PENETRATION FORCES FOR SUBSURFACE REGOLITH PROBES

A. El Shafie[1], R. Ulrich[1,2], L. Roe[1,3]
[1]Arkansas Center for Space and Planetary Sciences, University of Arkansas, Fayetteville, AR 72701
[2]Department of Chemical Engineering, [3]Department of Mechanical Engineering

Introduction: The Optical Probe for Regolith Analysis (OPRA) is a subsurface analytical probe being developed at the University of Arkansas and is currently at TRL 5. It will be a hollow tube 5 – 10 mm in diameter and 50 cm long with windows on its lateral surface as shown in Figure 1.

OPRA will be pushed down into the subsurface by landers or rovers to record near infrared spectra as a function of depth. Fiber optic cables will run from behind small prism windows to the top of the probe where they are connected to a Fourier Transformation Infrared (FTIR) spectrometer to analyze the subsurface material as a function of depth.

OPRA is a static penetrator that uses a linear actuator motor to provide the force to push it down into the subsurface [1]. Therefore, two main forces must be overcome: cone resistance which is the force against the tip and sleeve friction which is the force acting on the lateral surface of the probe.

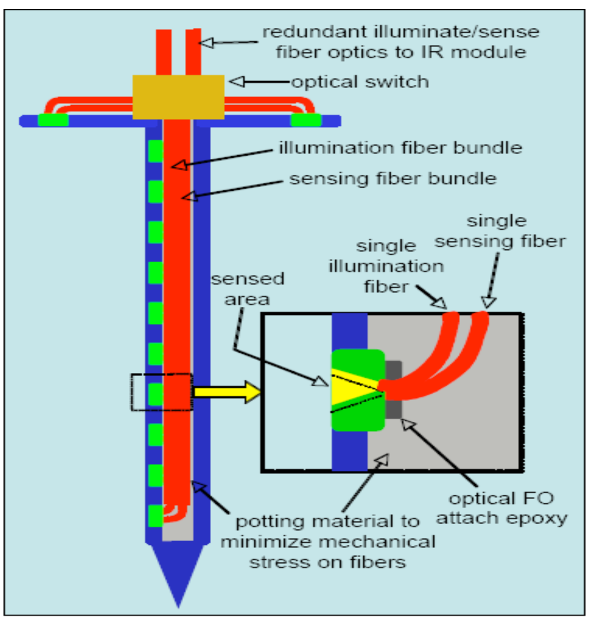

Figure 1. The Optical Probe for Regolith Analysis.

This part of the OPRA project involves determining the amount of force needed to insert and remove such a probe into and out of various types of regolith materials as a function of the probe's shape, length, weight, material and tip angle. These regolith simulation materials will include JSC Mars-1, JPL Mars Simulant and homogenous and layered icy soils.

Table 1 shows the materials that are going to be used through out the project and some other experiments. Window abrasion will be evaluated by repeatedly inserting and withdrawing the probe into basaltic regoliths and evaluating the windows ability to transmit infrared light as a function of the number of penetration cycles.

Topic	Investigating material
Penetration testing	Sand
	JSC Mars-1
	JPL Mars simulant
	Icy soils
	Solid carbon mixed with soils
	Layers of icy soils
	Heated pen probe
	Disturbance of layers
Window Scratch testing	JSC Mars-1
	JPL Mars simulant
	Icy soils

Table 1. List of materials and experiments

Forces Available for Penetration

The maximum force available would be the weight of the lander or rover on the planetary surface. Table 2 shows these weights for past, present and future vehicles.

Vehicle	Planetary Body	Weight (N)
Luna 13	Moon	184
Surveyor	Moon	480
Lunakhod	Moon	1360
Lunar-A	Moon	21
Viking	Mars	2210
Sojourner	Mars	39
Beagle 2	Mars	123
Spirit/Opportunity	Mars	683
Mars Science Lab	Mars	3320
Venera 13	Venus	6740
Rosetta	67P/Churyumov-Gerasimenko	≈ 0.08
Huygens	Titan	431

Table 2. Weights of various probes and rovers.

