Lunar COTS Concept: A Public/Private Partnerships Approach for Lunar Resource Prospecting, Extraction and Infrastructure Development.

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Introduction: A new concept study was initiated to gradually develop an economical and sustainable lunar infrastructure to facilitate lunar resource prospecting and extraction. A public-private partnership approach was recommended to be used in the approach to share development cost and risk for mutual benefit. This approach would establish partnership agreements between NASA and industry teams to develop cislunar and surface capabilities, such as, lunar cargo transportation, power stations, communication relay satellites, and autonomous rover operations for resource prospecting and extraction.

The public/private partnerships approach for this study leverages best practices from NASA's Commercial Orbital Transportation Services (COTS) [1] program which introduced a new affordable and economical approach for partnering with industry to develop commercial cargo services to the International Space Station (ISS). In this approach, NASA and industry share cost and risk in the development phase and then transfer operation of ISS cargo transportation services in the execution phase.

Following this strategy, the COTS program was planned together with the ISS Commercial Resupply Services (CRS) contracts which was responsible for initiating commercial cargo delivery services to the ISS for the first time. As a result of the COTS and CRS programs, two new launch vehicles and spacecraft were developed and have been successfully servicing the ISS program since 2012: 1)SpaceX's Falcon 9 launch vehicle and Dragon spacecraft; and 2)Orbital's Antares launch vehicle and Cygnus spacecraft. Recent studies showed that the NASA COTS funding investments provided less than one half of the development cost for these two commercial transportation systems (47% government funding for SpaceX and 42% government funding for Orbital as noted in Reference 1). Also, it has been estimated that the final development cost for SpaceX's Falcon 9 launch vehicle was about \$400M which was approximately 10 times less than projected costs for an equivalent launch vehicle using traditional cost-plus contracting methods. The COTS program not only was successful in dramatically reducing development costs but was also very successful in substantially reducing operational costs for these ISS cargo transportation services due to this innovative and economical public-private partnerships approach.

Similar to the NASA COTS program, the goals of this current study, named Lunar COTS (Commercial Operations and Transport Services), are proposed to: 1) demonstrate commercial and affordable cislunar and surface capabilities and services; 2) encourage creation of new space markets to share cost and risk with industry; and 3) enable development of a sustainable and economical lunar infrastructure to support lunar resource prospecting and extraction. A phased-development approach is also recommended to allow for incremental development and demonstration of capabilities needed for lunar resource use and development.

As noted in several references, there are a wide variety of lunar resources in the lunar regolith that can be useful to NASA's long-term human exploration missions to Moon, Mars and beyond. One major example is water-ice concentrations in the permanently shadowed regions of the lunar poles. Several remote-sensing, lunar missions in the last two decades including DOD's and NASA's Clementine mission launched in 1994; NASA's Lunar Prospector mission launched in 1998; NASA's Lunar Reconnaissance Orbiter (LRO) [2] launched in 2009 and NASA's Lunar Crater Observation and Sensing Satellite (LCROSS) [3] mission launched in 2009 have all indicated the presence of water-ice deposits at the lunar poles. Although these data are strong indications that the presence of water-ice is abundant at the poles, ground truth data is needed to validate these results and determine the composition, distribution, depth and accessibility of these areas with high concentrations of lunar ice.

Several studies have also examined the In-Situ Resource Utilization (ISRU) processes and facilities necessary to extract and convert the lunar water into LO2 and LH2 propellants. These studies have also provided cost estimates for putting the infrastructure in place for creating the propellant and then delivering it to a cislunar propellant depot for use in a future Mars architecture. Although these studies have provided an excellent strategy and approach for creating propellant on the lunar surface, ground truth data from the Moon is needed for a more refined cost estimate of the exact methods, tools and machinery that will be needed to extract the lunar ice and create the propellant. It is also best to obtain this ground truth data and develop extraction techniques in partnership with industry to share cost and risk as well as leverage on industry's capabilities and innovativeness in a competitive environment employing the COTS acquisition model.

