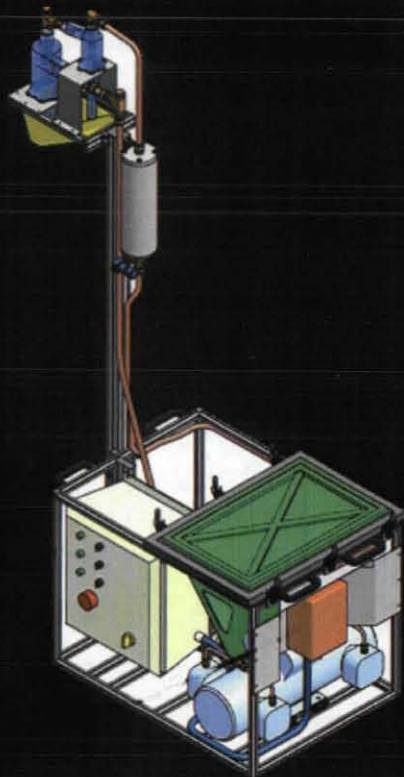


# Pneumatic Regolith Transfer Systems for In Situ Resource Utilization

R.P. Mueller (NASA KSC), I.I. Townsend (ASRC), J.G. Mantovani (NASA KSC), Kris  
A. Zacny and Jack Craft



Presented by Van Townsend,  
NASA Kennedy Space Center, Florida USA



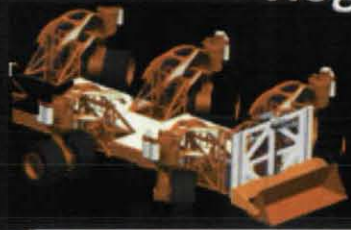
AMS 2010  
May 12-14, 2010  
Orlando, Florida

# Pneumatic Regolith Transfer Systems for In Situ Resource Utilization

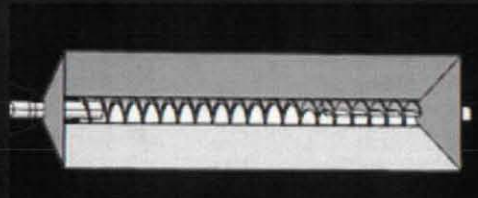
R.P. Mueller (NASA KSC), I.I. Townsend (ASRC), and J.G. Mantovani (NASA KSC)



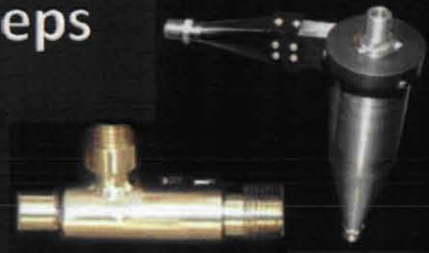
## Regolith Transfer and ISRU Processing Steps



Excavator Delivers  
Regolith to Trough



Regolith is  
Transferred to the  
Pneumatic Transfer  
System's Supply Bin



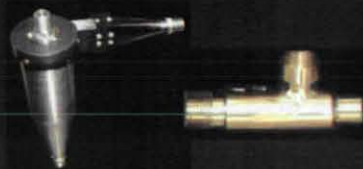
Regolith is Conveyed  
Pneumatically to an  
ISRU Reactor



Spent Regolith is  
Pneumatically Conveyed  
Out of the ISRU Reactor



Regolith is Chemically  
Reacted to Yield Useful  
Products Like Oxygen and  
Metals such as Titanium



E.g., Carbothermal,  
Hydrogen Reduction,  
Molten Oxide Electrolysis

# Pneumatic Regolith Transfer Systems for In Situ Resource Utilization

R.P. Mueller (NASA KSC), I.I. Townsend (ASRC), and J.G. Mantovani (NASA KSC)



## Possible Regolith Feed Systems

### Pneumatic Transport

#### Pros

- + Compact
- + Versatile - easily reconfigurable to fit other systems
- + Low temperature valves
- + Improved performance in 1/6 g
- + System commonality – reuse of ISRU fluidization components

