Laboratory-scale Distributed Stress Measurements of Blade Interaction with JSC-1A Lunar Simulant. A. T. Brewer[1] and R. H. King[2], [1]Colorado School of Mines Engineering Division, Brown Hall, Golden, CO 80401, abrewer@mines.edu, [2]279 Brown Hall, Engineering Division, Colorado School of Mines, Golden, CO 80401.

Introduction: NASA is designing a lunar outpost. Outpost development will require a lunar excavator for moving regolith, the fragmented and unconsolidated material that covers the surface of the moon. This excavator will be used to build berms, grade and compact roads, foundations, and landing pads, and excavate trenches. With the extraordinary cost of launching heavy equipment to the moon and the cost of providing power on the moon, the need for a precise excavator design becomes apparent. While some amount of "over design" is warranted, the cost of "over design" is much higher than with terrestrial excavators. Small changes in material properties and model outcomes will have a greater relative effect on lunar excavators because of the precision needed in the design. Therefore, careful studies of lunar material properties, property in situ measurement, and models used to estimate excavation forces are necessary to control costs while still providing a capable excavator.

Excavator design requires simulating the stress in the excavator blade and frame with finite element models. Finite element models are more precise when distributed forces are used on the blade surface. However, current measurements and models provide the average values over the surface of the blade. This presentation describes laboratory measurements of distributed stresses and forces on a laboratory-scale blade interacting with sand and lunar simulant.

Measurement Apparatus: Stresses and forces were measured with the soil excavation measurement test bed originally designed and built by Muff and Johnson [2] to measure bucket excavation force. Gefreh modified it for blade tools [3]. Figure 1 shows the test bed components. The test bed uses load cells to measure the total horizontal and vertical forces on a model blade as the soil box moves under it.

The test bed was modified for this work with the addition of a Tekscan pressure mapping system. The Tekscan system consists of a thin-film resistive sensor and an integrated electronic interface which connects the sensor and computer via a USB drive. The sensor is attached to the face of the blade being tested and the USB interface is mounted to the excavation tool chassis.

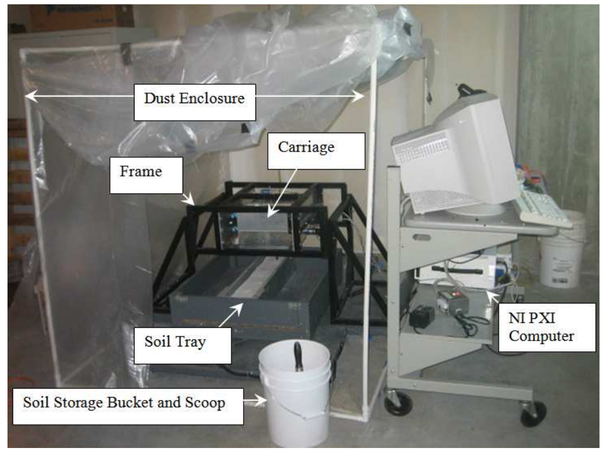

Figure 2: Soil Excavation Measurement Apparatus

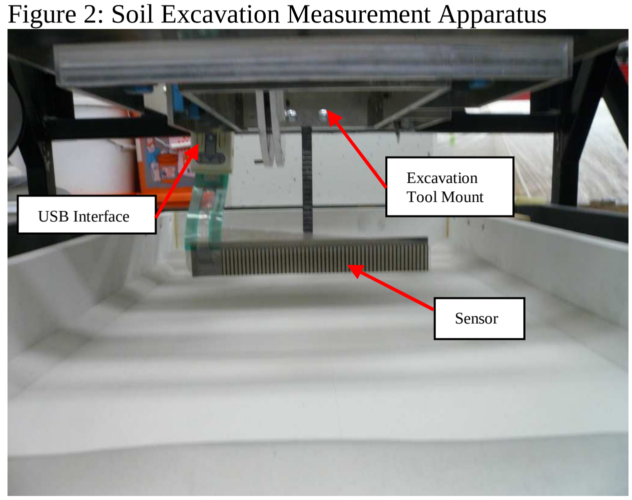

Figure 3: Under Carriage View of the Tekscan Pressure Mapping System Modification to the Test Bed

