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INSPECTION OF THE CIS-LUNAR STATION USING MULTI-PURPOSE AUTONOMOUS CUBESATS

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Abstract

The close observation of orbiting objects with Cubesats can efficiently support a wide range of applications, such as the inspection of defunct satellites for preparing active debris removal missions, or the inspection of operative spacecraft (International Space Station, telecom satellites) for maintenance purposes. Future applications can involve inspection of deep space objects, for example the cis-lunar human-tended station, that will constitute the Gateway for future exploration missions. From the ISS mission, it has been understood that an inhabited outpost in space needs heavy maintenance for keeping it in operations with the required capabilities and safety level over a long-duration mission. Inspection from outside the station is required for investigation on detected anomalies or for preventing failures, for structural measurements, and in general for monitoring the station configuration. Small space (semi)autonomous drones, such as CubeSats, can be deployed from transportation vehicles or from the station, and used in several phases of the mission, flying in the vicinity of the space habitat. The study presented in this paper investigates the feasibility of operating multi-purpose small inspectors in proximity of the future Lunar Orbiting Platform. The study focuses on the inspection / surveillance mission, for which a concept of operations and architecture have been developed and analysed. In particular, the possibility to have 3D vision and multispectral payloads has been investigated, to enhance inspection capabilities with respect to current state-of-the-art technology.

1 INTRODUCTION

The Global Exploration Roadmap (GER) developed by the International Space Exploration Coordination Group (ISEAG) draws the path to pursue the objective of expanding the human presence into the Solar System with the surface of Mars as common final destination [1]. The current version of the exploration scenario, recently updated in the framework of the Artemis programme, includes an orbiting human-tended facility in the lunar vicinity, the Lunar Orbiting Platform - Gateway (LOP-G), for supporting activities on the Moon surface, and serving as technology and operations test-bed for next destinations [2]. The orbiting station in the cis-lunar space will contribute to the sustainability of the surface missions, enabling reusability, testing and accessibility [3]. Regarding reusability, the lunar vicinity is the optimal location for staging and refurbishment of elements involved in the mission to the Moon surface (and Mars in the long-term). Having a test bed in the cis-lunar space allows technology and operations to be validated in relevant environmental conditions equivalent to deep space conditions. At the same time, being relatively close to Earth, it helps reducing the risk in case of an emergency as well as it facilitates reaching the station by governmental and commercial transportation systems [4]. The outpost will also serve the scientific community to do science of and from the Moon, to conduct studies related to Earth and physics of the Solar System, and to advance the knowledge in life-science [5].

The International Space Station (ISS) has shown the benefits of human activity in Low Earth Orbit (LEO), and it has demonstrated the importance of inhabited outposts in many areas of science and technology related to space exploration. From the ISS mission, it has been understood that an inhabited outpost in space needs special care for maintaining it in operations with the required capabilities and safety level over a long-duration mission. Current surveillance and inspection of the exterior of the ISS rely on Extra Vehicular Activities (EVAs), complex robotic operations, external TV technologies and imagery taken by the astronauts from windows and by visiting vehicles [6] [7]. However, crew time for imagery acquisition and inspection is limited, and the visual coverage of the ISS exhibits numerous blind-spots, as shown in Figure 1.

Inspection is required for investigating anomalies, for structural measurements, for verifying the station configuration, and possibly for planning maintenance actions. With this respect, it shall be noted that what it is currently critical for the ISS, it would be even more critical for a remote station in cis-lunar or deep space, which will be uninhabited for long periods of time and will be visited no more than once per year.

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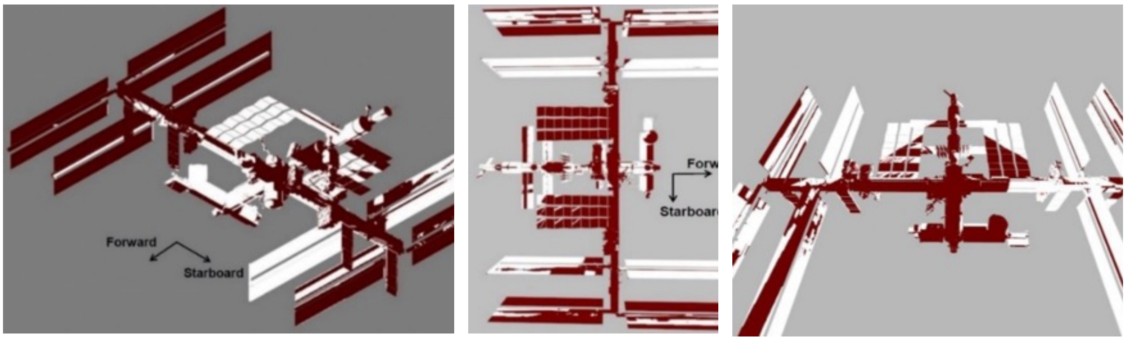

Figure 1: Blind-spots (brown areas) of the ISS

Few studies have been conducted so far for the inspection of the ISS using free-flyers to increase responsiveness and effectiveness while reducing the cost with respect to currently available inspection systems. A first demonstration mission was already accomplished during STS-87 in 1997 with the Autonomous Extravehicular Activity Robotic Camera Sprint (AERCam Sprint) when a small sphere was flown around the payload bay of the Orbiter, remotely controlled by astronauts in the Shuttle aft flight deck [8]. The AERCam Sprint was a prototype intended to demonstrate a light camera system that could have been used for the remote inspection of the ISS. Unfortunately, the operational version of this system, the Mini AERCam spacecraft, was built and tested on ground but never flew [9]. In 2003, the eXperimental Small Satellite (XSS) of the Air Force Research Laboratory was launched and successfully completed its mission of imaging the Delta II upper stage. More recently, NASA successfully flew the Seeker mission to demonstrate advanced autonomous inspection capability at low cost (1.8MUSD budget) and fast delivery (14-month schedule from sketch to operations). Seeker is a 3U CubeSat that operated around Cygnus on September 2019, taking images of the vehicle and performing a set of manoeuvres (including detumbling and target tracking, station-keeping, translations) and communication tests with its paired CubeSat Kenobi [10]. Another interesting study has been developed by the European Space Agency (ESA) for the inspection of the ISS with a multipurpose CubeSat (CubISSat Phase A study), and one study has just been completed for the observation of the Space Rider system (Space Rider Observer Cube Phase A study) [11]. Other studies related to the inspection of orbiting vehicles in LEO are reported in [12], where safety aspects related to ISS maintenance are highlighted, and [13], where a thorough analysis is presented for imaging needs and capabilities.

As for LEO mission, small space (semi)autonomous drones flying in the vicinity of LOP-G can be deployed to accomplish several functions:

1. External inspection / surveillance of the outpost, especially of (possible) blind spots to reduce the need for EVA and during uninhabited periods
2. Scientific payloads free-flying
3. Objects retrieval
4. Robotic maintenance and repair of the station

The primary objective of these missions would be providing the LOP-G crew and/or operators with effective tools to cope with a variety of situations related to inspection of the station, potentially avoiding to rely on complex robotics and/or on extravehicular activities as currently conceived on the ISS. Secondary objective would be providing scientists with low-cost opportunities for doing science in lunar environment [14].

The study presented in this paper investigates the feasibility of operating multi-purpose small satellites in proximity of a future lunar human-tended orbiting station, with reference to the LOP-Gateway concept. The study focuses on the inspection / surveillance mission, for which a concept of operations and architecture baseline have been developed and analysed, and high-level requirements have been defined. In particular, the possibility to have drones with 3D vision and/or multispectral payloads has been investigated to enhance inspection capabilities with respect to current state-of-the-art capability.

