A LUNAR RECONNAISSANCE DRONE MISSION CONCEPT FOR MAPPING AND CHARACTERIZING POLAR REGIONS V. Pozsgay[1], D. Rodríguez-Martínez[1], and J-P. Kneib[1], [1]eSpace – EPFL Space Center (PPH 335, Station 13, 1015 Lausanne, Switzerland; contact: david.rodriguez@epfl.ch).

Introduction: Upcoming exploration missions demand ever more capable robotic systems including the capability to explore longer distances (>100 km) under highly constrained time windows (e.g., lunar polar mission experiencing shorter daylight cycles) and to do so under extreme environmental conditions of which little to no data is readily available.

An effective, faster, and ideally unaltered characterization of these regions requires improved mobility systems as well as the use of high-resolution mapping and imagery, which most missions to date still lack. The highest resolution maps acquired from lunar orbit have been measured by the Narrow-Angled Camera (NAC) on board of NASA's Lunar Reconnaissance Orbiter (LRO). Despite the NAC being capable of imaging at resolutions as low as 0.5 m/px, permanently shadowed regions (PSRs) have been mapped at a maximum resolution of 10-20 m/px due to the need for longer exposure times [1]. Remote sensing from orbit has clear benefits when it comes to acquiring global measurements in a cost-effective manner. The data provided, however, is not of sufficient quality to pre-validate regions of interest for downstream scientific or commercial activities to follow.

We herein present the preliminary design of a lightweight, compact, and reusable reconnaissance drone capable of assisting other on-ground robotic systems for the characterization and high-resolution mapping of particularly challenging and pristine locations on the lunar surface.

Use case: The lunar reconnaissance drone is designed to assist other planetary robots operating on the surface into inaccessible environments—or those of which scattered, low-resolution data is available—, across unstructured, dynamic, and hazardous terrains, and over areas expected to hold highly valuable scientific information. The drone shall be capable of producing high-resolution maps (~0.1 m/px) of targeted regions of interest. It shall be fast to deploy and provide a simple, low-cost solution that prevents the contamination of scientifically significant locations. Reusability—capable of multiple flights—, modularity—capable of hosting different instruments for different purposes—, and adaptability—capable of being used across and alongside multiple platforms—are key design requirements for the implementation of these drones in a wide array of mission scenarios.

The Lunar Reconnaissance Drone payload envelope: The lunar reconnaissance payload envelope includes two main systems: the drone and its associated service station, i.e., a base located on top of the rover or vehicle the drone services, which apart from acting as a take-off and landing (TOL) pad provides shelter from radiation and low temperatures when in standby, refuels the tanks of the drone and recharges its batteries, and allows for major data transfers to take place on the rover itself; all with the objective of keeping the drone as simple, lightweight, and compact as possible.

The preliminary concept of operations (CONOPS) for the system defined thus far assumes the drone takes off from and always lands on its service station.

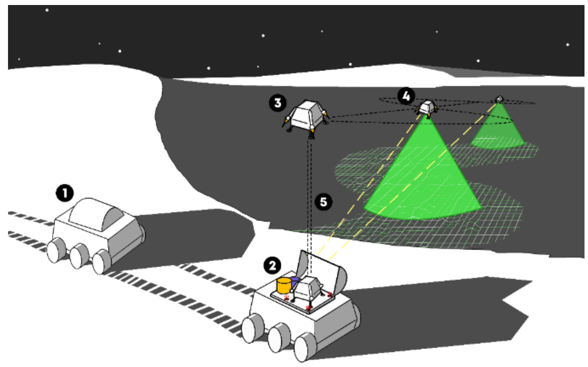

Figure 1: Illustration of the Lunar Reconnaissance Drone concept of operations: 1) standby mode, 2) flight preparation and deployment, 3) take-off and vertical ascent, 4) horizontal flight and mapping of the lunar surface, 5) vertical ascent and landing for data transmission, refueling, and standby. [2]

After take-off, the drone flies above the region of interest at a constant altitude while mapping the terrain or acquiring the necessary data. The altitude can be set to minimize the interaction with and potential contamination of the ground. The drone never lands on the surface. At the end of its flight, and while maintaining a constant altitude, the drone autonomously returns to its initial location to land back on the service station from which it took off. Data is then transferred to the rover for on-board processing or further transmission to ground or orbiting stations. The rover can afterward traverse to a different location for further examinations much more efficiently and with a higher locational awareness. Repeated flights can be performed ad hoc at different locations.

The drone is being designed to be completely autonomous. A preliminary study of the drone design resulted in a total wet mass, including margins, of about 17 kg, with a peak power consumption of 324 W, and external dimensions of 450x480x378 mm^3. A preliminary design of the service station is currently being conducted.