#### Cons

- Complexity
- Additional Cooling
- Sandblasting
- Size Sorting
- Compressor required if not already available

### Inclined Auger

#### Pros

- + Simple
- + Previous experience
- + Sprawl (good for spent pile)

#### Cons

- Wear concerns
- Sprawl (bad for volume and deployment concerns)
- Dump pile interference

## ROxygen Testing

### Successfully Assembled and Tested ROxygen System:

- Successfully Assembled and Tested the subsystem at JSC to qualify for the OPTIMA Field Test
- Assembled the complete system in Hilo for the OPTIMA Field Test
- Successfully performed reductions to achieve our goal of producing water from dry native soil then separated that water into hydrogen and



ROxygen

## ROxygen Testing

*Valves that are compatible with the flow of granular materials.* Figure: Spherical Disc Valve from Gemco, Inc



## ROxygen Testing

Figure: Hot Tephra flowing out of Gemco valve attached to the bottom of the ROxygen I Reactor.

.Show Movie



## ROxygen Testing

Figure: Flight experiment in May 2008 to test the flow of regolith simulant inside a hopper under reduced gravity conditions.

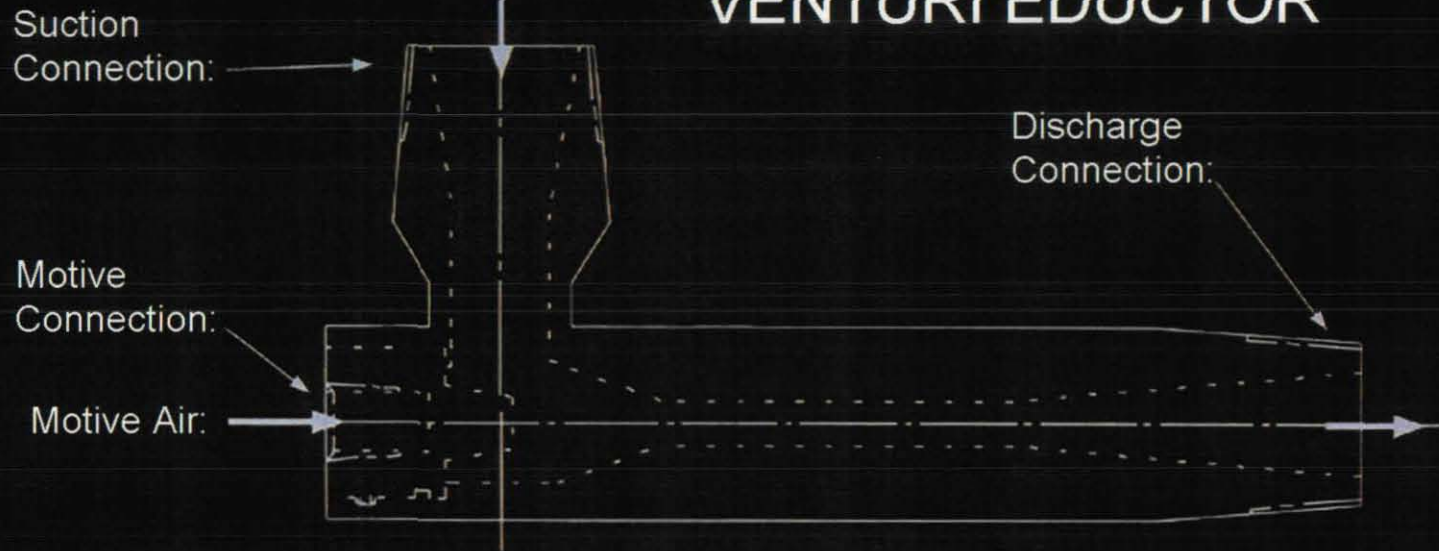


# Pneumatic Regolith Transfer Systems for In Situ Resource Utilization

R.P. Mueller (NASA KSC), I.I. Townsend (ASRC), and J.G. Mantovani (NASA KSC)



