Title: Lunar Orbit CubeSat Injector

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（ X ）**We apply for Student Prize.**

（ ）**Please keep our idea confidential if we are not selected as finalist/semi-finalist.**

Introduction

As a celestial object, the Moon serves as a location to respond the scientific demand and improving space applications [1]. It can help us to answer critical questions regarding science and exploration activities such as the long duration effects of the lunar environment on spacecraft, required mitigation techniques, plasma properties and lunar dust problems experienced by Apollo [2]. The proposed mission can prove the reliability of future multi-CubeSat missions to the Moon and other planetary bodies, and it will be the first nanosatellite to deliver several third-party CubeSats to the lunar orbit.

Need

Even though CubeSat technology have matured to support several kinds of missions, CubeSats are often developed without propulsion system for in-orbit maneuvers and hence are restricted to their initial insertion orbit. The Lunar Orbit CubeSat Injector (LOCI) is designed to overcome this incapacitation by inserting four 2U CubeSats into different orbits of operation. The mission target has been selected as the Moon for this project by the reasons mentioned shortly above. To insert CubeSats into the lunar orbit, a carrier nanosatellite idea is proposed to associate the following perspectives:

I. The opportunity to expand the capability of CubeSats for deep space missions

II. The promotion of interplanetary low-cost constellation missions through collaboration amongst various communities

III. Providing science return by the main satellite as the secondary mission

Mission Objectives

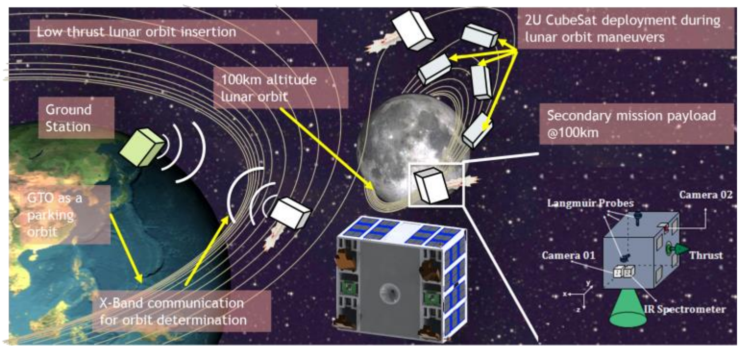

Figure 1. LOCI concept of operation.

- To deploy third-party four 2U-Cubesats into different orbits whose orbital ephemeris will be compatible with the nanosatellite lunar orbit insertion strategy
- To develop a nanosatellite structure capable to ensure the functional integrity of third-party four 2U-Cubesats
- To perform measurements of plasma density, temperature and potential throughout lunar orbit, density variation of submicron dust grains around 100 km altitude and the composition of lunar exosphere and surface

- To encourage collaboration with international organizations for the achievement of mission objectives towards lunar mission

Concept of Operations

Space segment consists on the nanosatellite LOCI which carries third party four 2U-CubeSats, and it will perform orbit transfer towards the Moon from an Earth parking orbit (GTO, Geostationary Transfer Orbit) (Figure 1). After its launch, orbit ephemeris will be received from a ground station network via X-band radio links, and low-thrust orbit transfer maneuvers will be performed by autonomous Attitude and Orbit Control System (AOCS) while visible from a ground station. In addition, on-board camera will provide the images of lunar approach. After the lunar capture, LOCI will deploy third party CubeSats according to their request while it approaches 100km altitude semi-polar circular orbit. Meanwhile, the on-board camera will provide visual evidences of the CubeSat deployments. After the main mission is complete, the following scientific measurements will be conducted as the secondary mission. First, lunar dust and plasma measurements will be performed to provide data to explain the relation between dust variance at 100 km [3] and ambient plasma properties throughout solar wind, bow shock, magnetosheath, magnetopause and geomagnetic tail by Langmuir probes, magnetometer and lunar optical scattering dust instrument. Second, lunar exosphere and surface composition measurements will be conducted with the IR spectrometer. During these measurements, z-axis of the LOCI must be pointed towards the lunar surface. While lunar final orbit, the telemetry data will be received by the ground station and sent to the user segment which consists on organizations who cooperate with the development of the mission and distribute the gathered information.

