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# Phobos Base

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**This paper reviews the trajectory of concepts for a human base on Phobos. It begins with Arthur C. Clarke's early concepts for human bases on Phobos and Deimos. It touches on some very recent NASA concepts for using Phobos as a way station and staging ground for the robotic and human exploration of Mars. Then, it describes the design and engineering thinking that went into the development of the AIAA 2017 Human Spaceflight Student Design Competition for Phobos Base. The paper concludes with the actual competition design brief/request for proposals that "hit the street" at the end of August 2016.**



## I. Introduction

THE major challenge in staging humans to Mars concerns what to do when a spacecraft carrying a crew, a habitat, or other payload arrives in cis-Martian space. The two conventional options are to circularize into low Mars orbit (LMO) before landing or to attempt direct atmospheric braking, entry, descent, and landing. This initiative addresses the alternative of creating a logistical and scientific base on Phobos, the larger and closer of Mars' two moons. This base would host and support crews in transit to Mars and returning from Mars to Earth. A major focus is to provide human health and habitability maintenance regarding microgravity and surface environments while minimizing health risks through enhanced radiation shielding and microgravity countermeasures. As a probable captured carbonaceous chondrite asteroid that may contain as much as 13% water by mass, Phobos may also provide a source of life support and propellant consumables, including fuel for a reusable Mars Descent/Ascent Vehicle (MDAV). A critical advantage of Phobos Base would be its contribution to making a strong infrastructure, which makes Mars exploration sustainable over a long-term of 50 years or more.

The purpose of the Phobos Base design competition is to develop an integrated solution for the next step in developing Mars exploration architecture: the Phobos surface base. Phobos base will support exploration of Phobos, the remote exploration of Mars, and the eventual staging of human expeditions to the Mars surface.

The AIAA Life Science and Systems Technical Committee (LSSTC) and the AIAA Space Architecture Technical Committee (SATC) are jointly organizing and sponsoring the Phobos Base Design Competition. In conjunction with the International Conference on

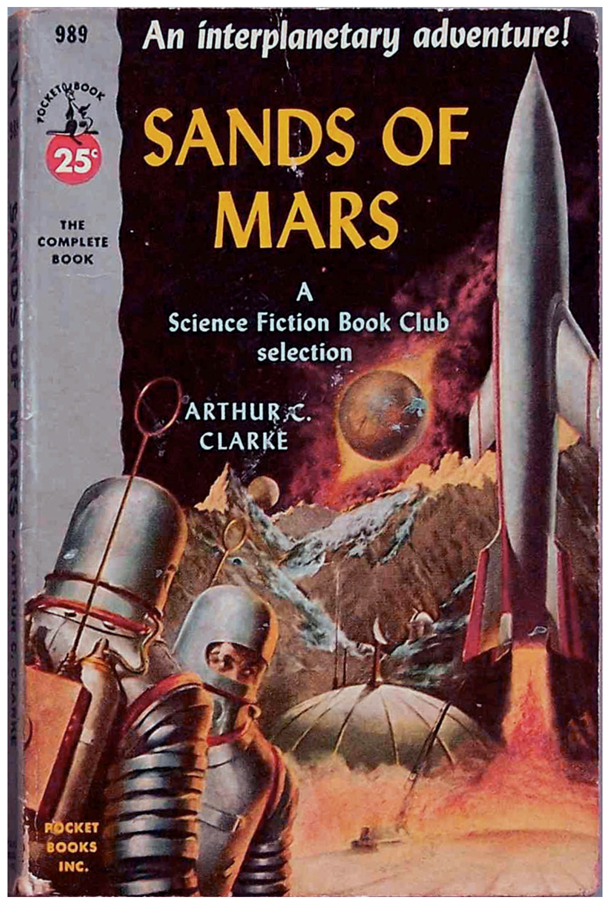


**FIGURE 1. Sands of Mars, 1951. Cover showing rockets launching from the Deimos spaceport, with Mars in the background. Artwork by Robert Schulz.**

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Environment Systems non-profit corporation, the two TCs supports the AIAA to become, once again, a co-sponsor of the International Conference on Environmental Systems at which the Design Competition winners will be announced and present their entries.

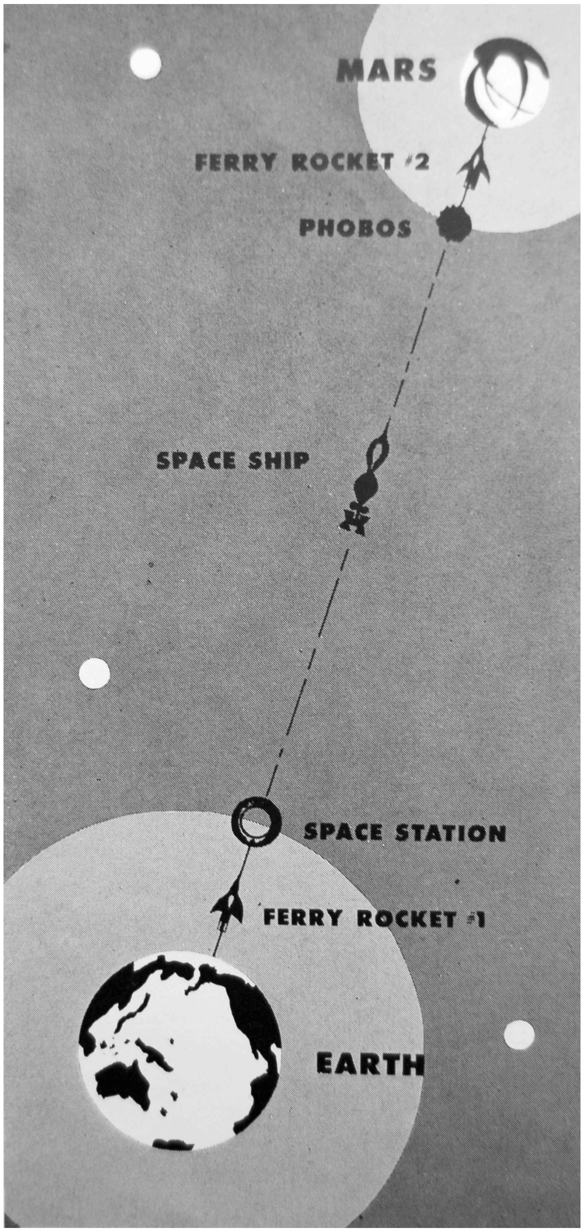


**FIGURE 2. Arthur C. Clarke, A Journey to Mars" in Holiday, March 1953. Artist unknown.**

The Design Brief for the Phobos Base student design competition is the core of this Invitation for Proposals.[2] It states the design requirements, covering the architectural and engineering aspects of the problem. The Design Engineering Criteria provide a metric for how the teams fulfill the design requirements.