Propulsion system, trajectory, and control: For a combination of efficiency, low mass, and simplicity, the most effective way we found to design the propulsion system is the use of monopropellant thrusters. Four of these thrusters generate enough lift and thrust for TOL and hovering, with the added benefit that they can also be used for precise attitude control, eliminating the need for additional heavier reaction wheels or more complex engines.

The flight strategy we adopted resulted from a tradeoff between fuel consumption, mass, and reliability, especially during landing. Taking advantage of the capability of monopropellant thrusters to throttle, we opted for a semi-ballistic trajectory—a mix between an initial short vertical take-off, followed by a ballistic climb and a constant 50-m altitude flight profile. The trajectory is followed in reverse during landing. This mixed profile increases safety, since small corrections can be performed during the vertical TOL, and presents over 13% lower fuel consumption than a completely vertical TOL. A 50-m altitude was chosen to achieve the required resolution with the selected payload (see “Mapping instrument”) and to prevent any contamination of the surface from the plume of the thrusters.

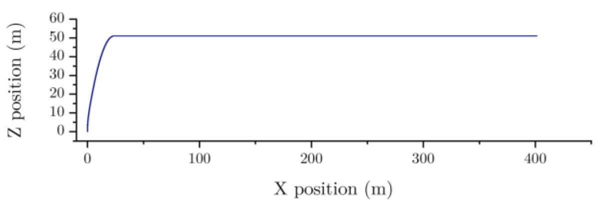

Figure 2: Drone’s 2D symmetric flight trajectory.

Flight simulations of this trajectory output a total flight time of 120.4 s for an 800 m flight, and a total fuel consumption of 1.86 kg per flight.

A requirement for our mission concept is that the drone shall perform at least 10 flights, refueling after every single flight, which means the service station shall carry at least 27 kg of additional propellant.

Payload: As a reference for our preliminary design study, we opted for a single payload that could be used both for mapping the terrain and as the prime sensory input for hazard detection and avoidance maneuvers.

We chose a flash Lidar for this application. Despite being an emerging technology, it provides high resolution, a 3D mapping capability, and it is highly reliable in fast-moving, unstructured environments. In addition, the use of a flash Lidar prevents the need for additional moving mechanisms such as gimbals or pan-and-tilt units. The European Space Agency (ESA) is currently pursuing the development of lightweight miniature flash Lidars for future space exploration [3]. The requirements formulated by ESA, particularly the ones concerning expected mass, volume, and power consumption, were used as a baseline to model the payload in our analysis.

Final configuration: The drone has been designed to be as compact as possible, with a low center of gravity for better control, while striving for simplicity and reliability during landing and docking with the station. TOL is always conducted from a known location (i.e., the service station), which simplifies the design from a mechanical and thermal standpoint compared to other solutions such as landing or hopping on the ground [4]. Minimizing the interaction with the ground, which potentially harbors scientifically valuable information and resources, was a must.

The current drone design lacks any power generation device on board and instead carries a 22.5 kWh battery pack that can be recharged while on the service station. While docked on the station, data can be transmitted either through a wired communication or a UHF wireless system.

The outer structure and inner skeleton are made of carbon fiber plates.

All the electronic components are located inside a warm electronic box to maintain them at a uniform operating temperature.

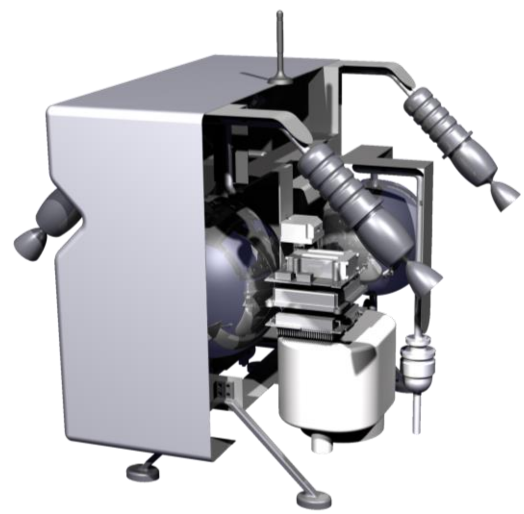

Figure 3: Drone’s final configuration.

Conclusion: We have presented a preliminary design of a lightweight and compact lunar drone usable under multiple scenarios (PSRs, skylights, etc.). While further analyses need to be conducted, particularly on the design of the service station and the optimization of the thermal design of the drone, and insights from the scientific community need to be considered in the selection and adaptation of different payloads, the results presented here constitute a promising baseline for an effective, low-impact, and faster characterization of scientifically valuable regions on the Moon.

References:

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