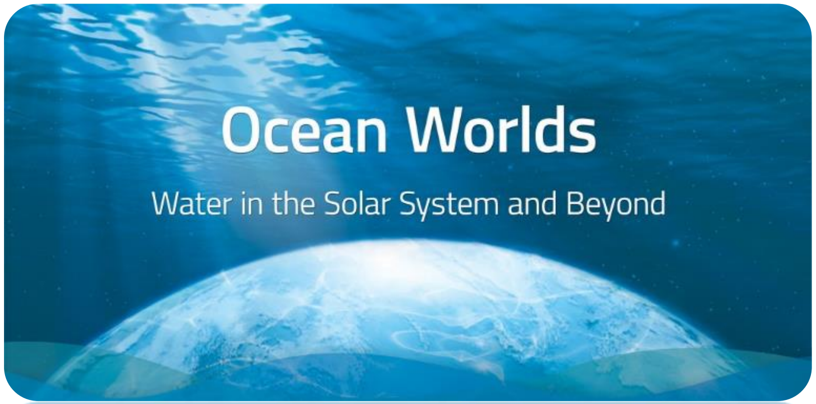
Jameil Bailey	HBR	Avionics Lead
Nick Traeden	HBR	Mechanical Engineer

Background

COLDTech - Concepts for Ocean worlds Life Detection TECHnology



credit: NASA

NASA-funded ocean worlds technology development program:

a) science instruments

b) sample acquisition & delivery systems

c) spacecraft technology for ocean access

Dragonfly Mission

- New Frontiers IV - mission finalist
    - 1-year phase A study
- Titan rotorcraft lander with drills & **pneumatic sampling system**

credit: Johns Hopkins Applied Physics Lab

Ocean Worlds Sampling Challenges

Ocean Worlds ...

SEARCH FOR LIFE

LOW GRAVITY (< 0.15 g)

CRYOGENIC TEMPERATURES

WET/COHESIVE MATERIAL POSSIBLE

<u>Key Sampling Strategies</u>

- Minimize heat transfer into sample
  - Keep sample system cold
  - Sample quickly
- Minimize surface contact between sample and spacecraft

Mechanical vs Pneumatic Transport

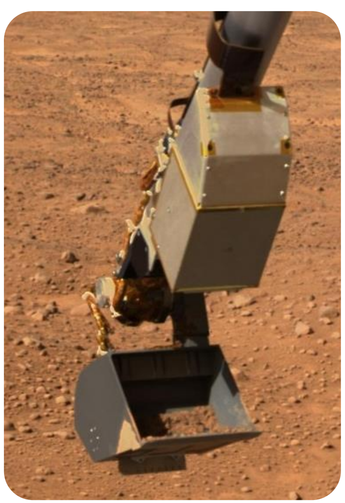
Mechanical Transport

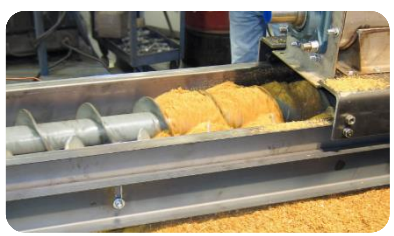
- Robotic arm & manipulator
  - Scoops (Phoenix, MSL)
- Screw / Auger (Resource Prospector)
- Brush (Resource Prospector)
- Vibrating mechanisms (MSL)
- Gravity drop
- Belts, buckets, trays

Energy efficient

Complex / multiple moving parts

Issues with cryogenic temperatures





credit: JPL / Caltech

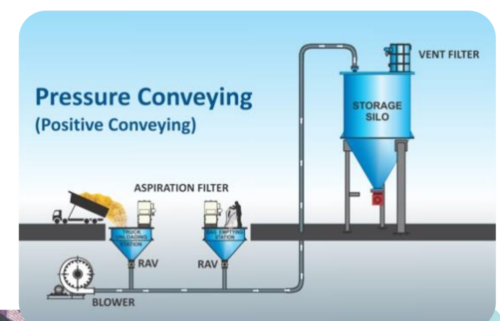
Pneumatic Transport

- Uses gas flow to transport materials
  - E.g. Vacuum cleaners
- Pipeline + pressure source
- Pressure sources – fan or gas tank
- Negative pressure (Venus - Vega & Venera)
- Positive pressure (PlanetVac)