A lunar infrastructure development strategy was introduced by Zuniga et al [4]. The primary goal of this development was to extend the life, functionality and distance traveled of surface mobility missions and to reduce cost, complexity, mass and volume of all surface missions. Presently, surface mobility or rover missions are heavily constrained by power demands, battery life, direct line-of-sight communications with Earth, extreme thermal conditions, traverse distances, landing conditions and 14 lunar day/night cycles. To date, there have not been any U.S. surface mobility mission that has survived a full 14 lunar day/night cycle primarily due to the extreme cold temperatures that exist during the 14-day lunar night (approximately as low as -250C). Therefore, the mission life of lunar surface missions is typically limited to less than 14 lunar days. The traverse distances are also severely limited primarily due to batteries not surviving the extreme cold temperatures in dark craters and throughout the 14-day lunar night.

A lunar infrastructure system with power, communication and navigation elements as well as autonomous rovers was conceptually designed and described in [4] and shown in figures 1 and 2. This system was designed to have the capability to extend mission life to several years by providing power generation, storage, recharge and thermal control functions to the autonomous rovers and other payloads. In addition the communication tower, as shown in figure 2, will be able to increase communication links to the rover systems and not be limited to direct-line-of-sight to Earth communications. The local navigation aids located on the top of the communication tower will also aid the rover systems to navigate in dark areas, such as craters, where visibility is limited. A mobile infrastructure system will also have the added capability to extend the traverse distances of the mission to hundreds of kilometers. Therefore, this new infrastructure system together with autonomous rovers have the potential to provide valuable and extensive lunar prospecting data over several years and cover numerous lunar sites over hundreds of kilometers. By partnering with industry to develop and own the infrastructure services using the COTS model, this plan will also result in significant cost savings and increased reliability and mission probability of success.

This presentation will describe the Lunar COTS concept goals, objectives and approach for developing an economical and sustainable lunar infrastructure as well as a plan for lunar prospecting and testing of new extraction techniques. It will also describe the technical challenges and advantages of each infrastructure element towards supporting future lunar resource prospecting and extraction techniques of various minerals and elements. Finally, the presentation will also look forward to the potential of a robust lunar commercial economy supporting resource use and development and its potential effect on the next 50 years of space exploration.

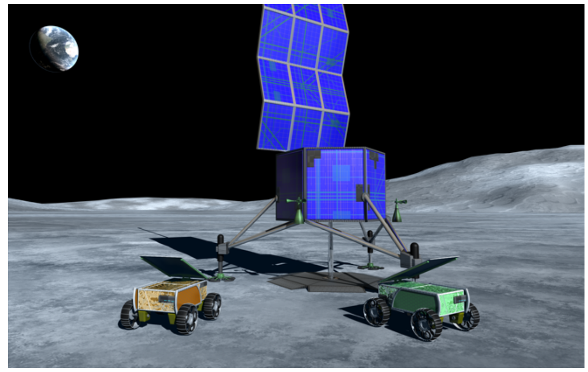

Figure 1. Lunar Lander and Power Station with 2 Small Autonomous Rovers

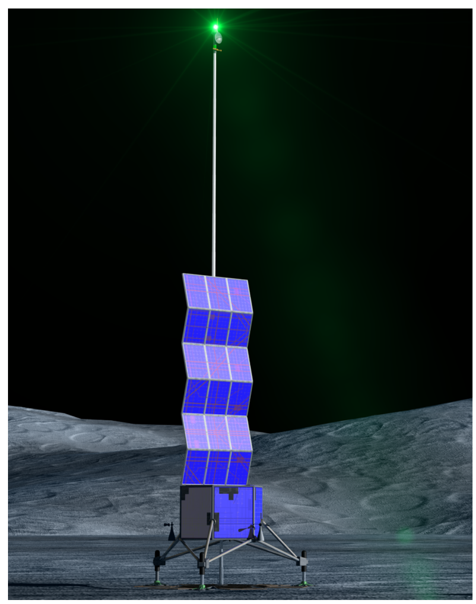

Figure 2. Lunar Lander and Power Station with communication tower and navigation aids.

References:

[1] "A New Era in Spaceflight," NASA Commercial Operations and Transportation Services Program, U.S. Government Printing Office, Washington, DC, Feb 2014. [2] Spudis et al 2013 Journal of Geophysical Research; [3] Colaprete et al 2010, SCIENCE Journal; [4] Zuniga et al 2017, "Building an Economical and Sustainable Lunar Infrastructure to Enable Lunar Industrialization," AIAA Paper 2017-5148.