Students from all accredited post-secondary colleges and universities are eligible to enter. There are two categories of student teams: undergraduate and graduate. There is no monetary fee to submit an entry in the competition. However, each student member of the submitting team must become a student member of AIAA (for a fee of $25 USD).[3] Competition teams consist of up to 10 students currently enrolled at a college or university, plus a faculty advisor. The students are responsible for doing all the work on the design entry.

The submission consists of a report to be submitted to the AIAA. The Request for Proposals states the design evaluation criteria following the Design Brief. Team members should stay cognizant of the evaluation criteria throughout their project. The judges will be members of the AIAA, plus guest experts invited by the sponsoring Technical Committees.

## II. The Early Concepts for Phobos Base

The story of the 21th century will be of humankind breaking through our gravity-boundedness, returning to the Moon, and turning our eyes in two directions: earthward and beyond the Moon. We are now in the second decade of this 21st century, but no national or international space agency, no major aerospace corporation, nor any "NewSpace" enterprise offers a coherent, technically achievable, and sustainable plan for human exploration beyond low Earth orbit (LEO). While politics and finance play key roles in enabling such a major undertaking, what humankind lacks most is a persuasive concept, a forceful vision for what we can achieve in deep space. To some extent, this lack of unity derives from divisions within the space exploration community, particularly the split between the Moon-first and the Mars-first advocates. The vision for Phobos Base incorporates some of the advantages of both approaches.

Arthur C. Clarke proposed the first concept for a Phobos Base before the dawn of the Space Age in his first novel, Sands of Mars, completed in 1951. The cover of a paperback edition (science fiction is best read in paperback) appears in FIGURE 1. The cover art shows the view of Mars from either the Deimos spaceport, but the design of the Phobos spaceport would be quite similar. This painting shows a variety of elements that composed the Deimos/Phobos Base architecture. A crater rim or mountains surround it. It includes an astronomical observatory and a large pressurized dome module for the crew living environment. It shows a landing zone area with a rover that traverses it to carry the crew to and from the rockets or

[2] AIAA Student Design Competitions Page. Look for Phobos Base. https://www.aiaa.org/DesignCompetitions/
[3] AIAA Student Membership: https://www.aiaa.org/Secondary.aspx?id=252

landers. It portrays EVA crewmembers in space suits with a portable life support system (PLSS) and a variable volume convolute at the shoulder. Clarke followed this first novel with an article “A Journey to Mars” in the March 1953 issue of Holiday, a travel magazine that featured the trip to Mars on an equal footing with the cover article, a trip to Mexico. In this article, Clarke provided a diagram showing Phobos as a transfer point to Mars, presented in FIGURE 2.

Phobos offers some obvious attractions for access to the surface of Mars and observation of it, many of which Clarke perceived or guessed. These advantages pertain today, but with a much deeper and more detailed level of appreciation from the space exploration community.

Phobos presents potential advantages over both the Moon and Mars as a human-operated outpost from which to conduct many different types of scientific investigation:

- To study Mars and the Martian system,
- To study Phobos as a moon that probably began as an asteroid; and
- To use Phobos as serviceable platform for astronomical observatories.

What is most important, Phobos offers an excellent position due to its gradient gravity stabilization with respect to Mars. Phobos presents potential advantages over and Mars as a human-operated outpost, at least in the early stages of *real-time* Mars exploration and future development. What is most important, Phobos offers an excellent position due to its gradient gravity stabilization versus Mars, from which to conduct the foregoing studies and many kinds of mission operations. Reaching Phobos does not require the costly development of a major propulsive or aerobraking lander, nor does it require the delivery of that lander to lunar or Mars orbit.

Phobos affords a practicable waypoint at which to locate an astrobiology laboratory that can safely conduct examination of Mars samples with reduced danger of back-contamination to the Earth. The topography of Phobos, its orbit close to the Martian surface, and rotation with one side always facing Mars provide advantages for in-situ radiation shielding.

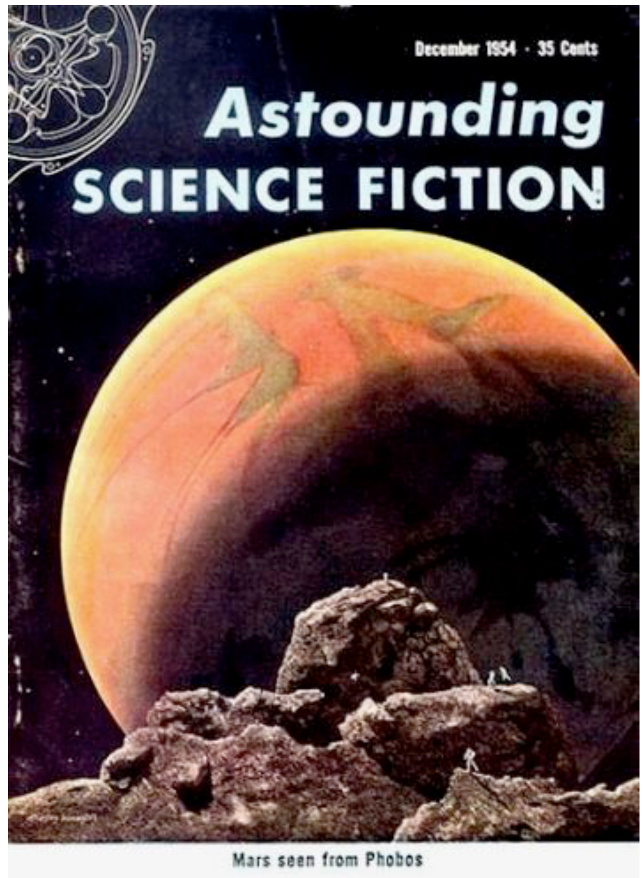


**FIGURE 3. Chesley Bonestell. View of Mars from Phobos. Note the EVA crew in the foreground.**

Reaching Phobos does not require the costly development of a major propulsive or aerobraking lander, nor does it require the delivery of that lander to lunar or Mars orbit. As a trade-off for not needing a big, expensive lander, the near-microgravity of Phobos will demand solutions and technologies to attach or adhere all elements of the base to the Phobos Surface

