Background

NASA and international partners are planning the next steps of human exploration by establishing assets near the Moon, where astronauts will build the systems that are needed for deep space exploration. The space near the Moon offers an excellent environment for testing the systems that are needed for extended exploration missions to other destinations like Mars. To support these missions, NASA is working with commercial partners to develop hardware to support missions around the Moon that are more ambitious than ever before. The first phase of this development effort will utilize current technologies to allow astronauts to gain operational experience spending weeks, rather than days, away from Earth. These missions will enable NASA to develop the techniques and systems that will solve the challenges that astronauts will face when traveling to Mars and other exploration destinations.

Although NASA is focusing on Mars exploration as its long term mission planning goal, there are a plethora of exploration missions that can be conducted in cis-lunar space that can extend our knowledge of the solar system and prepare for those future missions. NASA and its international partners are keenly interested in the exploration of the lunar surface and the potential utilization of lunar resources. Establishment of a permanent lunar surface base could provide both experience for astronauts and potential resources that can be utilized to support future Mars missions. The deployment of a lunar base camp is the first step towards the establishment of a permanent lunar base for long duration human exploration.

This Request for Proposal seeks an innovative idea and engineering design to commercially procure a fully functional lunar base camp for a planned lunar expedition in 2031. The RFP seeks a detailed design of a lunar base camp that can sustain a crew of 4 for a period of 45 days on the lunar surface; where the crew will perform tests of deep space exploration and surface habitability systems to help us understand and plan for future exploration missions. The crew of 4 will arrive at the lunar base camp with a government supplied lunar lander that can support the crew on the surface for up to 72 hours after landing to help facilitate the transition the crew to the base camp. The 45 days crew surface expedition begins after the 4 crew transitions fully from their landing vehicle to the lunar base camp.

Design Requirements and Constraints

- Design a fully functional lunar base camp for the first long duration Lunar expedition mission
    - The basecamp should be designed to support a crew of 4 for a nominal mission duration of 45 days on the lunar surface
    - The location of the basecamp should be chosen to maximize scientific return, crew survivability, and potential extensibility to enable future deep space missions
    - The design should take into consideration the potential for the base camp to be expanded to accommodate more crew for longer duration in subsequent expeditions
    - The design should consider the various activities, resources, and systems that future exploration missions to other solar system destination would require and how the base camp would help enable those missions
- Design and define the mission operations, including launch, orbit transfer, station keeping, and other maneuvers necessary to deliver the base camp components to the lunar surface
    - The design must include all of the necessary systems to launch and deploy the base camp elements to the lunar surface
    - If assembly is required by the crew, detail the necessary tasks that are required to bring the base camp to operation to sustain the crew for the duration of the expedition
    - Assume the expedition crew lander can only sustain the crew of 4 for a period no longer than 72 hours after landing; any payload capability that the crew lander has will be fully utilized to support the crew for the 72 hour period and for crew ascent. The crew lander and ascent stage is not part of the base camp design
- Perform trade studies on system options at the system and subsystem level to demonstrate the fitness of the chosen base camp design. It is highly desirable to use technologies that are already demonstrated on previous

programs or currently in the NASA technology development portfolio. Advanced technology can be used; however, cost, schedule, and risk consideration of utilizing advanced technology must be discussed

- Discuss selection of subsystem components, including mass, power, and volume, and how the design requirements drove the selection of the subsystem
- Discuss the estimated lifetime of each of the components, determine the lifetime of the system and number of surface expeditions the basecamp can sustain, and detail the potential upgrades/expansions that are available with the design and how extensibility and longevity considerations impacted the design choices
- Describe in detail how the base camp components will be packaged, launched, and deployed to the lunar surface, whether any on-orbit or on-surface assembly or rendezvous of components will be required, and what systems would be required to assist in the delivery of the components to the lunar surface
- The initial cost for the lunar base camp shall not exceed $12 Billion US Dollar (in FY19) from the start of the program to the human expedition, including design development test and evaluation (DDT&E) and theoretical first unit (TFU) costs of all of the base camp elements.
- If advanced technology options are utilized in the design, the technology advancement cost must be included
- The cost cap includes launch costs to deploy the base camp systems, but does not include the cost of the human expedition mission and its associated lander/ascent stage
- The base camp must be ready to receive the first expedition crew no later than December 31, 2030.