Section 2 presents the mission concept, with definition of the Concept of Operations and architecture of the mission, highlighting objectives, high-level requirements and constraints. In Section 3, mission-critical areas and technology are discussed. Highlights are given on the observation payload and its implication on the system architecture. Section 4 concludes the paper with the discussion of the results of the study and recommendations for future implementation of the concept. The requirements list and the mission phases description are reported in Appendix A and B, respectively.

2 MISSION DEFINITION

It is assumed that the experience gained through the ISS mission is the basis for operating a future lunar orbiting platform. With respect to the external inspection of the station, we have learnt that it is needed for:

- Monitoring external conditions: materials degradation, surface anomalies and/or damages, Micro-Meteoroid Orbital Debris (MMOD) impacts
- Verification of configuration: installation of components, solar array deployment, structural dynamics
- Assessment of anomalies: surveillance of external systems after anomaly detection
- Supporting operations of visiting vehicles

Current inspection of the ISS is conducted through extra vehicular activities and robotic arm operations, and it is supported by a TV system throughout the station (fixed cameras installed outside the station and crew equipment used from windows and during EVAs). However, TV coverage of the station is not complete, and blind spots exist. Moreover, astronauts time for inspection is (and must be) limited, while robotic inspection requires very complex operations making routine (general purpose) monitoring unfeasible. This makes the general ISS periodic inspection a lower priority task with respect to science and maintenance. As a result, regular inspection operations are limited to line-of-sight views during visiting vehicles approach.

Albeit not yet defined into the detail and notwithstanding similarities, operations of LOP-G will differ with respect to ISS to a great extent for several reasons. Differences between ISS and the future LOP-G which have an impact on the inspection-related tasks are reported in Table 1.

Table 1: Differences between ISS and LOP-G relevant to the inspection mission

ISS	LOP-G	Comments
Earth orbit (LEO)	Lunar orbit (NRHO)	• Environment: different in terms of radiation • Distance from Earth: 400 km vs 400,000 km (strong impact on communication, transportation) • Navigation and orbit control/maintenance strategy • Current orbit of LOP-G is a near-rectilinear halo orbit (periapsis and apoapsis at 3.000 and 70.000 km respectively) to minimise eclipses
1000 mc pressurised volume	100 mc pressurised volume (ROM)	Current design of LOP-G includes 7 modules for a total of 125 mc pressurised volume at completion
Permanently inhabited	Occasionally inhabited	LOP-G will host astronauts during Moon sorties, for short duration. It will be uninhabited for long periods of time
Regular visiting vehicles	Infrequent visiting vehicles	While the ISS is routinely visited by vehicles carrying goods and crew (approx. once per month), LOP-G will be visited at longer intervals of time (schedule is not defined so far, once per year is assumed as prospective option)
Science laboratory	Exploration outpost	LOP-G has the main objective of supporting Moon sortie missions (short term), whether the ISS is mainly devoted to scientific experiments in the long term

These differences will make inspection of LOP-G be possibly rather dissimilar with respect to ISS-targeted missions, in terms of objectives, capabilities, and operations. Thus, considering these differences and similarities, objectives of the study presented here are: 1) to assess what functions/capabilities/technologies can be transferred from the ISS case to the LOP-G case, 2) to understand how inspection capabilities can be enhanced, and 3) to propose a mission concept for an effective inspection of an orbiting station in cis-lunar space.

2.1 Mission objectives and high-level requirements

The problem to be solved with the mission can be defined as follows: how is it possible to deliver inspection functions needed to support operations of the future lunar orbiting station?

It is assumed that the study must consider basic inspection needs comparable to those of the ISS, but specific functions related to observation of the cis-lunar station are also investigated. The needs identified through the analysis of available documentation for the ISS and the context given by the exploration framework programme, and tailored for the cis-lunar station, are listed in Table 2.

Having a set of small specialized drones readily available, reusable and capable to:

- observe the station from outside, taking pictures and/or videos of the station

- operate autonomously, limiting or avoiding/replacing EVAs and robotic operations dedicated to inspection
- collaborate with the crew for inspection and surveillance of the external part of the station, during inhabited periods of time of LOP-G (optional)
- host multi-purpose sensing instruments providing a variety of measurements (e.g. radiation environment, thermal and structural characterisation, biology studies)
- communicate with the station and/or with ground

might help to address some of the needs mentioned in the table.

Table 2: Identified needs addressed by an inspection mission

Area of interest	Need	Objectives and Improvement wrt ISS
Inspection of the exterior of the station	To have complete and continuous view of the station from different points of view	To increase image quality and type To increase observation time To operate autonomously
Support to exploration goals	To fill the gaps related to technology and science for future missions	To perform science experiments and technology demonstration autonomously in deep space environment
Crew workload	To maximise the time spent by the crew for doing science and exploration	To minimise astronauts' time for maintenance of the station
General public engagement	To get the interest of the general public in space exploration	To document the mission for outreach activities by streamlining unprecedented videos and imagery

These small platforms will first serve crew on board the station (when present) and ground mission operators of the participating space agencies. Depending on what payload suite is embarked on the platforms, the scientific community can be considered either primary (end-) or secondary user. The general public might also be engaged through availability of high-resolution 3D imagery.

The mission statement can be expressed as follows: *The mission aims at deploying & operating low-cost/fast-delivery small drones in the vicinity of the cis-lunar human-tended station, to provide enhanced capabilities of inspection and surveillance of the station, and to complement scientific, technological and outreach objectives related to the global exploration roadmap.*

The objectives of the mission have been drawn from the needs' analysis and mission statement:

- The primary objective of the mission (OBJ1) is to provide data of the exterior of the station, delivering inspection and monitoring capabilities of the cis-lunar station by using multi-purpose, (semi)autonomous systems
- Secondary objectives are: (OBJ2) to increase the capability to conduct scientific research and technology demonstration in the vicinity of the Moon, and (OBJ3) to provide unprecedented imagery of the station for outreach purposes.

The high-level mission requirements and design drivers can be derived from the mission objectives, and the analysis of context given by the stakeholders' needs analysis, in the framework of the existing exploration roadmap. The Science Traceability Matrix (STM) [15] has been developed to identify measurement performances and to derive requirements. Safety requirements applicable to the ISS have been considered at this stage of the design for similarity. The list of requirements and drivers used to derive the Concept of Operations (ConOps) and the Mission Architecture is reported in Appendix A.

2.2 Concept of Operations

The proposed Concept of Operations is driven by the high-level requirements and mission drivers, payload requirements and trajectory analysis. It must be considered that very few details are available about the architecture and operations of the future cis-lunar orbiting platform, thus assumptions have been made by the authors based upon their knowledge and available documentation and considering similarity with the ISS whenever deemed possible.

The ConOps developed and described in this paper is related to the execution of a "routine" inspection mission, i.e. to accomplish at least the primary objective (OBJ1) of the mission (as stated in paragraph 2.1). The "routine" mission refers to a mission executed on a regular basis when LOP-G will be finally fully operative. Some variations with respect to the baseline ConOps have also been considered in order to increase robustness of mission design to adapt to a changing scenario, to accomplish secondary objectives, and to implement a credible development plan for the mission. For example, the first mission has been set to take place with the Artemis III in 2024. This mission might require variations with respect to the standard routine mission, as LOP-G will not be fully completed nor fully operative (e.g. deployment and/or retrieval facility for the CubeSats can still be missing). Moreover, in the first mission, a certain set

of key functions and critical technologies of the CubeSats must be demonstrated before going fully operative (i.e. limited operations will be allowed in the vicinity of the station, and rehearsals around virtual points at a safe distance will be required). Should the first mission be planned before 2024, some alternative options (reduced scenarios) are described in Section 3.
The description of the phases of the baseline ConOps is detailed in Appendix B. The routine inspection mission is illustrated in Figure 2:

