CONSOLIDATED MATERIAL MINING FOR ISRU. J. M. Schuler[1], J. D. Smith[2], R. P. Mueller[3], A. G. Langton[4], A. J. Nick[5], I. I. Townsend[6], L. Sibille[7], [1,2,3] NASA Kennedy Space Center, UB-R1, Kennedy Space Center, FL 32899, jason.m.schuler@nasa.gov, jonathan.d.smith@nasa.gov, rob.mueller@nasa.gov, austin.g.langton@nasa.gov [5,6] The Bionetics Corporation, LASSO-6720, Kennedy Space Center, FL 32899, andrew.j.nick@nasa.gov, bradley.buckles@nasa.gov [7] Southeastern Universities Research Association, LASSO-013, Kennedy Space Center, FL 32899, laurent.sibille-1@nasa.gov

The majority of prior work on excavation for resource utilization has focused on surface unconsolidated regoliths. However, the highest yield resources might actually be found in much harder consolidated materials. This is may be the case on Mars where the presence of gypsum has been confirmed from orbital and ground data. Gypsum is a mineral that can contain up to 20% water by mass. This water can be extracted from the gypsum and used to supply human missions with a local source propellent.

The small, low mass robotic excavators that have been developed for planetary resource mining to date may not be able to excavate the gypsum because it is significantly harder than surface regolith.

Excavators that will be sent to Mars will not be able to produce excavation forces like the mining equipment we have on earth. So the rock cutting will need to be done in such a way to limit the reaction forces needed from the mining vehicle. Gypsum is on the low end of the hardness scale for rocks. The team surveyed the existing rock cutting models and determined that shallow cuts in gypsum are at the low end of test range from previous work.

$$FC = \frac{12\pi\sigma_t d^2 \sin^2\left\{{}^1\!/_2\left[90-\left(90-\frac{\alpha}{2}+\theta_A\right)\right]+1\right.}{\cos\left\{{}^1\!/_2\left[90-\left(90-\frac{\alpha}{2}+\theta_A\right)\right]+10\right\}}$$

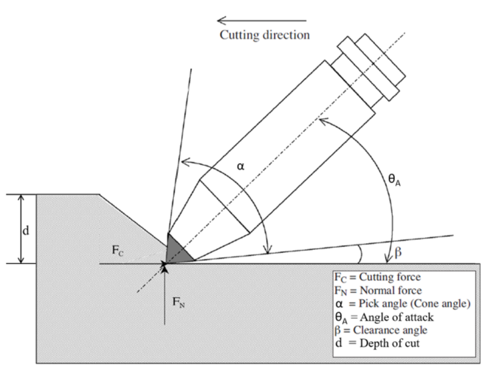

Fig. 1 Single pick cutting model and geometry.

The goal of this work was to determine if existing mathematical cutting force models accurately predict the forces for cutting gypsum with shallow depths of cut (<9mm).

A series of fundamental rock cutting experiments were performed to verify that these models are valid for this regime. Gypsum rocks were procured, unconfined compressive strength (UCS) and brazillian tensile strength (BTS) tests were performed. A test stand was prepaired using an existing Bridgeport CNC mill and custom rock cutting pick fixture. A test matrix was developed that varied attack angle, depth of cut, cutting speed, and pick tip angle.

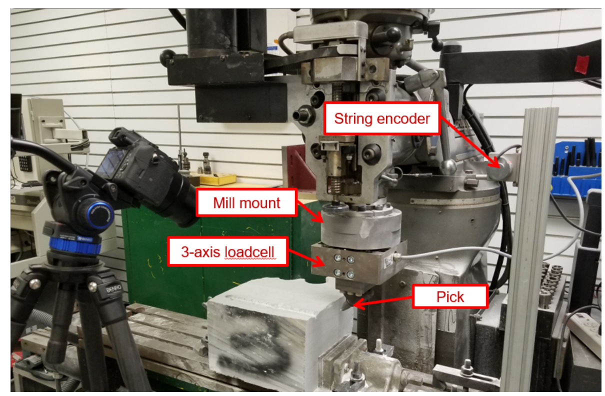

Fig. 2 Single pick cutting setup

During the testing, a 3-axis load cell recorded the forces during excavation. Cuttings were collected and their mass and particle size distribution were measured. The volume of the cut was determined using a 3D laser scanner.

The results of the experiments produced the following conclusions:

- **Existing rock cutting models such as Goktan (2005) are appropriate for predicting low force cutting in soft rock such as Gypsum**
- **The trends and contributing variables as measured in this work agree with the existing models**
- **Between 6%-20% of cuttings are finer than 300µ depending on the cut geometry**
- **Shallower cuts produce less material overall per unit energy but they produce more material in the <300µ range for less excavation force.**