The Phobos mission will entail exposing its human crew to space radiation outside the friendly confines of the Earth's magnetic field and unmitigated by any significant atmosphere. One potential mitigation might derive from the shielding afforded by Stickney crater, the planet Mars overhead (~25% of the visible hemisphere above a point on Phobos' surface), and the mass of Phobos itself (effective shielding >2π steradians). The mission will also expose the crew to a microgravity environment for the full duration of nearly three years on a conjunction class mission (600 days at Phobos plus over one year in transit) total for outbound and return transits). This combined environments challenge is unmatched by any of the alternative lunar or Mars surface missions making this a particularly interesting design requirement.

The pedagogical objective of this design competition concerns more than just an exercise in developing an integrated solution for the next step in Mars exploration architecture in a specific design and engineering project. This challenge requires an interdisciplinary approach to problem solving to assess the issues posed by these environments and countermeasures needed, based on current research, including the results of space station experience. The successful design solution will apply environmental countermeasures that protect and support the crew to maintain their health, safety, and productivity.

## III. Recent Phobos Exploration Concepts

***Fast-forward nearly two thirds of a century since Clarke and Bonestell.*** Phobos has been attracting increasing attention in recent years as both a robotic and human mission destination. Although United States/NASA interest in Phobos is relatively recent, in some other countries there has been longstanding interest in Phobos. The Royal Observatory at the Catholic University of Louvain in Belgium has been a leader in Phobos and Deimos studies.[4] Russian and USSR teams tried for a long time to send a probe to Phobos and return samples from it.[5] More recently, the European Space Agency (ESA) and the Russian Space Agency (RSA or Roscosmos) studied a joint mission.

**FIGURE 4. In 2008, NASA's Mars Reconnaissance Orbiter captured this color-enhanced view of the Martian moon Phobos. Please note the streaks running from upper left to lower right, to the rim of Stickney crater. NASA / JPL-Caltech / Univ. of Arizona.**

[4] For example http://adsabs.harvard.edu/abs/2011epsc.conf.1021L

[5] https://en.wikipedia.org/wiki/Phobos_program.

Phobos is believed by some (but not all) planetary scientists to be a captured carbonaceous chondrite asteroid that may contain as much as 13% water by mass. The design of the Phobos Base and its systems may consider the possibility of obtaining consumables and materials through the in situ resource utilization (ISRU) potential there. The potential to exploit these in situ resources may create a profound impact upon the design of Phobos Base. Some of the current publications about Phobos include the following:

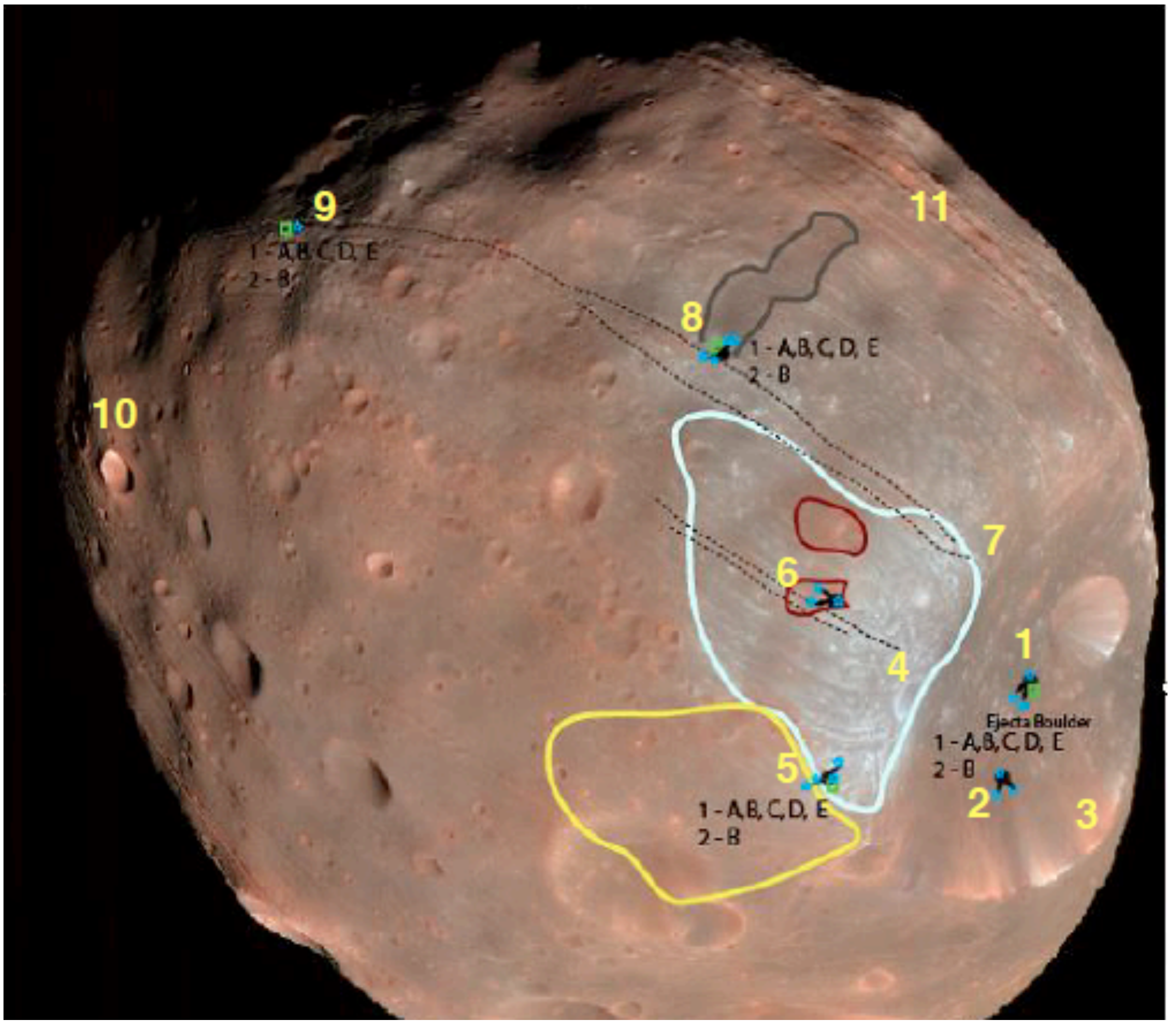


**FIGURE 5. Mapping of sites of scientific interest on Phobos, courtesy of Dr. Michael Gernhardt, NASA Johnson Space Center.** http://spirit.as.utexas.edu/%7Efiso/telecon/Gernhardt_7-8-15/ **Dr. Gernhardt provides these captions:**

1. Floor of Stickney Crater.
2. Sidewall of Stickney Crater.
3. Far rim of Stickney Crater.
4. Overturn of Stickney Crater and grooves.
5. Overlap of yellow and white units.
6. Overlap of red and white units with grooves.
7. Opposition rim of Stickney and start of grooves.
8. Brown outlined Unit and "midpoint" of grooves.
9. "End point" of grooves.
10. "Young," fresh crater.
11. "Deep" groove structure

In March of 2015, Caltech conducted a five-day mission design competition for a crewed mission to Phobos to return samples to the Earth.[6]

In June 2015, Japan's space agency JAXA announced a plan for robotic return of Phobos Samples.[7]

[6] http://www.caltech.edu/news/caltech-space-challenge-mission-martian-moon-39143, http://www.csc.caltech.edu/talks/mazanek.pdf

Most recently, a new set of Phobos geological findings were released by Terry Hurford and his colleagues of NASA's Goddard Space Flight Center in Greenbelt, Maryland The findings pertain to the long, shallow grooves lining the surface of Phobos likely being early signs of the structural failure that will ultimately destroy this moon of Mars by it being pulled apart by Mars gravity in 30 to 50 million years.[8] FIGURE 4 shows an image of Phobos with these grooves visible.

In the July 8, 2015 Future of In-Space Operations (FISO) telecon, the astronaut Mike Gernhardt presented a set of concepts for a human mission to Phobos.[9] Dr. Gernhardt displayed a map of areas and targets of scientific interest on Mars, shown in FIGURE 5.

## IV. Developing The Competition Design Brief: The Thought Behind It

The 2016-2017 Human Spaceflight Student Design Competition for a Phobos Base focuses upon how to advance and develop human life support and habitation capabilities on Phobos for the exploration of Phobos and the cis-Mars system. The Phobos infrastructure can then serve as the jumping-off point for the eventual human exploration of the Martian surface.

The participants in crafting the design brief developed this philosophy to shape the Request for Proposals:

- The main challenge for the technical committees was to allow the student teams freedom to be creative while maintaining a strict composition and presentation standard so that the entries will be directly comparable.
    - Specified topics for the teams to cover.
    - Uniform location of contents in the team report.
    - Clear statement of reviewers' evaluation criteria.
    - Engineering deliverables.
    - Space Architecture parameters and deliverables.
- Manage the scope to be feasible for the student team to complete an entry in one semester.
- While providing pointers to key resources, expect the students to pursue all their own research.

The Competition focuses upon how to advance and develop human life support and habitation capabilities on Phobos for the exploration of Phobos and the cis-Mars system. The AIAA Life Science and Systems Technical Committee supports the Environmental Control and Life Support (ECLSS), EVA, and other engineering aspects. The AIAA Space Architecture supports the habitation and crew accommodations in the living and working environment, including architectural planning, structures and configuration. The Phobos infrastructure can then serve as the jumping-off point for the eventual human exploration of the Martian surface.

This design brief consists of three main sections, Mission Design, Engineering and Architecture, each of which divides into several subsections. These sections correspond in large part to the design disciplines that comprise the sponsoring technical committees and how they practice professionally. In addition, the Mission Design section connects the design brief to spacecraft, propulsion, and trajectory design. Architecture encompasses the general site plan and functional design parameters, the mission design, the living and working environment in the space habitat.

While developing the Design Brief, the joint Space Architecture/Life Science team debated intensively how far to go in suggesting particular approaches, technologies, or other solutions. This dialogue applied to nearly all aspects of possible design solutions, with some members advocating certain broad strategies or guidelines, while others argued fiercely that the Brief should contain nothing that advocated or "dictated" any specific design approach. For example, the question of how a spacecraft might dock to the "spaceport" on Phobos might entail whether to include a robotic arm to grab and gently bring the spacecraft to its docking port, as on the ISS for some cargo vessels. The most hotly debated topic was artificial gravity. The issue was whether to provide any guidelines. The "no suggestions" party argued successfully that to even imply guidelines would bias the competition entries toward a specific concept. The outcome was that the Brief provides an overview of the requisite capabilities while giving as few particulars as possible while keeping it clear and sufficient to create a design entry.

The AIAA Space Architecture Technical Committee maintains a website with over 700 technical articles and papers that a can help apply Space Architecture precepts to many of the Phobos Base requirements.[10]

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[7] http://www.nbcnews.com/science/space/japan-plans-rock-collecting-trip-martian-moon-phobos-or-deimos-n374701.

