

Sub-Surface Soil Sampling with Penetrators

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ABSTRACT

This paper summarizes the techniques currently under study at the Jet Propulsion Laboratory for using micro-penetrators to sample subsurface soil and perform analysis on that sample. The work is in conjunction with the New Millennium Mars Microprobe Program (or Deep Space-2), a four kilogram micro-penetrator that will arrive at Mars in December 1999. Two broad classes of sampling techniques are considered, passive sampling and active sampling. Three passive options are studied: rear sampling, side sampling, and a digestive tract. Two active designs are included: a novel scraper mechanism and a more conventional side mounted drill. Mechanical models of these designs were constructed and fired at flight-like velocities into soil with hardness representative of the Martian surface. This paper reports on the nature of these designs and the results of the tests. It is found that the passive options are not likely to work because, surprisingly, the penetrator carries a laminar layer of surface soil down into the hole, and almost all passive samples are contaminated heavily with this surface material. Active options, necessarily more complex and resource intensive, appear to be the only way to guarantee collection of soil at depth.

1. INTRODUCTION

There is a strong argument in the planetary science community that Martian winds have distributed dust such that it is fairly consistent around the planet. Surface and near-surface samples represent young material that contains little information about the geologic past of Mars, while clues regarding the planet's history lie deeper below the surface. Clearly, a lander equipped with a drill is the straightforward solution to obtaining samples at depth. However, in the era of "better, faster, cheaper" where the emphasis is on building spacecraft with limited resources, a lander with a drill represents a complex solution requiring a fairly massive spacecraft with plenty of available power.

Digging a trench with a robotic shovel, like the Viking missions, is also difficult because the loose surface material continually falls in the hole as the side walls break down [1]. This limits the practical depth that can be achieved with this technique.

A penetrator, in contrast, is a simple device that uses the incoming kinetic energy to impact the planet and bury itself below the surface. It is smaller and cheaper than the lander with a drilling device or a shovel. Because of the small size, mission scenarios can be considered that will place many of these penetrators in different areas of the planet, allowing a global study of the planet. These network missions are of interest to the scientific community.

However, it is not trivial to collect the material around the penetrator after it is implanted. While the Russian Mars '96 Penetrator was not designed to actually collect soil (it placed its instruments in the soil of the side wall with an arm), many science instruments, such as an evolved gas experiment, require collecting soil into a suitable container that can be sealed. The remainder of this paper discusses the various designs we have considered and tested, along with background information on the Mars Microprobe penetrator and testing facilities employed in the study.

1.1 THE DS-2 PENETRATOR

The New Millennium Program is a NASA program at the Jet Propulsion Laboratory designed to allow flight validation of technologies that are considered important for space exploration in the next century [2]. The second flight in the program is the Deep Space-2 (DS-2) Mars Microprobe, scheduled for a January 1999 launch. The current design for the DS-2 Penetrator is shown in Figure 1. The unit is comprised of two primary parts, the forebody and the aftbody. The forebody contains the soil sampler and science experiment and descends to depth because of its slender shape, and the aftbody contains batteries and telecommunications equipment and is designed to stop near the surface of the planets to allow unhindered communications with the Mars Surveyor Orbiter. The

two parts are connected by a flex cable which pays out from the penetrator during the impact event.

The assembled penetrator unit is mounted in a 350mm diameter aeroshell (not shown), which protects the unit from the entry heat loads and aerodynamically stabilizes the vehicle. Because this is a single-stage mission, there are no separation devices and no parachutes or rockets; the penetrator rides inside the aeroshell from orbit to impact. The aeroshell is fabricated primarily from ceramic materials and shatters on impact, allowing the penetrator to proceed into the surface unhindered.

The entire assembly, penetrator and aeroshell, is a 3.8kg mass. Two of these vehicles will be attached to the cruise ring of the Mars '98 Lander. Seconds after the Lander separates from the cruise ring, the 1) S-2 Microprobes are separated and enter the atmosphere. Approximately 300 seconds later, the penetrators impact Mars at approximately 180m/s. Shortly after the impact event, the sample is taken and analyzed, and the resulting data transmitted. The probe will survive for 14 days, collecting atmospheric pressure and temperature data along with soil temperature data.

