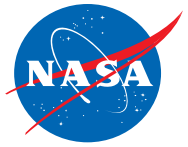

Experimental Facility to Measure Power and Forces to Excavate Lunar Regolith Simulants

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Cleveland, Ohio

Tenth Joint Meeting of the Space Resources Roundtable and the
Planetary & Terrestrial Mining Sciences Symposium

Colorado School of Mines

Golden, Colorado, USA

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ISRU Excavation – GRC team

LMT/Margaret Proctor - Technical Lead
LMT/Phil Abel - ISRU - Excavation Element Lead
FTB[HX5 Sierra]/Tom Barkis - Electrical and controls
LMT/Steve Bauman - Design
LTT/Bilal Bomani - Enclosure
LMT/John Breckenridge - Design analysis
LMT/Colin Creager - Soil and soil bins
FA00/Scott Cutlip - Design analysis
LED/Yu Hin “Billy” Hau - APEX motion analysis & Instrumentation
LMT/Kyle Johnson - Consultant
JA00/Marla Kennedy - Soil and soil bins
LMT/Isaac Lopez(intern) - Instrumentation
LMT/Erin Rezich (co-op) - Instrumentation
LMT/Fransua Thomas - Test plan
LMT/Zachary Zoloty (intern) - Instrumentation

LMT/Damian Ludwiczak - LMT Branch Chief

Excavation Laboratory at NASA Glenn houses APEX

Advanced Planetary Excavator (APEX)

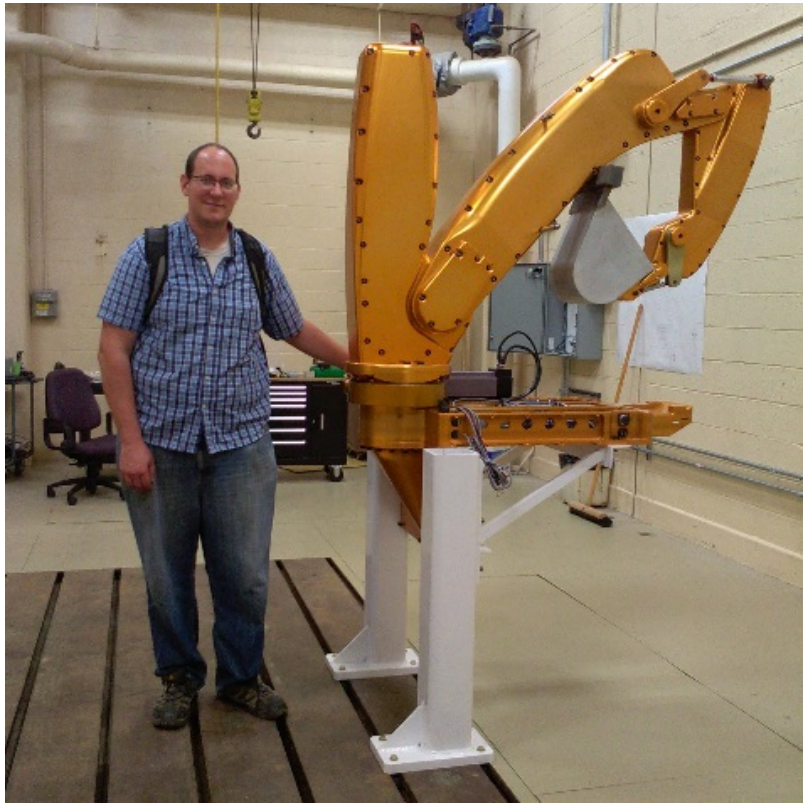
Field demonstration of APEX at JSC mounted on Centaur 2 rover.

APEX has electrically powered linear actuators to move the digger components.

APEX can rotate 360 degrees.

2.3 meter maximum swing around radius with bucket and load cell.

