CULPRIT: Carleton University Lunar Penetration Regolith Investigation Team

Space Mission Project

Introduction

The space mission 4th year design project focuses on the design of a lunar penetrator. The design of Lunar Penetrator 1, or LP-1, began last year. This project is unlike others in previous years where the focus was on Earth observation satellites. The design project team began the task by defining the mission statement, objectives and top level requirements. As the detailed design of circuitry, instrumentation, material selection and orbit manoeuvres continued, a comprehensive mission profile was drafted. Some testing has begun but much more will be required before manufacturing LP-1.

Mission Statement

"To design a micro-penetrator to survive lunar impact and report upon the characteristics of the sub-surface regolith "

Mission Objectives

Primary: *To survive as a tech demo and report on impact characteristics*

Secondary: *To detect water proxies*

Top level requirements

The measurements shall,

1. Be made at a vertical depth of one and a half meters (1.5 m) to two and a half meters (2.5 m) as measured from the surface of initial contact

The penetrator shall,

2. Conform to general micro class penetrator requirements (i.e. mass ≤ ten kilograms (10 kg), dimensions consistent with requirement 9 and power ≤ 30 W)
3. Once on the moon, be functional for at least five (5) days

4. Make two (2) types of measurement with at least one (1) sample, related to the secondary objective
5. Measure the vertical depth of its own penetration
6. Record penetrator temperature changes at mid length and aft points during and after penetration with a range of 100 K to 500 K, with a resolution of 1 K
7. Transmit all collected data to Earth
8. Conform to CCSDS
9. Be compatible with SELENE I as a carrier (volume, mechanical, electrical, orbit, launch vehicle and environments, communications)
10. Contain a camera working in the visible spectrum, with a resolution 256 x 256 pixels [TBC] that shall image the regolith sample(s)

Mission Profile

The mission profile is separated into three phases: the travel phase, the descent phase and the data phase. The travel phase involves LP-1 leaving Earth while attached to a Japanese lunar satellite (SELENE-1) and the 35 day travel time before SELENE-1 enters a polar orbit at 100 km altitude around the moon. The descent phase begins when LP-1 separates from it's carrier. Some time later the propulsion module will fire in the anti-velocity direction for a period of more than 10 minutes to begin reducing LP-1's velocity. At 28 km altitude, LP-1 will have near zero velocity and the propulsion module will detach. LP-1 enters a freefall for about 4 minutes before impacting the south pole of the moon at 300 m/s. The data phase begins when the instruments on board LP-1 begin taking measurements and transmit them back to Earth. It ends after the five day life of LP-1.

Current Design

LP-1 has a cylindrical body with a cone nose. Its total length is 58 cm and its outer diameter is 6 cm. The total mass of the structure and all of the internal components is 10 kg exclusive of the propulsion module. The nose cone is made of tungsten due to its favourable thermal properties. The cylinder is made of steel (exact type to be decided) due to its resistance to buckling. LP-1 is being designed to resist an impact load of up to 30 000 g.

A regolith sample will be extracted using a rotary drill. This sample will be collected in a sample container where it will be heated with the objective of identifying water vapour. This vapour will pass through a tunable diode laser absorption spectrometer (TDLAS) and over a set of micro-cantilevers. The TDLAS passes a laser through the vapour that will only change wavelength if water is present. The micro-cantilever has a porous coating that allows for water sized molecules to deposit on its surface.

Current estimates indicate that LP-1 will be able to communicate with OKINA (S-Band), the relay satellite that is also deployed from SELENE-1, for an average of 4.5 minutes per day. OKINA will then relay the information back to Earth. The data budget for all of the measurements made over the course of the five day lifespan of LP-1 is 4 Mb.

There are five Lithium Thionyl Chloride ($LiSOCl_2$) batteries powering LP-1. The patch heaters will draw the most power from the batteries in order to ensure the payload instruments remain in their functional or optimal operating temperatures while taking measurements.

The propulsion module has three 20 N hydrazine thrusters to slow LP-1 down, and four smaller hydrazine thrusters to control its attitude. The current estimate for the amount of hydrazine required for the descent burn is 16.4 kg. The attitude determination and control system will spin-up the penetrator during descent to increase its stability. The propulsion module will have standalone power, communication as well as a command and data handling system.

Testing and Future Work

In order to test component survivability, impact testing will need to be done. This can be done by building a prototype of LP-1, placing the electronics inside and firing it from an airgun or dropping it from a hot air balloon. Also, regolith stimulant can be acquired to test radio frequency transparency through lunar soil.

Some testing has already been completed. Crater mechanics have been studied to determine how much back fill there will be post impact. This was done to see if LP-1 will be completely buried or exposed to space after impact.

A to-scale model of LP-1 will need to be made in order to begin designing the internal circuit layout and component placement. All sub-systems will need to have their designs refined, and begin interfacing with each other. The detachment mechanism from SELENE-1 needs further development. A first iteration of the standalone sub-systems onboard the propulsion module needs to be created. Further investigation into how temperature readings will be made during impact is required.

The preliminary design of LP-1 has met expectations. For the next year, the work will focus on additional analysis and testing. CSA showed significant interest in this work, and our ultimate goal is to manufacture LP-1 at Carleton University with the help of our industrial partners.