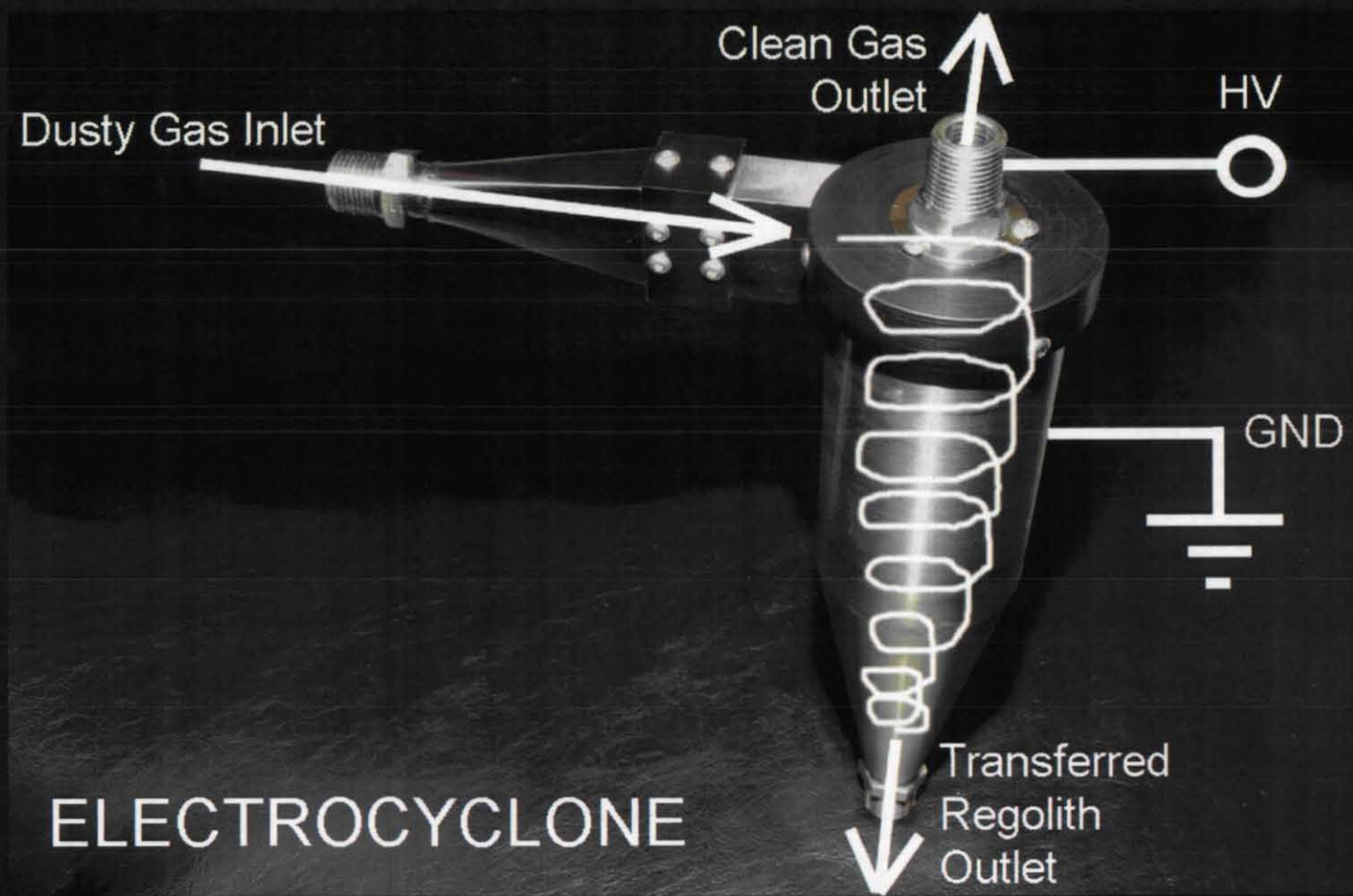
## VENTURI EDUCTOR





# Pneumatic Regolith Transfer Systems for In Situ Resource Utilization

R.P. Mueller (NASA KSC), I.I. Townsend (ASRC), and J.G. Mantovani (NASA KSC)