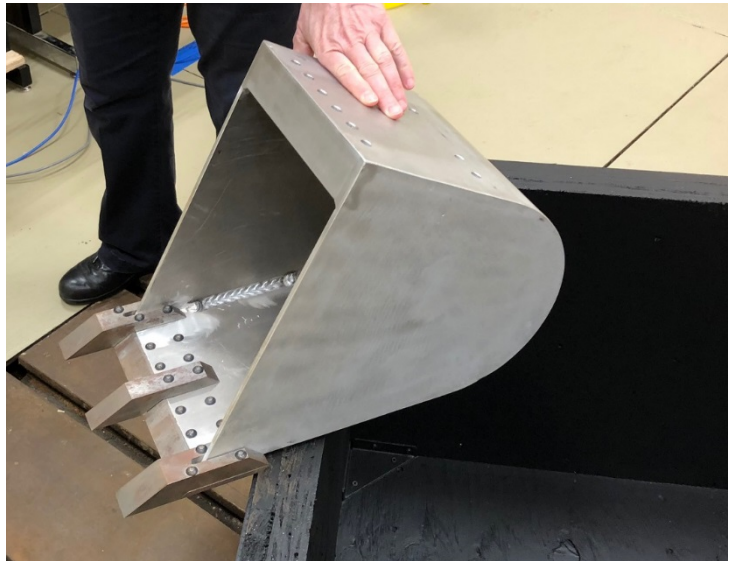
208 VAC – 3 phase power is converted to 325 VDC, 100 amps to power the actuators in APEX.

