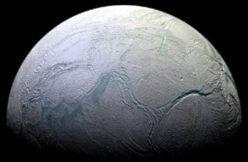
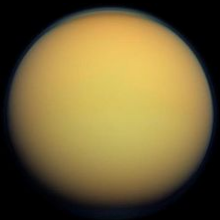
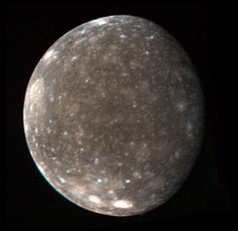
15th International Planetary Probe Workshop
June 13th, 2018
Boulder, Colorado

Pneumatic Sample Transport for Ocean Worlds

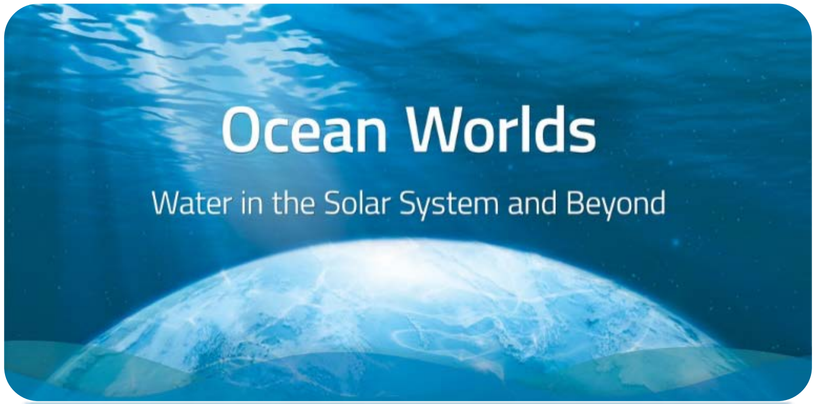


Presenter:
Joey Sparta
Mechanical Engineer
Honeybee Robotics (HBR)
jsparta@honeybeerobotics.com

Kris Zacny	HBR	ColdTech PI
Ralph Lorenz	APL	ColdTech Co-I
Fredrik Rehnmark	HBR	Sr. Systems Engineer
Tighe Costa	HBR	Pneumatic Subsystem Lead
Zach Mank	HBR	Sample Delivery Subsystem Lead
Jameil Bailey	HBR	Avionics Lead
Nick Traeden	HBR	Mechanical Engineer

Background

COLDTech - **C**oncepts for **O**cean worlds **L**ife **D**etection **TECH**nology



credit: NASA

NASA-funded ocean worlds technology development program:

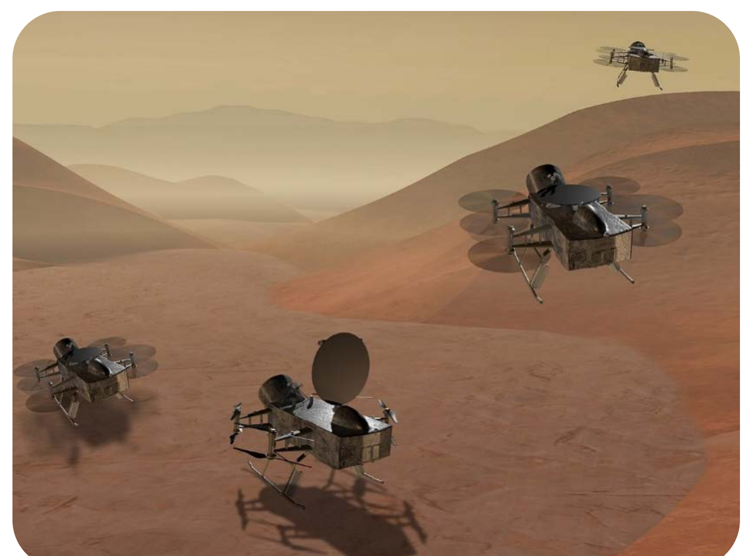
a) science instruments

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

Key Sampling Strategies

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

Mechanical vs Pneumatic Transport

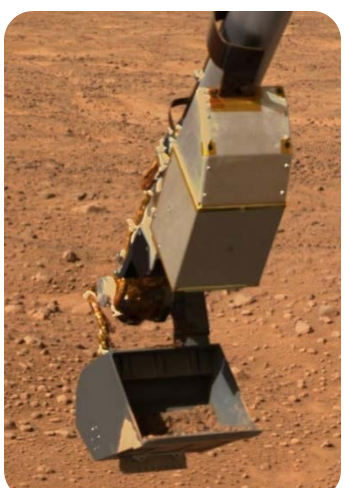
Mechanical Transport

- 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

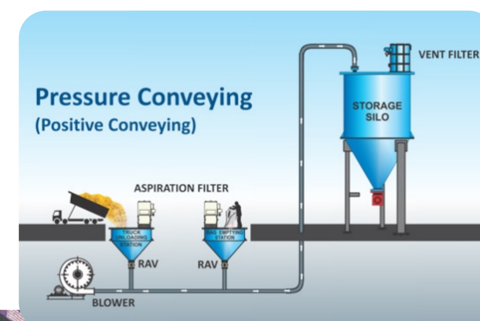
Pneumatic Transport

