RESEARCH ARTICLE OPEN ACCESS

Utilization of a 6U Nanosatellite for Lunar Sampling Mission

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Abstract:

The Moon has been one of the primary driving forces of mankind as it is the closest object to Earth. Naturally, it creates a lot of interest and many missions have been conducted before to study the Moon. Unfortunately, the cost of such missions has been prohibitive for more global engagement in lunar research. However, now with the advancing technology, it has become very evident to use nanosatellite technology to send a mission to the moon as launching and deploying a nanosatellite is far easier and less costly as compared to a full size satellite or a full size stellar probe. Thus, this paper discusses a case study of a Lunar Mission which utilizes a 6U Nanosatellite for a Lunar Sampling Mission.

Keywords **—Lunar Mission, 6U Nanosatellite, Lunar Sampling, Moon Mission, Cubesat to the Moon, Lunar Mission Fesability.**

I. INTRODUCTION

Planning and sending a mission to the moon is still the most popular space flight mission possible due to the proximity of the moon. The first moon mission started with the ill-fated Luna 1 of the Soviets which missed the target and ended up in an orbit around the sun. Luckily Luna II Mission was a success and while it crash landed on the moon, we were able to extract many important data from the mission.

Naturally many other missions were then subsequently planned by the Americans, Russians, Europeans, Chinese and Indians throughout history. Of course, perhaps the most productive missions to the moon were the Apollo Missions as they allowed mankind to travel to the moon and to extract lunar samples for further experimentation. In fact, even today, majority of our data related to the Moon comes from the Apollo Missions.

Furthermore, many missions were conducted as a follow up unmanned missions to the Moon by the Russians and the Americans that helped to advance the knowledge gained during the Apollo missions. Chinese were also very useful with the Chang-E missions which allowed a detailed mapping of the lunar surface and the lunar maria. The Indians with the famous ISRO mission named Chandrayan which found the traces of water on the moon. In fact the Chandrayan mission was a huge success as water is the most important resource for having a lunar outpost and thus this mission made future endeavors possible.

The biggest challenge with the moon missions is the cost of these missions. The reason for that comes from the fact that large amounts of payload are transferred to the moon and this requires a lot of fuel and large spacecraft that can send these objects to the Low Moon Orbit. The rockets used in the Apollo missions were longer than 100 meters in length and they were as large as a small Navy Destroyer. Obviously the cost would be prohibitive for sending these large missions to the moon unless you have a space agency behind these missions.

One way to overcome this challenge is to use Cubesat technology which has become very popular over the recent years. In fact, even high schools and universities are making Cubesats nowadays and as a result many experiments are being conducted which were not possible before due to the cost factors involved.

This paper discusses the possibility of using a Cubesat style mission to send to the moon to deploy some experiments. Basically, a 6U Nanosatellite is used in this particular Lunar Mission and the paper will outline the components that are part of this particular nanosatellite and the paper will also detail the scientific payloads that will be inserted into this Lunar Cubesat spacecraft. Naturally, the power requirements and the orbital mission parameters will also be briefly discussed to give an overall ideal of a Cubesat mission to the Moon. It can be seen that the mission would not be very costly and that it can be implemented easily from cost point of view with a consortium of universities. Basic orbital parameters of a 6U Cubesat mission is discussed along with the payloads that can be inserted into this mission for lunar sampling analysis.

II. COMPONENTS OF THE LUNAR CUBESAT

A. Mechanical Structure system

The Cubesat structure must be stiff and strong yet have a very low mass to satisfy the mass and launch vehicle requirements. A 6U Cubesat frame with a mass constraint of 12Kg maximum will be a favorable design for lunar mission as it offers sufficient volume for attitude control, power and propulsion system. The simple truss frame for the skeleton will be fabricated using Aluminum Lithium alloy due to its high strength, low cost, rigidity and increased toughness at cryogenic temperatures. The exterior panels can be fabricated with the help of carbon-carbon composites (that can sustain high temperatures).

Fig. 1. Skeleton of Cubesat

B. Propulsion system

Orbital maneuvering is the next challenge in the development of Cubesat. Propulsion capability is crucial in increasingmission capabilities and it is very important to have an efficient and light weight propulsion system for our lunar probe that can produce required thrust and ΔV.

In an Ion thruster as shown in the figure below the electrons enter through the discharge cathode and combine with the green colored propellant atoms to form positive charge carrying atoms and two electrons. These electrons move towards the anode and the positively charged atoms move from the positive to the negative acceleration grid.