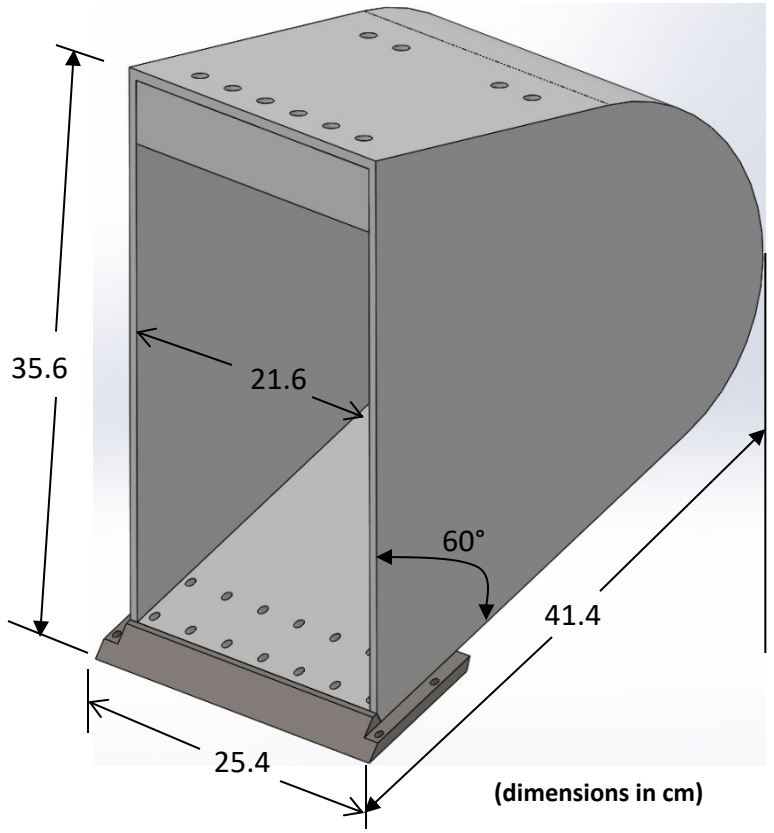


APEX mounted to new stand in NASA GRC's Excavation Lab

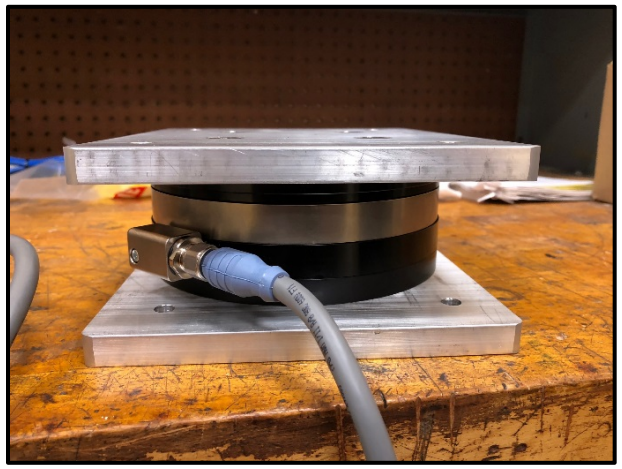
Bucket

- 21.6-cm wide aluminum bucket
- 25.4-cm wide steel leading edge, 30º blade angle
- Three teeth can be added
  - 4.44-cm wide, 30º blade angle
  - extend 5.1 cm beyond leading edge
- Bucket volume = 15600 cm^3





Instrumentation

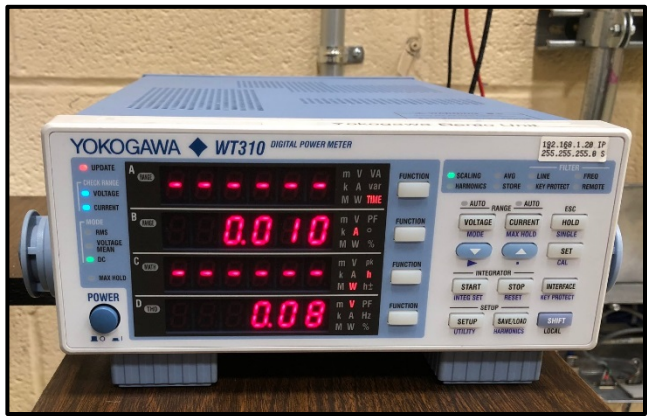


Load Cell & Adapter Plates

Range: 1300 N Fx, Fy /3900 Fz;
203 N-m Tx, Ty, Tz

Max. FS Uncertainty:
1.25% Fx, Fy, Tx, Ty
2.00% Fz and Tz

Size: 156.5 mm diameter



Yokogawa Power Meter

- Used with 50 Amp shunt to measure DC power to the APEX.

Platform scale

- 61 cm x 61 cm
- Range = 2224 N x 0.22 N

Data Acquisition and Control – LabVIEW, C-RIO, CANBUS

Soil Bins

- Pea gravel bin
  - Wooden bin painted with flame retardant paint
  - Inside dimensions: 61 W x 91 L x 51 H (cm)

- GRC-3B soil bin
  - Welded carbon steel, powder coated
  - Inside dimensions: 76.2 W x 183 L x 76 H (cm)
  - Empty weight = 2064 N
  - Filled weight not to exceed 17790 N (Crane capacity)
  - 1587 kg GRC-3B leaves about 10 cm head space
  - Sits on shaker table

- Dump bin on 61 cm x 61 cm platform scale, for delivered load.