Extremely fast transport (reduced heat transfer)

Mostly passive system

Requires a supply of gas

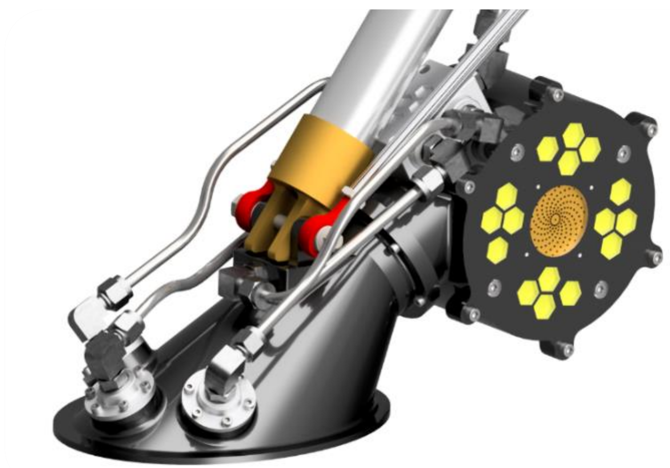


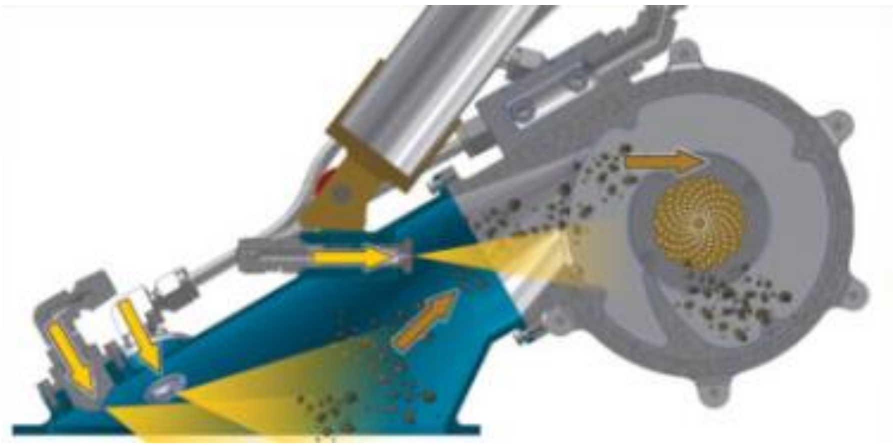
credit: NASA/GSFC/NSSDC

Pneumatic Transport

- **Atmospheric ocean worlds (Titan)**
  - Can use local air as carrier gas (using a fan / pump)
  - Negative pressure: pulls sample down pipeline
  - Positive pressure: pushes sample down pipeline

- **Airless ocean worlds (Europa, Enceladus, Ganymede, Callisto)**
  - Must bring your own carrier gas
  - Must provide manifold to seal against the surface
  - PlanetVac – Honeybee Robotics & The Planetary Society