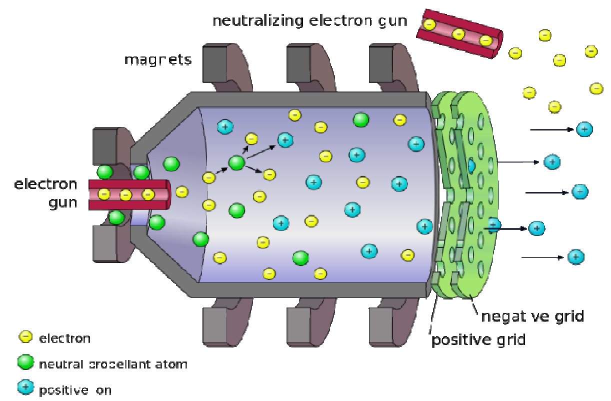


Fig. 2. Ion Propulsion Diagram

Busek's BIT-3 RF ion thruster is a mission enabling, iodine-fueled ion propulsion system scheduled for launch on two deep-space Cubesat missions aboard NASA's Space Launch System rocket in 2019. The BIT-3 uses an inductively-coupled plasma (ICP) discharge to eliminate the need for an internal hot cathode and increase overall lifetime. The most unique feature of BIT-3 is its compatibility with iodine propellant, a demonstrated drop-in replacement for xenon in terms of thrust and Isp performance. Iodine stores as a dense solid (>2x storage density than xenon) and eliminates the need for high pressure tanks. Also Gimbal can be used for primary propulsion and attitude control.

TABLE 1
SPECIFICATIONS OF ION THRUSTERS

Propellant	Iodine
Size	180X88X102mm
Wet mass	3Kg (1.5 kg propellant)
System power	56-80W
Input Voltage	28 V DC
Ion beam current	9-18mA
Propellant mass flow	48µg/sec
ΔV	Up to 2.9Km/sec (14Kg Cubesat)
Specific Impulse	1400-2640

C.Attitude determination and control system (ADCS)

The Attitude Determination and control system of a satellite is a critical subsystem that is aimed at stabilizing and orienting the satellite towards the required direction. ADCS & GNC (Guidance, navigation, and control) is based on a 3-wheel Reaction Wheels Assembly (RWA), star tracker, sun senor and IMU.

The gimbaled primary thrusters is used to provide trajectory and orbit maneuvers during delta V operations. During Sun Acquisition Mode, initially at deployment for power positive control we will use RWA and sun sensors and during science data taking and cruise operations we will use RWA, startrackers, and IMU to provide inertial, sun, and nadir attitude control as well as slew maneuvers.

Sensors for attitude adjustment:

- Star Tracker: It consists of cameras looking in different directions for different star patterns. And an onboard computer compares camera images with stored star catalog to determine which way the s/c is oriented. It needs to be designed with minimized dimensions, low mass, and low power consumption. We require a star tracker that can be used for highly accurate attitude determination, even at high slew rates.

- Sun Sensor: It measures angle between "sun line" and a reference axis in the s/c and an onboard computer uses this angle to help determine overall orientation of s/c.

Nano- SSOC – A60 analog sun sensor

Sun Sensor on a Chip (SSOC) is a two-axes and low cost sun sensor for high accurate sun-tracking, pointing and attitude determination. The device measures the incident angle of a sun ray in two orthogonal axes, providing a high sensitivity based on the geometrical dimensions of the design. NanoSSOC-A60 has minimum size, weight and power consumption.

TABLE 2
SPECIFICATIONS OF SUN SENSOR

Dimensions	27.4X14X5.9mm
Mass	4gms
Current	< 2mA
Voltage	3.3, 5 V

D. Power management and distribution system

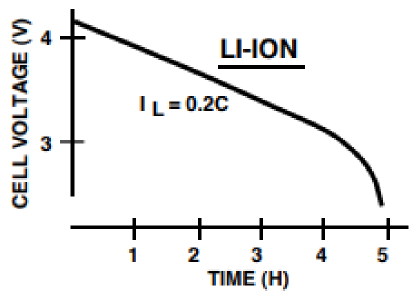
Power management and distribution system (PMAD)
It is an integral part of Power system design which is used to interface the solar panels with the battery pack. All the electronic devices with in the Cubesat requires different voltages to operate and PMAD will handle it by controlling and monitoring batteries, degradation of solar arrays, and switching off the load distribution system.
Fundamental criteria that must be met for proper power system design for satellites includes Reliability (most important criteria), Low Weight/Volume, High Power Density, Lower Costs, Compatible with the mission/payload of the satellite, Safety and easy serviceability. The solar panels will act as the primary power system and a Lithium Ion battery pack as the secondary power system.