[8] http://nineplanets.org/news/phobos-breaking-apart/

[9] http://spirit.as.utexas.edu/%7Efiso/telecon/Gernhardt_7-8-15/

[10] http://spacearchitect.org/pubs/pub-biblio.htm, http://www.spacearchitect.org

### A. Mission Design

Although the mission design is not the primary focus of the Phobos Base competition, the design team needs a clear concept for delivering construction payloads to Phobos and how to accomplish the base construction consistent with the crew and robotic capabilities. The mission design integrates with both Space Architecture and Engineering, while fitting within several broad constraints. These constraints include mass to LEO; launch frequency, trajectory, and arrival at the Mars system. Each payload mass may range from 70 to 130 metric tonnes launched to LEO. Mission design relates closely to the External Functions that provide many of the capabilities needed to perform the mission objectives.

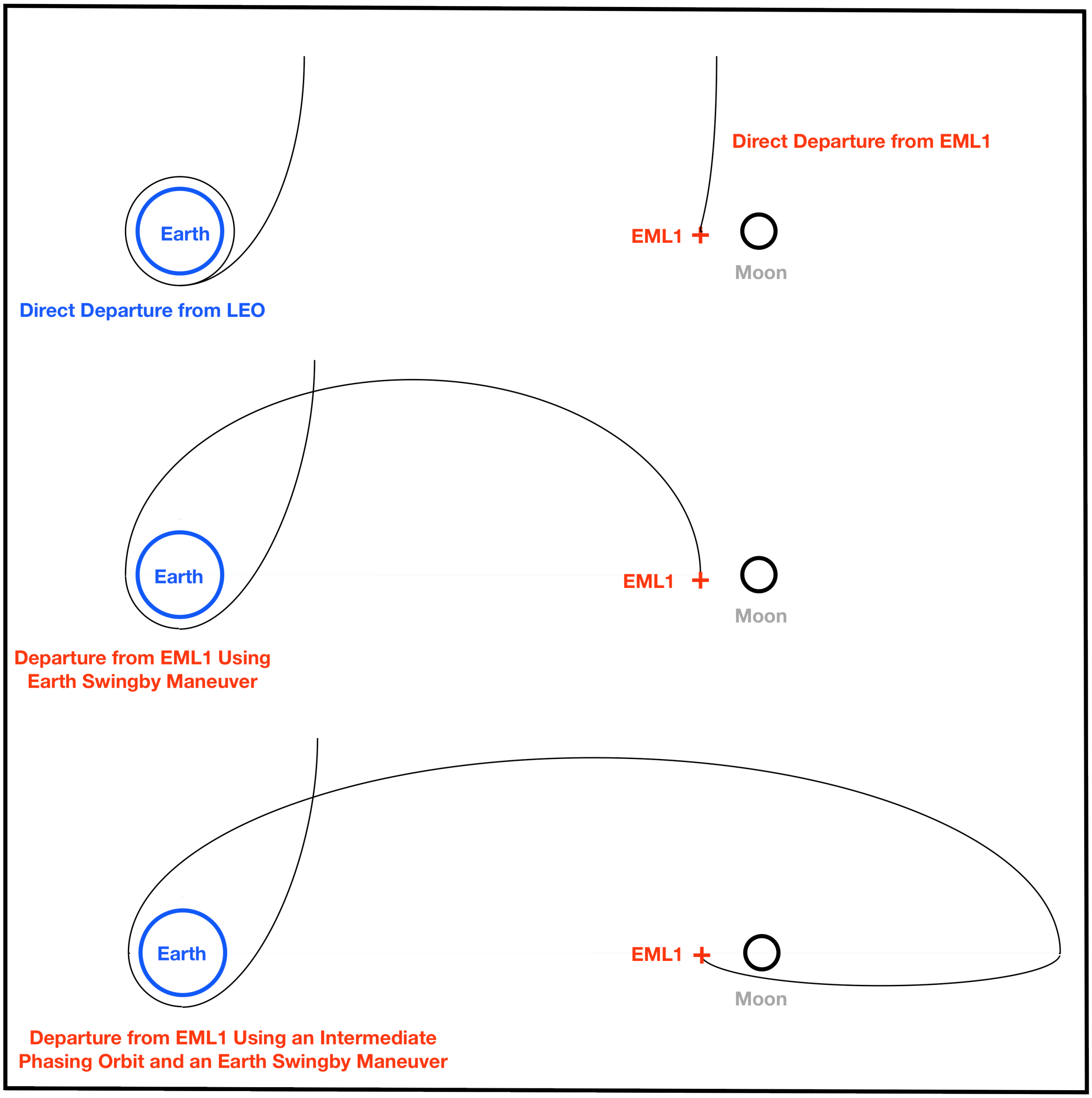



**FIGURE 6. Example of an EML1 Departure and return nodes by Warren W. James for *Robotic Asteroid Prospector*, 2012 NIAC Phase I.**

*1. EML-2 Departure and Return Node*

The flight operations shall stage the departure from the Earth system from Earth-Moon Lagrange Point 2 (EML-2) on the far side of the Moon from Earth. The launch frequency from EML-2 shall support approximately four to five interplanetary vehicle (IPV) departures within a 60-day synodic window to the Mars system every 26 months.

This guideline implies the launch of a heavy lift vehicle to deliver a payload to EML-2 on average every four to five months during the period between launch windows. These IPVs will bide their time at EML-2 until the synodic window opens, when they will inject to Mars. The build-up and completion of the Phobos base must be accomplished with the payloads delivered within four synodic windows.

*2. Mission Class*

The design teams may consider designing any class of mission from the Earth-Moon System to the Mars-Phobos-Deimos System such as conjunction class, opposition class, Aldrin cycler, or other alternative trajectory for crew or cargo and crew return to Earth. The teams may propose to improve on the baseline for the purpose of reducing human exposure to radiation and microgravity (μg) and improving mission performance. The teams may also consider hybrids of different classes of missions, for example conjunction-class outbound to Phobos and opposition-class inbound to Earth. The design team must make a clear and strong case for whatever mission class they may choose.

The payload transfer trajectory design is open. Ideally it should be at least as mass-efficient or as fast as a low-energy Hohmann transfer.[11] Please see for further explanation. Realistic alternative propulsion systems (e.g. solar electric, solar thermal, or nuclear electric) may enable alternative trajectories and mission designs.

