Feasibility Study and Preliminary Design of a Lunar Reconnaissance Drone

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MISSION

"Assist a lunar rover mission in Permanently Shaded Regions (PSRs) or extreme topography with a compact lunar reconnaissance drone module."

The goal of this study is to propose a conceptual design of a lightweight and compact lunar drone module for scouting and exploration to assist large scale lunar rover missions into inaccessible or extreme environments.

The drone shall perform high-resolution mapping and if possible be reusable and modular to adapt to various mission scenarios. Based on NASA's Viper rover and ESA's EL3 Polar Explorer, the following mission objectives are defined:

- **Penetrate up to 250 m into PSRs (EL3)**
- **Survive Lunar nights of up to 4 Earth days in standby mode (VIPER)**
- **Experience 25% day/night duty cycle (EL3)**

MOTIVATION

With orbiting stations and ground bases planned to be built on our Moon, we are yet to master the ability to explore long term and long range over areas of our natural satellite often characterized by an extreme topography, dauntingly low temperatures, and wedged with what are known as Permanently Shadowed Regions (PSRs). This represents significant challenges for traditional ground exploration approaches, often relying on individual, limited-range, slow, wheeled rovers. Precise knowledge about the terrain for an optimized route planning is crucial and often relies on limited-resolution satellite data from lunar orbiters, which are even more limited in PSRs.

The need for a long-range yet simple, quick and lightweight scouting method is becoming more and more apparent.

CHALLENGING ENVIRONMENT

Surface temperatures: 40 K in PSRs to 230 K at daytime.

Dust & rock fragments: Lunar Regolith.

Extreme topography: Rocks & high slopes.

Low res. optical maps: Images from orbiters are not sufficient for rover route planning in PSRs (10-20 m/px).

Radiation: Negative impact on electronics.

PRELIMINARY DRONE DESIGN

Using Systems Engineering tools and approaches, this study focuses on the main aspects defining the mission of a lunar reconnaissance drone such as mapping, propulsion and thermal effects. The main conclusions drawn from the various decision-making processes based on trade-offs, calculations and simulations are here.

General data:

- Total mass: 15-20 kg
- Propellant capacity: 1 kg
- Power source: Li-ion batteries
- Flight time: 10 min
- Flight distance: 1 km
- Mapping resolutions: 10 cm/px

Mapping sensor

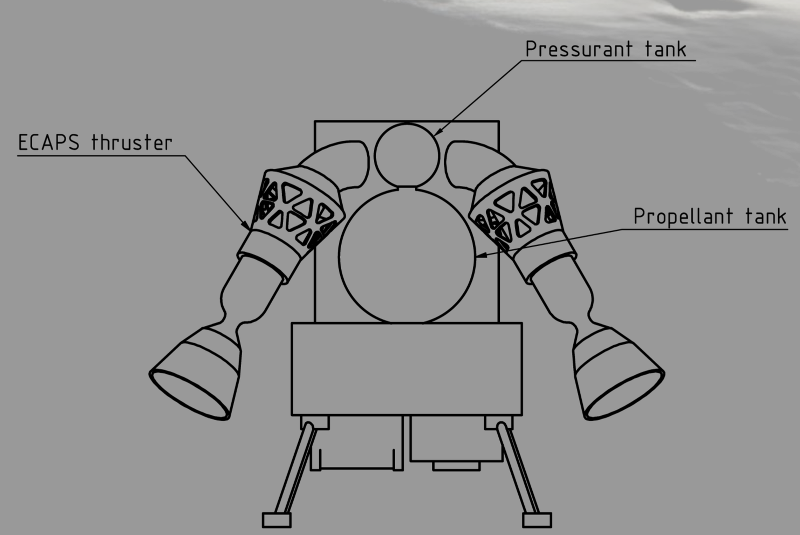
A flash Lidar is chosen as the drone's mapping sensor. This technology is currently rather heavy, though lightweight Lidars for space applications are expected to be developed soon. The choice of mapping sensor defines the flight height (50 m AGL) and speed (30 m/s).

Flight Profile

After a vertical ascent, the flight is performed horizontally at a constant height above the lunar soil to ensure a uniform mapping. The drone is required to land back on its base to avoid the contact with the lunar soil. It is then recharged and refueled to perform its next flight.

Propulsion system

The propulsion system consists of four fixed monopropellant thrusters using the LMP-103S green propellant (Bradford ECAPS HPGP Thrusters). Attitude control is performed by differential thrust. The propellant is pressurized using helium. The tanks hold a total of 1 kg of propellant, which is sufficient to cover up to 1 km of horizontal distance.



