UTILIZING THE DEEP SPACE GATEWAY AS A PLATFORM FOR DEPLOYING CUBESATS INTO LUNAR ORBIT. Fisher, Kenton R.[1]; NASA Johnson Space Center 2101 E NASA Pkwy, Houston TX 77508. Kenton.r.fisher@nasa.gov

Introduction: The capability to deploy CubeSats from the Deep Space Gateway (DSG) may significantly increase access to the Moon for lower-cost science missions. CubeSats are beginning to demonstrate high science return for reduced cost. The DSG could utilize an existing ISS deployment method, assuming certain capabilities that are present at the ISS are also available at the DSG.

Science and Technology Applications: There are many interesting potential applications for lunar CubeSat missions. A constellation of CubeSats could provide a lunar GPS system for support of surface exploration missions. CubeSats could be used to provide communications relays for missions to the lunar far side. Potential science applications include using a CubeSat to produce mapping of the magnetic fields of lunar swirls or to further map lunar surface volatiles.

International Space Station CubeSats: The International Space Station (ISS) has been a major platform for deploying CubeSats in recent years. A commercial organization supporting the ISS, Nanoracks, has been providing checkout and deployment services since 2011 [4]. CubeSats are brought to the ISS on cargo missions as a small subset of the total payload, allowing for significantly reduced launch costs for each CubeSat experiment. CubeSats deployed from the ISS enter a low-Earth orbit (LEO) with an orbital life of 8-to-12 months and, to date, do not have propulsion systems [4].

ISS CubeSat Deployment: The International Space Station has a well-documented process with a high-technology readiness level (TRL) system for deploying CubeSats that could be leveraged for the DSG. CubeSats are packaged and loaded as internal payloads on cargo re-supply missions to the ISS. After being unpacked from the pressurized capsule, each CubeSat is loaded into a Nanoracks CubeSat Deployer (NRCSD) by the astronaut crew. The NRCSD is then loaded into the Japanese Experiment Module (JEM) airlock and grappled by the Japanese Remote Manipulator System (JRMS). The JRMS then positions the NRCSD to deploy the CubeSats. Each NRCSD can deploy up to 6U of CubeSats and each JEM airlock cycle holds 8 NRCSDs which allows for a total of 48U deployment capability [4]. See Figure 1 for an image of an NRCSD being positioned by the JRMS.

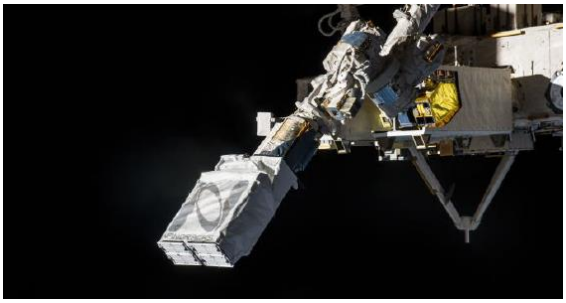

Figure 1: Nanoracks CubeSat Deployer (NRCSD) being positioned by the Japanese Remote Manipulator System (JRMS) for deployment on ISS [4].

Present Lunar CubeSat Architecture: While there are many opportunities for deploying CubeSats into Earth orbits, the current options for deployment to lunar orbits are limited. Propulsive requirements for trans-lunar injection (TLI) from Earth-orbit and lunar orbital insertion (LOI) significantly increase the cost, mass, and complexity of a CubeSat while also reducing the size of potential science payloads. Various propulsion systems have been in development for CubeSats but few have been tested and demonstrated on a lunar transfer. In 2015, NASA initiated the Cube Quest Challenge which resulted in thirteen CubeSats being chosen for launch as secondary payloads on the SLS Exploration Mission 1 (EM-1) [2]. These CubeSats will be put on a cis-lunar trajectory and will need to utilize their on-board propulsion capabilities to transfer into their final science orbits.

Building a CubeSat that can perform a TLI and LOI requires a propulsion system that can meet significant delta-*v* requirements (ranging from ~1300 m/s for weak stability boundary transfers and up to ~4000 m/s for direct transfers) [1]. Chemical engines that can produce this delta-*v* require large (relative to CubeSat dimensions) propellant tanks which reduce the volume and mass that can be utilized by the science payload. Low-thrust engines are being developed that can fit within some 3U and larger CubeSat designs while providing the delta-*v* required to reach lunar orbit, however the alternative use of a low-thrust engine significantly increases the transfer time. The Lunar Icecube mission, one of the EM-1 secondary CubeSats, will utilize an ion-propulsion system which will require a ~247 day transfer to reach lunar capture [3].