Deliverables

This project will require a multi-disciplinary team of students. Traditional aerospace engineering disciplines such as structures, propulsion, flight mechanics, orbital mechanics, thermal, electric power, attitude control, communications, sensors, environmental control, and system design optimization will be necessary. In addition, economics and schedule will play a major role in determining design viability. Teams will make significant design decisions regarding the configuration and characteristics of their preferred system. Choices must be justified based both on technical and economic grounds with a view to the extensibility and heritage of any capability being developed.

The following is a list of information to be included in the final report. Students are free, however, to arrange the information in as clear and logical a way as they wish with the exception of the 5 page executive summary which must be place at the beginning of the report.

1) Requirements Definition – the report should include the mission and design requirements at the vehicle, system, and subsystem level. The requirements definition should demonstrate the team's understanding of the RFP *Design Requirements and Constraints* and lay the foundation for the design decisions that follow.

2) Concept of Operation – A detailed concept of mission operation should be included to describe all phases of the mission and to demonstrate the realization of the mission requirements in *Design Requirements and Constraints*. The report should show that the team has performed historical analysis of similar concepts to evaluate the merits and deficiencies of previous designs, and demonstrate that alternative concepts were considered while providing justification for the chosen concept.

3) Trade Studies – the report should include the trade studies for the vehicle architecture, mission operations, and subsystem selections, and must discuss in detail how the system level requirement are developed from mission requirements by describing the pro and cons of each subsystem options. The report must discuss how each subsystem level decision is made, with description of the selection metrics and their associated weightings when appropriate, and provide detailed discussions on how each decision impact system level metrics such as cost, schedule, and risk.

4) Design Integration and Operation – The report should discuss how the trades selected in section 3 are integrated into a complete architecture. This section should discuss design of all subsystems: structures, mechanisms, thermal,

attitude control, telemetry, tracking, and command, electric power, propulsion, payload and sensors, and the mission concept of operations. Discussion on the extensibility of the overall system design and how it can support future exploration mission should be included. A mass and power budget must be included, broken down by subsystem, with appropriate margins assigned to each system based on industry standards. The report must clearly describe all of the tools and methods utilized for the system and subsystem design and provide brief description of the inputs, outputs, and assumptions for the design. A discussion on the validation of the tools and methods must be included. A summary table should be prepared showing all mass, power, and other resource requirements for all flight elements/subsystems with the appropriate mass and power margins clearly labeled and discussed.

5) Cost Estimate – a top level cost estimate covering the life cycle for all cost elements should be included. A Work Breakdown Structure (WBS) should be prepared to capture each cost element including all flight hardware, ground systems, test facilities, and others. Estimates should cover design, development, manufacture, assembly, integration and test, launch operations and checkout, in-space operations, and final delivery to the lunar surface. Use of existing/commercial off-the-shelf hardware is strongly encouraged. Advanced technology utilization must be fully costed with appropriate cost margin applied. A summary table should be prepared showing costs for all WBS elements distributed across the various project life cycle phases. The report should discuss the cost model(s) employed and describe the cost modeling methods and associated assumptions in the cost model. The cost analysis should provide the appropriate cost margin based on industry standards.

6) Schedule – A mission development and operation schedule should be included to demonstrate the mission meets the schedule deadline established in the RFP. Schedule margin should be applied to appropriate areas with funded schedule reserve detailed in the cost estimate. Any advanced technology assumption should have corresponding technology development schedule and cost associated with the technology and appropriate contingency plan should be discussed.

7) Summary and References. A concise, 5 page "Executive Summary" of the full report must be included and clearly marked as the summary at the beginning of the report. The executive summary should provide a clear sense of the project's motivation, process, and results. References should be included at the end. A compliance matrix listing the page numbers in the report where each these sections, as well as the items identified under the "project should" section can be found, is mandatory.