- 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

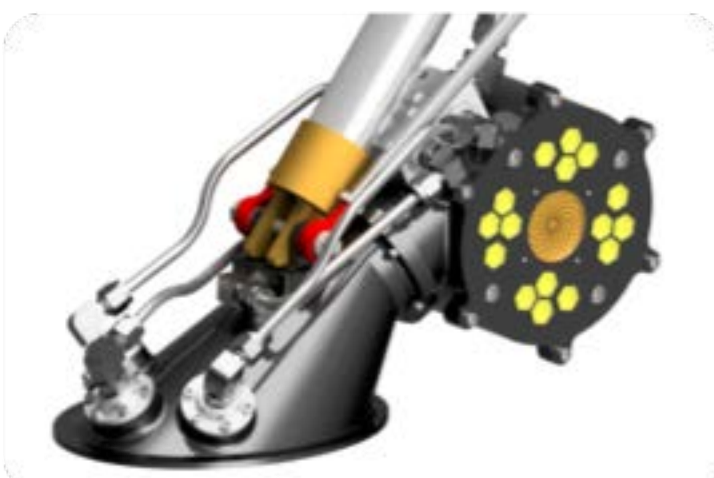


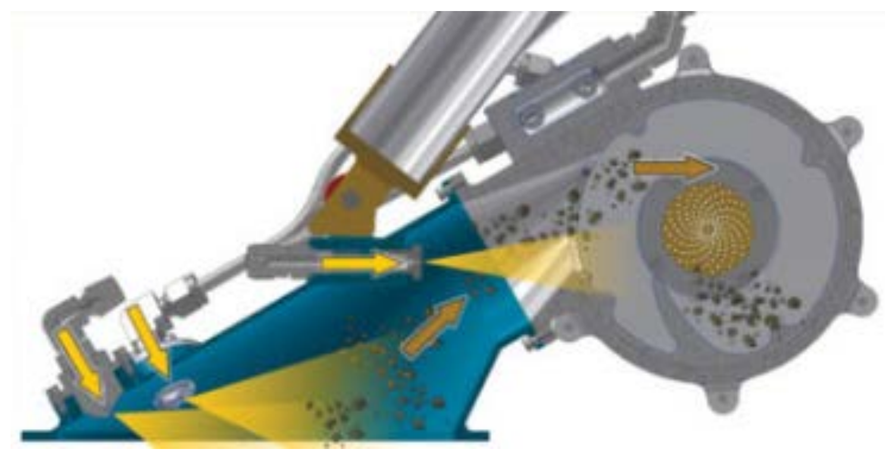
credit: NASA/GSFC/NSSDC

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

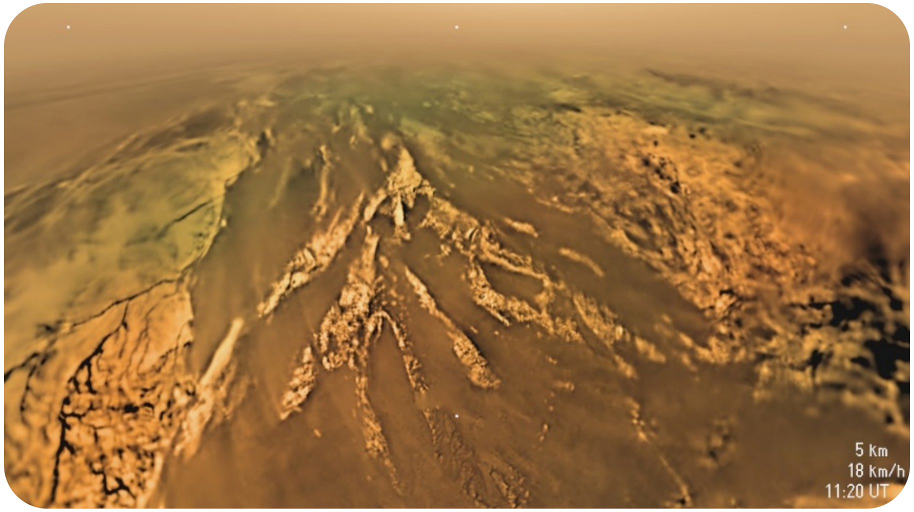




credit: The Planetary Society

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:

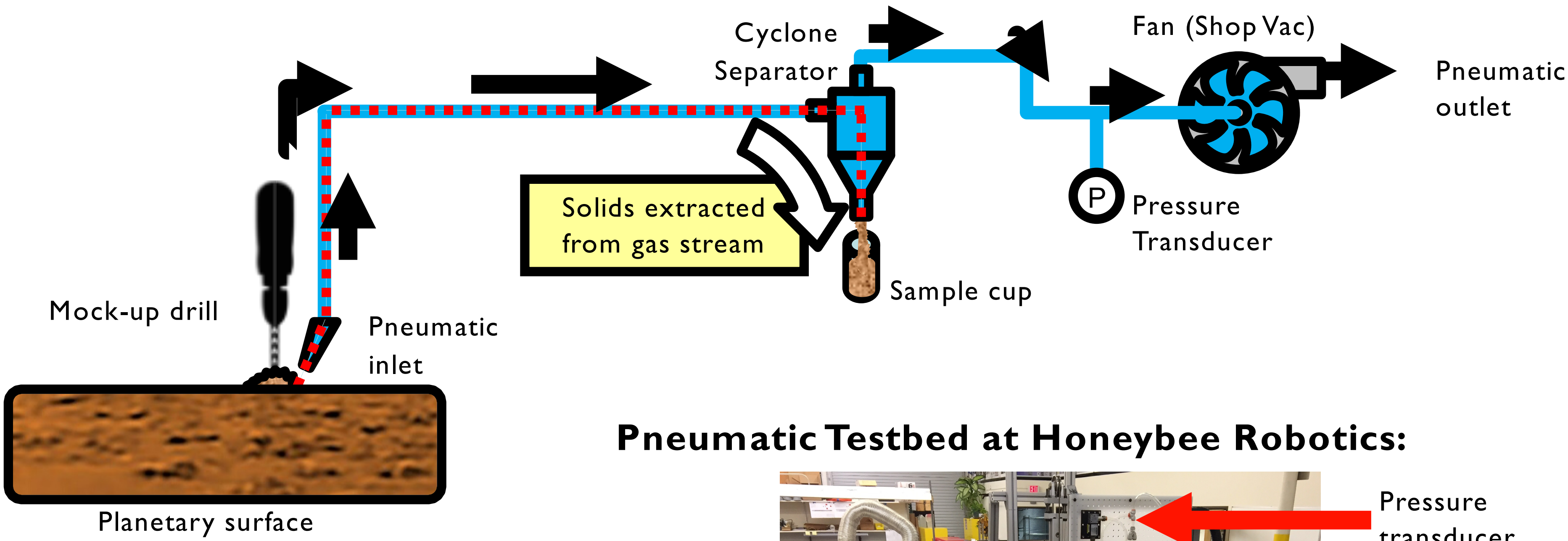
(credit: ESA/NASA/JPL/University of Arizona)