- Solar panels:
  A solar array is an assembly of thousands of solar cells connected in way to provide appropriate power levels as needed for the particular operation of the satellite. Deployable GaAs solar panels will be used for the power generation for payload and ADCS. Some properties of solar panels are:
  1. Side panel is made up of FR4-Tg180 and Deployable panels of Titanium CP2 99.8% pure, 0.25mm thick.
  2. Supply Voltage: 19.2V top side to 14.4V bottom side and 2A at the rate of 20V Schottky diodes integrated

3. Power Delivered: 1U High power AzurSpace 3G-30: 7.2 W minimum
4. Mass: 107g
5. Thickness: 6.5mm (Folded configuration) 1.5mm (deployable configuration)
6. Cell Efficiency: 30% (High power) or 19%Release in 19 seconds using 152 jouleanddeploys in 10 seconds using 52 joules

We are planning to use 3-panel array which deploys as pannels with 16.8W each.

- Batteries
  The main Selection criteria for batteries include Charge / Discharge rate (cycles), depth of discharge (percentage of the battery capacity discharged during the eclipse), extent of overcharging, thermal Sensitivity and temperature. Miniaturized Lithium Ion (Li-Ion) cells are used for high-power batteries in space for Cubesat. It is low cost, safer and able to adapt interface and mechanical form factor.
  A high capacity rechargeable Li-Ion battery will be feasible for our mission and solar panels mentioned above will be used to recharge the battery which will fulfill the power requirements of every subsystem of Lunar Probe. Multiple batteries can be connected in parallel to enhance our power requirements.The capacity of each battery pack will be roughly around 10400 mAh.



.Fig. 3. Battery discharge curve

E. Communication System

The communication system is composed of antenna subsystem and transponders.

- Transponders: It is a wireless communication device which receivers and transmits radio signals at a specific frequency range.
- Antenna subsystem: Deployable combined Dipole antenna system. The ISIS hybrid deployable antenna system contains up to four tape spring antennas of up to 55 cm length.

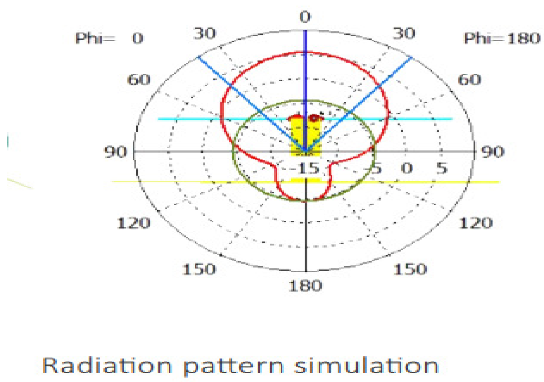


Fig. 4. Radiation Pattern of Antenna

TABLE 3
SPECIFICATIONS OF ANTENNA

Mass	77-85gms
Antenna length	UHF : 17cm avg VHF : 55cm avg
Power consumption	Nominal : <40mW During Deployment: <2W
Interfaces	I2C
Temperature Range	-20°C to +60°C
Operating Voltage	3.3V or 5V

F. Command and data handling system

The Command and Data Handling system is the processing unit of the orbiter and controls all spacecraft functions.
Command and data handling will be controlled by a cube computer which is a general purpose on-board computer for Cubesat. It will be built around an ARM 32-bit Cortex-M3 MCU which delivers high performance at very low power. It is fully compatible with the Cubesat standard and can be integrated with a wide variety of other components. It is also radiation tolerant.

TABLE 4
SPECIFICATIONS OF CUBE COMPUTER

Operating Voltage	3.3V
Power consumption	< 200mW
I2C Bus voltage	3.3V/5V
Operating Temperature	-10°C to 70°C
Mass	50g-70g
Dimensions:	90X96X10mm

G. Thermal control system

The need for this control system arises due to the thermal unbalancing of Cubesat because of the direct sunlight, excessive heating up of onboard components, infrared energy emitted from earth and sunlight reflected off earth and also temperatures due to the eclipses. The thermal control system consists of two types of system active and passive. The passive one is lighter and less costly. Therefore, the thermal control system of CubeSat is managed by using a passive control system.