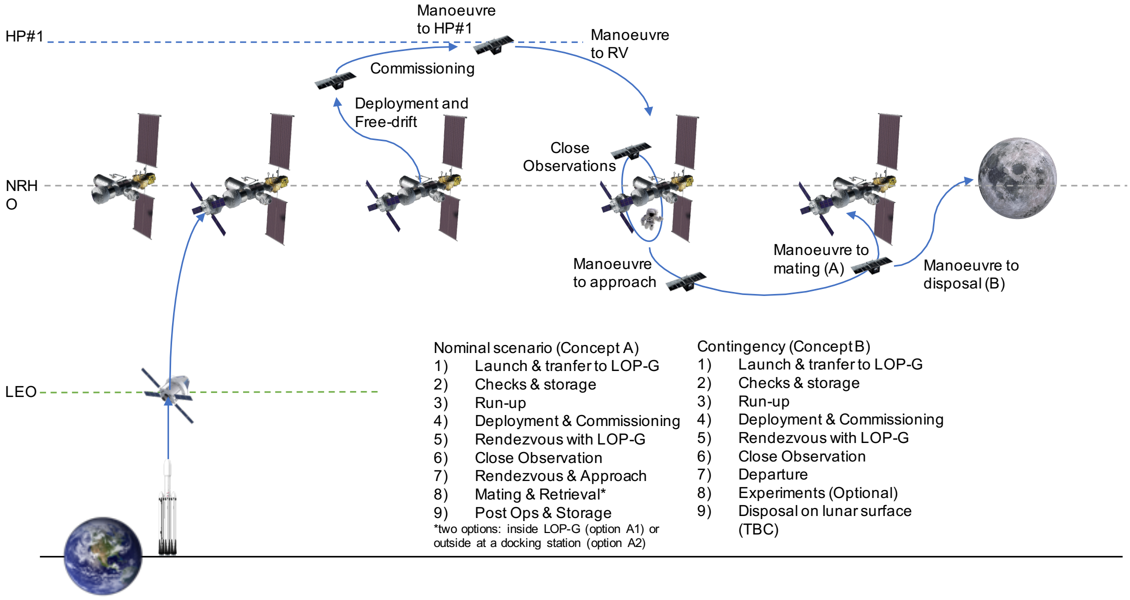

Figure 2: Design Reference Mission and ConOps

After completion of the observations, two possible scenarios are considered. The first concept (A) describes the nominal mission in which the inspector CubeSat goes back to the lunar orbiting platform. Different mating strategies (berthing and docking, with different mating mechanisms) can be followed, as described in Section 3. From the operational point of view, it is possible to identify two different options: the inspector is retrieved inside the platform (option A1), or it remains attached at the external docking point (option A2). The first solution requires human intervention, thus affecting crew workload. The second solution implies a very high level of autonomy of the spacecraft, which must be able to perform autonomous refurbishment to restore the system and be ready for next mission. Typical refurbishment will be: battery recharging, re-fuelling, data download and software update, and overall system check. In the second concept (B), once the observation is completed, the inspector CubeSat is dismissed on the lunar surface by an end-of-life manoeuvre. In this case, it would be possible to consider an optional phase in which the satellite performs scientific and/or technological experiments before crashing on the Moon. Concept B describes either a simpler mission with respect to Concept A or the contingency scenario of Concept A, in case a failure prevents safe mating with the station. The description of the phases of the ConOps is detailed in Appendix B.

2.3 Mission Architecture

The mission for the inspection of the cis-lunar orbiting platform requires that small-spacecraft are deployed and perform proximity operations at the station. Main elements of the mission architecture are listed in Table 3. One of the drivers for designing the architecture is minimizing the impact of the CubeSat mission on LOP-G design and operations, that means to limit to a minimum the interactions between the inspector(s) and the station.

The space segment features:

- one or more inspectors with the adequate sensing payload and the service module. Depending on the observations of interest, two cooperative spacecraft might be necessary (or at least preferred) for each measurement. The number of satellites is a function of several factors: mission geometry, measurements (observation) requirements, operational scenario, reliability, risk, cost and complexity of the mission. The dimension of the single satellite is mainly driven by requirements on volume, mass and power needed, orbital and attitude manoeuvres, and configuration constraints. The minimum form factor for the single spacecraft is 6U, but the 12U size seems to be more appropriate to leave some margin given the early stage of the design, for reliability and safety reasons, and for hosting optional payloads (e.g. scientific experiments)

- one or more deployment & retrieval systems. This system shall accomplish the traditional function of CubeSat deployment, and the novel functions of retrieval, refurbishment/resupply, and stowing. These latter functions can be optional for some of the mission concepts, but they are considered in the proposed architecture as final goal. The deployment & retrieval system can also act as a relay for communications between the inspector and the station, and/or between the inspector and Earth. Not necessarily the same equipment must accomplish all the functions, but a distributed system can be considered in which each element is in charge of a particular function. The final decision will be strongly dependent on interface requirements with LOP-G.

For the ground segment, the Deep Space Network is considered as baseline, but additional stations for increasing the access slots to the inspection mission are recommended (e.g. the Estrack network). Another important element of the ground segment is the Mission Control Centre, but this point cannot be addressed until the operations of the Gateway are defined. It is most likely that the inspectors are controlled as part of the Gateway mission from Houston, but options for having dedicated Payload Operations Control Centres (POCC) can be considered in case the inspectors pursue scientific objectives.
The launch segment is assumed to be the Space Launch System and the Orion spacecraft. This is the baseline choice at least for the first inspection mission, which is planned with the Artemis III flight in 2024. This flight will be the first crewed mission to LOP-G. The presence of the astronauts is essential for the preparation of the first inspection mission.

Table 3: Mission architecture summary

Mission element	Description	Trade-offs/Comment
Subject	LOP-G	Visual and Multi-spectral images of the exterior of the Lunar Gateway
Space Segment	Inspector(s) Deployment and Retrieval System	12U form factor baseline (6U is still an option for reduced mission objectives, and/or for demo missions). Number of spacecraft: Twin-CubeSat System or Single CubeSat System, depending on measurements needs. Other spacecraft can be stored onboard for next use Deployment and Retrieval Mechanism (DARM) or Standard deployment system (e.g. Nanoracks) + mechanism on robotic arm for retrieval. Strong dependency on LOP-G interface (unknown)
Observation Payload	Multispectral imager VIS camera	Re-design of Hyperscout Spectral Imager, with reduced FOV and adjusted wavelengths in the following bands: • Visual • Near InfraRed • Thermal InfraRed Visual camera
Orbit & Constellation	Formation flying with respect to LOP-G	Safety ellipse with relative inclination change. Drivers: safety and coverage of the station
Communication Architecture	Store & Forward architecture	Link to Earth through LOP-G interface for DARM (TBC) Interlink between the inspector(s) and DARM Interlink between inspectors (if two spacecraft are considered) Direct link to Earth
Ground Segment	Ground station network MCC	Deep Space Network (enhanced) Compatibility with Estrack network MCC TBD in accordance to LOP-G operations. POCCs (TBC)
Operations	Ground + crew	Ground operators and/or LOP-G crew
Launch Segment	Orion + SLS	Not tradable. Launch assumed in 2024 Artemis 3 mission (crewed). Compatibility with commercial launchers and transportation vehicles

3 MISSION-CRITICAL AREAS AND TECHNOLOGY

Mission-critical areas and/or technologies means that 1) the mission cannot be accomplished without these elements (i.e. they are mission-enabling), 2) they are peculiar of the mission (i.e. no other missions flown so far needed these elements), and 3) they (potentially) require significant effort for new development. Mission-critical areas constitute technical and/or programmatic challenges for mission development. On the other hand, the development and/or demonstration of new technologies associated to the inspection mission-critical areas have the potential to significantly contribute to the accomplishment of complex CubeSat missions with unprecedented objectives.