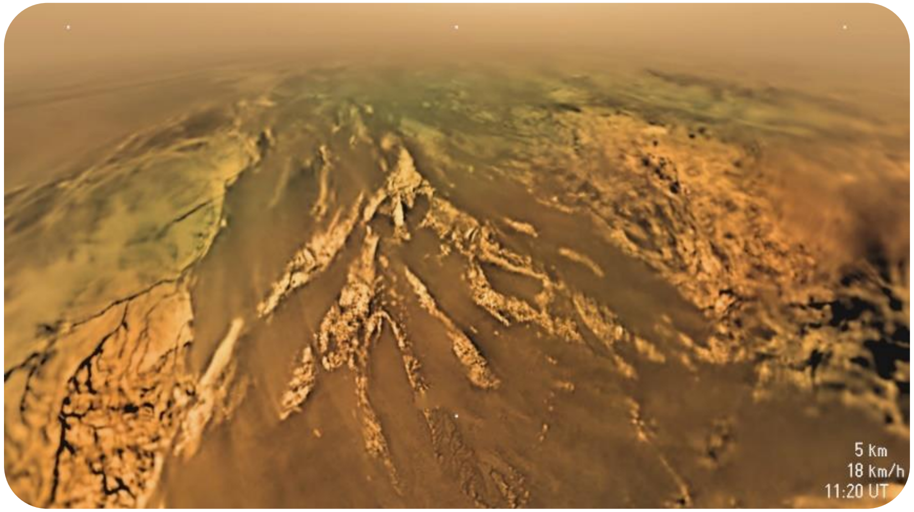




credit: The Planetary Society

Titan Environment

- Surface:
  - Cryogenic (94 K, -180 C)
  - 1.5 bar
  - Air: 95% Nitrogen, 5% Methane, < 0.1% other
- Sand dunes (up to 150 m high)
- Methane rivers and lakes
- Ammonia-rich subsurface ocean?
  - Estimated 10% NH_3 by mass
- Cryovolcanoes – Ammonia-water "lava"



(credit: ESA/NASA/JPL/University of Arizona)

View of Titan surface from Huygens Probe, 2005:

(credit: ESA/NASA/JPL/University of Arizona)

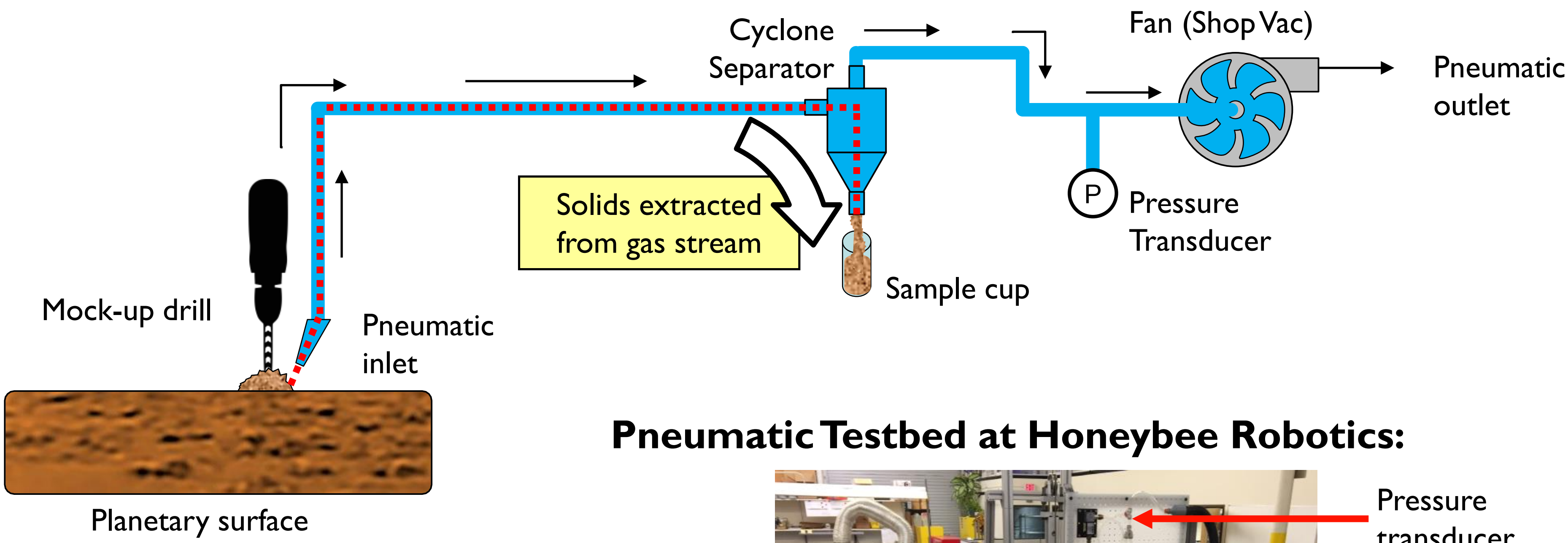
Pneumatics on Titan

- Titan's dense atmosphere and low gravity make it much easier to fly AND to convey pneumatically!