1.2 PENETRATOR TESTING FACILITY

Penetrator system testing was accomplished using an air gun owned by Sandia National Labs and operated by the New Mexico Institute of Mining and Technology's Energetic Materials Research and Test Center (EMRTC). The gun, shown in Figure 2, consists of a 1.15m x 5.49m pivoting barrel connected to an compressed air system. Firing is accomplished by pressurizing the fill chamber until a burst disk is ruptured. Velocities ranged from 168 m/s to 208m/s.

The penetrators were fired into a variety of targets. The targets were classified by their S number, a parameter related to soil penetrability presented in [3]. A low S number (3-5) indicates a very hard target, while higher numbers (15-20) are indicative of softer soils. The Martian soil is expected to be within the range of S = 3-17 at the EM-2 impact site. The most common target consisted of a clay matrix soil which was native to the test site. For some of the tests other materials were layered on top of the native soil, including different grades of sand as well as cement mix. Colored construction chalk was placed on the top of all targets to indicate surface soil.

2. PASSIVE SAMPLING

Passive sampling uses only the kinetic energy of the penetrator and gravity to collect the sample. This is desirable for mechanical simplicity and robustness. Testing parameters for the passive sampling tests are summarized in Table 1.

2.1 REAR SAMPLING

The rear sampler consisted of an open hole in the back of the forebody. It was believed that the first dirt to reach the sample chamber would be from the depth where the penetrator came to rest.

Surface dirt was consistently collected in the sample chamber. In some cases the sample collected was layered, with the surface dirt on the bottom underneath subsurface soil. The collection of surface dirt occurred regardless of depth or target composition. For example, in Test 6 the sample chamber was almost completely filled with the cement powder even though the probe was recovered from well into the sand. Shot 38 was not planned as a passive sampling experiment, but it did demonstrate the ineffectiveness of rear sampling - a 5x8 mm hole in the back of the forebody was almost filled with material from the surface.

2.2 SIDE SAMPLING

The side sampler, shown in Figure 3, consisted of twelve holes around the diameter of the forebody on three levels. All of the holes were angled 45° down. The belief was that the dirt falling into the sample chambers would be from the level at which the penetrator came to rest. The holes were spaced around the diameter to eliminate biases from impact orientation. The interior of the probe had a mechanism which allowed the sample chamber assembly to be rotated relative to the outer wall to allow the sample chambers to be closed before removing the probe from the ground. This avoided forcing dirt into the chambers after the impact.

Surface dirt was consistently collected in all of the sample chambers. It made no difference what side of the probe impacted the ground first: all holes contained the surface dirt.

2.3 DIGESTIVE TRACT SAMPLING

The digestive tract sampler, shown in Figure 4, consisted of a tapered hole which passed along the penetration axis of the forebody. The belief was that material would pass through the probe as it penetrated, therefore obtaining a sample from the depth at which it came to rest.

Subsurface samples from a known depth were not collected. In shot 17, the probe left a trail of extruded dirt behind it, but the depth of final sample collection could not be determined. In shots 18-19 & 22, there was still surface material in the sample tract, indicating that the sample was not taken from depth. Shot 23 collected a subsurface sample, but its depth could not be determined.

3. ACTIVE SAMPLING

Because of the failure to achieve uncontaminated soil with passive techniques, active techniques were developed. Although these are necessarily more complex than passive samplers, options exist that work with limited resources. The current baseline for the DS-2 Penetrator is to use active sampling, because it is a science priority to demonstrate sample collection at depth.

3.1 SCRAPER MECHANISM

Figure 5 is a drawing of a scraper mechanism designed to sample the soil next to the penetrator in one revolution. It is an off-center cylindrical section that is not perpendicular with the wall of the penetrator. Configuration at impact is Figure 5b. Once the penetrator is implanted, the cylinder rotates through one revolution (180 degrees is shown in Figure 5a), thereby forcing material into the science cup and sealing the cup off.

A model was constructed that allowed rotation of the scraper through a fitting at the rear of the penetrator. First, the unit was implanted in plaster (which simulated the hardness of the soil), and the scraper was rotated with a torque wrench to measure the torque needed to collect the sample. The torque in the plaster was approximately 12 N-m. This penetrator was also fired into soil, and the cylinder rotated with a torque wrench. The required torque in these tests was approximately 6 N-m.