# Pneumatic Regolith Transfer Systems for In Situ Resource Utilization

R.P. Mueller (NASA KSC), I.I. Townsend (ASRC), and J.G. Mantovani (NASA KSC)



Reduced Gravity Flight Experiment to Evaluate the Pneumatic Regolith Transfer System at  $1/6$  g and to Compare with Results at 1 g

# Pneumatic Regolith Transfer Systems for In Situ Resource Utilization

R.P. Mueller (NASA KSC), I.I. Townsend (ASRC), and J.G. Mantovani (NASA KSC)



## Pneumatic Regolith Transfer System for 1 g and 1/6 g



HEPA Filters for Exhaust Air from Electrocyclone

Cyclone/Electrocyclone Gas-Particle Separator

Secondary Containment Enclosure w/Hinged Door (Total Weight: 195 kg)

Regolith Supply Partially Hidden in Back (17kg of NU-LHT-2M)

Receiving Bin (Empty) Serving as an ISRU Reactor Mockup

Venturi Eductor (hidden) attached to Supply Bin for Gas-Solids Mixing

High Voltage DC Power Supply for Electrocyclone

Gas Supply (from Reg. Compressed Air Bottle)

# Pneumatic Regolith Transfer Systems for In Situ Resource Utilization

R.P. Mueller (NASA KSC), I.I. Townsend (ASRC), and J.G. Mantovani (NASA KSC)



The NASA KSC Reduced Gravity Flight Experiment was supported by the NASA Innovative Partnership Program and flow from the JSC Reduced Gravity Office at Ellington Field in Houston



# Pneumatic Regolith Transfer Systems for In Situ Resource Utilization

R.P. Mueller (NASA KSC), I.I. Townsend (ASRC), and J.G. Mantovani (NASA KSC)



# Pneumatic Regolith Transfer Systems for In Situ Resource Utilization

R.P. Mueller (NASA KSC), I.I. Townsend (ASRC), and J.G. Mantovani (NASA KSC)



# Pneumatic Regolith Transfer Systems for In Situ Resource Utilization

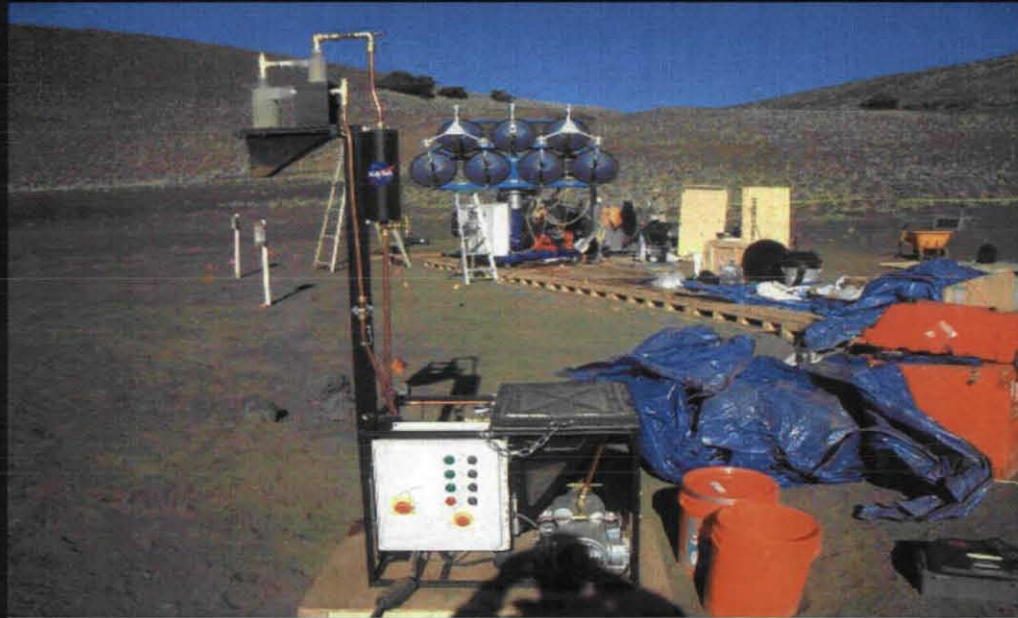
R.P. Mueller (NASA KSC), I.I. Townsend (ASRC), and J.G. Mantovani (NASA KSC)