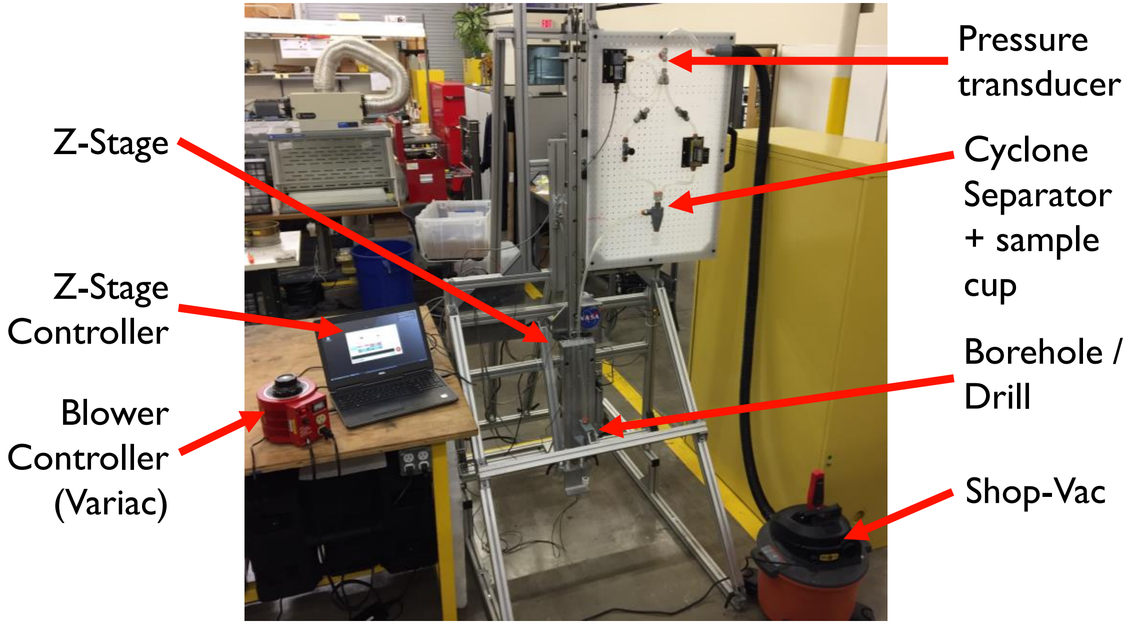
		Earth	Titan	Titan-Earth ratio
Air Density	$\boldsymbol{\rho}$	1.2 $\mathrm{kg/m^3}$	5.4 $\mathrm{kg/m^3}$	**4.4**
Viscosity	$\boldsymbol{\mu}$	1.8 x 10^{-5} $\mathrm{Pa{-}s}$	6.0 x 10^{-5} $\mathrm{Pa{-}s}$	**0.33**
Gravity	$\boldsymbol{g}$	9.8 m/s^2	1.4 m/s^2	**0.14**

		Equation	Velocity
Equivalent Dynamic Pressure	q	$\frac{1}{2}\rho u^2$	$\mathbf{u_{Titan}} = \frac{\mathbf{1}}{\mathbf{2}}\,\mathbf{u_{Earth}}$
Equivalent Particle Terminal Velocity	u_T	$\sqrt{\frac{4d_p g(\rho_p - \rho_{air})}{3\rho_f C_D}}$	$\mathbf{u_{Titan}} = \frac{\mathbf{1}}{\mathbf{5}}\,\mathbf{u_{Earth}}$

Room Temperature Testing



Pneumatic Testbed at Honeybee Robotics:



Pneumatic Transport Velocity

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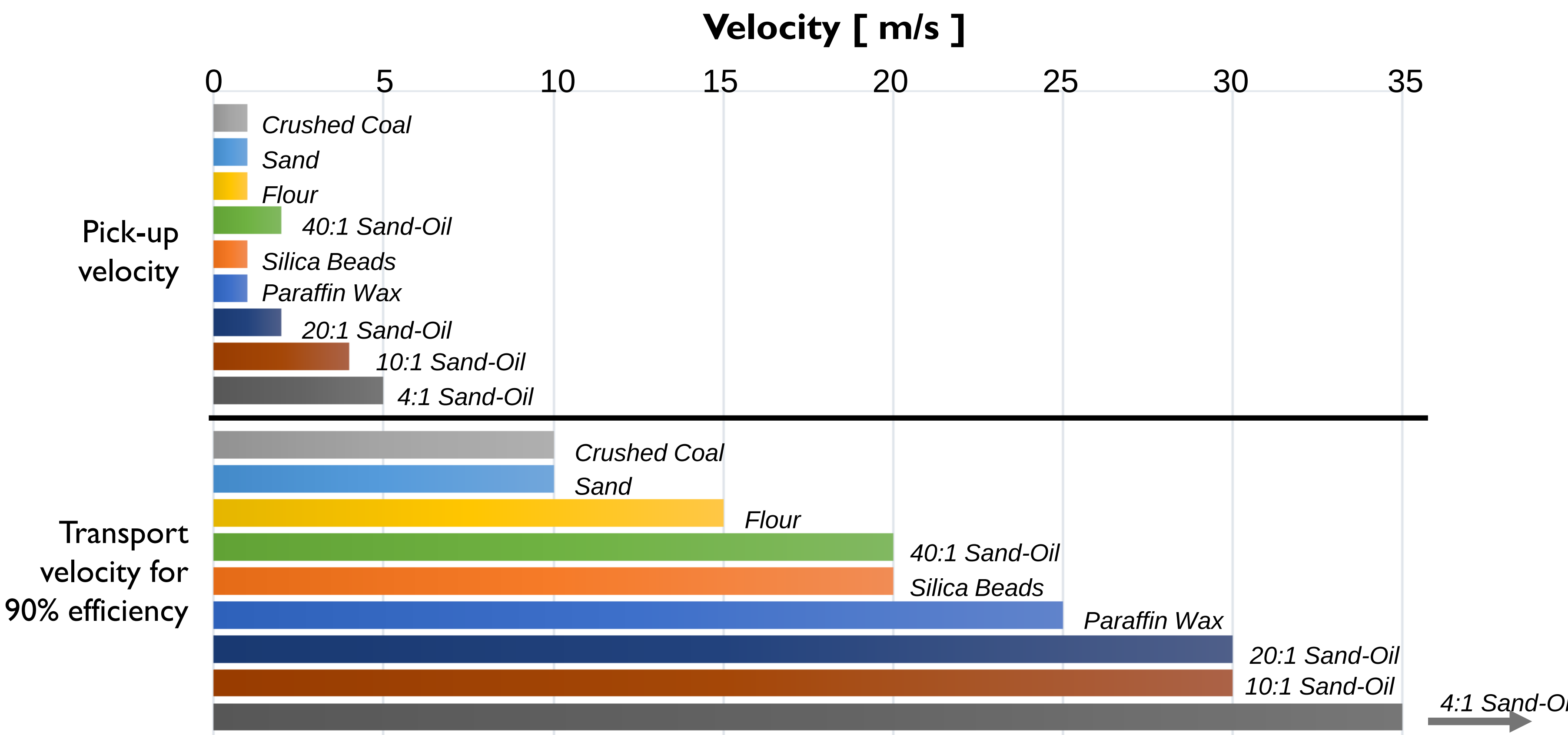
Non-sticky Simulants:

- Silica sand (250-500 um)
- Silica beads (40-80 um)
- Coal (0-1700 um)
- Ground walnut shells

Sticky Simulants:

+

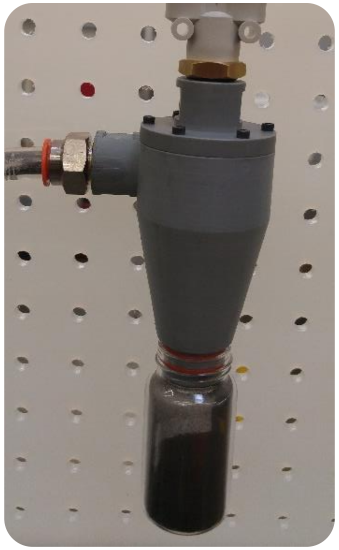
→

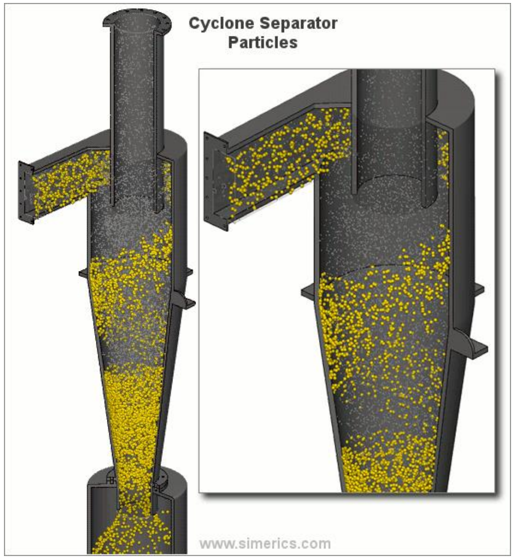


Solid Particle Extraction

Cyclone Separator

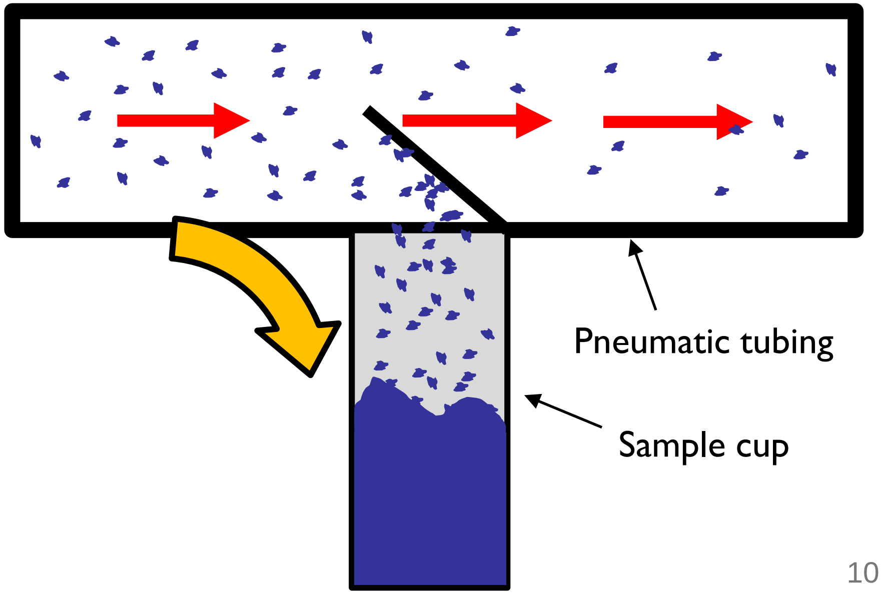
- Creates gas vortex or "cyclone"
- Centrifuge-like separation
- Delivery into cup by gravity
- Widely used in industrial conveying
- Demonstrated in lunar gravity (parabolic flights)





Deflector Cup

- Intercepts particulates with mesh screen
- Deflect into cup outside airstream
- Highly inefficient
- Gravity independent
- Clean / minimal cross-talk between samples



Solid Particle Extraction

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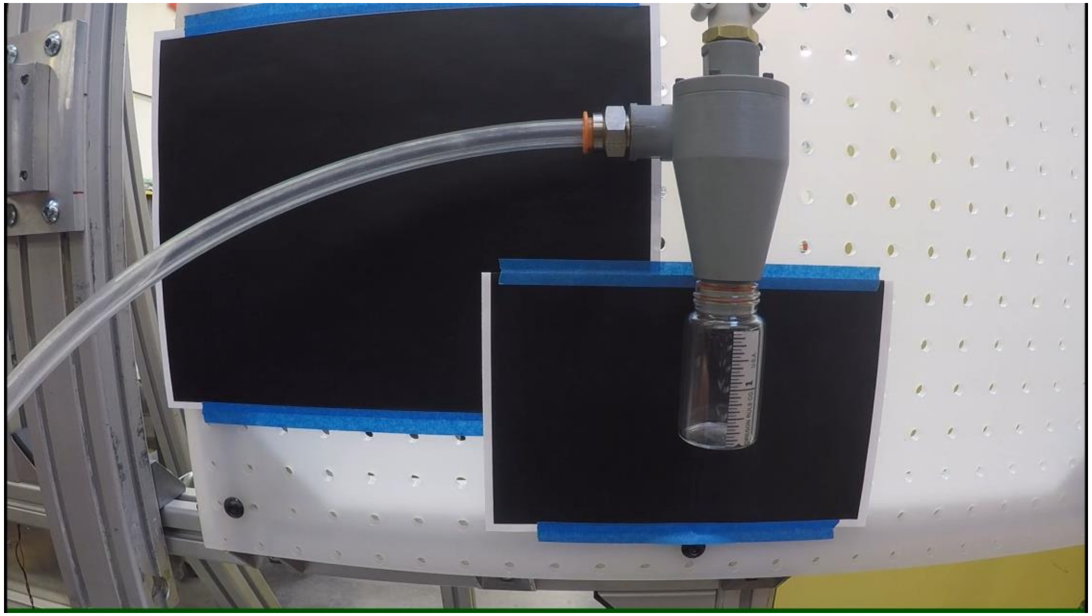
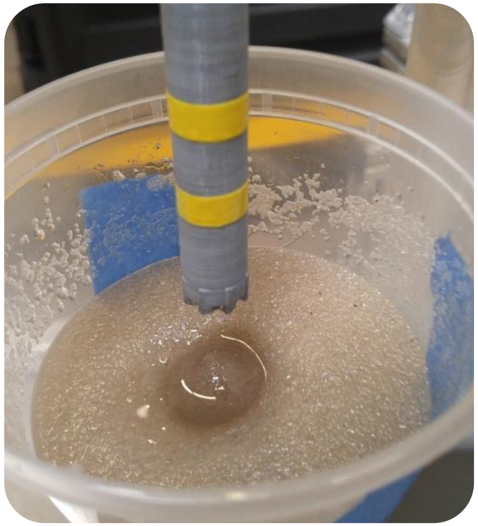