Measurements: Excavation tests were performed at a constant forward speed of 200 mm/min using various blade shapes and configurations. Baseline measurements were performed in Ottawa sand using a 12 in. flat blade at a cutting depth of 0.25 in. A set of measurements of varying blade geometries and cut depths were then done in JSC-1A lunar soil stimulant. The affect of the blade width was investigated by performing excavation tests using 12 in, 10 in, and 8 in wide flat blades at a constant cutting depth of 0.25 in. Then, cutting depths ranging from 0.05 in. to 0.25 in. in 0.05 in. increments were tested using the 12 in. flat blade. Next, the optimal cutting angle was investigated by performing tests on the 12 in. flat blade with a 0.25 in cutting depth and a cutting angle varying between 15-30 degrees. The affects of a curved blade vs. a flat blade were then tested by repeating all of the flat blade tests with curved blades of inner diameter 2.157 in. The final tests that were performed tested the affects of varying operation angles. These tests were done at a 0.25 in. cutting depth using 30 degree, 60 degree, and 90 degree V shaped blades, all of which have 8 in. long side pieces.

Results: Figure 3 shows the pressure distribution across the 12 in. blade face for one test measured using the Tekscan system. Also, as shown in Figures 4 and 5, the total loads measured for each blade are within range of calculated loads from analytical average force models. Furthermore, Figure 5 shows a general trend of decreasing loads with smaller blades and curved blades, which was expected. Further analysis is underway to develop a precise force distribution profile and to compare the profile across the blade geometries and cut depths.

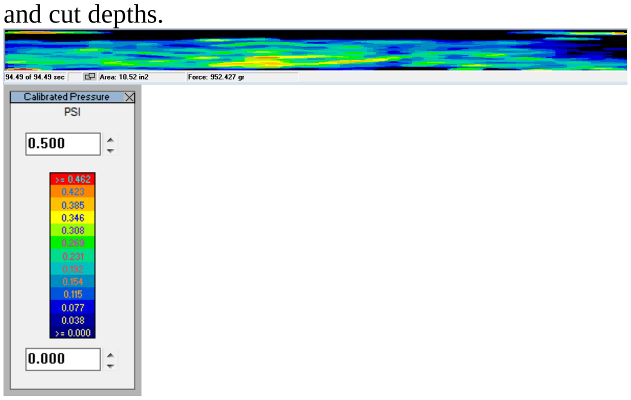

Figure 4: Pressure map from Tekscan sensor at a single time step for the 12 inch x 1.5 inch flat blade with 1.5 in cut depth in JSC-1a. The sensor area is 10.4 inch x 1.32 inch.

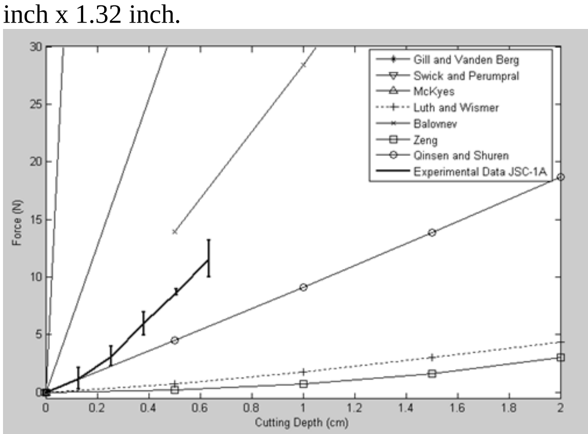

Figure 5: 12 in. flat blade load vs cutting depth results compared to analytical total force models

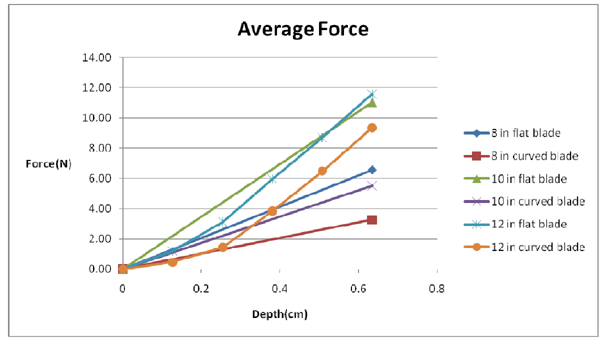

Figure 6: Total load results for different blades and cutting depths

References: [1] R. P. Mueller and R. H. King (2008) *Trade Study of Excavation Tools and Equipment for Lunar Outpost Development and ISRU*, AIP Conf. Proc. 969, 237-244. [2] Johnson, Lee L. and R. H. King (2010) *Measurement of Force to Excavate Extraterrestrial Regolith with a Small Bucket-wheel Device*, Journal of Terramechanics, v47(2), 87-95. [3] Gefreh M. et al. (2008) *Comparison of Excavation Forces in JSC-1A Lunar Simulant to Theoretical Models*, CSM Master's Thesis.