Figure: Pneumatic Regolith Feed System for the Carbothermal O<sub>2</sub> reactor at the Mauna Kea field test in February 2010. *Pneumatic system tested in Feb 2010 at Mauna Kea.*

*Find a better picture and insert video*

*Get Rover delivering material*



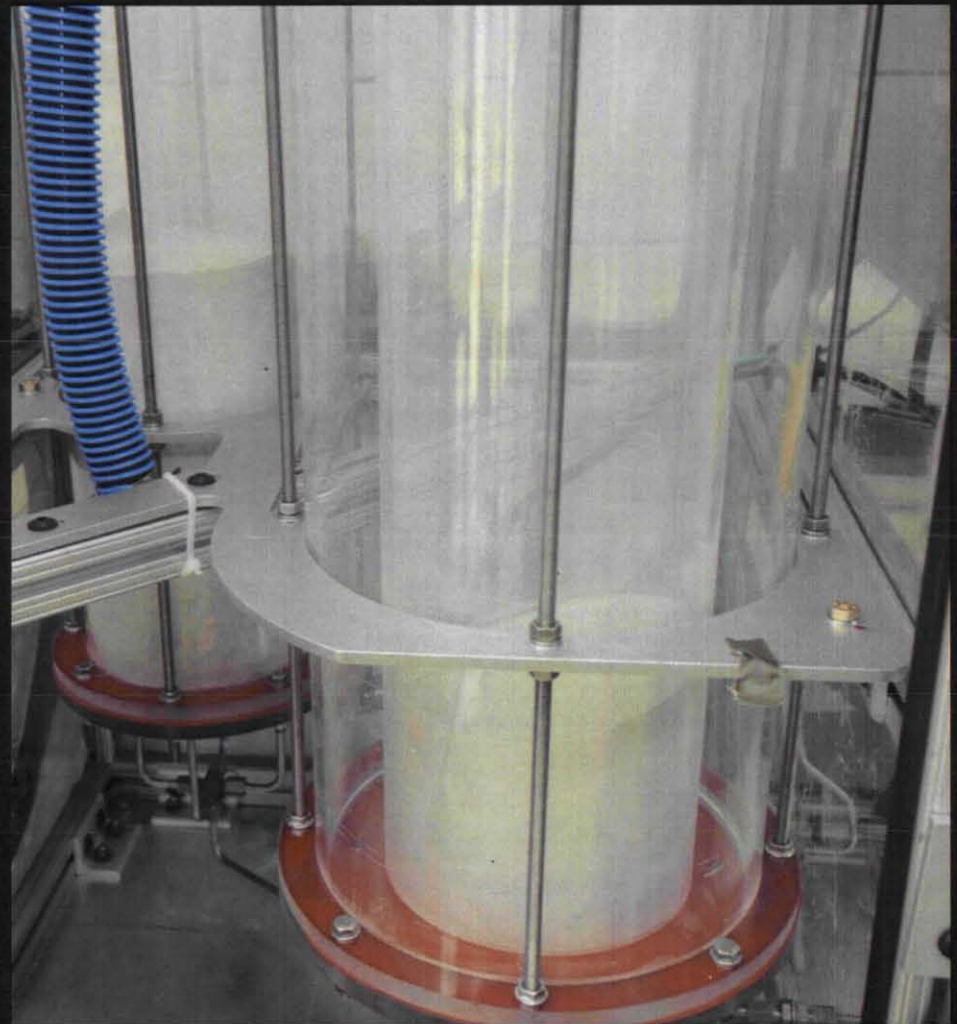


# Pneumatic Regolith Transfer Systems for In Situ Resource Utilization

R.P. Mueller (NASA KSC), I.I. Townsend (ASRC), and J.G. Mantovani (NASA KSC)