Shaker Table

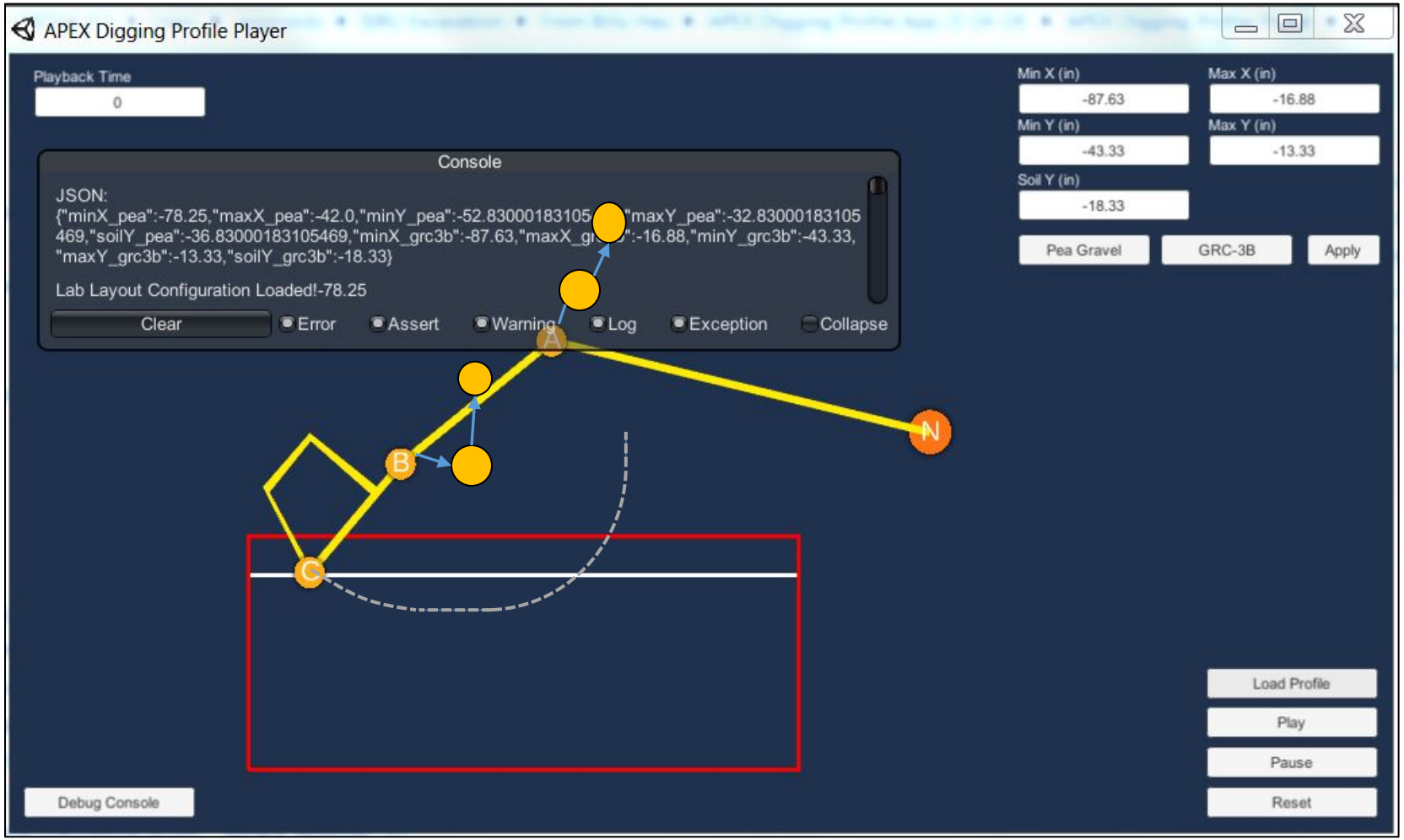
For consistent soil preparation before each test.

- 81 W x 188 L x 36 H cm Custom Compaction Table
- 22.24 kN Max. load
- Carbon steel and powder coated
- 2 counter rotating 3600 rpm electric drives
- 4 Goodyear air springs
- Manual controls
- Controller with variable frequency drive, on/off switch, 0-100 Hz brakes motor starter and overload 230 V/ 3 phase in and out, NEMA 4 Enclosure