*3. Payload Accommodation*

All payloads to Phobos shall fit within a dynamic envelope within the fairing atop the chosen launch vehicle. All the components, equipment, elements, modules, and structures to construct the Phobos base must fit within this dynamic envelope and its mass limits. Payload design must include the means of berthing, docking, or unloading upon arrival at Phobos.

*4. Proximity Operations*

The mission design should include a concept for proximity operations around Phobos. This concept includes Mars orbit injection, transfer to a rendezvous orbit near Phobos, safe approach to the Base, terminal descent, and landing. It includes all operations on and around Phobos. See further description in *External Functions*.

## B. Engineering

Engineering spans the range of environmental controls and life support systems (ECLSS), structures, EVA systems and other external capabilities for operating in the vacuum of space, structures including pressure vessels for habitable modules, power systems, communication systems, and mechanical design or rotating systems.

*1. Safety Strategy*

Human explorers on Phobos can neither return to Earth, nor expect rescue, nor receive emergency supplies quickly or timely. Therefore, Phobos Base must be fault-tolerant and highly reliable. Each element or operation would play a role in safety for the crew and mission success. The Safety Strategy should consider how to manage risk for these roles, as crews will not be able to return to Earth quickly, nor be rescued, nor receive emergency supplies in less than many months. The Design Team should research, select, and articulate their safety strategy and integrate it with the Safe Haven strategy above. Describe the approach to achieving fault tolerance in critical functions and to integrating systems in the habitat.

*2. Life Support Systems*

Environmental Control and Life Support Systems constitute the central engineering challenge of the competition. The design parameters follow the following simple, declarative reasoning.

Maintain Critical life support functions through any two failures. Provide atmosphere revitalization (CO2 removal and O2 production). Monitor and remove contaminants from air and water. Provide clean water. Maintain temperature, humidity, atmospheric pressure, and gas mix to support crew health and safety. Recycle all consumables to the extent feasible. Address hygiene and waste management within the framework of an integrated, regenerative, and recycling ECLSS. Provide food production within the scope of the ECLSS system.

Select the key life support and habitation technologies (including choices between physical/ chemical and bio-regenerative technologies) and the reason for those choices, Indicate the degree of loop closure on oxygen, water,

[11] http://www2.jpl.nasa.gov/basics/bsf4-1.php

and other consumables and waste products. Explain the disposition or recycling of waste / expended materials and interaction with required functions. Quantify the parameters for resupply of consumables, space parts, and replacement of equipment.

These systems include but are not necessarily limited to:

- Atmosphere revitalization, including
    - Oxygen generation,
    - Carbon dioxide removal,
    - Contaminant control of
        - Volatiles, and
        - Semi-volatile hydrocarbons
        - Particulates, including moon or planetary dust
    - Pressure control
    - Temperature control (sensible heat),
    - Humidity control (latent heat), and
    - Gas mix balance with buffer gas (nitrogen).
- Water systems, including,
    - Water production from on-spacecraft or on-habitat systems, such as
        - Urine recycling
        - Condensate capture and recycling
        - Water production from local resources (if any),
    - Contaminant monitoring and removal,
    - Water extraction from solid wastes and food wastes
    - Recycling/reprocessing, and
    - Distribution and return to the reprocessing system.
- Energy management and conservation to run the life support.
- Data systems management and integration to monitor and operate the life support.
- Agricultural Systems to provide fresh vegetables,
    - Planting systems
    - Growth chambers and systems
    - Fertilizers
    - Harvesting techniques, and
    - Biomass waste handling and reprocessing

ECLSS also provides all the above systems for the EVA systems including suits, Suitports, and other airlocks.

*3. External Functions*

The base connects to the external environment through a variety of interfaces and instruments. These connections encompass the physical, structural connection between Phobos Base and the Phobos surface, the operational connections for Extravehicular Activity (EVA), proximity operations, and local flight, and the instrumentation installed in situ. The operations include exploration, set-up of external utilities and equipment, and resource extraction and refinement processes.

*4. Communications*

Communications equipment includes antennas for communications back to Earth, to approaching and departing spacecraft, and to the Mars surface. These antennas can serve as relays for communications between landers and rovers on the Mars surface and the Earth. They can also transmit and receive signals from Mars satellites and from astronomical instruments or observatories installed on Phobos or Deimos. The antennas should be able to work alone as they constitute a unique relay from Mars to Earth, much better than an orbiter around Mars.

*5. Extravehicular Activity (EVA) Operations and Systems*

The EVA systems integrate with the ECLSS that provides the consumables for spacesuits and pressurized rovers. It provides for supporting multiple EVAs at the mission destination and contingency or experiment support EVAs in transit. The NASA EVA protocol since the Space Shuttle program states that a minimum of two crewmembers perform each EVA.

The EVA capability on Phobos includes an airlock system to facilitate egress and ingress of space-suited astronauts. The airlock system includes an airlock that the crew can use to bring equipment and suits into the regular pressurized habitat workshop for servicing or repair. The airlock has a pressure port to allow it to connect to a pressurized vehicle for exploring Phobos. The team may contemplate the design of such a Phobos exploration and operations vehicle to inform the design of the EVA support system. Because the mission concept anticipates frequent EVAs compared to ISS, the design teams may consider innovative design concepts for these functions. EVAs require suit maintenance and repair operations and the means to perform them.

*6. View Angle Factors*

With the Phobos Base situated in Stickney Crater, the view angles from the base site may become an issue for several functions. The same topographic features that protect a crew from space radiation also diminish the effectiveness of active thermal radiators, photovoltaic arrays, or communications antennae.

*7. In Situ Resource Utilization (ISRU)*

The Phobos Base may benefit from several ISRU functions. These functions can include extraction of water for life support system and habitability use and for propellant. The teams could conceptualize a system to electrolyze water into liquid oxygen (LOX) and liquid hydrogen (LH2) to provide propellant for a reusable Mars descent/ascent vehicle (DAV), including fuelling procedures. Since no such technology currently exists for use in spaceflight, and the power consumption could be massive for electrolysis (which produces gas) and the subsequent compression to liquids. Students proposing ISRU systems should consider the power demand and other costs. Another ISRU function could be to extract and process regolith material for radiation shielding, micrometeoroid protection, and to build structures. Submissions that include these aspects of ISRU use should address their equipment requirements and risks incurred based on current knowledge of materials to be used on Phobos and current maturity of the required utilization technologies.