## RESULTS

- Tephra (16.5kg) transferred well in 1 g
- Tephra (16.5kg) transferred better in 1/6 g
- NU-LHT-2M transferred well in 1 g. Sieved (1.4 mm) 12.5 kg was transferred in ~3 min in 1g.
- NU-LHT-2M (8.8kg) transferred better in 1/6 g (rocks in unsieved sample plugged the eductor that halted regolith transfer)
- Fluidization was evident
- Eductor formed a hole that collapsed as a result of fluidization
- Cyclones were overwhelmed by simulant flow (electrocyclone needs a dilute flow)
- Cyclones to be re-designed for dense flow



1 g and 1/6 g Testing of Pneumatically Conveyed Lunar Regolith Simulants



# Pneumatic Regolith Transfer Systems for In Situ Resource Utilization

R.P. Mueller (NASA KSC), I.I. Townsend (ASRC), and J.G. Mantovani (NASA KSC)



## Conclusions

- ✓ Pneumatic regolith transfer was successfully demonstrated at 1 g and at 1/6 g.
- ✓ It is possible to pneumatically convey a dense flow of the lunar regolith simulants NU-LHT-2M and Tephra to a vertical height of 1.52 meters (limited by the aircraft).
- ✓ Since the RGF experiment hardware experiences periods of increased gravity (~1.8 g), this likely compacts the granular regolith simulant material.
- ✓ Turning off the flow of dusty gas between parabolas resulted in inefficient cyclone performance, and likely contributed to the cyclones being overwhelmed by the dust flow during the RGF experiment.



# Pneumatic Regolith Transfer Systems for In Situ Resource Utilization

R.P. Mueller (NASA KSC), I.I. Townsend (ASRC), and J.G. Mantovani (NASA KSC)

## Conclusions

- ✓ Cyclone separators are essential to a closed-loop pneumatic regolith transfer system in which the gas must be reused.
- ✓ Reduced gravity flight experiments and ground tests demonstrated that lunar regolith simulant is very easily conveyed pneumatically into a simulated ISRU oxygen production plant reactor, and that the regolith can be fluidized within the hopper feed system. The ground testing demonstrated that regolith can also be expelled from the ISRU reactor for disposal (or possibly for later resource processing, e.g., to extract silica, aluminum, titanium, iron, etc.).

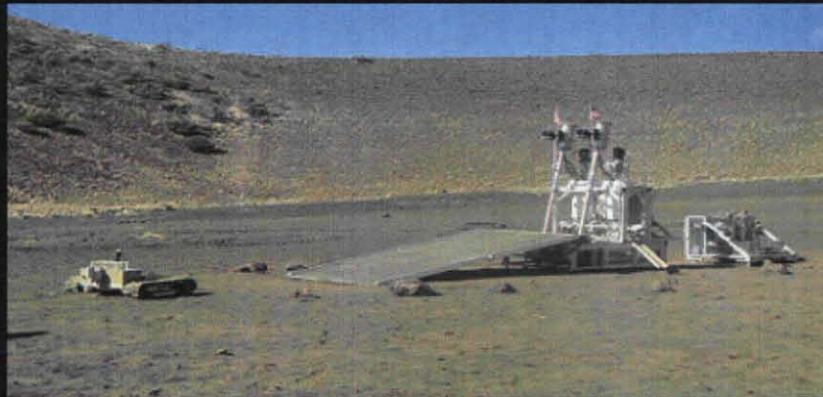


## Pneumatic Regolith Transfer Systems for In Situ Resource Utilization

R.P. Mueller (NASA KSC), I.I. Townsend (ASRC), and J.G. Mantovani (NASA KSC)

### Future Work and Integration Plans

- ✓ Metering the regolith feed will make it possible to test the electrocyclone by producing a moderate dense flow of dusty gas that yields a sufficient mass transfer rate while lessening the burden on the cyclones to filter the exhausted gas.
- ✓ The results of these experiments influenced the design of the regolith feed systems of the ROxygen second generation oxygen production system being developed by the NASA ISRU project, as well as the Carbothermal oxygen production plant, which was recently field tested on Mauna Kea.