Test Objectives

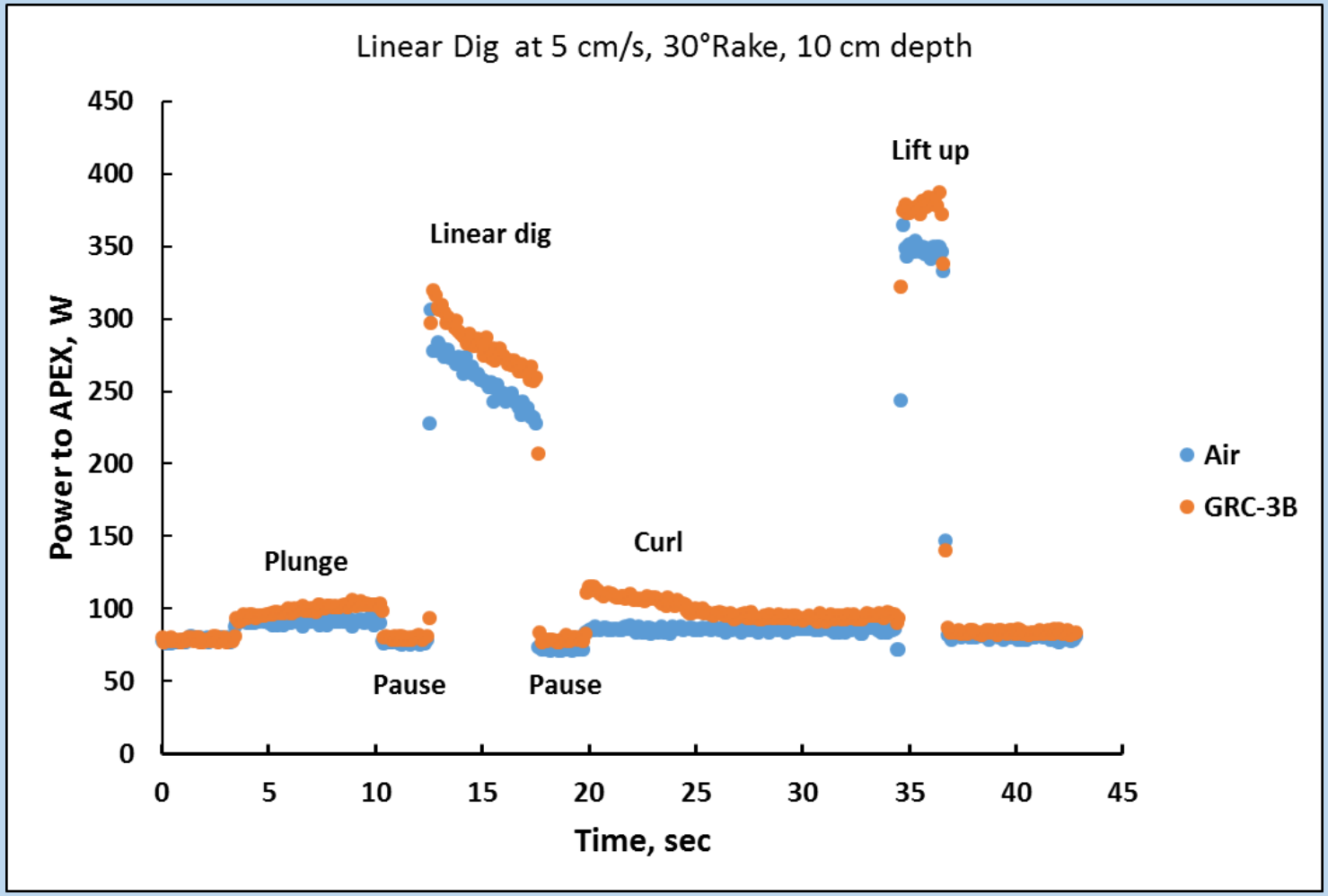
- Measure the forces at the bucket and power used by APEX to dig granular material.
- Independent variables:
  - Rake angle
  - Digging depth
  - Digging trajectory
  - Density of the soil
  - Bucket features: no teeth and with teeth
- Approach:
  - Measure power & forces to dig in air and in simulant using same motion profile.
  - Subtract tare values to determine power and forces required to dig granular material.