*8. Observatories*

Phobos Base may support a variety of observatories as cited in Communications above. These observatories may address any suitable portion of the electromagnetic spectrum including infrared, radio, ultraviolet, and visible wavelengths. There may also be observatories that focus inward toward the Mars surface or the other celestial bodies of the Solar System. Teams proposing to support observatories may ask: Are these nearby, separate installations that are accessible from the base? Are they just instrument packages included as part of the base? Or do they consist of orbital platforms some distance and $\Delta v$ from Phobos.

*9. Power Systems*

The Phobos Base may deploy external energy systems such as photovoltaic panels or a nuclear system to generate electrical power. This external system includes structures to mount the power sources, to transmit it through cables to the Base, and to transform and condition it for use in the electrical service.

*10. Launch Vehicle Selection and Compatibility*

The systems and crew vehicle element dimensions as launched from Earth and the vehicle mass must be compatible with fairing dimensions and payload mass capability of the launch vehicles. The design team may select any launch vehicle or combination of launch vehicles.

*11. Location of Assembly*

The Design Team may consider and analyze various locations for construction and assembly of the Phobos Base, such as on-orbit (LEO) assembly, EML-2 assembly; Mars orbit assembly, or assembly on Phobos. These location choices and related logistics considerations act as mission cost and complexity drivers.

*12. Micrometeoroid Protection*

The Phobos Base Habitat should achieve 99.9% or higher probability of no penetration by micrometeoroids during the mission and to assure crew safety to perform a repair after such a penetration occurs.

*13. Structures and Materials*

Analyze and Select vehicle and habitat structural concepts and materials (e.g. inflatable versus rigid or hybrid, wall thickness, thermal and micrometeoroid shielding, etc.).

*14. Microgravity Countermeasures*

Provide the engineering analysis and concept for a microgravity countermeasure strategy and systems to maintain the crew in good health and fitness. The design team may consider various approaches, including exercise, medication, nutrition, and artificial gravity.

*15. Logistics and Resupply*

Estimate the amount and type of logistics and consumables resupply needed. Correlate these logistics to the launch opportunities and capacity.

**C. Engineering Deliverables**

Engineering deliverables typically involve quantitative results rather than qualitative concepts.

*1. Mass*

A Mass estimate for all elements with supporting data at each stage of transfer to Phobos is the currency by which the student designs can measure cost. Proper use of this currency enables minimizing the total mass of the Phobos Base construction, materials, equipment, and supplies (a major driver for total mission cost). Estimate the mass of launch vehicles, modules, and major equipment directly from their engineering properties. Estimate the mass indirectly for life support systems, consumables, power, thermal control, ISRU, and resupply, expressed as *equivalent system mass (ESM)* as defined in NASA/TM-2003-212278 (2012) Advanced Life Support Equivalent System Mass Guidelines Document.

*2. Timelines for:*

- Overall mission and project development, deployment, implementation, and execution over four launch windows to Mars.
- Mission operations and scheduling during a crew tour of duty comprising one launch window and return, and
- "A Day in the Life" of Phobos Base.

*3. Radiation Protection*

Define and quantify of radiation shielding approach (total habitat, specific crew quarters, emergency storm shelter, etc.), provide estimates of required mass of material involved and interactions with other design elements and crew operations. The ruling document for NASA is NASA STD-3001, Vol. IA (12 FEB 2015). *Section 4.2.10 Space Permissible Exposure Limit for Space Flight Radiation Exposure Standard.*

*4. Scientific Investigation and Experiment Agenda*

Describe and characterize the scientific exploration and experiments that the Phobos Base will enable and support. Explain this support in terms of the capabilities that the base will provide and how they integrate into the base's functions, operations, and resources.

*5. Cost*

The Design Competition will not require cost estimating as engineering deliverable. However, the design submission should cover Committee will provide a cost-estimating template with key parameters tied to cost that the teams shall use to calculate a cost figure of merit. This template will normalize the field of "cost prediction" so that one team can't lowball it just by making optimistic assumptions. The cost parameters will include, for example:

a. Number of launches and total launch mass of the launch increments. Mass stands in as a first order surrogate for cost in funding.
b. Timelines of the Phobos exploration program and the Phobos Base.
c. Number, mass, and size of modules or individual units landed on Phobos
d. Number of EVAs to set up Phobos base.
e. A metric for consumables (fuel, food, atmosphere, water, etc.) both on the initial arrivals and for logistics resupply. Comparisons of logistical resupply or production on Phobos (with attendant landed mass of production equipment) will be meaningful for measuring life-cycle cost.

*6. Logistics Expansion*

The Phobos Base promises to serve as the "doorstep to Mars." It should be able to operate as the logistics and resupply base for crew and cargo lander departure and return. The design submission should include schematic planning for the growth of Phobos Base to support humans and cargo to the Mars surface.

**D. Space Architecture**

Space Architecture encompasses the functions, habitation provisions, and crew operations of the Phobos Base. The design team should clearly indicate an architectural design thesis in their proposal such as one or more design principles applied to biological, environmental, mechanical, or physics-derived space design issues. The evaluation panel will be looking for how each team defines its assumptions and what boundaries the team establishes for a limited study -- given the available time to create a meaningful and compelling design solution. Provide a summary of your design rationale and approach to generate the design concept.

