LUNAR DEMONSTRATION OF PLANETVAC: A SAMPLE ACQUISTION AND DELIVERY SYSTEM FOR INSTRUMENTS AND SAMPLE RETURN.

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Introduction: The Lunar PlanetVac (LPV) pneumatic sampling system was successfully demonstrated in March 2025 on Firefly's Blue Ghost Mission 1 (BGM1). LPV successfully demonstrated sample collection (Figure 1), sample capture and particle size sorting (Figure 4), both image and non-image based sample verification, captured images of dusted LARC-provided material coupons, and (as a bonus) effective cleaning of camera lenses. This demonstration proves that PlanetVac can serve future instruments as a robust and resource efficient (low mass, power, data, operational time) sample delivery partner.

Figure 1: PlanetVac mid-sample capture at Mare Crisium, March 3rd, 2025. Photo credit: Firefly Aerospace [1]

How PlanetVac Works: PlanetVac is comprised of three subsystems: the sampling head, transfer tubes, and the capture system (Figure 2). The sampling head requires access to the regolith surface. This can be accomplished by incorporating it into one or multiple lander footpads, or by deploying it on a dedicated system such as a boom or 5th leg (as was the case on BGM1). It is connected to instruments or sample return containers via a pneumatic transfer hose. The exact location and type of the instruments and sample container are flexible given that the transfer hose can be routed anywhere.

PlanetVac samples by using gas jets inside the sampling head that are pointed down to loft then sweep regolith into the transfer tube. The capture system separates the sample from the flow and delivers it to an instrument. This process is incredibly resource efficient. Gas acts like an explosive in vacuum, meaning only a small volume of gas is required to move large amounts of regolith, agnostic of gravity. Sample collection occurs in a matter of seconds after initation. As a result, total power draw and operational overhead are also very low.

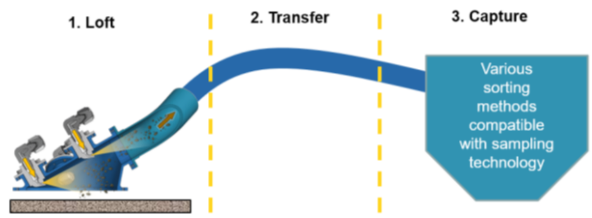

***Figure 2:** PlanetVac sample acquistion and capture.*

Firefly Integration: On BGM1, the PlanetVac sampling head and sample transport tubing is attached to the Firefly-provided Sample Access Arm (SAA), shown in Figure 3. The lander team deployed the SAA via launch-lock following landing. This, in a nominal scenario, places the sampling head flush against the lunar surface. The sample transport tube runs from the sampling head, through a supporting bracket along the SAA, and terminates at the sample collection system located in the temperature controlled mid-deck of the lander. This sample collection system is purpose built for general sample collection, dust coupon testing, and foremost for imaging; other instruments would have more tailored sample collection implementations.

***Figure 3.** Illustration of PlanetVac Sampling Head deployed to the lunar surface. Image credit: Firefly Aerospace. [2]*