Thermal Control Coatings such as white/black, or gold or silver foil, have special radiation properties which govern heat transfer through applied surface. It is desirable to have a highly emissive and minimally absorbing surface to reject as much heat into space as possible without collecting much.
It also consists of multi layered insulation, thermal switches and high conductance cold plate.

III. PAYLOADS

Naturally, besides the subsystems of the spacecraft mentioned above, we also need to mention the scientific payloads that will be included in the mission to make the necessary experiments, observations and data collection. Of course, the number of payloads is selected based upon their size and their power consumption as we are limited by the amount of mass that we can put in the spacecraft and also by the power requirements. The power systems of a Cubesat would have limited power, so the scientific payloads have been chosen keeping this factor in mind.

A. Inertial measurement unit (IMU):

An IMU is an electronic device that measures and reports a body's specific force, angular rate and sometimes the magnetic field surrounding the body using a combination of accelerometers and gyroscopes and sometimes also magnetometer.

B. Camera: SCS Gecko Imager

The Gecko imager is an easy-to-integrate imaging solution for your CubeSat mission. RGB images are captured at up to 5 frames per second. Data may be streamed out to an on-board computer and downlinked a lower data rate, as required.

TABLE 5
SPECIFICATIONS OF CAMERA

Dimensions	97X96X60mm
Mass	<480gms
Radiation Tolerance	30Krad
Interface	SPI and I2C
Storage	120 Giga bites
Resolution and frame rate	2.2Megapixel and 5fps (frames per second)

C. Cosmic Ray Detector:

WBG LET Detector will be used to provide multidirectional, comprehensive (composition, velocity, and direction) in-situ measurements of heavy ions in space plasma environments. These are silicon-based PIN diodes or lithium drifted silicon wafers (Si (Li)) with high bias voltage and thermally sensitive detectors. Also these type of detectors made of SiC have much better resistance to radiation damage from energetic charged particles that can form defects in the semiconductor. The wide band gap nature of SiC also makes measurements by the detectors unaffected by thermal drift due to sun/shade transitions. Current and voltage requirement for the SiC detector will 50mA and 35V respectively. The specifications for the detector proposed above has been listed below:

TABLE 6
SPECIFICATIONS OF COSMIC RAY DETECTOR

Active area	3.7 mm²
Dose rate, max	1.27 Gy(SiC)/s (127 rad(SiC)/s)
Dose sensitivity	1.27 mGy(SiC)/pulse (127 mrad(SiC)/pulse)
DAC	Charge integration, 4-Channel input, 1 kHz TTL output
Supply voltage, max	35 V
Supply current, max	50 mA
Weight	8 g single-channel, 30 g max
Size	4 by 3 by 2 cm

D. Infrared Spectrometer:

Argus 1000 infrared spectrometer will be used for the detection of energy that would be invisible to human eyes and to collect data about it. It can also be used for Real-time radiation monitoring. The spectrometer operates in the near infrared band 1000 nm to 1700 nm (or up to 2400 nm in the extended rand version). The device uses an InGaAs detectorarray of approximately 100 illuminated elements that is actively cooled.

TABLE 7
SPECIFICATIONS OF INFRARED SPECTROMETER

Mass	Less than 230 g
Dimensions	45 mm x 50 mm x 80 mm
Input Voltage	3.6-4.2 V
Current	350mA
Operating Temperature	-20°C to +40°C
Material	InGaAs

IV. ORBITAL MISSION.

The type of indirect trajectory that is planned for this mission is toutilize a similar orbital trajectory such as the one used by ESA- SMART 1 mission. The probe will be first put into a geostationary transfer orbit and then it elongates its earth ellipse orbit. The energy of the Geosynchronous Transfer Orbit (GTO) is much higher than the energy of a LEO orbit. This results in significant fuel savings that translate into major cost reduction.

However, it requires modern optimization techniques to minimize the fuel usage, while at the same time satisfying trajectory constraints. GMAT (General Mission Analysis Tool) is an open source platform that is designed to model, optimize and estimate spacecraft trajectories in flight regimes ranging from Low Earth orbit to Lunar applications, interplanetary trajectories and other deep space missions.

