Experimental Facility to Measure Power and Forces to Excavate Lunar Regolith Simulants. M. P. Proctor[1] [1]NASA Glenn Research Center, 210000 Brookpark Rd., M.S. 23-3, Cleveland, OH 44135, Margaret.P.Proctor@nasa.gov

Introduction: An Excavation Lab has been built at the NASA Glenn Research Center in support of the NASA In-Situ Resource Utilization (ISRU) program objectives to measure the power and forces needed to excavate granular lunar regolith. The data obtained will be used to validate excavation models used in system studies and for developing light weight, energy efficient digging devices for activities on the Moon and Mars. The Excavation Lab, Fig. 1, houses the Advanced Planetary Excavator (APEX), an electrically actuated backhoe arm with a bucket, which is used to dig GRC-3B, a simulant of granular lunar regolith comprised of silica sand and silt. A load cell is mounted between the arm and the bucket to measure digging forces. Dig trajectories files are created and used to control the APEX for repeatability. Comparison of preliminary data recorded for the same trajectory in air and in GRC-3B shows measurable difference in power and load cell measurements.

Fig. 1. - Excavation Lab at NASA Glenn Research Center houses the Advanced Planetary Excavator (APEX) and soil bins inside a dust enclosure.

APEX: APEX was designed and fabricated under a contract managed by Glenn Research Center. A field demonstration of APEX mounted on the Centaur 2 rover occurred at Johnson Space Center in 2014. APEX can rotate 360 degrees, has a maximum swing around radius of 2.3 meters with the bucket and load cell. The facility supplies 208 VAC, 3-phase power which is converted to 325 VDC, 100 amp to power the actuators in APEX. A new stand was designed and built to hold the APEX and transfer loads to a bed plate in the floor.

Bucket: The aluminum bucket, Fig. 2, is 21.6 cm wide with a 25.4-cm wide steel leading edge with a 30 degree blade angle. Three teeth that are 4.44 cm wide with a 30 degree blade angle can be added to the bucket. The teeth extend 5.1 cm beyond the leading edge when installed. Bucket volume is 15600 cm^3.

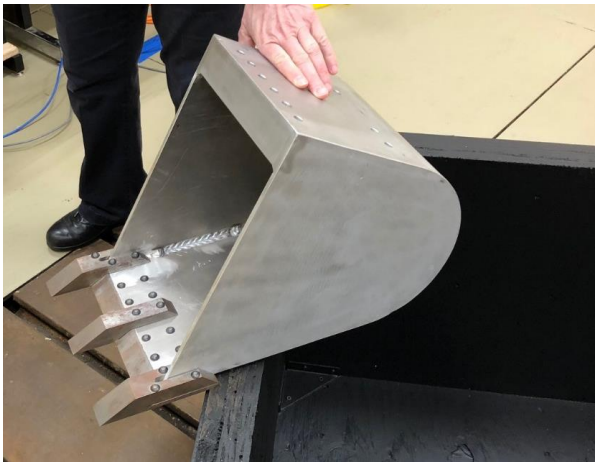

Fig. 2. - Bucket for APEX with teeth installed.

Instrumentation: A 6-axis load cell is mounted between the wrist plate of the APEX and the bucket. The load cell range is 1334 N in the x and y directions and 3892 N in the z direction. Torque range is 203.4 N-m in x, y, and z directions. A 0.61-m square platform scale is used to weigh the soil dug. It has a range of 0 to 2224 N and resolution of 0.22 N. A digital power meter and 50 amp shunt are used to measure total DC power to the APEX.

Data Acquisition and Control: LabVIEW and NI CRIO and CANBUS are used to control the APEX and to record actuator position, active and inactive current, and bus power at 10 Hz. Presently, shunts and an eight-channel Dewetron are used to record the bus voltage and current to each of four actuators to obtain power use, sampling at 10 kHz. Plans are to make these measurements with the CRIO and LabVIEW as well. The load cell measurements are made in LabVIEW. The power meter can record the power used for an entire dig trajectory and has USB connection for control and recording data.

Soil Bins and Shaker Table: A 61-cm W x 91-cm L x 51-cm H wooden bin for pea gravel was used for checkout testing. A smaller plastic box with handles is used on the platform scale for weighing the soil dug.

The bin for the GRC-3B soil was built of welded carbon steel and powder coated. Inside dimensions are 76-cm W x 183-cm L x 76-cm H and empty weight is 2064 N. When filled with 15,570 N of GRC-3B there is about 10 cm of head space. Filled weight is limited to 17790 N, the overhead crane capacity. This soil bin sits on a shaker table used for compacting the soil. The shaker table has a 22,240 N capacity, four air springs, manual controls, and variable frequency drive.