The ROxygen 1 Field Test used an Auger Regolith Feed System. ROx 2 design uses the Pneumatic Regolith Feed System.

# Pneumatic Regolith Transfer Systems for In Situ Resource Utilization

R.P. Mueller (NASA KSC), I.I. Townsend (ASRC), and J.G. Mantovani (NASA KSC)



## Acknowledgments

The NASA Innovative Partnerships (IPP) Program and the Facilitated Access to the Space Environment for Technology Development and Training (FAST) Program,

the Reduced Gravity Office (RGO) at NASA Johnson Space Center,

Structural analysis: Greg Galloway at NASA KSC (NE-S),

RGF Team: Dave Mclaughlin and Adam Dokos of the NASA KSC Prototype Development Laboratory (NE-L3),

the NASA Kennedy Space Center CDDF program,

the ROxygen ISRU project under NASA ETDP,

the management of the NASA Lunar Surface Systems (LSS) Office,

the KSC Engineering Directorate (NE),

and the KSC Surface Systems Office (NE-S).



# Pneumatic Regolith Transfer Systems for In Situ Resource Utilization

R.P. Mueller (NASA KSC), I.I. Townsend (ASRC), and J.G. Mantovani (NASA KSC)

## Acknowledgments

Figure: Jet-Lift Regolith Transfer



# Pneumatic Regolith Transfer Systems for In Situ Resource Utilization

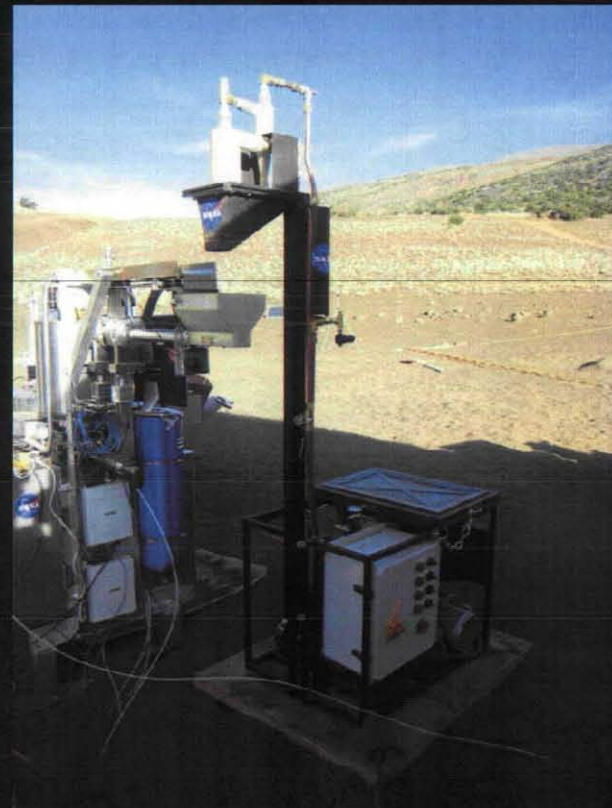
R.P. Mueller (NASA KSC), I.I. Townsend (ASRC), and J.G. Mantovani (NASA KSC)



Figure: Pneumatic Regolith Feed System for the Carbothermal O<sub>2</sub> reactor at the Mauna Kea field test in February 2010.

*Pneumatic system tested in Feb 2010 at Mauna Kea.*

*Find a better picture and insert video*



# Pneumatic Regolith Transfer Systems for In Situ Resource Utilization

R.P. Mueller (NASA KSC), I.I. Townsend (ASRC), and J.G. Mantovani (NASA KSC)



Figure: Pneumatic Regolith Feed System for the Carbothermal O<sub>2</sub> reactor at the Mauna Kea field test in February 2010.

*Pneumatic system tested in Feb 2010 at Mauna Kea.*

*Find a better picture and insert video*