Unfortunately, these torque levels are difficult to achieve in a unit as small as the DS-2 Penetrator. The motor under consideration has a stall torque of 1 N-mm, requiring a miniature 12000:1 gearbox. To overcome this difficulty, we have looked at impact mechanisms, which use the motor to spin a flywheel to high speed and allow the flywheel to impact the scraper cylinder, thereby transmitting larger torques; but these concepts have proved unwieldy.

3.2 SIDE DRILL

The more conventional active sampler, a side drill, is shown in Figure 6a. This device uses a motor to rotate a drill which is mounted on a splint. A spring applies an axial force on the drill, forcing it into the position shown in Figure 6b. Material is collected and forced down the flutes of the drill, where it is deposited into a sample chamber. A peculiarity of this design is that in the pre-impact configuration, the drill tip must seal the flutes so that the flutes are not exposed to the soil; otherwise, during impact, the flutes would be filled with surface soil, similar to the passive side sampler described above. The initial rotation of the drill allows the drill tip to rotate relative to the drill stem and expose the drill flutes.

Although we have not yet fired a working mechanism, we have constructed a test set up where we can alter drill geometry's and materials, axial forces, torque's, and temperatures on a bench. We are searching for the optimum combination of parameters that will maximize the performance of the drill, that is the sample collected per unit energy expended while delivering an adequate amount of sample within a specified amount of time.

4. FURTHER WORK

This paper presents a work in progress. Currently, the DS-2 mission is under primary development at JPL, and this is expected to last until late summer. The baseline for the mission is the active side drill mechanism. The tools described above will be used to further develop the components for the side drill mechanism until mission requirements are comfortably met. A functioning side drill mechanism is in fabrication, and will be fired to test both its survivability of the impact loads and operability post-impact. The mechanism not only has to satisfy the performance requirements of delivering adequate samples of a wide variety of simulated Martian soil in severe power and time limits, but also has to fit within the volumes dictated by the small size of the spacecraft. Because of the severe limitations on available volume, this is a considerable challenge.

5. CONCLUSIONS

Various passive and active sampling techniques from penetrators have been discussed. It is shown that the surface soil that the penetrator brings with it poses problems for allowing passive collection techniques to acquire non-contaminated soil. Active techniques, although more complicated, should minimize this contamination. Preliminary active side drill results have been discussed, which will lead to the development of an operable unit inside the New Millennium Mars Microprobe Mission. Although the resources are extremely limited, in terms of volume, mass, and power, this appears feasible.

6. ACKNOWLEDGEMENTS

The authors would like to acknowledge Tom Rivellini, the Mechanical Project Element Manager for the DS-2 Mars Microprobe, for his efforts in guiding the design along with Chris Voorhees, who has spent considerable effort refining the test techniques that will allow the design of the side drill sampler to proceed.

REFERENCES

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- [2] Casani, E. and Wilson, B., "The New Millennium Program: Technology Development for the 21st Century," AIAA Paper 96-0696, Jan, 1996
- [3] Young, C. W., "Dynamic Cone Penetrometer," DN #SC-DR-68-178, Sandia Labs, March 1968

Shot	Sampler	Target	Target S#	Depth (m)	Velocity (m/s)
1	Rear	native soil	5-7	.26	168
2	Rear	native soil	5-7	.17	172
3	Rear	native soil	5-7	.14	195± 27
5	Rear	native soil	5-7	.25	N/A
6	Rear	cement powder on construction sand	20+	.69	180
7	Rear	native soil	5-7	.29	N/A
8	Rear	#100 sand on native soil	7-8 on 5-7	.33	175
9	Side	# 100 sand on native soil	7-8 on 5-7	.38	172
10	Side	#100 sand on native soil	7-8 on 5-7	.37	N/A
17	Digestive	native soil	7-10	.45	208
18	Digestive	native soil	4-7	.31	191
19	Digestive	native soil	6-13	.45	206
22	Digestive	24" construction sand on native soil with fine sand on top & colored chalk every 6";	20-40	.66	168
23	Digestive	native soil	3-5	.35	202
38	Rear	9mm heatshield material on native soil	3-4.5	.33	N/A