The most critical aspects of the LOP-G inspection mission can be traced back to safety issues and technology availability. The execution of the mission requires the demonstration in deep space of safety-critical functions and technologies in the areas of:

- *Observation*
- *Deployment and Retrieval*
- *Proximity navigation*
- *Motion control*
- *Communication*
- *Mission operations*

For each of these areas, specific issues have been identified and are discussed in the next paragraphs.

3.1 Safety

The safety aspects are of paramount importance for a mission in which the inspector operates in a severe environment and in proximity of the station with risk of collision. The safety requirements of LOP-G are not yet available, but it is assumed that the approach to safety will be similar to that of the ISS. For this conceptual study, a Keep-Out Zone (KOZ) has been considered as a volume around the station in which the inspector can enter only during deployment and final approach phases, with similarity to the keep-out sphere of the ISS. Moreover, all trajectories shall be passive safe throughout the proximity operations phase (except for the final approach and mating). Collision avoidance strategies are mainly implemented by applying escape manoeuvres from the target should the satellite try to break the KOZ. The inspector shall be able to execute active Collision Avoidance Manoeuvres (CAMs) to achieve positive separation rate away from the station and reach a passively safe trajectory.

Fault avoidance and fault tolerant techniques can be implemented to mitigate the effects of system failures due to internal faults or to the lunar environment. Passive redundancy techniques use more than one module (e.g. sensors, actuators, acquisition circuits, driving circuits, processors/controllers) to perform safety-critical functions (i.e. time-keeping, data handling and storage, command execution). Active redundancy techniques apply failures detection, identification/isolation and recovery (FDIR) strategies on faulty modules. Many researches are ongoing for improving the FDIR capability of CubeSats, exploiting mainly Artificial Intelligence and machine learning techniques [16]. Solutions with distributed architecture foresee that two or more modules can execute different tasks until one of the modules fails and its tasks are redistributed on the other modules. In general, the best solution is to merge these techniques in hybrid and versatile architectures. This area deserves special attention for CubeSats, due to extensive use of Commercial Off The Shelf (COTS) items, low maturity of Quality Assurance processes, small form factor (size and mass), and (usually) short development time.

3.2 Observation Payload

The payload functions and performance stem from the measurement requirements, and they shall be assessed in close interaction with the trajectory design. Basically, the payload shall take images of the lunar orbiting platform in different spectral bands for complete monitoring of the overall station's conditions, for accurate inspection of critical elements (e.g. solar panels) and for investigating damages due to lunar environment (e.g. MMDO impacts).

For an effective inspection, a spatial resolution of 1 cm or better (for the visible band) and of 10 cm (for the infrared band) shall be reached. Moreover, precious additional information could derive from depth information of the elements on the surface, if a depth resolution of at least 2 cm is guaranteed. The detection of surface temperatures and materials conditions can be accomplished through thermal and chemical analyses. The most suitable solutions for accomplishing the required observations are electro-optical instruments operating at least in the visible (VIS) and infrared (IR) wavelengths. One multi-spectral imager plus one visual camera is the preferred solution for the payload at this stage of the design. A survey and assessment of available technology led to the baseline selection. The instruments have been selected considering measurement requirements, size, mass, power consumption, focal length, and pixel dimension, and suitability for 6U/12U CubeSat form factor.

For the visual cameras, the maximum distance from the target for which they satisfy the spatial resolution requirement has been defined (Figure 3). Tele-Xenar 2.2/70 offers the best spatial resolution and the related requirement is satisfied up to 500 m of distance from the target [17]. The vertical and horizontal Field of View (FOV) are 4.00 deg and 5.32 deg, respectively. The vertical and horizontal linear instantaneous FOV (IFOV) are respectively 35.00 m and 46.5 m for a total focused area of about 1610 m^2. For the detector, a possible choice is a 12 Mpixel Digital Image Sensor (2/3" format) with a pixel size of 2,2 micron.

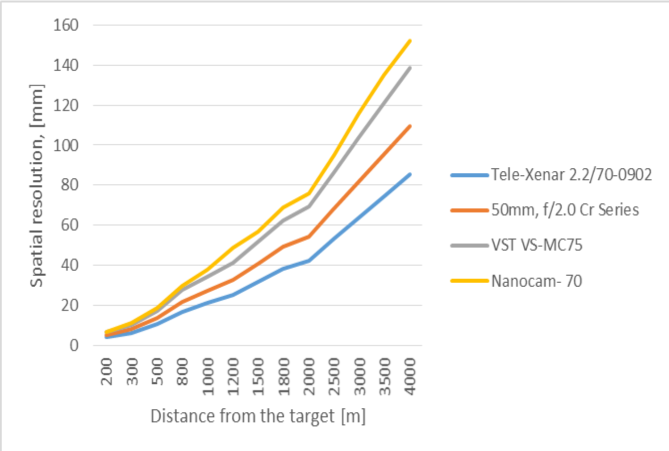

Figure 3: Spatial resolution vs distance from the target

The measurement of the depth of a feature adds interesting information for inspection purposes. The detection of objects depth in the imaged scene is possible through several techniques.
Stereoscopy creates the illusion of depth by means of stereopsis for binocular vision. Stereoscopic images are obtained after the elaboration of a pair of images, which must be compliant with stereoscopic requirements: desired depth resolution, acuity angle (or stereoscopic angle), disparity pixel quantity between the two images, and illumination conditions. Then, a set of images is assessed and the most suitable images are selected before the elaboration, in order to prevent wasting computational resources. To elaborate the stereoscopic image, the 3D-RIG algorithms can be used, relying on disparity pixels evaluation and features recognition, that operate on the convergence of the images: Converged Stereo Rig, Parallel Stereo Rig, Off-axis Stereo Rig are three examples of algorithms that differ for convergence of the two cameras.
The second way to obtain information about the object's depth is working on two (or more) images taken by the same camera changing the focal length by zooming in/out or changing the relative distance to the target while maintaining the pointing direction. These images are elaborated, for example, calculating the angle of light to each pixel ("light field moment imaging" methods) [18] and then are stitched together to create a sort of stereoscopic effect.
A third approach is based on the recovery of depth information from a single camera by features recognition and comparison with a database of pre-processed images. For this approach, a very promising solution is given by the implementation of the supervised learning approach. A set of monocular images of the target (provided with all the reference data about position and depth) are used to train an artificial neural network. Then the algorithm (e.g. Markov Random Field - MRF) compares the picture, elaborated through multiscale local and global image analysis, with the database evaluating the relation between depth at different points and obtaining accurate depth-maps [19].
Many Earth Observation satellites are equipped with multi-spectral imagers. When using these instruments for the observation of another spacecraft in deep space, some specific requirements apply, and modifications or re-design of available technology are needed. Usually, instruments for Earth Observation have large Field of View to image large portions of the planet surface, and they work in frequency bands which are dependent on the subject to be detected (e.g. fires, vegetation, water). In the case of the inspection of a spacecraft, typically we need narrow FOV and specific wavelengths determined by the characteristics of the target. Regarding the former point, the required FOV is dependent on the distance between the instrument and the target, thus it is strongly related to trajectory design, and depends on the relative dimensions of the inspector with respect to the target. Regarding the wavelengths, indeed the choice is driven by the materials of the target spacecraft surface, assuming that the emission spectrum of each element is unique. It is important that the spectral band used for the detection of a particular chemical compound contains the peak of the reflectance spectrum. While for

visible and IR cameras many products for CubeSats are easily available, very few multispectral or hyperspectral imagers can be found on the market that fit the CubeSat form factor. One candidate instrument is the HyperScout II imager, which however needs re-design of the FOV and calibration of the spectral bands [20].
The considerations on the payload led to the definition of possible architectures of the space segment. As far as the satellite part is concerned, two main architectures have been evaluated to enable 3D information:

- **Twin-CubeSat System (Architecture A)**. Two inspectors operate together, coordinated through a cross-link communication system (Figure 4). Each spacecraft is equipped with one camera. The CubeSats shall operate maintaining a defined, but variable, parallax while pointing at the same target. The images are taken at the same time.
- **Single CubeSat System (Architecture B).** The architecture includes only one inspector, equipped with a single camera. It is possible to emulate a situation in which the parallax is variable, but the images cannot be taken simultaneously. In Configuration 1 (Figure 5), the satellite flies-around or back and forth along the orbit with respect to the station, generating a variable inter-axis separation. Once the images are taken, 3D-reconstruction algorithms can be applied in post-processing. Configuration 2 (Figure 6) foresees that the satellite maintains a hold-point as near as possible to the Keep-Out-Zone boundary and depth information are recovered through algorithms based on single image.