Deep Space Gateway Capabilities: A CubeSat deployment system, such as the one used on the ISS, could be implemented at the DSG. The key capabilities for the system would be:

- Robotic arm of similar capability to the JRMS
- Airlock of similar volume to the JEM airlock
- Minimal crew time to load NRCSD and load/unload from airlock.

Assuming these capabilities are available, a deployer would be simple to integrate within a wide range of potential DSG architectures.

Access to Science Orbits from Deep Space Gateway: Near-rectilinear halo orbits (NRHO) are currently being proposed for the Deep Space Gateway [5] and are shown in Figure 2. The NRHOs being considered are highly eccentric with perilunes below 6000 km, apolunes above 70000 km, and orbital periods of 8 days or less [5].

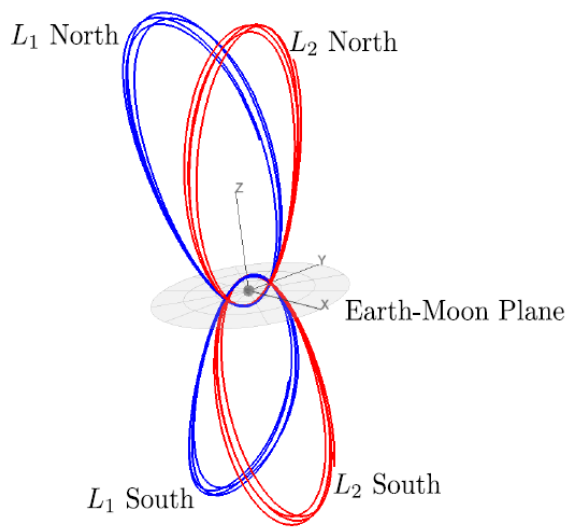

Figure 2: Sample NRHOs with r_p = 4500 km. Figure from Whitley et al [6].

These orbits are not desirable for most CubeSat missions and therefore introduces the need for on-board propulsion. The delta-*v* needed to access various lunar polar orbits from a sample polar near-rectilinear halo orbit is shown in Table 1. Access to low lunar orbits (LLO) and elliptical lunar orbits (ELO) from an NRHO requires significantly less delta-*v* than required for TLI.

CubeSat Thruster Systems: Various thruster systems for CubeSats are in development. Many of these propulsions systems are being designed to fit in a 1U volume to be easily integrated within any CubeSat design. A few of the numerous propulsion systems in development include radio-frequency ion, pulsed plasma, and green monopropellant thrusters. As these systems improve, the potential applications for CubeSats within planetary science missions will increase significantly.

Sample DSG Orbit	
Perilune	2000 km
Apolune	75000 km
Period	8.4 days
Inclination	Polar
Transfer to ELO	
Perilune	110 km
Apolune	310 km
Inclination	Polar
Delta-*v*	~630 m/s
Transfer to LLO	
Radius	100 km
Inclination	Polar
Delta-*v*	~670 m/s

Table 1: Delta-v estimates for transfers from sample NRHO to polar ELO and LLO. No inclination change included in this example. Sample DSG orbit from [5].

Conclusion: The Deep Space Gateway could serve as an important platform for deploying CubeSat missions to the Moon. The DSG would be leveraging existing technologies developed for the ISS to provide deployment services. The required DSG capabilities (robotic arm, airlocks) are common across the many proposed DSG architectures.

References

[1]Biesbroek, R. and Janin, G. Ways to the Moon? (2000), *ESA Bulletin 103*.

[2]Cockrell, Jim. CubeQuest Challenge. (2016) *AIAA/USU Small Sat Conference*.

[3]Folta, David. Et al. The Lunar Icecube Design: Construction of feasible transfer trajectories with a constrained departure. (2016), *AAS, 16-285*.

[4]Pournelle, Rich. And Johnson, Mike. Nanoracks Cubesat Deployment Services. (2014) *AIAA/USU Small Sat Conference*.

[5]Whitley, Ryan. And Martinez, Roland. Options for Staging Orbits in Cis-Lunar Space (2016), *Aerospace Conference IEEE*.

[6]Williams, Jacob. Et al. Targeting Cislunar Near Rectilinear Halo Orbits for Human Space Exploration. (2017), *AAS, 17-267*.