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

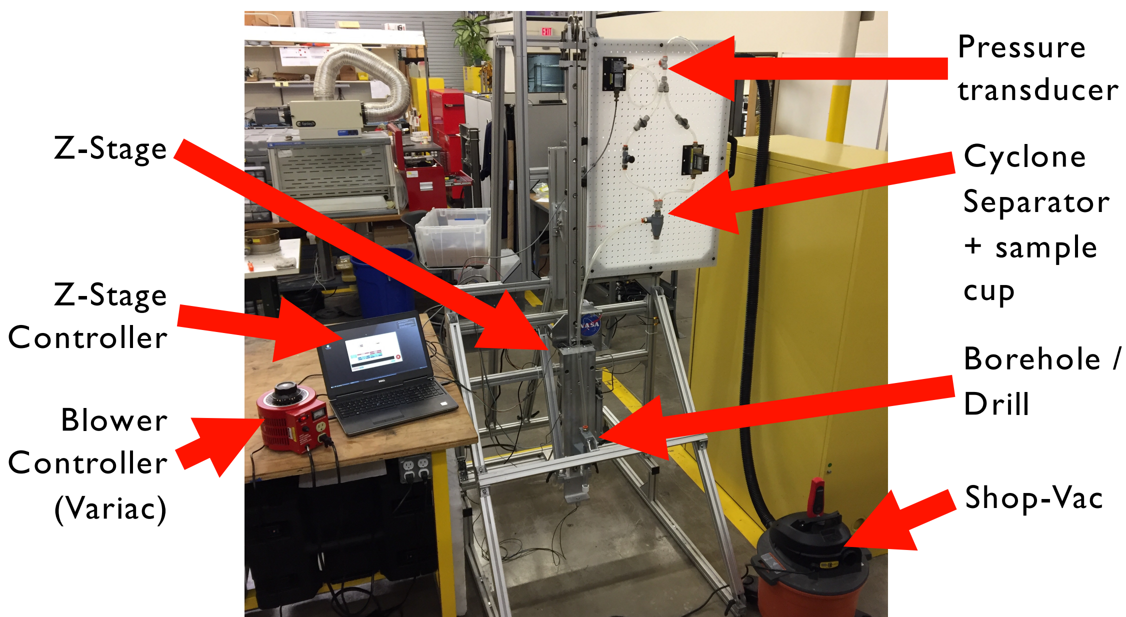
		Earth	Titan	Titan-Earth ratio
Air Density	ρ	1.2 $\mathrm{kg/m^3}$	5.4 $\mathrm{kg/m^3}$	**4.4**
Viscosity	μ	1.8 x 10^{-5} Pa–s	6.0 x 10^{-5} Pa–s	**0.33**
Gravity	g	9.8 m/s^2	1.4 m/s^2	**0.14**

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

Room Temperature Testing



Pneumatic Testbed at Honeybee Robotics:



Pneumatic Transport Velocity

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

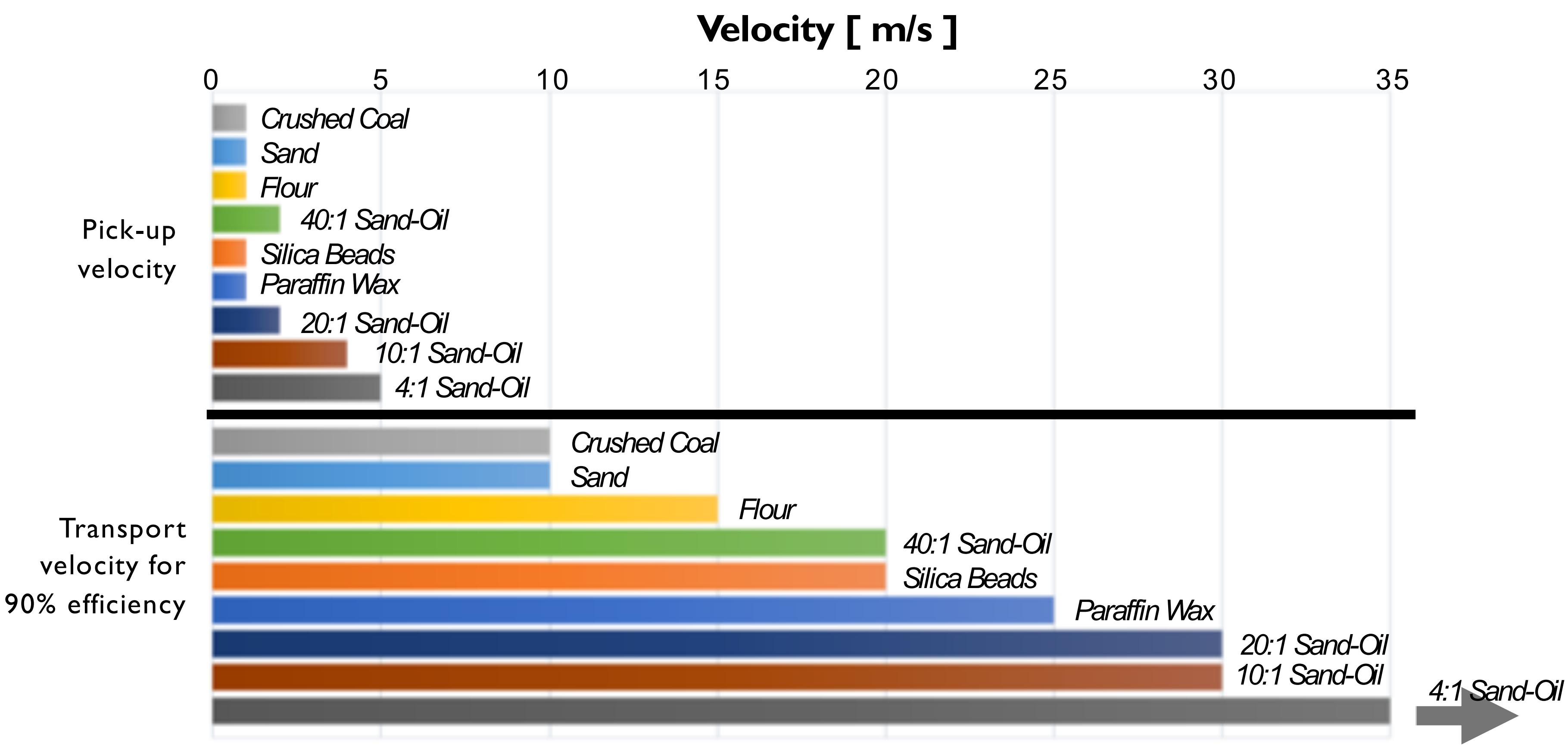
HONEYBEE ROBOTICS

Non-sticky Simulants:

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

Sticky Simulants:

+

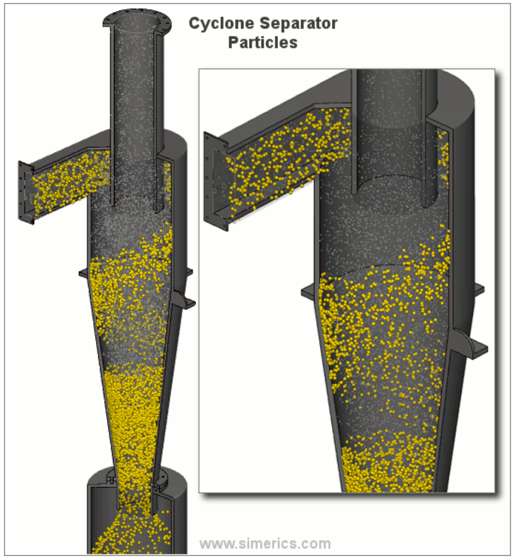


Solid Particle Extraction

JOHNS HOPKINS APPLIED PHYSICS LABORATORY · HONEYBEE ROBOTICS

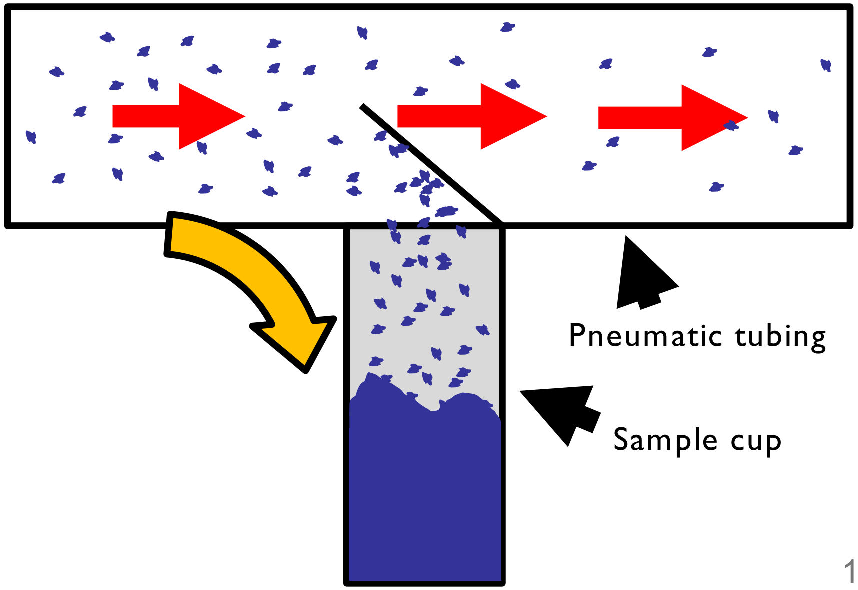
Cyclone Separator

- 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



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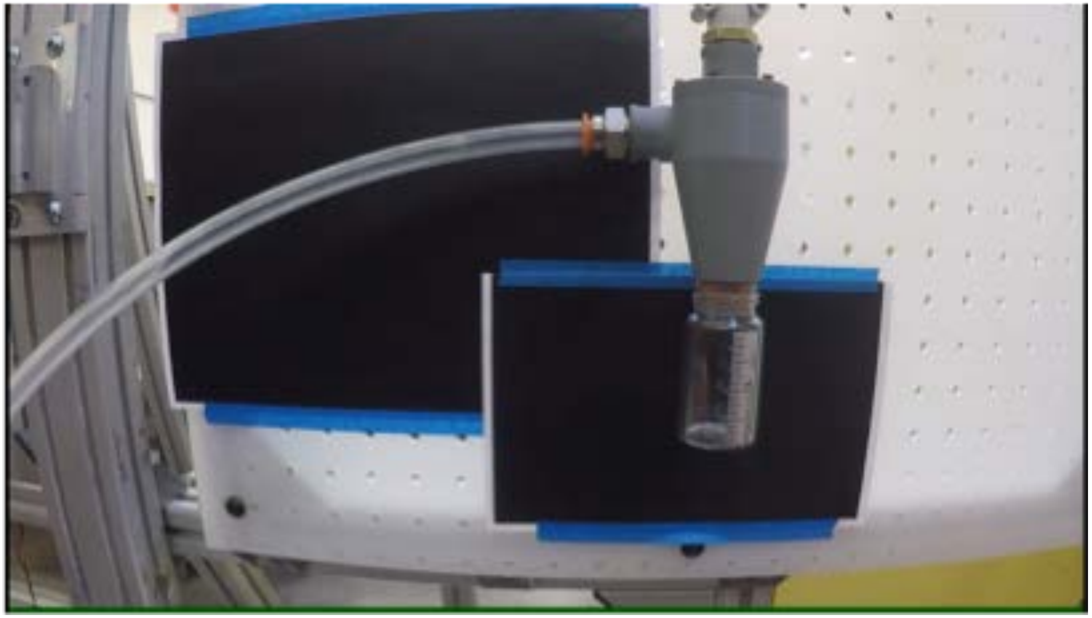


