Constellation Program Lunar Exploration Science Goals and the Impact on Communications Requirements. J. R. Thompson[1] and M. T. Kezirian[2]. (Justin.R.Thompson@nasa.gov), [2](Kezirian@USC.edu), University of Southern California, Astronautics and Space Technology Division, RRB 230, mc 1192, Los Angeles, CA 90089-1192

Introduction: NASA is pursuing development of the Constellatoin Program (CxP), to return mankind to the moon and to establish a sustained human presence on the lunar surface, with the eventual goal of manned missions to Mars. In conjunction to developing spacecraft and new launch vehicles, NASA will need to set requirements for enhanced communication and navigation. Currently, CxP requirements are being developed, focusing on the needs to execute proposed exploration missions. However, scientific goals of CxP will place additional requirements for data transfer, global positioning and real-time communication. Here we consider the the driving requirements for future CxP lunar missions. The identified requirements, specifically in the area of communication and navigation, must be met by developing a particular CxP Communication Network architecture. Architectures to meet this need are proposed and discussed.

NASA CxP Lunar Mission Profile: NASA's Constellation Program (CxP) will seek to develop a permanent output on the lunar surface for scientific discovery. The primary goal for returning to the lunar surface is to broaden the scientific knowledge of the lunar surface. By establishing a base on the moon, NASA can pursue scientific activities that increase humanity's knowledge of Earth, space, and the history of the universe. The lunar surface is also a prime location for testing new technology, flight operations, and exploration techniques to reduce risk and increase productivity on future expeditions to Mars and beyond.

The CxP architecture consists of two launch vehicles and spacecraft. The Launch vehicles are the Ares I (for crew transport) and Ares V (for cargo). The Orion spacecraft, an Apollo-like capsule, will transport six astronauts to space. Altair is a two-stage lunar lander.

The CxP has identified three lunar surface reference missions: Lunar Sortie, Lunar Outpost, and Lunar Cargo. The Lunar Sortie mission is deisnged for four crew members to operate from the Altair lander for 7 days, similar to Apollo missions. The Lunar Outpost mission is the proposed long-duration (nominal 6 month) mission. The Lunar Cargo mission will deliver habitat and living supplies to buildup and re-supply of the lunar outpost.

Lunar polar sites are being examined as possible outpost site; the leading contender is the the Shackleton Crater at the lunar south pole. Low or mid-latitude outpost sites are also be considered. The south polar site, with a notional Outpost buildup strategy is shown in Figure 1.

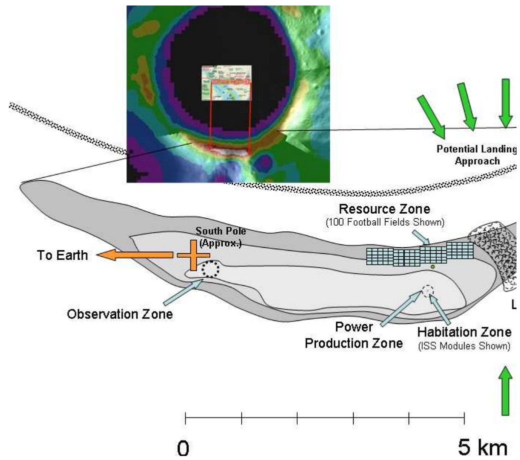

Figure 1: Lunar Outpost at Shackleton Crater

Altair Lunar Mission Requirements: CxP requirements for lunar missions and the selection of the lunar outpost will drive subsequent requirements on the Altair program. Several areas are directly impacted, most notably communications and positioning.

The nominal Altair mission profile is for the vehicle to enter lunar orbit in a polar inclination. This orbit will enable Altair to directly land at identified primary landing sites, specifically at the lunar poles and/or mid latitudes. Currently, CxP is assessing the effects of mandating a global access requirement on the Altair vehicle. This would require the vehicle to have the ability to access and perform functions at diverse landing sites across the lunar surface, including the lunar poles.

At a minimum, the CxP program shall have continuous real-time communication with the Orion spacecraft during landing on the surface. Orion would maintain real-time communication with mission control (in Houston).

The CxP is currently defining the communication requirements necessary for the Altair vehicle for a lunar outpost mission. It is expected that for the CxP to be successful in its mission for global lunar surface capability that continuous 24/7 communication must be provided by the CxP communication architecture for ~96% of the lunar surface. Additionally, it is expected that a CxP communication architecture must be required to perform continuous real time navigation and geoposition functions to the crew and mission command, respectively. This would allow the crew on the surface to safely and effectively execute any mission activities while mission control maintains complete knowledge of the location and status of any crewmember on a lunar surface extra-vehicular activity (EVA).