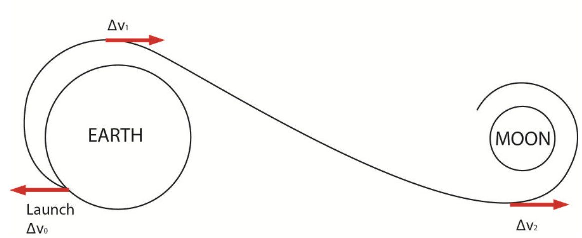


Fig. 5. Hohmann Trajectory to Moon

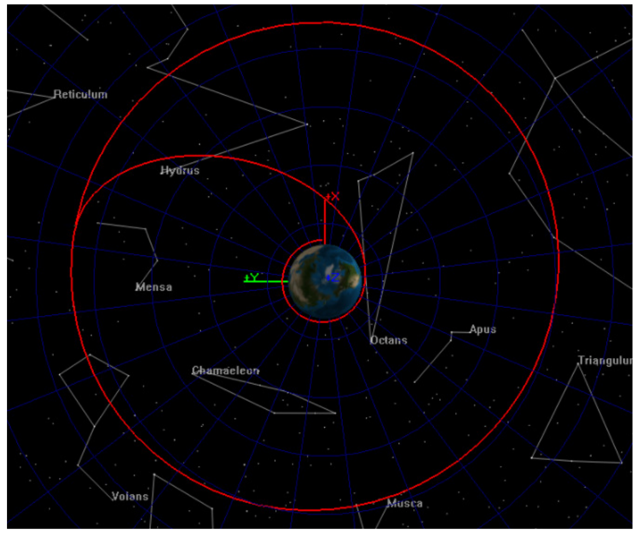


Fig. 6. GMAT Trajectory to Geosynchronous orbit

The above GMAT trajectory plot shows a Hohmann transfer orbit from a low earth parking orbit to a geosynchronous orbit to send the CubeSat to moon. It would be relatively a low cost endeavor to launch the Cubesat to a appropriate Earth orbit and a basic Hohmann transfer can be used to create a trajectory to the Moon. Unlike a regular single burn transfer, this will cause savings in energy and the Cubesat probe can utilize momentum wheels to create circular revolution which can be translated into linear momentum energy which would reduce propulsion requirements.

V. MISSION OUTCOME

This mission will be able to demonstrate a plethora of possibilities. It would initially make lunar missions and lunar research become economically feasible by the utilization of CubeSat technology which is less costly to launch and operate. Thus, it would become a reality for universities, research centres and even non-profitorganizations and companies to participate in lunar research. Hence, it would pave the way for academic alliances between smaller organizations where lunar research can easily become a global reality for the benefit of all mankind.
Of course, such a mission would also have some immediate mission outcomes such as preliminary analysis of magnetic properties of the moon and the lunar dust, some fundamental remote sensing observations and other scientific data would be collected. However, the main outcome would be the fact that it would demonstrate the possibility of a low cost Lunar Mission using Cubesats.

ACKNOWLEDGMENT

We thank UPES and CSSTEAP for their support for this research.

REFERENCES

[1]. Garrick-Bethel, I., et al. "*Lunar Impactor-Lunar Science with a Versatile Cubesat Platform.*" (2014).

[2]. Freeman, Anthony, and Charles Norton. "*Exploring our solar system with cubesats and nanosats*." (2015).

[3]. Lee, Jeong-Ah, et al. "Mission Orbit Design of CubeSat Impactor Measuring Lunar Local Magnetic Field." *Journal of Astronomy and Space Sciences* 34.2 (2017): 127-138.

[4]. Tsay, Michael, et al. "*LunarCube: A Deep Space 6U CubeSat with Mission Enabling Ion Propulsion Technology*." (2015).

[5]. Tsay, Michael, et al. "Maturation of Iodine Fueled BIT-3 RF Ion Thruster and RF Neutralizer." *52nd AIAA/SAE/ASEE Joint Propulsion Conference*. 2016.

[6]. http://www.aerospacelectures.com/

[7]. http://www.cubesatshop.com/

[8]."*Design and analysis of thermal control system for a nanosatellite"*https://www.researchgate.net/publication/267593033

[9]. *"The cubesat book"* - princeton satellite systems

[10]. ActaAstronautica- *Miniature attitude control systems for nano satellites* www.elsevier.com

[11]. http://www.isispace.nl/

[12]. Wrbanek, John D., and Susan Y. Wrbanek. "*Multidirectional Cosmic Ray Ion Detector for Deep Space CubeSats.*" (2016).

[13]. Simulating an orbit by GMAT software http://gmat.sourceforge.net/doc/R2014a/html/SimulatingAnOrbit.html

[14]. Radio occultation measurements of the lunar ionosphere http://sait.oat.ts.astro.it/MSAIS/12/PDF/53.pdf

[15]. ActaAstronautica- *A survey and assessment of the capabilities of Cubesats for Earth observation*.