Key Performance Parameters

- Successful deployment of four 2U CubeSat into their requested orbit with a position accuracy of 10m, which is the error of navigation for orbit determination.
- The LOCI satellite is going to confirm the CubeSat deployment by sending images and telemetry of AOCS.
- The measurement of 3- axis magnetic field with 6.5 nT resolution and solar wind and magnetospheric plasma properties with home-made Langmuir probe.

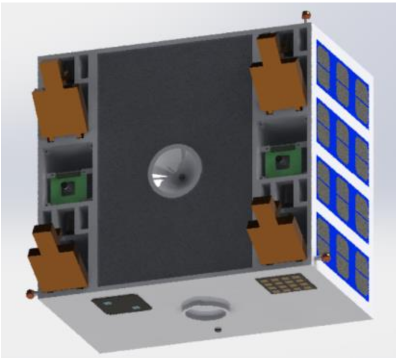

Figure 2. LOCI Structure

- The measurements of submicron dust grains (<1 μm) will be performed by a Lunar Optical Scattering Dust Instrument (LOSDI), an in-house developed instrument which includes a cleaning mechanism to extend its lifetime.
- Adaptive exposure capability to analyze lunar exosphere and surface composition with approximately 6nm spectral resolution

Space Segment Description

- Due to high levels of radiation present beyond GEO orbit [4], LOCI structure will provide radiation shielding to the CubeSats by using aluminum structure. It will also contain 4 PPOD for the deployment of 2U CubeSats which includes a release mechanism based on a pin-puller. In Figure 2, the CubeSats are arranged in such a way that the variation center of mass will not affect AOCS performance dramatically.

- The propulsion system will employ a RF BIT-3 ion thruster and iodine as the propellant. The thruster will operate at constant 1.4mN of thrust and a specific impulse of 3500 seconds. Iodine, which is a reactive chemical, requires a careful approach in selecting materials that it would make contact with. Although the propellant poses no handling risk, it will however be ensured that required launch leak standards are met. The wet to dry mass ratio of LOCI is expected to be about 1.07 [5].

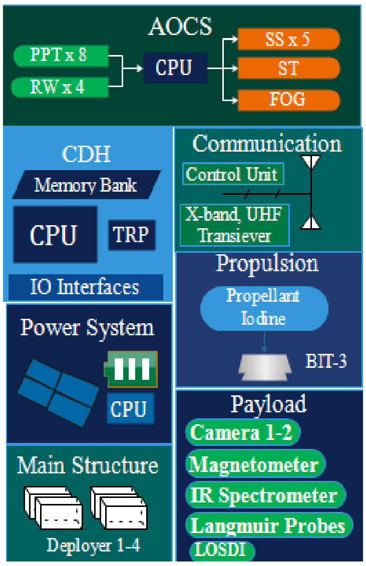

Figure 3. LOCI Block Diagram

- The communication system is a commercial off-the-shelf X-band transceiver. It has capabilities for ranging, two-way Doppler and to generate Delta-DOR tones for orbit determination purpose. Patch array Medium Gain Antenna (MGA), which requires pointing, is used as the main transmitter while another Low Gain Antenna (LGA) is used as a receiver and a backup for transmission [6]. Communication relay through LOCI to the Earth is possible if it is required by the third-party CubeSats as the transponder supports UHF Tx/Rx. For that, additional LGA will be added to support the communication.