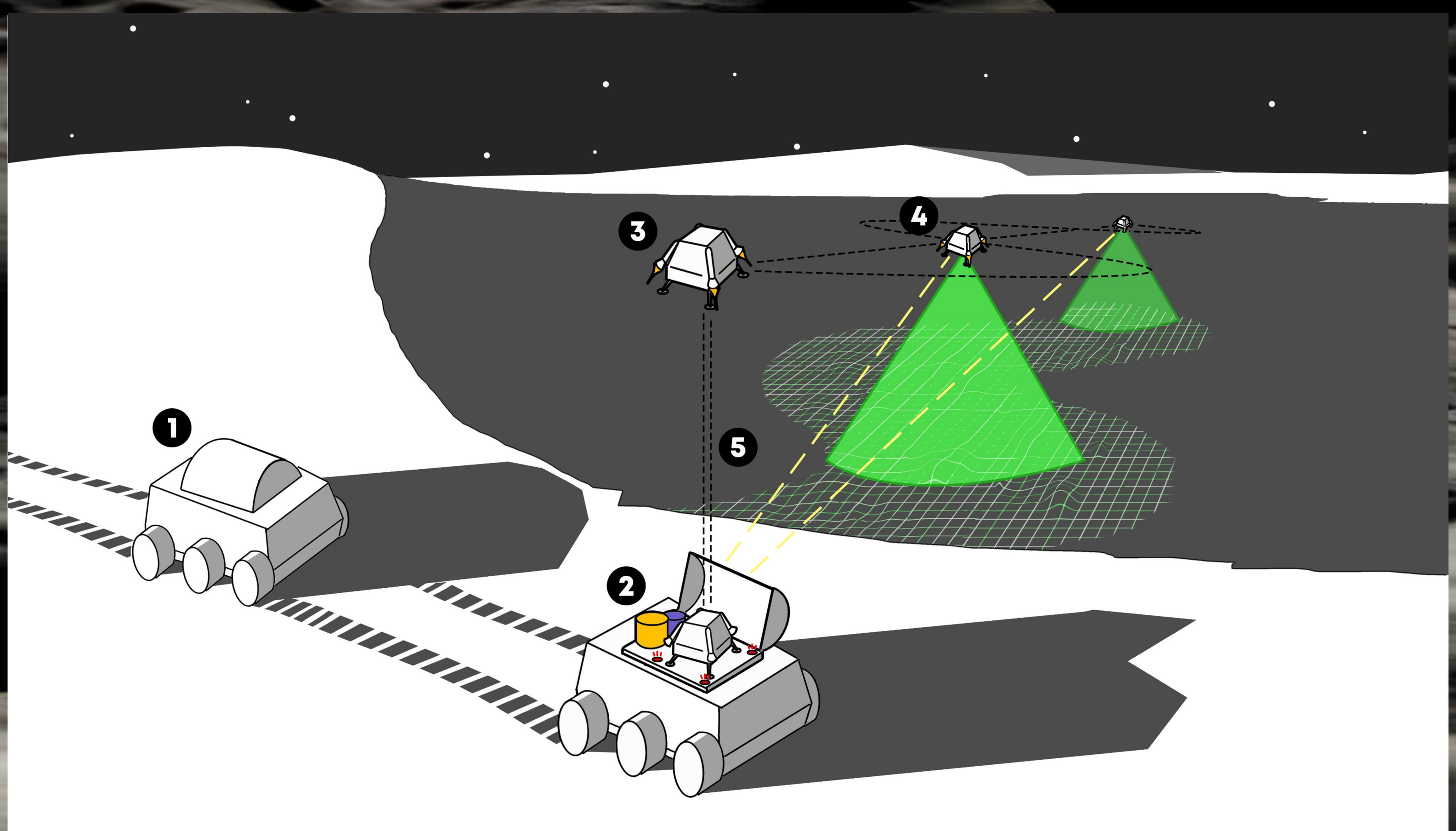
Thermal effects

The thermal control of the drone is one of the main challenges for the detailed design phase. Most of the drone's electronics shall remain between 0 and 50 °C. The preliminary study shows that no active thermal control systems nor large radiators are required for the drone if the incoming heat flux stays below 1500 W. This main heat sources are the thrusters, the heating from the Sun and the Joule heating from the electronics.

Reusability and stand-by

To keep the drone as lightweight as possible, all the systems needed to make the drone reusable are included in the drone base on the rover. The thermal protection systems for stand-by times between flights are also included in the base.

CONOPS



0. Pre-mission phase
1. Stand-by mode
2. Flight preparation & deployment
3. Take-off & vertical ascent
4. Horizontal flight
5. Vertical descent & landing
6. End-of-life phase

PRELIMINARY BASE DESIGN

The design of the drone base is out of the scope of this study. However, its main functions and interfaces can be described as follows:

Provide shelter for the drone when not in use
- Reversible hold down and release system
- Radiation cover to prevent large temperature losses
- Connection to the thermal system of the drone

Provide a take-off and landing base
- Flame diverter to direct thrusters' exhaust away from the rover
- Ease the landing with optical markers/lights

Provide a data connection to transfer the mapping sensor data from the drone to the rover

Allow for the refueling and recharging of the drone to make multiple flights possible
- Propellant and pressurant tanks
- Fuel line connection and disconnection systems

CONCLUSION & FUTURE WORK

This feasibility and initial design study sets a foundation for lunar drones and exploration of the Moon using flying spacecrafts. Many open questions remain to be solved and detailed designs have to be performed. Special attention needs to be given to the detailed analyses of the propulsion and the thermal systems. The next steps to be realized are a feasibility and preliminary design study of the drone's base.

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