Trajectories are planned and repeatable

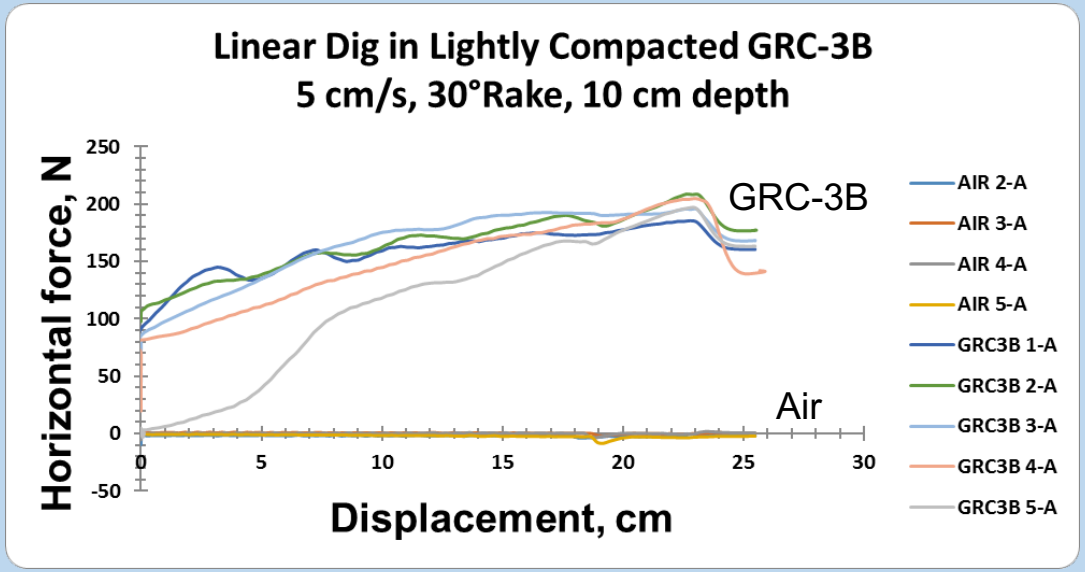


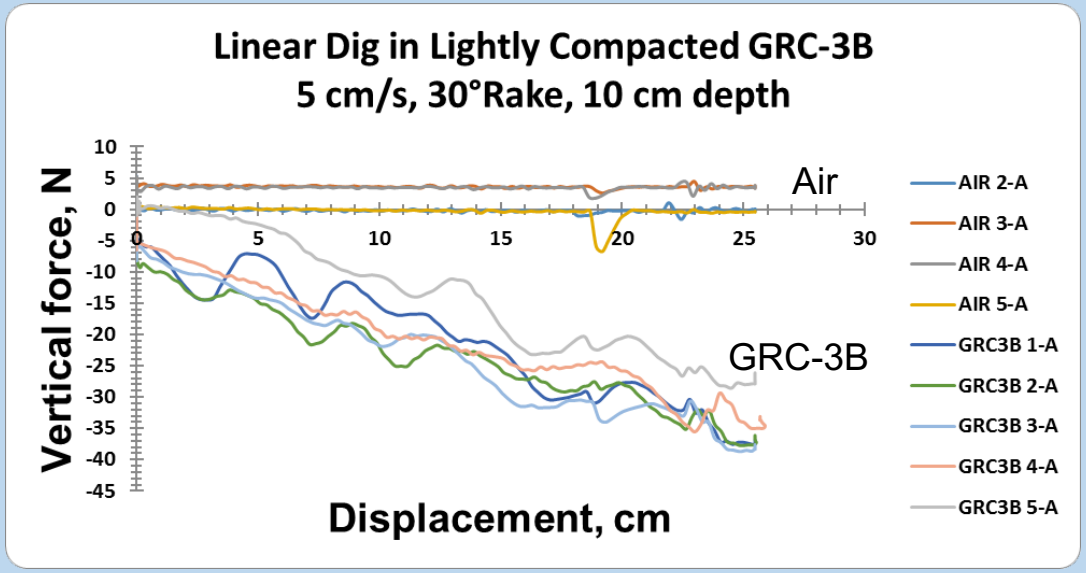
Trajectory Designer → Profile Simulator → LabVIEW Controller → APEX