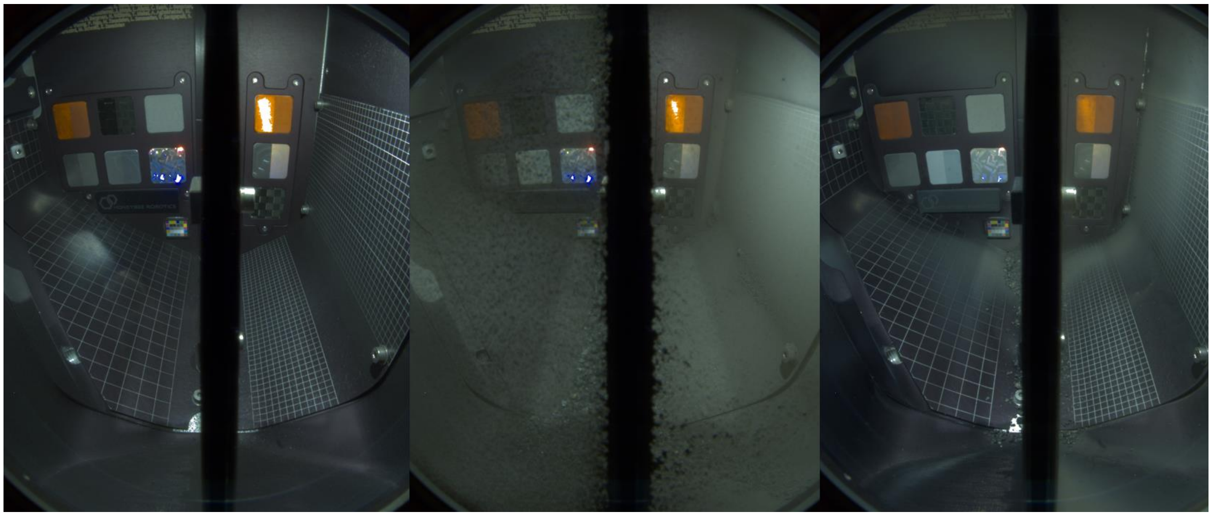

Figure 4: *PlanetVac sample capture chamber before sampling (left), after sampling but before sieving (middle), and after the sieving operation (right)*

Surface Operations: When sample collection was commanded the following occurred over five seconds:

1) A pneumatics manifold located on the mid-deck of the spacecraft released gas, which travelled down the SAA via a gas supply hose into the sampling head.
2) This gas exited from nozzles located in the sampling head, lofting material up the transport hose. In less than one second, the lofted sample arrived at the sample collection container.
3) At the inlet of the collection container, a pair of infrared (IR) break-beam sensors captured high-speed data about material passing into the chamber.
4) Sample was captured by the capture chamber via a series of etched screens along a labyrinth path.

After collection, the device captured images of the collected sample to provide correlation data for the break-beam sensors and to image dust coupons located on the back wall of the collection chamber. These are shown on the left and middle panels of Figure 4.

Following verification of sample collection, a second burst of air was injected into the sample container via a secondary path. This removed the finest portion of regolith from the system (these were vented along with the gas via the exhaust) and separated particles ± 1 mm in diameter on either side of the center dividing wall, with >1 mm particles remaining on the left, and <1 mm particles settling on the right (right panel of Figure 4). This was done to demonstrate particle size selection capability, as it may be desired for some instruments.

Results: Analysis of flight results is ongoing, but early conclusions from the sampling event indicate a collection of ~5 cc of regolith. This exceeded the threshold of 1 cc of collected material, but was lower than the objective of 10 cc. Early analysis of the video indicates that the PlanetVac sampling hood was not flush with the surface: it appears to have been aggressively angled and/or may not have been touching the lunar surface. Indeed, the resulting collection volume is similar to off-nominal laboratory testing performed during system development, i.e. with PlanetVac multiple inches off the surface being sampled. The flight demonstration of this configuration showed the robustness of the PlanetVac sampling approach to collect sample even from an off-nominal position.

An additional, unexpected, finding was that the use of pneumatic operations also cleared significant dust accumulation from camera lenses. This can be observed in both the sample capture chamber after sieving (Figure 4), but also in the sample collection video (still frame shown in Figure 1).

Further analysis of the particle sizes of sieved regolith, relative dust accumulation on material coupons, and an investigation of the relative position of the sampling hood with the lunar surface are currently underway.

References: [1] Firefly Aerospace (2025). *Blue Ghost Mission 1 - LPV Surface Operations Video.* *https://flic.kr/p/2qQkj7S* [2] Firefly Aerospace (2024). *Blue Ghost Mission Overview Animation*. https://flic.kr/p/2qwgaRd

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