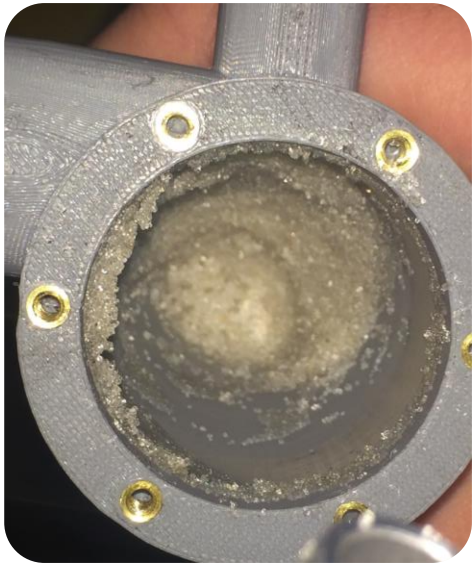
Pathological Testing

Most materials are transported easily, **however** tests with sand-oil helped to identify challenges of transporting sticky materials

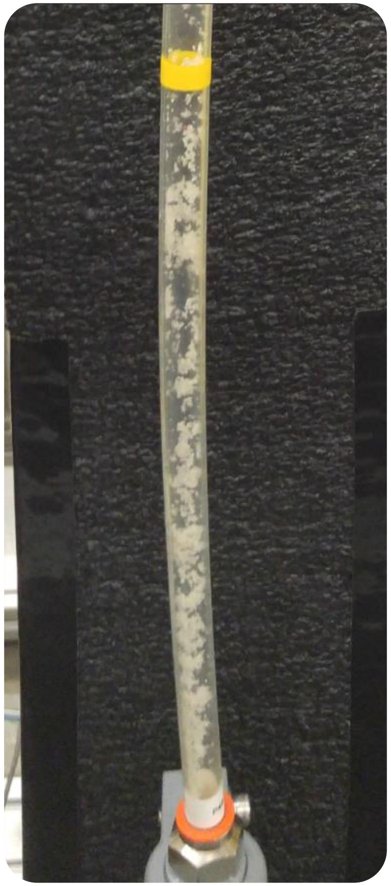
Saturated sand-oil mixture



Sticking inside cyclone:



Sticking to tubing walls:



Lessons learned:

- Do not arrest sample until reaching final destination (i.e. keep it airborne)
- Minimize all disruptions in the pipeline – sharp bends, blockages, etc…
- Flexible tubing instead of rigid tubing
- More air velocity = cleaner transport