Pathological Testing

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:

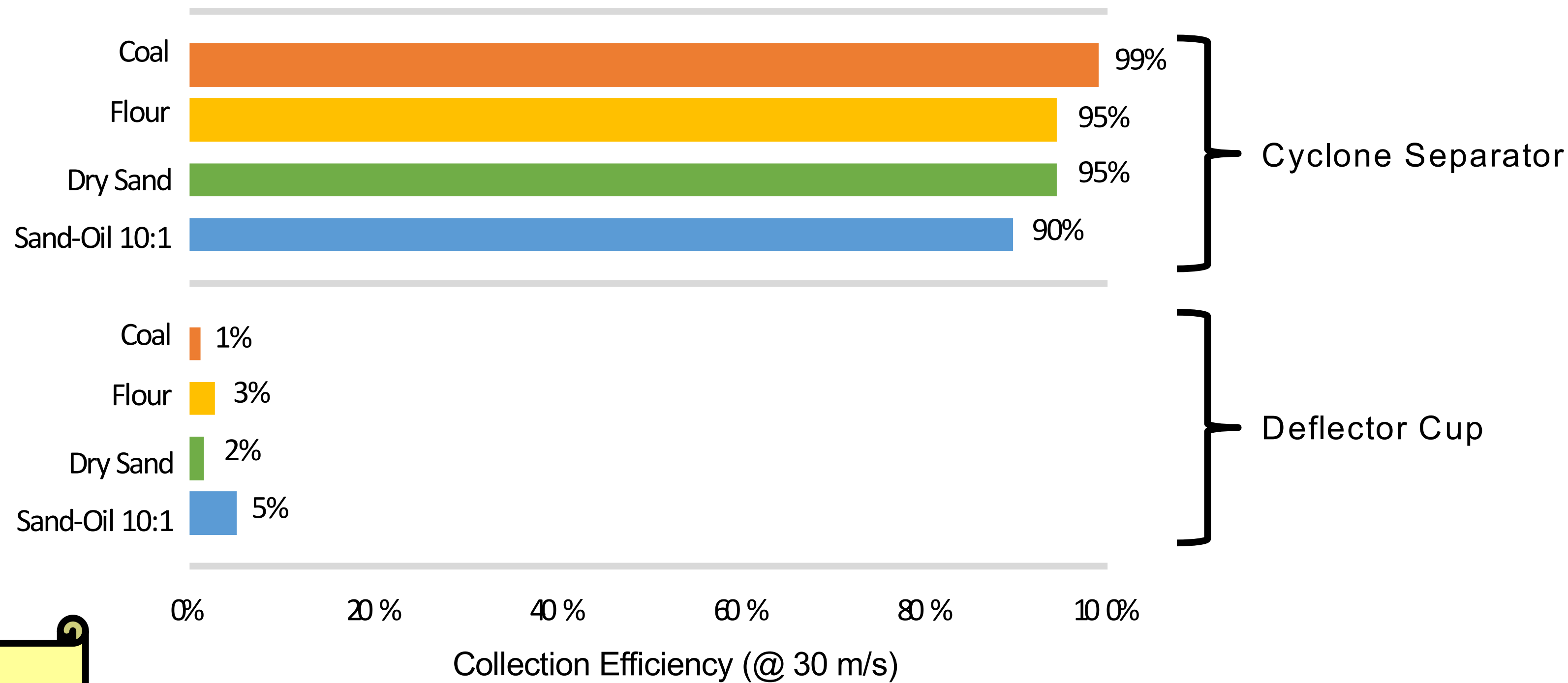
Sticking to tubing walls:

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

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



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?