Table 1: Passive Sampling Test Parameters

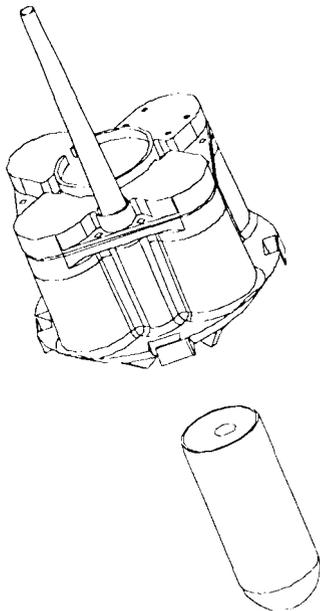


Figure 1: 1) S-2 Penetrator

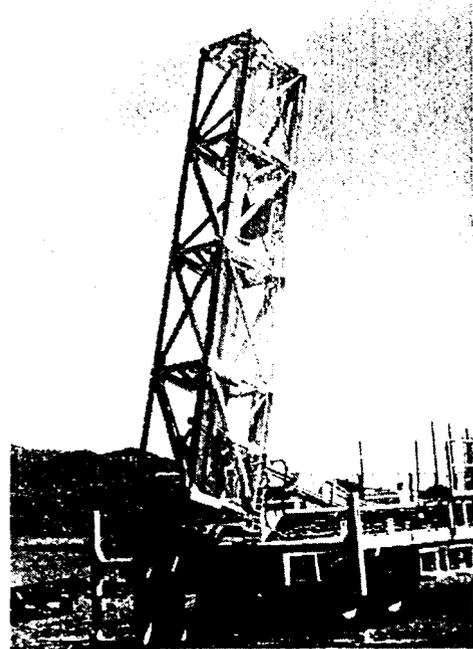


Figure 2: Sandia Air Gun

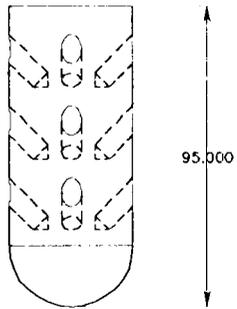
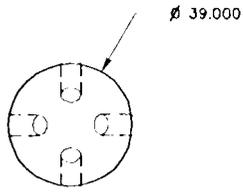


Figure 3: Side Sampler

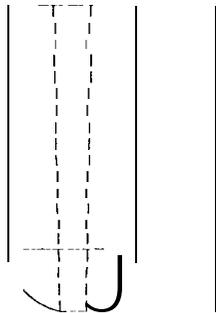


Figure 4: Digestive Tract

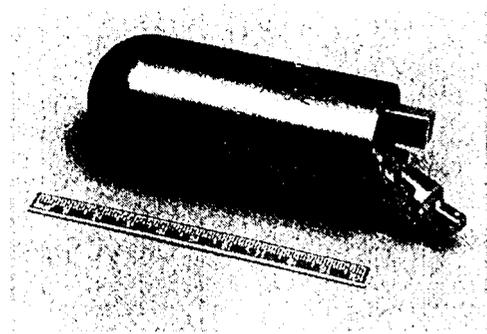


Figure 5b: Closed Scraper Mechanism

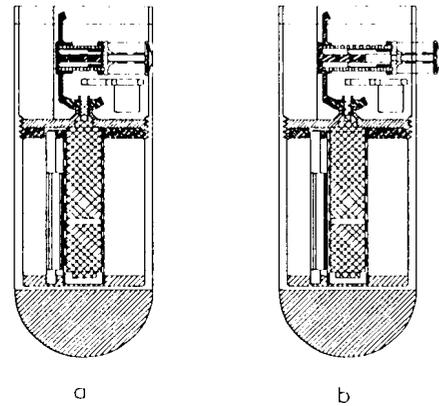


Figure 6: Drill Mechanism

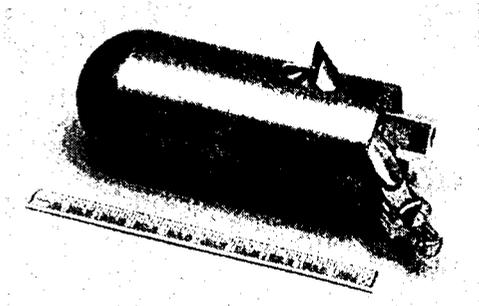


Figure 5a: Open Scraper Mechanism