Architecture A supports the implementation of the stereoscopic approach, while architecture B is suitable for having a single image capture in different instants and, if required, different positions. Architecture A requires the interlink to transfer one of the two pictures to the other CubeSat to perform stereoscopy (in case processing is carried out onboard the inspectors); moreover, shooting synchronization shall be guaranteed in order to take advantage from the stereoscopy (e.g. same illumination conditions). Parallax and relative distance should be maintained and a precise formation flying capability is required.

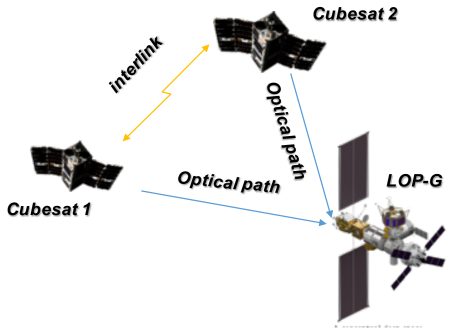

Figure 4: Architecture A

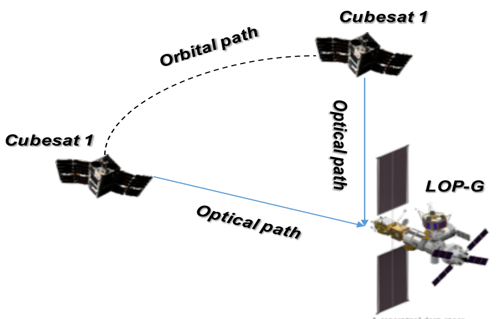

Figure 5: Architecture B - Configuration 1

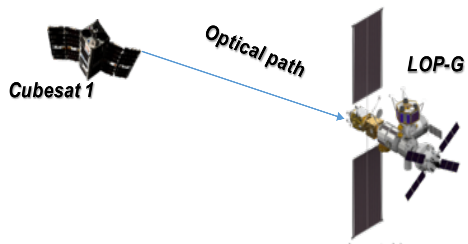

Figure 6: Architecture B - Configuration 2

In Architecture B – Configuration 1, two pictures could be taken with slightly different external conditions dependent on the time needed for the CubeSat to reach the new position and attitude to shoot the second picture. Neither shooting synchronization nor interlink are required to reconstruct depth information, differently from architecture A. Architecture B – Configuration 2 is easier to be managed because a single picture is taken and elaborated without the necessity of synchronization, interlink, and position change, but the quantity and quality of information about depth are not comparable with those obtained with two images. If a misbehaviour affects one of the inspectors of Architecture A, a reconfiguration to one of the cases of Architecture B could be reached; instead, any payload failure on the satellite of Architecture

B, has the potential to reduce the observation functionality to a great extent, degrading or compromising mission success.
Considering the selected camera system, the stereoscopic requirements have been evaluated. Long distance from the target, small inter-axis and high acuity angle strongly reduce the stereoscopic range (Table 4). Architecture A and Architecture B - Configuration 1 allow very high depth resolution because few meters of inter-axis value can be reached. However, both solutions imply a high pointing accuracy of the satellite(s) is achieved and require the capability to assure the pointing of the same scene on the target for both images.
Should the requirement for 3D vision be removed, one satellite is sufficient for fulfilling the mission objectives.

Table 4: Depth resolution for different inter-axis separation and distance from the target with acuity angle of 0.1 deg

		Inter-axis separation [m]			
		1	10	50	100
Distance from target [m]	30	0,262	0,026	0,005	0,003
	50	0,727	0,073	0,015	0,007
	100	2,910	0,291	0,058	0,029
	200	11,638	1,164	0,233	0,116
	300	26,186	2,619	0,524	0,262
	500	72,738	7,274	1,455	0,727
	750	163,660	16,366	3,273	1,637
	1000	290,951	29,095	5,819	2,910
	1250	454,612	45,461	9,092	4,546

3.3 Deployment and Retrieval

Two possible approaches can be pursued for the deployment and retrieval of the inspectors: using the same mechanism for both functions, or using different mechanisms for each function.
Deployment strategies can be either passive or active. Traditional passive deployment consists of the release of the CubeSat from the deployer through spring-loaded mechanisms: in this case, neither separation mechanism nor propulsion capability are needed on the small spacecraft, with mass and volume saving, but a certain amount (usually high) of kinetic energy shall be damped by the spacecraft, thus some time is necessary for detumbling and for attitude acquisition. Active deployment foresees that the inspector hosts mechanisms and/or propulsion elements in order to have a controlled exit from the deployer. Active strategies might reduce the duration of the commissioning phase but separation mechanisms and/or propulsion system weigh on the spacecraft design. However, given that propulsion is needed for motion control all over the mission, this is not seen as a showstopper for the mission under study. Instead, it is possible that constraints will exist on contamination of the station due to the plume of the thruster, which might dictate that the propulsion system is activated only at a certain distance from the station or that some propellant and/or technology are prohibited. No "standard" system is available today for active deployment of CubeSats, whereas many solutions exist for passive deployment [21] [22] [23]. Whatever the system, a minimum exit velocity at the deployment will be required for safety reason. The direction of the velocity vector is another important parameter for guaranteeing collision avoidance (typically a small component in the Vbar direction in needed, but detailed simulations are needed for deployment requirements definition).
The mating strategy can follow 1) a berthing approach or 2) a soft-docking approach. Through the robotic arm of the lunar orbiting platform, the inspector can be grasped when it reaches and maintains the "berthing box". The soft-docking approach depends on the point of mating. A mating point on the external surface requires high accuracy of the attitude and position control, and a docking station. A more effective solution would be docking in the airlock of the lunar orbiting platform. In this case, lower accuracy on the position and attitude is required due to the dimensions of the "mating point". If the airlock is used, the satellite should reach and maintain a safety point inside the airlock bay that should be equipped with protection systems to reduce the damages of undesired impacts. Unfortunately, the robotic arm will be available only in 2027, and the airlock later in 2028, according to current plans of the Gateway development. All these options are considered for the baseline routine inspection mission, and the final choice needs to be discussed with the LOP-G project.

The only possibility for deploying and retrieving the CubeSat(s) for the first inspection mission, should it be planned with Artemis III in 2024, can be the following:

- Deployment from Orion in the vicinity of the station (Orion will deploy many CubeSat during Artemis I and II missions, thus it is assumed that this will be possible for Artemis III)
- No retrieval (disposal on lunar surface or deep space)

Another option for deployment and retrieval of the inspector could apply, in case the CubeSat is sent before with a cargo mission, as part of the Power and Propulsion Element - PPE, or the minimal habitation module. In this case, it would be useful to develop a dedicated deployment and retrieval mechanism such as the one proposed for the SROC re-entry vehicle [11]. The system, called DARM, is a modified standard CubeSat deployer in which the pre-loaded spring is replaced by a motorised pantograph mechanism. The CubeSat stays attached to the moving plate thanks to an electro-mechanical interface based on the concept proposed for the AAReST mission by CalTech [24]. The current design of the DARM includes also an avionic pack to support communications with the inspector and with the hosting vehicle, and for housekeeping purposes. The DARM (or a similar system) could be attached outside any module of the lunar Gateway, and it can be used also for next routine missions from/to the station.