Table 1. Mass and power budget

SUBSYSTEM	MASS [kg]	MAX POWER [W]
AOCS	6	60
Payload	1	9
Structure	10	0
Communications	1	25
Propulsion	3.5	70
Thermal	3	30
C&DH	1.5	15
MODES OF OPERATION AND CRITICAL SUBSYSTEMS		
Transfer orbit mode (AOCS, Thruster, Comm, Thermal, C&DH)		
Nominal Power [W]	60	
Maximum Power [W]	200	
CubeSat release mode (AOCS, Comm, Thermal, Camera, C&DH)		
Nominal Power [W]	80	
Maximum Power [W]	130	
Secondary mission (AOCS, Comm, Thermal, Payload, C&DH)		
Nominal Power [W]	70	
Maximum Power [W]	135	
Electrical Power System		
Battery Capacity [Wh]	360 @ 24V	
Solar cells power [W]	135	

- For payload system, CubeSat separation and lunar approach imaging will be performed by the on-board cameras. Next phase can be described as lunar dust and plasma measurements, which uses triple Langmuir probes, one magnetometer and the dust instrument. Lunar Optical Scattering Dust Instrument (LOSDI) and Langmuir probes are being developed in-house. In addition, Argus 1000 IR Spectrometer has been selected for lunar surface and exosphere composition measurements [7].

- AOCS has to be sufficiently accurate in order to insert the four 2U CubeSats in the requested orbit; hence a set of sensors and actuators based on 4 reaction wheels in tetrahedral configuration, 8 pulsed plasma thrusters, one star tracker, one 3-axis fiber optic gyroscope and 5 digital sun sensors will ensure 36 arcsec for pointing accuracy and 3.6 arcsec for pointing knowledge [8].

Table 2. Comms specification

Uplink	7.2 GHz
Downlink	8.4 GHz
Downlink Data rate	1k – 512kbps

- Thermal control is considered to be active by heaters which would be employed to further maintain strict temperature compliance of some components and modules. With the exception of the protruding components such as the scientific sensors, antennas and thrusters, the external surface of LOCI will be covered with low emissivity multi-layer insulation blanket.

- Electrical power system is based on 7 rechargeable lithium-ion batteries and body mounted triple-junction solar cells with 29.5% efficiency [9]. The size of batteries and solar arrays was made considering 30% deep of discharge and 3300 cm^2 effective area respectively. A power processing and control unit is considered to meet the high voltage requirements of BIT-3 ion thrusters.
- The Command and Data Handling (C&DH) subsystem consist on a single board computer Maxwell SCS750, radiation hardened and proven in space, whose architecture increase error-free processing tasks by Threat Response Processing (TRP) unit.

Orbit Description

The LOCI satellite will perform a low-thrust transfer consist on the next orbit maneuvers [10]. In Table 3, the required ΔV is indicated and the travel time was estimated according to LOCI's mass:

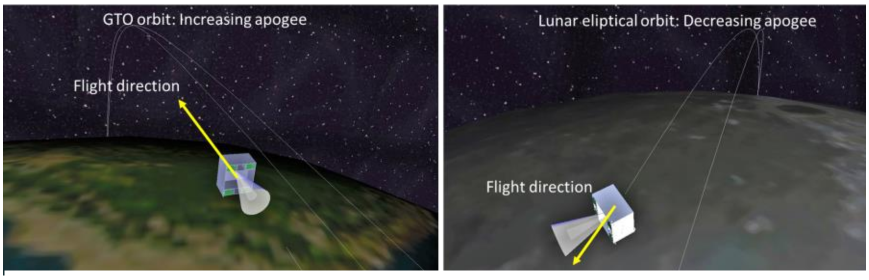

Figure 4. Simulation of LOCI orbit and illustration of transfer maneuvers.

- 1st series of thrust arcs near GTO perigee to increase the radius of apogee above GEO altitude (36,000 km)
- 2nd series of thrust arcs near apogee to raise the radius of GTO perigee and ensure lunar capture
- 3rd series of thrust arcs and spirals to stabilize the lunar orbit
- 4th series of thrust arcs and spirals to circularize and decrease the orbit radius until 100km altitude

During this phase, the CubeSats can be deployed to achieve different orbits according to the developer's requests. Once LOCI achieves its 100km lunar circular orbit, secondary mission operations will be performed.

