Background

NASA and international partners are planning the next steps of human exploration by first establishing assets near the Moon and Lunar surface where astronauts will build and test the systems that are needed for deep space exploration with eventual human missions to the surface of Mars. The primary goals of a surface Mars mission are to search for current life or evidence of past life and establish human presence outside the Earth sphere of influence. One of the primary challenges for sustained human presence on the surface of Mars is finding life sustaining elements such as water. Several Mars rovers have discovered and analyzed Mars subsurface ice deposits using on-board sensors. To increase our understanding of the chemical makeup of these ice deposits and further humanity's goal of being a multi-planet species, a sample return mission to retrieve a Mars ice core sample is desired.

Water covers approximately 70% of the Earth's surface and is the most important resource to sustaining life. Many NASA science missions to other planetary bodies have an explicit goal of searching for water. For crewed missions, water is the cornerstone of the environmental control and life support systems for the crew. In addition, water can be broken down into hydrogen molecules to provide propellant for the propulsion systems and oxygen molecules for breathing. The discovery and utilization of water from in-situ locations could potentially increase the performance and reduce the cost of exploration missions relative to the reliance on delivery from Earth. Martian ice deposits can provide the life sustaining water for future human missions or provide the necessary propellant for crew return.

This Request for Proposal seeks an innovative ideas and engineering designs to return samples of Mars ice to Earth for scientific evaluation and to inform future analyses and designs for human systems. The RFP seeks a detailed mission design of a robotic system to land on the Martian surface, identify and find Martian ice deposits, retrieve multiple ice core samples from the ice deposits, and return those ice core samples back to Earth. The returned ice core samples will provide invaluable insight into our closest planetary neighbor and will pave the way for future exploration of Mars and beyond.

Design Requirements and Constraints

- Design a robotic mission to the surface of Mars with the primary goal of returning a minimum of 2.5 kg of ice core samples back to Earth
    - The designed system should deliver a robotic system that can land on or near Martian ice deposits
    - The system should be capable of perform drilling operation on the Martian surface with the express purpose of retrieving ice core samples
    - The ice core samples should be at least 25 millimeters in diameter, and 100 millimeters in length
    - The robotic system needs to be capable of storing the ice cores in a frozen state during surface operations
    - The system must return a minimum of 2.5 kg of ice cores in its frozen state back to Earth and accommodate the safe transfer of the ice cores to Earth-based laboratories in their frozen state"

- Design and define the end-to-end mission operations, including launch, transit to Mars, entry/descent/landing, surface operation, ascent, and return to Earth
    - Select a mission architecture and vehicle design that maximizes the science data return within the cost and schedule constraints
    - Discuss the selection of target locations and the values of the selected site, including the assessment criteria

- Perform trade studies on system options at the system and subsystem level to demonstrate the fitness of the chosen mission 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 included in proposal.

- Discuss selection of subsystem components, including mass, power, and volume, and how the design requirements drove the selection of the subsystem

- The cost for end-to-end mission shall not exceed $1 Billion US Dollars (in FY20), including launch, design development test and evaluation (DDT&E) and flight unit costs for the mission

- If advanced technology options are utilized in the design, estimation of technology advancement cost must be included

- The ice core sample must be returned to Earth for scientific analysis 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 other requirements for the design. Estimates should cover design, development, manufacture, assembly, integration and test, launch operations and checkout, in-space operations, and final delivery to the Martian surface and return to the Earth. 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 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 schedules and costs associated with the technology and appropriate contingency plans 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 section as well as the items identified under the *Design Requirements and Constraints* and *Deliverables* sections can be found, is mandatory.

Additional Resources:

Bonitz, Robert G., et. al., "NASA Mars 2007 Phoenix Lander Robotic Arm and Icy Soil Acquisition Device." Journal of Geophysical Research, Vol. 113, E00A01, 2008. doi: 10.1029/2007JE003030

Mars Exploration Program Analysis Group. Jet Propulsion Laboratory. California Institute of Technology. National Aeronautics and Space Administration. url: https://mepag.jpl.nasa.gov/reports.cfm

Pike, W.T., et. al., "Quantification of the dry history of the Martian soil inferred from in situ microscopy." Geophysical Research Letters, Vol. 38, L24201, 2011. doi: 10.1029/2011GL049896

Zacny, K., et al., "Reaching 1m Deep on Mars: The Icebreaker Drill." Astrobiology, Vol. 13, Num 12, 2013. doi: 10.1089/ast.2013.1038

Zacny, K., et. al., "Drilling Systems for Extraterrestrial Subsurface Exploration." Astrobiology, Vol. 8, Num 3, 2008. doi: 10.1089/ast.2007.0179

Zacny, Kris A., and Cooper, George A., "Methods for cuttings removal from holes drilled on Mars." MARS 1. 1-13, 2005. doi: 10.1555/mars.2005.1.0

Zacny, Kirs A., and Cooper, George A., "Considerations, constraints and strategies for drilling on Mars." Planetary and Space Sciences, Vol. 54, page 245-356, 2006. doi: 10.1016/j.pss.2005.12.003