3.4 Navigation and motion control

Navigation and control of the motion of the inspector are key functions for proximity operations, especially in the close vicinity of a human-tended station. First, the CubeSat shall be able to determine its relative position with respect to the lunar orbiting platform and the Moon. The proximity navigation with the target can be obtained 1) using radio signals, 2) using passive electro-optical instruments (e.g. visual cameras), and 3) using active electro-optical instruments (e.g. LIDAR). At a certain distance from the target (d > 200 m), all the solutions seem adequate: radio-signals and image processing can be used without additional instruments, and they provide sufficient ranging accuracy. The accuracy can be increased by data fusion techniques. For the final rendezvous, close approach and mating phases, only navigation with electro-optical systems provides the required accuracy [25][26] [27] [28].
The navigation with respect to the Moon can be based on indirect or direct techniques. Indirect methods mainly consist of propagating the orbit through models loaded on board and they require knowing the positions of the lunar orbiting station with respect to the CubeSat and with respect to the Moon. Direct methods use optical information (such as landmarks/features identification and tracking, limbi fitting or centroid-based triangulation algorithms) or radiometric information, or an optimized combination of optical and radiometric information. The indirect methods can provide an easier way to obtain the real position of the CubeSat in the Moon orbit. Direct methods are effective but requires either dedicated instruments, influencing the mass, volume and power budgets, or slew manoeuvres of the satellite to point cameras to nadir, reducing the time to take picture of the observation target (LOP-G). GNSS signals for navigation task at lunar distance can be also used, as documented in [29][30][31], but the techniques still need to be demonstrated.
Regarding the motion control, the ideal solution would be having a propulsion system enabling 6DOF fine control (thrust vectoring and low minimum impulse bit), delivering deltaV higher than 30 m/s, and super agile to guarantee adequate responsiveness for CAMs (high thrust, and no/short warm-up). Cold-gas system is the preferred technology for this kind of applications. Warm gas systems would serve the application as option B, while hot gas technology is not suitable. Electric propulsion is another excellent option for CubeSats, but the very low thrust makes this technology not applicable for proximity operations. All relevant CubeSat missions flown so far feature cold-gas propulsion for rendezvous and docking, however no system is readily available on the market for supporting the inspection mission under study. A comparison of propulsion technology is given in Table 5, with highlights on criticalities with respect to the present mission.

Table 5: Overview of propulsion technology

Technology	Criticalities	Suitability
Cold Gas	None	Yes
Warm Gas Chemical (e.g. monoprop)	Hot and reactive exhaust Most systems have 1 DOF thrust (Typically) long preheating time	Limited Need to waive some requirements
Hot Gas Chemical (e.g. bipropellant)	Hot and reactive exhaust Most systems have 1 DOF thrust High MIB	No
Resistojets/Arcjets	Hot and reactive exhaust Most systems have 1 DOF thrust (Typically) long preheating time	Limited Need to waive some requirements

Radio Frequency Plasma Thrusters	Excessive power/thrust ratio	No
Hall Effect Thrusters	Hot and reactive exhaust	
Gridded Ion Thrusters	Highly ionized exhaust	
Pulsed Plasma Thrusters	Most systems have 1 DOF thrust	
FEEP Thrusters	Potential EMI issues	

3.5 Communication Architecture

The communication architecture depends on the availability of the link with other elements of the mission architecture, such as the lunar orbiting platform, the ground stations network, and, in future perspective, the lunar surface outpost (e.g. Moon Village). The small drones can communicate 1) only with the lunar orbiting platform, 2) with both lunar orbiting platform and Earth, and 3) with both lunar orbiting platform and the Moon outpost. Moreover, an interlink between the inspectors should be introduced if a distributed solution is adopted. In general, the main communication channel is with the lunar orbiting platform because of proximity, so that a strong radio-frequency link is available using relatively simple technology already available for CubeSats, and because the lunar orbiting platform is directly engaged in the CubeSat mission. Similarly, interlink between two CubeSats is easily closed thanks to the low relative distance (max 30 km) of constellation formation. Communications with the DSN is now based on specific CubeSat technology available for the direct communication Moon-Earth [32]. This link is generally closed thanks to the DSN performance so that the major issues are the DSN network availability and cost. The CubeSat communication with the Moon Outpost on the surface is strongly affected by the orbit and the desired link availability. In fact, due to LOP-G orbit, high slant ranges occur, provoking space attenuation up to 195 dB. Considering the limited resources on board, the link could be closed with high values of EIRP and S/N of the Moon Outpost. Considering a Moon station with the performance of a typical TDRSS station [33] in a S-band communication channel, uplink is closed along the entire orbit while the downlink is possible for a maximum slant range of 10000 km. Preliminary link budget for a UHF line (dedicated to housekeeping telemetry and telecommand), an S-band line (for images transmission) and an X-band line (for interplanetary communication) have been developed. Figure 7 shows the communication network and the link performance for one CubeSat, the same links are repeated for the second CubeSat for ConOps featuring distributed systems. Finally, new technology solutions based on laser-communication could be considered: in this case, high data rate would be obtained but a very high pointing of the antennae shall be guaranteed. For short slant ranges (i.e. lunar orbiting platform-CubeSat), laser communication is an interesting alternative to the traditional radio-links and might worth further investigation.

3.6 Autonomy

The autonomy of the mission is a crucial point for interplanetary missions. High autonomy should be achieved on mission operations plan, on activation of onboard hardware units and software tasks, on payload management, and on the management of contingencies [34]. The selection of the possible strategies for autonomy implementation depends on many factors, among which: 1) the link with ground and/or lunar surface outposts (if available and if included in the selected concept of operations), and with the lunar orbiting platform, and 2) the available onboard resources. The autonomous decision-making process can follow “traditional approaches” based on deterministic algorithms (“if-then-else” control chain) or “new approaches” based on artificial intelligence algorithms.

3.7 Other areas

Excellent technology is available to date for CubeSat platforms. Apart from the critical areas mentioned above, other key features of the LOP-G inspector will be:

- high computational capability is required for image processing, which must be likely supported by data fusion and AI algorithms. Implementing autonomy onboard is also extremely demanding in terms of computational resources
- state of the art power generation is necessary for supplying the adequate amount of electrical power to the satellite, driven by power consumption of imaging instruments and the communication system
- state of the art attitude determination and control for accurate and stable pointing of optical payload(s), high-gain antennae, and for precise manoeuvring execution.