Table 3. Estimated travel time for the lunar transfer orbit.

Segment	Δv(m/s)	Travel Time (days)
GTO's apogee augmentation	1157	390
GTO's perigee augmentation	150	49
Lunar capture	450	148
Circularization of lunar orbit	910	280
Total	**2667**	**867**

Implementation Plan

Kyutech would lead the development of the project from design, development of the engineering version of LOCI and testing the flight model. A prospective organization which possesses a ground station network would participate in this project by providing facilities for orbit determination tasks and telemetry gathering. At the beginning of the project, an announcement for lunar mission by using CubeSats would be open to possible customers which can contribute to the lunar mission by developing their own CubeSat (Figure 5), as well as license for frequency usage. The launch and lunar orbit allocation costs can be budgeted and made affordable

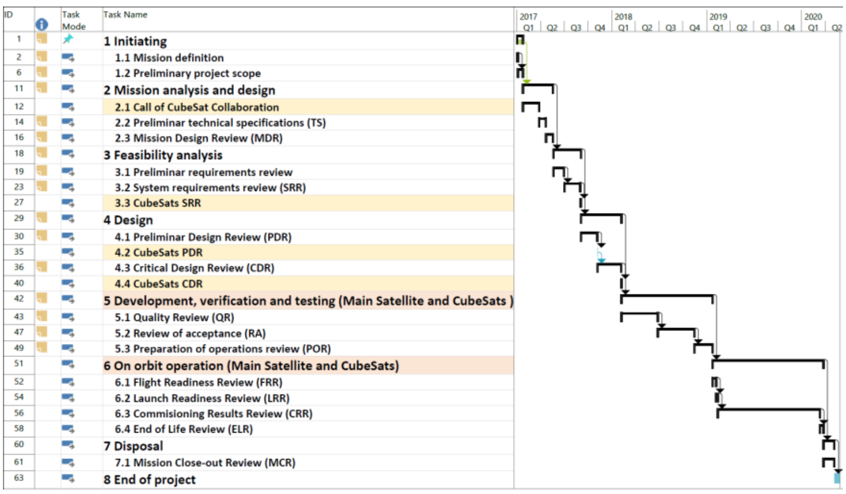

Figure 5. Gantt chart for LOCI mission development.

by comparing the average of a CubeSat launch to LEO orbit (40,000-200,000 US$). The economical retrieval would be received by the stakeholders to reduce development and launch costs. Thermal, mechanical, radiation and environment interaction tests as well as all calibrations can be performed in our facilities. Therefore, this will reduce the mission risk factor, cost and development time. Considering the development of one engineering model, one flight unit, testing, integration and launch expenses, the cost of development is approximately 11 million US$. To reduce technical project risks, mature technology will be used for the development of LOCI. it will be launched as a piggyback into GTO from where it will begin its maneuver to the Moon. For instance, considering the ARIANNE rocket for the launch, A.S.A.P 5 will be the adapter between the satellite and the launcher. Therefore, LOCI's mass and dimension will match with the adapter requirements [11]. Being a piggyback does not affect mission launch date. Therefore, subsystem designs consider launching to LEO to increase LOCI's launch opportunities. Hence, the propellant tank, power, structure, and communication subsystems have been designed to accommodate either of these initial orbit transfer cases. We plan to use available DSN in Japan. By doing that Kyutech can focus on compatibility issue of communication standard as well as frequency license application which Kyutech has experienced before for the current S-band ground station. Disposal procedures consider scheduled deorbit maneuvers for the main satellite to the Moon surface, while CubeSats deorbit time will be estimated by considering their initial orbital ephemeris and the lunar gravitational field influence [12].

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