Power to move APEX in Air and GRC-3B

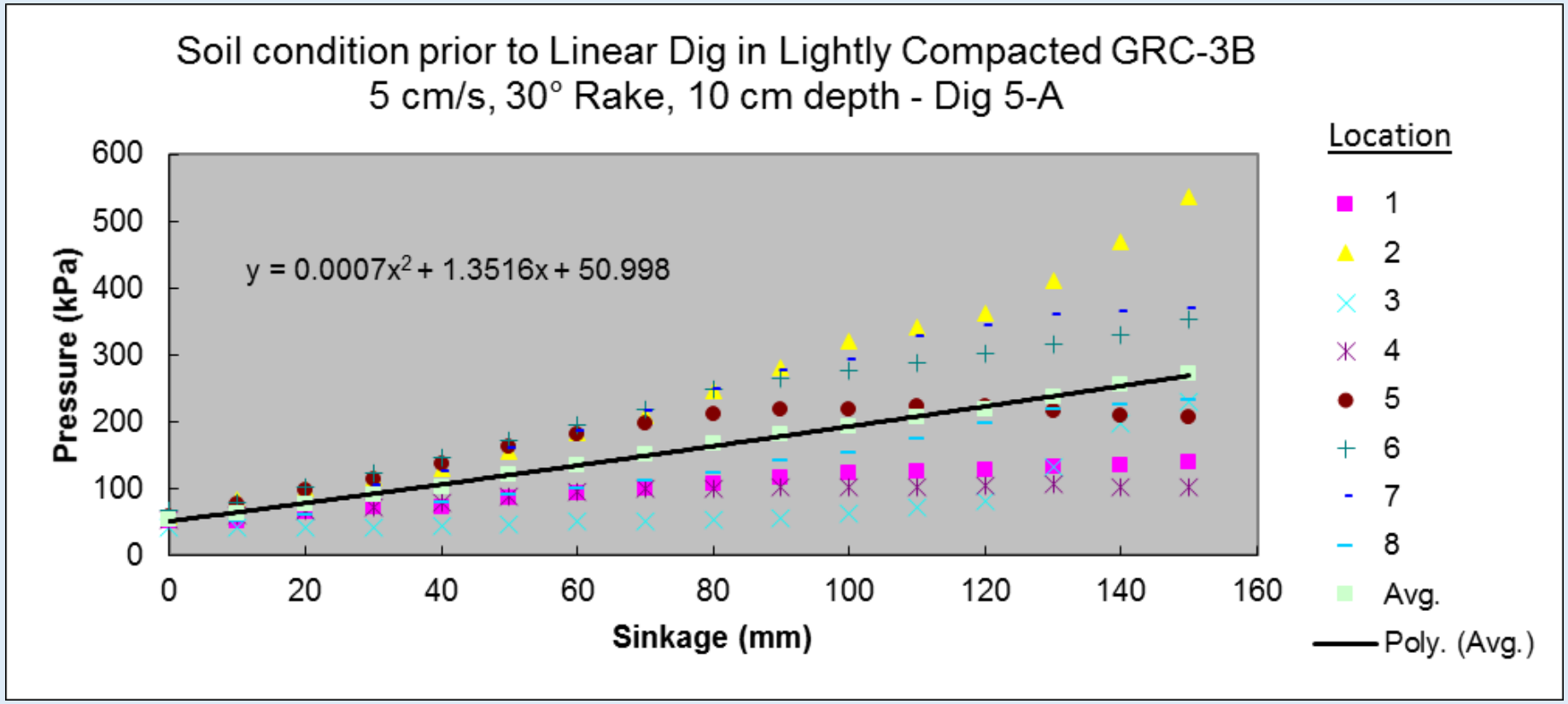


Sample Force Data from Linear Dig





Sample results from Cone Penetrometer Tests



Comparison of bow wake at end of linear dig at 5 cm/s, 30° Rake, 10 cm depth

Lightly compacted

Compacted

Summary

- The Excavation Lab at NASA Glenn is operational and being used to measure forces and power needed to excavate Lunar regolith simulants.
- APEX provides a stable platform for testing various digging devices and repeatable dig trajectories.
- Dust enclosure controls respiratory hazards.
- Shaker table provides various soil compaction conditions.
- A sample of preliminary data was presented.

Stay tuned for future updates!