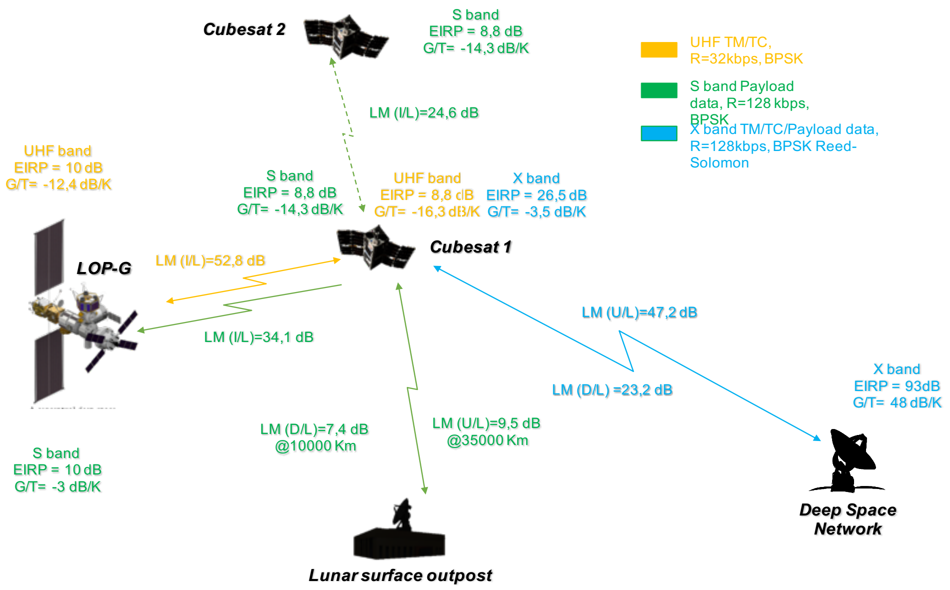

Figure 7: communication architecture

4 DISCUSSION AND CONCLUSIONS

The study developed a mission concept for an inspection mission of the future lunar orbiting platform, carried out by specialized small spacecraft acting as inspectors. The first iteration of the study has been presented in the paper, with preliminary results and the identification of drivers and critical areas of the mission. The functions required for a mission for the inspection of a lunar orbiting platform are not that different with respect to the same mission conducted in the vicinity of the ISS. However, substantial differences between the proposed concept and studies already performed exist and they are mainly related to the mission environment and operations.

4.1 Environment

- The environment plays a crucial role in relation to technology of the spacecraft (radiation effect) and in relation to trajectory and orbit control (gravitational effect and solar pressure). The radiation environment in cis-lunar space is comparable to deep space,.Development of adequate technology and effective verification processes will be required for future reliable missions of small spacecraft in deep space. As a consequence of the combined effect of the gravitational field and solar pressure, orbit dynamics is very different with respect to LEO. In particular, navigation and orbit control will require very accurate measurements and fine thrust control (small impulse bit). This aspect is magnified by the specific features of the inspection application due to proximity operations requirements and safety issues.

4.2 Operations

Operations are different with respect to LEO missions due first to the distance of the spacecraft to be operated. Operations of the inspection mission are also influenced by the operations of the main mission in terms of crew availability, cargo traffic plan, and in general they will depend on how the lunar orbiting platform will be used and operated. Another aspect is the deployment of the drones from the station, and in particular the time and location along the orbit at which the deployment occurs, as LOP-G will be in a highly eccentric NRHO. **4.3 Conclusions**

With this study, we tried to find answers to the question "how is it possible to deliver inspection functions needed to support operations of the future lunar orbiting station?". The answer to this question can be drawn from the mission statement: *deploying & operating low-cost/fast-delivery small drones in the vicinity of the cis-lunar human-tended station, to provide enhanced capabilities of inspection and surveillance of the station.* The rationale for this mission has been thoroughly discussed before going into the study of the mission concept.

The first result of the study is that providing inspection capability to LOP-G is useful for monitoring the external part of the station without the need of complex robotic activities or dangerous EVAs. The advantages of the solution based on inspectors increase gradually as the autonomy of the drones increases. In fact, fully autonomous drones might well serve the purpose of inspecting the station during the uninhabited periods, thus providing operators in the MCC a great tool for maintenance of the space asset.

The second result of the study is that the inspection of LOP-G with CubeSats is technically feasible, although not easy. The complexity of the mission is mainly determined by safety issues, which in turn define very stringent functional requirements for the system. Advanced technology is key to meet these requirements, at least in the areas of Guidance Navigation and Control (sensors and algorithms), propulsion system, and onboard autonomy. Other technologies that deserve development are deployment and retrieval mechanisms, and observation instruments. For all technology, improvements are needed for surviving the harsh radiation environment.
The third result is the proposition of a possible mission concept able to be adapted to several scenarios, for which main options and challenges have been discussed, leaving to future studies the choices for the final mission and system architectures. The present study has been carried out on the basis of reasonable assumptions which might or might not be correct, given the lack of information about the future LOP-G. For next iteration of the inspection mission design, a close interaction with the LOP-G study team is deemed necessary.
One additional consideration is that the key functions identified for the inspection mission of LOP-G are also important for many other applications such as debris inspection or spacecraft servicing. Thus, apart from the mission presented here, the development of capabilities in the areas addressed as mission-critical has the potential of enabling many other objectives to be accomplished.
The concept presented in the paper also enables possible extension of the mission, for pursuing secondary objectives as defined in the mission statement: *"to complement scientific, technological and outreach objectives related to the global exploration roadmap".* The choice of the 12U form factor leaves room for scientific experiments (e.g. radiation and biological payload [36]) or technology demonstration (e.g. COTS optics validation [37]). For the baseline concept, the execution of these tests is carried out at the end of the life of the CubeSat, before disposal. However, there are no particular obstacles to implementing some of these experiments during the nominal mission profile if required.
The last comment is related to the possible development plan for the mission. Considering the safety implications, and to mitigate the risk associated with the accomplishment of the inspection mission of LOP-G, it is possible to implement In Orbit Demonstration missions first at the ISS, and then in the Artemis II mission. Missions like Seeker demonstrated that this approach is affordable and effective.
The study presented in the paper will be carried on further as soon as the Lunar Orbiting Platform - Gateway concept matures.

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Appendix A

High-level requirements (Mission Requirements – MR, System Requirements - SR) and mission drivers (D)

ID	Requirement/Driver	Traceability
MR10	The mission shall operate in the cis-lunar space	Mission statement
MR11	The reference orbit of the cis-lunar station for the mission is a Near Rectilinear Halo Orbit (perilune radii: 3232.94 km; apolune radii: 65799.10 km; period: 6.66001 days; 9:2 synodic resonant orbit) (TBC)	LOP-G mission
MR20	The mission shall provide data for inspection and surveillance of the cis-lunar orbiting platform to ground operators and crew (when applicable)	OBJ1
MR21	The mission shall provide VIS images with spatial resolution in the image plane < 1 cm	MR20, STM
MR22	The mission shall provide VIS images with spatial resolution perpendicular to the image plane (depth) < 2 cm	MR20, STM
MR23	The mission shall provide NIR images with a spatial resolution < 10 cm	MR20, STM
MR24	The mission shall provide spectral images in the following band 0.20 μm – 14.00 μm	MR20, STM
MR25	The mission shall provide spectral images with a spectral resolution < 20 nm	MR20, STM
MR26	The mission shall provide data of the cis-lunar station every TBD days or upon request from ground during uninhabited periods	OBJ1
MR27	The mission shall provide data of the cis-lunar station upon request from crew or ground operators	OBJ1
MR28	The mission shall provide data of the cis-lunar station autonomously every TBD hour when inhabited	OBJ1
MR30	The mission shall provide a test bed for technology demonstration and science experiments	OBJ2
MR40	The mission shall provide data for outreach purposes (videos and/or images TBC)	OBJ3
MR50	The mission shall be compatible with launch by SLS, Falcon Heavy, New Glenn, and Ariane V launch vehicles	Assumption
MR60	The mission shall include #TBD specialised drones (small spacecraft) able to carry out proximity operations in the vicinity of the cis-lunar station	OBJ1
MR70	The mission shall comply with safety requirements imposed by the cis-lunar orbiting platform*	Safety
MR80	The mission shall be operated both from the cis-lunar orbiting platform and from ground	Safety
MR81	The spacecraft shall communicate with the cis-lunar orbiting platform	MR80
MR82	The spacecraft shall communicate with the ground control stations	MR80
MR100	The mission shall be compatible with different mission scenarios (number and characteristics TBD)	D30
MR101	The mission shall be compatible with different duration of the inspection phase, depending on the specific mission scenario. Maximum duration of the inspection phase is 20 days (TBC)	MR100, LOP-G operations
MR102	The mission shall be compatible with different duration of the scientific phase or tech demo phase, depending on the specific scenario	MR100
SR10	The spacecraft shall be delivered to the cis-lunar orbiting platform as cargo in transportation vehicles (Orion is assumed as reference vehicle – TBC)	MR10, assumption
SR11	The spacecraft shall be deployed from or in the vicinity of the cis-lunar orbiting platform through a proper facility	MR20
SR12	The spacecraft shall autonomously phase away out of the Keep Out Zone (KOZ) of the cis-lunar orbiting platform, at TBD km distance (the distance depends on the possibility to perform manoeuvres needed to acquire the desired relative holding position and to comply with safety requirements)	Safety
SR13	The spacecraft shall rendez-vous the station through a series of manoeuvres needed to acquire the desired position for starting the operational (observation) phase	MR20
SR14	The spacecraft shall maintain the desired relative position wrt the cis-lunar orbiting platform for the duration of the observations	MR20
SR15	The spacecraft shall implement the termination strategy according to the specific mission scenario: a) departure and phase away + passivation + disposal to lunar surface b) rendez-vous and mating + post mission analysis + refurbishment + storage	MR20
SR16	The spacecraft shall be able to perform Collision Avoidance Manoeuvres	Safety