Dust Enclosure: A custom built dust enclosure was procured and installed. It has tempered glass windows in the sidewalls. Removable panels allow use of the overhead crane. HEPA air filtering blowers exhaust clean air from the enclosure into the test cell and maintain a small pressure differential to contain the dust. The fixed portion of the enclosure ceiling has LED lighting. Personnel doors at both ends of the enclosure allow easy access for test operators.

Preliminary Data: A sample of preliminary data is presented here for the bucket with the leading edge only, (no teeth). The planned trajectory, Fig. 3, shows the x and y position of the bucket leading edge relative to the APEX shoulder pivot point. The soil level is at negative 46.5 cm. The bucket tip starts just above the soil surface. The bucket plunges into the soil at a bucket swing rate of 5 deg/s to the start position for a linear dig with the bucket angle of 30° at a depth of 10 cm. After a 2 second pause, the linear dig proceeds at 5 cm/s for a distance of 25.4 cm. After another 2 second pause the bucket swings out at 5 deg/s close rate and 5 deg/s swing rate. Fig. 4 compares power to APEX for a single dig of this trajectory in air and in GRC-3B and shows measurable difference.

Fig. 3. - Planned trajectory: Swing in to 30° bucket rake angle, 10-cm deep, pause, linear dig at 5 cm/s for 25.4-cm long, pause, swing bucket out and lift.

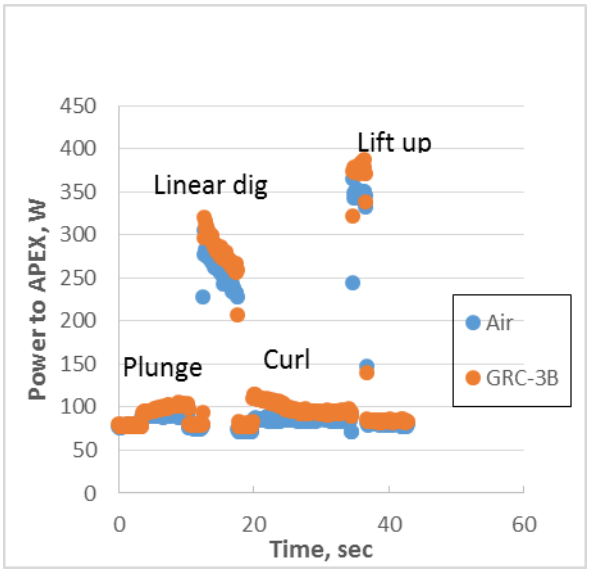

Fig. 4. – Power to move APEX through planned trajectory in air and in GRC-3B.

During this linear dig, the load cell y-axis is parallel to the soil surface (horizontal) and the z-axis is perpendicular (vertical). The force to dig the GRC-3B is the difference between forces measured in GRC-3B and in air. Curve fits of the data during the linear dig were used to calculate the net forces as a function of distance shown in Fig. 5. At this bucket angle, linear motion results in a plowing effect with soil piling up in front of the bucket more than in it. Hence, while there is substantial increase in horizontal force, there is little change in the vertical force. After the swing out, the GRC-3B in the bucket was poured into the dump bin and weighed on the platform scale. The GRC-3B dug weighed 105 N and has a mass of 10.7 kg.

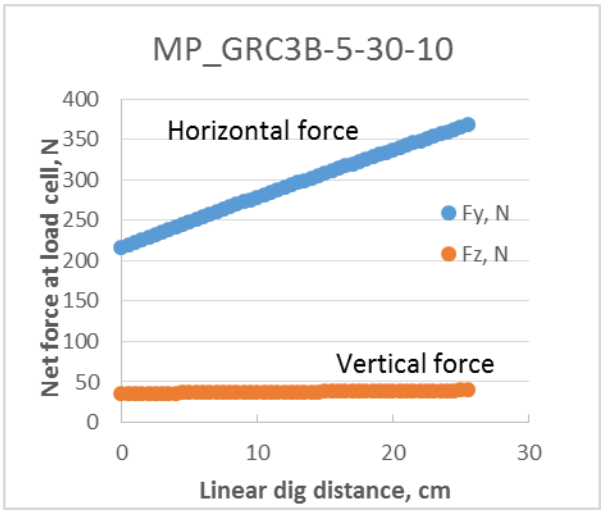

Fig. 5. - Net force at load cell during linear dig at 5 cm/s, 30° bucket rake angle, and 10-cm deep.