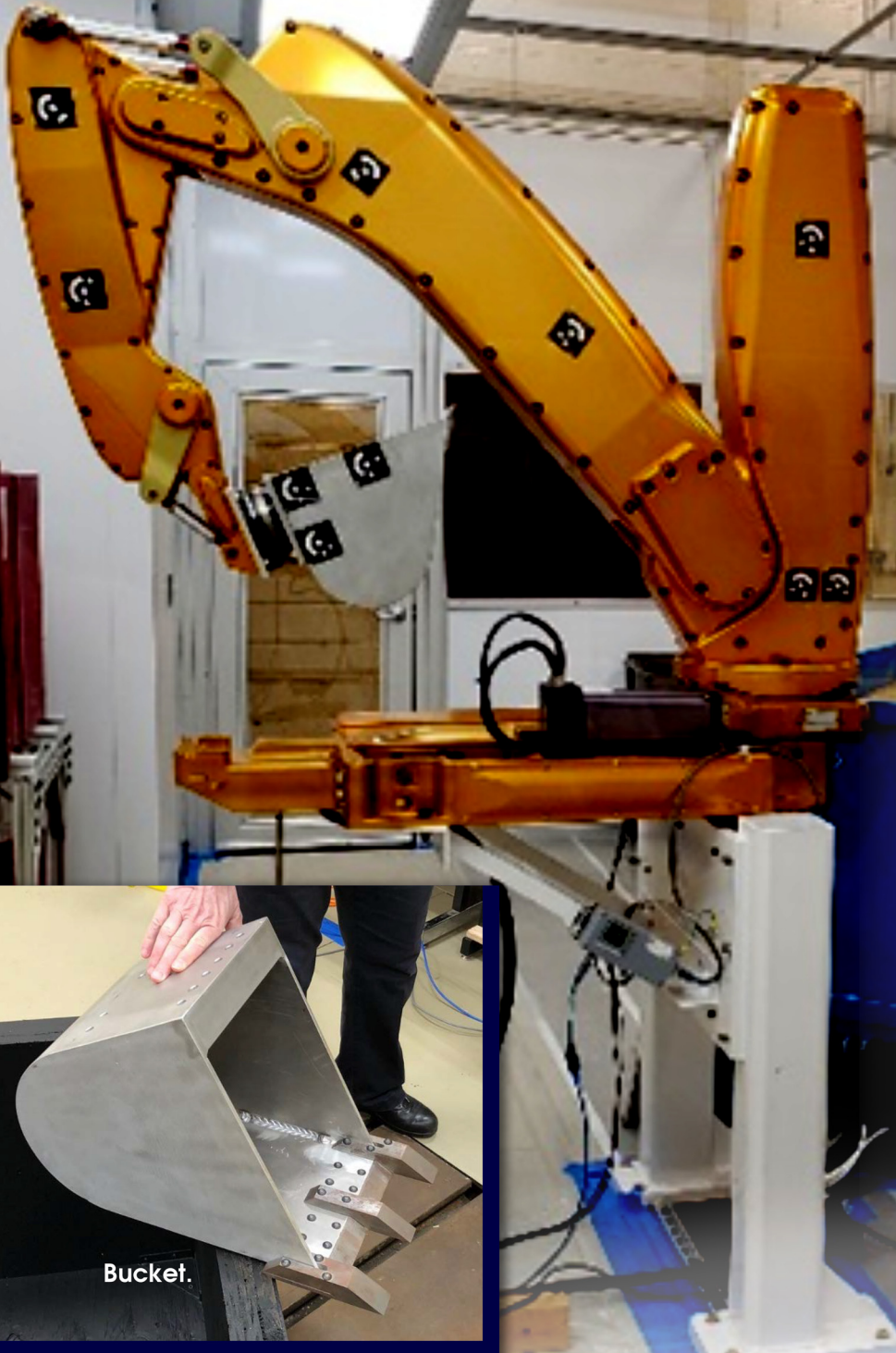


# Advanced Planetary Excavator (APEX): A Platform To Measure Excavation Forces and Power

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APEX provides a platform to measure the forces and power needed to excavate granular lunar regolith simulants at various compaction levels using different tools, various rake angles, and tool trajectories. Data produced can guide development of efficient digging tools and approaches and inform mission planners about power requirements and rates of material acquisition.

Excavation Lab houses the APEX and soil bins inside a dust enclosure.



## Advanced Planetary Excavator

- Four-degrees-of-freedom arm
- 2.3 m max. swing around radius including load cell and bucket
- Aluminum housing protects components from dust exposure
- Electric linear actuators operate backhoe arm
- Programmed tool paths in control software provide repeatable trajectories

## Instrumentation

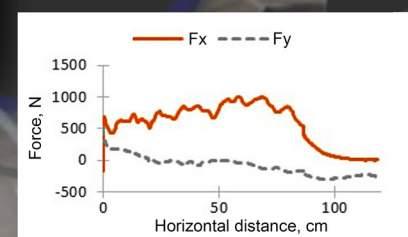
- 6-axis load cell between APEX and bucket to measure forces
  - x, y range 1334 N,  $\pm 16.7$  N uncertainty
  - z range 3892 N,  $\pm 29.2$  N uncertainty
  - Torque range 203.4 N-m
- Platform scale to weigh amount of soil dug; range: 0 to 2224 N and resolution: 0.22 N
- In-line digital power meter and 50-amp shunt to measure total direct current (DC) power to APEX
- Cone penetrometer to test soil compaction

## Lunar soil simulant GRC-3B

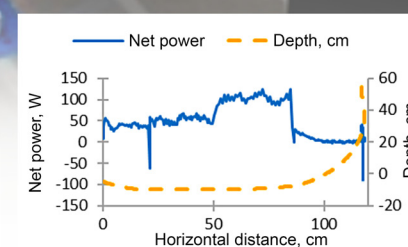
- Formulated of silica sand and silt
- Similar to GRC-3, but different source materials
- Soil bin interior dimensions 76 cm wide by 183 cm long by 76 cm high
- Bin sits on shaker table used to compact soil

## Results

Example force and net power measurements made in GRC-3B using 21.6-cm-wide aluminum bucket, with 25.4-cm-wide steel leading edge (no teeth) with 30° blade angle.



Horizontal and vertical forces,  $F_x$  and  $F_y$ , on bucket during trajectory in compacted GRC-3B.



Net power to excavate and depth of bucket tip during trajectory in compacted GRC-3B.

Bucket.

## References:

- (1) Abel, P. B. et al. (2019) SRR-PTMSS, 9-2.
- (2) Proctor, M. P. (2019) SRR-PTMSS, 9-3.
- (3) He, C. et al. (2013) J. Aerospace Eng., 26: 528-534.