Cyclone & Deflector Cup

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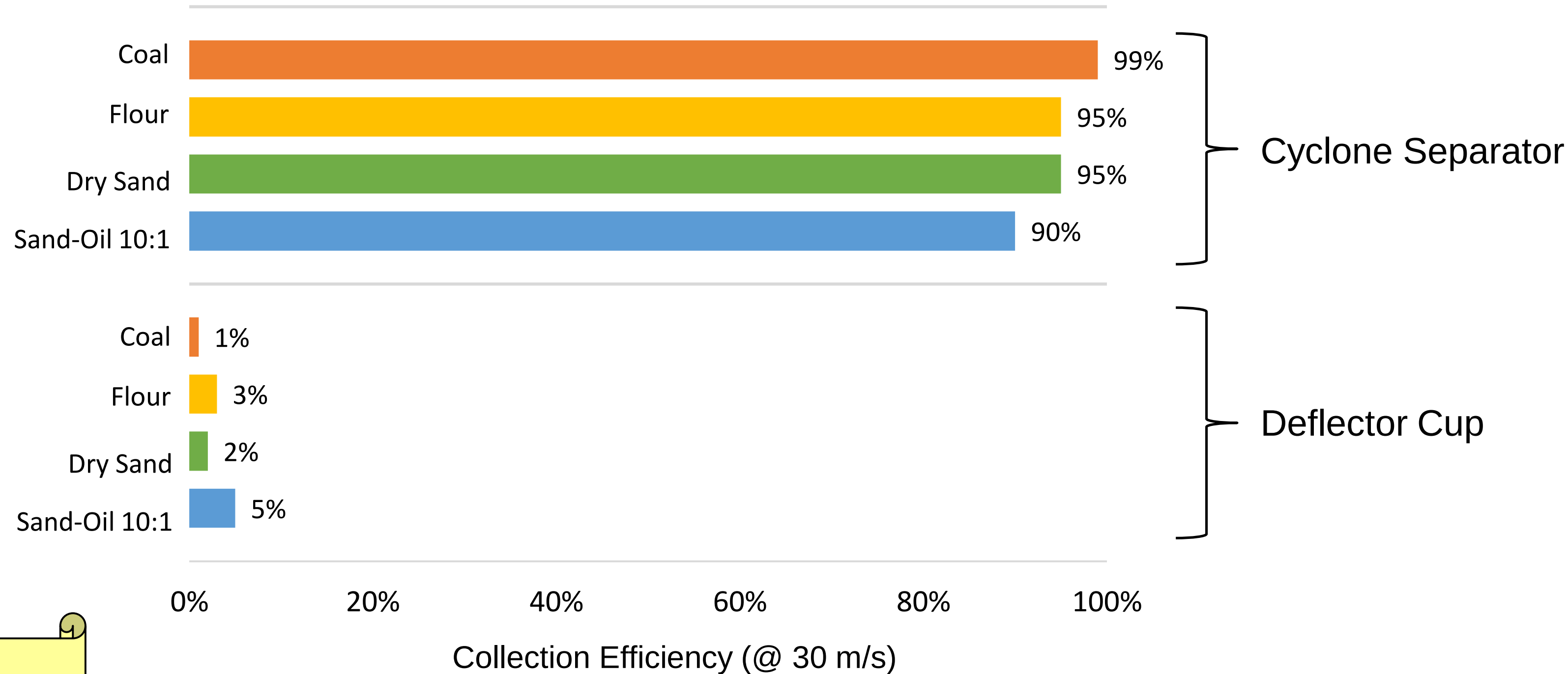
$$\text{Collection Efficiency} = \frac{\text{mass collected in sample cup}}{\text{mass of sample ingested by pneumatic system}}$$



Key Differences:

Cyclone

- Uncollected mass is stuck inside system
- Very efficient (> 90%)
- More efficient with dry materials
- Bulk collection
- Surface analysis recommended

Deflector Cup

- Uncollected mass is expelled via fan exhaust
- Very inefficient (< 5%)
- More efficient with sticky materials
- Less prone to cross-talk between sample attempts
- Finite collection (typically small quantities of sample)

Conclusion

- Honeybee is developing a pneumatic sampling system for Titan exploration
  - Could be adapted for operation on other ocean worlds (e.g. Planet-Vac)

- Two types of particle extractors tested to determine strengths and weaknesses
  - Room temperature analog testing to identify and characterize performance with different simulants

Thank you for your attention…

Any questions?

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