D10	The mission shall mainly use low-cost technology, i.e. CubeSat technology and COTS	Mission statement
D20	The mission shall implement low-cost operations concepts	Mission statement
D21	Mission autonomy level shall be maximised	Mission statement
D30	The mission shall be flexible and shall adapt to evolving mission scenarios	Mission statement
*For the purpose of the present study, it is assumed that the ISS safety requirements apply MR: Mission requirement SR: System requirement D: driver		

Appendix B

Mission phases according to baseline ConOps (routine inspection), including contingency scenario.

Table 6: Mission Phases

#	Phase	Description
1	Launch and transfer to lunar orbiting station	The spacecraft is(are) launched and delivered to the lunar orbiting platform during either a cargo or a crew mission. The launch system can be the SLS (reference) or other launchers available or under development for the Artemis programme. Orion is assumed as reference vehicle. The system is switched off during this phase.
2	Storage	The spacecraft is(are) checked out at arrival, and then stored in the pressurised compartment of the lunar orbiting platform and maintained by the crew if needed. The system is switched off during this phase, apart for functional test at arrival (test mode of operations). Depending on the storage time, periodic checks and battery charging must be considered.
3	Run-up	The spacecraft is(are) prepared for the mission of interest, and this might require different processing depending on the specific mission. Replacing parts of the spacecraft is an option to be considered for the long-term scenario. Health checks are performed. The system is switched into the test mode of operations.
4	Deployment and Commissioning	The spacecraft is(are) deployed from the lunar orbiting platform. No details are available regarding the deployment facility of the future outpost, but it is assumed there will be at least one. The satellite is released with an initial velocity allowing for a naturally safe and slow free drift trajectory, in order to exit the Keep Out Zone - KOZ (size is TBD) of the station and acquires the desired holding position relative to the lunar orbiting platform. In case more than one satellite is needed for mission accomplishment, they are released in sequence. The system is totally switched off until reaching TBD m relative distance from the station, then activated for commissioning. During commissioning: the spacecraft nullifies its attitude rate relative to the station, thrusters and sensors are calibrated, checks are executed on all on-board systems. It is possible that two operative modes are necessary for complete commissioning (e.g. one for detumbling the satellite and another for calibration of instruments). The spacecraft free-fly up reaching a holding point in space. The duration of this phase depends on time needed for deployment & commissioning/calibration, and on orbital dynamics. The position of the holding point will be optimised considering safety and delta-V requirements as parameters. Apart from commissioning, the spacecraft is in the free-flight mode until entering the manoeuvre mode to stay in the hold point.
5	Rendezvous	Out-of-plane and in-plane manoeuvres are performed in order to rendezvous and acquire a safe point in proximity of the station. For the baseline mission, i.e. the routine inspection of the lunar orbiting platform, two options are considered: 5a) The spacecraft is/are put into a trajectory that allows to fly-around the station, or 5b) The spacecraft is/are put along the station Vbar (either forward or backward, or both) The system is either in the manoeuvre or in the free-flight operative mode.
6	Observations	The spacecraft performs a series of manoeuvres to maintain the desired trajectory, depending on the specific mission (i.e. different targets can be considered that require different trajectories, or different payload can be activated that require to stay at different distance from the target). All trajectories are passive safe. For the baseline mission two options are considered: 6a) The spacecraft flies around the station while scanning the surface from different points of view (Figure 8) 6b) The spacecraft flies the same orbit of the station and takes images of the station along Vbar (Figure 9) The system is in the observation operative mode.
Nominal scenario		
7A	Rendezvous and approach	The spacecraft performs a series of manoeuvres to follow a safe path towards the station. A collision avoidance strategy must be implemented to handle contingencies. However, passive safe trajectories are considered for the approach to the station. The approach depends on location of the airlock and on mating strategy. The system is in the manoeuvre operative mode.
8A	Mating and retrieval	The spacecraft makes final manoeuvres to mate with the station. Several mating strategies can be implemented, including berthing and docking, which depend on the lunar orbiting platform design and/or operations. Whatever the strategy, at the end of this phase the spacecraft is again in the station or attached at the station. The system is in the docking operative mode.
9A	Post-operations and storage	In case the spacecraft is retrieved inside the station, the crew accesses the system to download mission data, and to refurbish and check out the system before storing in the pressurized compartment.

		In case the spacecraft remains attached at the exterior of the station, automatic refurbishment operations must be designed and performed at the "docking station". The system is in the test operative mode then switched off.
Contingency scenario		
7B	Departure	The spacecraft performs a series of manoeuvres to phase away at a safe distance from the lunar orbiting platform and reach a desired position in space. The system is in the manoeuvre operative mode. Departure can be accomplished also without manoeuvring as the trajectories are passively safe, thus the spacecraft is in the free flight operative mode. Depending on the cause (and its criticality) that determined the departure from LOP-G, the spacecraft can enter one or more safe modes of operations.
8B	Experiments	(Optional) The spacecraft performs science and/or technology demonstration. The system is in the relevant operative mode (specific for each mission).
9B	Disposal	The spacecraft performs a series of end-of-life manoeuvres to change the orbit and land (crash) on the Moon. The system is in the manoeuvre operative mode. After the last manoeuvre is completed, the spacecraft is passivated and switched off.

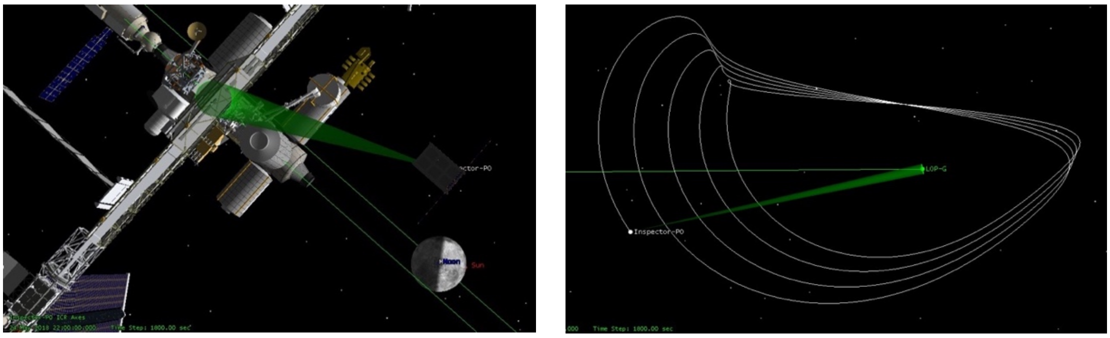

Figure 8: CubeSat Inspector fly-around the lunar orbiting platform

Figure 9: CubeSat Inspector along Vbar of lunar orbiting platform