Experimental Equipment and Method:

Penetration testing is being performed in constant velocity mode at a rate of 1-7 mm/sec. The test system, shown in Figure 2, consists of a constant-speed motor driving a linear actuator screw that pushes the probe down and pulls it back out. The probe does not rotate during testing. A load cell is mounted between the force actuator and the probe for force measurement, both in and out.

Figure 2. OPRA penetration test apparatus.

Effect of Bulk Density: Soil compaction has a profound effect on the required insertion force. Figure 3 shows forces required for a 1.8 cm diameter probe with a 60° tip angle in the same JSC Mars-1 regolith with two amounts of compaction. It is expected that regoliths on planets, moons and comets would be compacted.

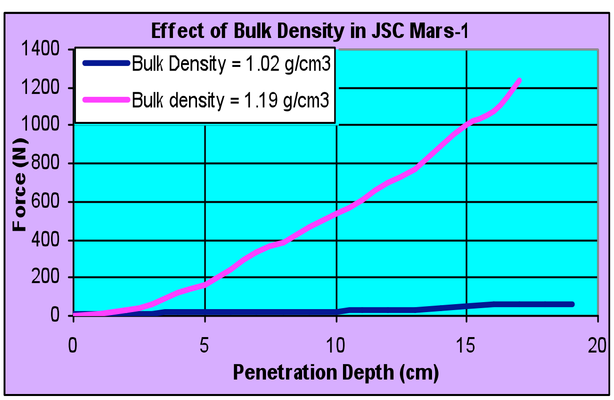

Figure 3. Effect of compaction on insertion force for a 1.8 cm diameter probe with a 60° tip angle

Effect of Probe Diameter and Tip Angle: Figures 4 and 5 show insertion forces into JSC Mars-1 for various probe diameters and tip angles.

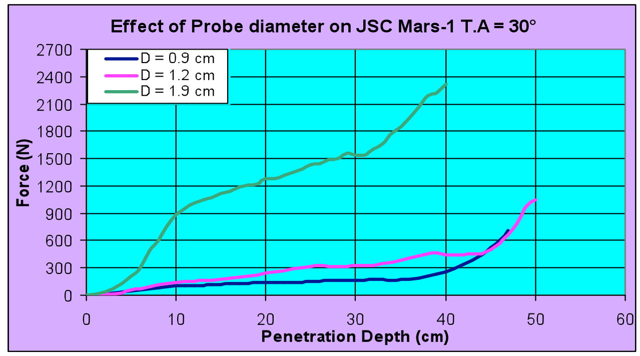

Figure 4. Effect of probe diameter with a tip angle of 30°

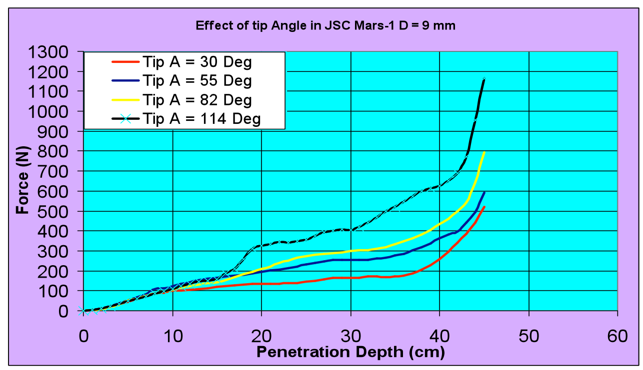

Figure 5. Effect of probe tip angle for a 9 mm diameter probe

Conclusion: The degree of regolith compaction has a profound effect on the required penetration forces. It is expected that surface materials on most bodies will be compacted to some degree. Insertion force increases non-linearly with probe diameter because the cone resistance goes up with the square of diameter. In all cases, withdrawal force is much less than insertion force.

References: [1] Ball A. J. and Lorenz R. D. 2001. Penetrometry of extraterrestrial surfaces: A historical overview. In *Penetrometry in the solar system*, edited by Kömle N. I., Kargl G., Ball A. J., and Lorenz R.D., Graz, Austria: Space Research Institute, Austrian Academy of Sciences. pp. 3–24.