CxP Communication Network Requirements: In addition to the global access requirement, it is currently understood that "global access"does not mean "land in the lunar night", or dark side of the moon. Instead, CxP requirements specify that the Altair vehicle must conduct soritie missions during daylight. If we are to establish a base on the lunar surface, presumably the lunar astronauts will explore the surface and perform scientific missions. To do that they will need a reliable communication network and a means to accurately determine their position on the lunar surface. A system comparable to GPS would be needed for extended lunar exploration and also for high-precision scientific experiments.

The requirements of exploration should define the communications requirements. Exploration of the back side of the moon. Will a sortie mission to the dark side need contact to the lunar outpost, or to mission control through Orion? The current significant interest in the far side of the mood drives a need for a communications network. Communicating directly to the earth is difficult given visibility and power requirements; communication from the far side is impossible.

Will scientists collect samples or place long term monitoring devices across the lunar surface? Autonomous data retrieval would enable sensors to be placed and not collected by astronauts.

The requirements and feasibility of various architectures to meet this requirement are discussed.

Currently, the Constellation program is identifying the lunar surface science goals and objectives for each mission (sortie, outpost and cargo). A general overview of the mission goals is defined. Currently, the CxP has significant interest

Two possible lunar communication network architectures have been identified to achieve the requirements identified above. The first architecture, adopted as the current standard by the NASA Constellation program, involves placement of multiple "communication nodes" across the surface. A second alternative concept is the deployment of a lunar satellite constellation. Architectures of this type have been proposed throughout lunar exploration programs, but has not been pursued by any NASA lunar exploration program. There are perceived technical challenges. Also such a network requires large upfront costs.

Lunar Surface Network: NASA has proposed the creation of an Lunar surface network of communication nodes for lunar surface communication. Current architechture for this network is through Altair, Orion and to the International Space Station. The data will presumably reach the Earth through the Tracking and Data Relay System (TDRS) satellite network.

Current CxP high priority landing sites, as identified by the Constellation Program Exploration Systems Architecture Study, do not specify direct communication with NASA mission control. In order to realize real-time communication during landing, alternative lunar architectures have been designed which involve the development of a lunar constellation of satellites. This constellation would consist of lunar orbiting satellites, and satellites orbiting the moon in a "Halo orbit". [1] A satellite in a halo orbit orbits the L2 Earth Moon Lagrange point. These satellites could relay communications from the lunar far side and south pole to Earth. They could also be used to track other lunar missions, and broadcast navigation signals. Several concepts involving vehicles in halo orbits within a lunar constellation have been proposed throughout the history of lunar exploration. Farqhuar [2] proposed using halo orbits during the Apollo program.

Carpenter [3] and others have discussed the relative advantages of lunar surface coverage by placing several satellites in halo orbits when compared to the number of necessary satellites in low lunar orbits or communication nodes on the lunar surface. Halo orbiters have longer communication contacts with the surface, meaning that there are fewer times when it is necessary to break contact with one spacecraft to acquire signal of another. Also, tracking antenna pointing is easier because of the slower apparent motion of a halo orbiter when viewed from the lunar surface. Additionally, halo orbiters are illuminated by the Sun more than typical low lunar orbiters. A disadvantage to the halo orbit constellation architecture is that the link distance from the Moon to a halo orbiter would be larger.

Conclusion: The current development of the NASA Constellation Program, necessary communication requirements to meet identified CxP missions, and identifies and discusses possible architectures for a lunar communication network. A lunar communication network is required to meet the lunar surface goals of Constellation, and to enhance the capabilities of the crew over a mission timeline. Two conceptual lunar communication architectures are discussed: a network of surface communication nodes and a constellation of orbiting spacecraft. While both of these architectures have inherent advantages and disadvantages, it is the hope of the community that each be considered in order to enhance the lunar science capabilities of the Constellation program.

References: [1] Hill K. (2006) *AIAA Astrodynamics Specialist Conference,* AIAA 2006-6662.[2] Farquhar R.W. (1970) *NASA Technical Report* TR R-346 [3] Carpenter, J. (2004) *AIAA Astrodynamics Specialist Conference*, AIAA 2004-4747