*1. Site*

The site location sits in the bottom of Stickney Crater, facing the Mars surface. The topology of Stickney Crater provides a measure of radiation shielding and micrometeoroid protection, which can be enhanced by applying additional ISRU materials. Stickney Crater may be covered with fine dust, subject to landslides, and has a diameter of 9 km. Phobos has a weak gravity (less than 1/1000$^{th}$ the gravity of Earth). For more detail, go to the NASA Solar System Phobos in Depth site.[12]

*2. Crew*

The crew capacity consists of an initial crew of six, with a planned increase to approximately 12 to 18 crewmembers to support future expansion a possible permanent Phobos Base with continuous or near-continuous occupancy. This expanded base would serve as a stepping-stone to the Mars surface. The skill mix of the crew includes pilots, mission specialists, payload specialists, scientists, engineers and medical doctors. Cross-training among the crewmembers will be essential. The crew that may consist of any mixture of men and women of any adult age, size, and weight within the nominal anthropometric range from the "5$^{th}$ percentile Japanese female" to the "95th percentile "American Male", as described in NASA Standard 3001, the NASA Space Flight Human System Standards [13] and in the NASA Anthropometric Source Book, NASA Reference Publication RP-**1024.**

The crew skill mix will require more varied and perhaps more complex skills than on ISS. Operating rovers on the surface in real time and building parts in the workshop will be new vocations requiring new skills and more crewmembers. The design teams should think beyond sizing the mission and crew to the capacity of a specific module or capsule. Instead the teams may size the spacecraft and habitat modules to fit the ECLSS needed for long duration reliability and the mission design.

*3. Safe Haven Strategy*

If crew A cannot depart from the Mars System for Earth, they must abort the mission in place (aka abort to the surface) on Phobos, a strategy first articulated in the 1997 NASA Mars Design Reference Mission, (NASA SP-6107). [14] If crew B is already en route to Phobos, then two crews must live together in the base until one or both can return to Earth. The pressurized volume and the amount of consumables stored in it should anticipate this contingency of two overlapping crews.

*4. Base Design*

The base design must incorporate countermeasures for the debilitating effects of long-term exposure to microgravity. The Phobos base design will be strongly influenced by your team's choice of integrated countermeasures for microgravity deconditioning, dust exposure, and space radiation exposure. The base provides the living and working spaces and all other accommodations to sustain the crew and effectively support them in accomplishing mission objectives. The effects of countermeasures chosen e.g. added mass and mass distribution requirements, operational impacts of shielding and microgravity counter-measures selected, etc., should be clearly defined and addressed in your submission. Any solution involving a moving system must account for it into the crew safety strategy, including crew translating (moving) between sections that may move relative to one another.

*5. Spacecraft Docking Port(s)*

The design should provide pressurized docking ports for both Earth-Phobos transit spacecraft and smaller local exploration craft used as Phobos surface "rovers" (potentially free flying given Phobos' minimal gravity.)

[12] http://solarsystem.nasa.gov/planets/phobos/indepth

[13] https://www.nasa.gov/hhp/standards. As of 2015, NASA STD-3001 supercedes the predecessor NASA STD-3000, the Man Systems Integration Standard (MSIS), although MSIS remains a valuable reference work in many technical areas.

[14] Defined in Hoffman, Stephen J.; Kaplan, David I.; Eds. (1997). Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team, (NASA SP-6107). http://spacecraft.ssl.umd.edu/design_lib/NASA-SP6107.Mars_DRM.pdf, and its source materials (e.g. Stoker, Carol; Emmart, Carter; Eds, (1995). *Strategies for Mars: A Guide to Human Exploration* (American Astronautical Society, Science and Technology Series, Vol. 86, p. 465-512). San Diego, California, USA: Univelt, Inc.)

*6. Space Habitat Living and Working Environment*

The Habitat design includes the definition of the overall volume, configuration, and layout including a discussion of habitability features and relationships among mission operations, logistics, crew interaction and private functions. The Space Habitat is comprised of one or more modules, their assembly and layout concept.

The spatial and volumetric requirements for the Living and Working Environment appear in Appendix A, TABLE 1. These requirements represent the architectural design program. The crew will live in the pressurized environment that is supported by the environmental control and life support system, which may include both physical/chemical and bioregenerative aspects.

*7. Design of the Habitat Interior*

The design of the habitat interior should be visually coherent and cohesive, with clear system-vertical or local vertical orientation. Habitability accommodations and outfitting are the primary medium by which the Phobos base supports crew health and sanitation (control of infectious microbes, odors, and waste materials or fluids), productivity, safety, and crew psychological well-being and mental health. Habitability considerations include acoustics and control of noise to International Standards Organization (ISO) designated limits. Quantitative requirements for the pressurized volume of the habitable modules appear in Appendix A, TABLE 1.

*8. Human Factors and Ergonomics*

The design teams must consider and accommodate human factors principles in design. For example, if sustained artificial gravity is a chosen counter-measure, among the most critical issues are its operational impact and human vestibular responses, which are closely linked in this case whereas if that is not a chosen path, the design must consider and address human factors for all required operations in a microgravity environment. Another example is that, there are human factors consideration in designing a medical support facility that includes a unit for crew infection control, emergency surgery, and the possibility of crew physical and mental dysfunction. Both the medical support facility and the recreation facility should be approached comprehensively to enable not only physical recreation and monitored exercise, but also consider a sensory stimulation unit for such human factors including auditory (balance and noise), olfactory (degraded sense of smell), visual, and tactile sensations and responses. Apply “best practices” for human factors and ergonomics. This discipline includes creating a consistent system of vertical orientation cues throughout the habitat volumes, although it may change reference frames between modules or sections of the base.

### E. Space Architecture Deliverables

The Space Architecture deliverables consist largely of the drawings, models, and renderings to describe the Phobos base and its elements, both as an ensemble and in terms of the modularity of its components. These drawings should make explicit the scope and attributes of the habitable living and working environment for the crew and the interface between the habitat/base and visiting spacecraft.

## V. Conclusion

The process of developing the Phobos Base design brief created a remarkable interdisciplinary collaboration between the two AIAA Technical Committees, Space Architecture and Life Sciences and Systems. The participants engaged in lengthy discussions of what would be essential and would be unnecessary to include in the design brief. There was an ever-present temptation and risk of over specifying the requirements or other design considerations. Some members fought a battle against including too much material, while other members continued to gather more material even after the allowable page length from the AIAA began to limit the contents. These discussions led to several major revisions of the design brief, with a final rewrite nearly from scratch to piece the essentials together within the page length.

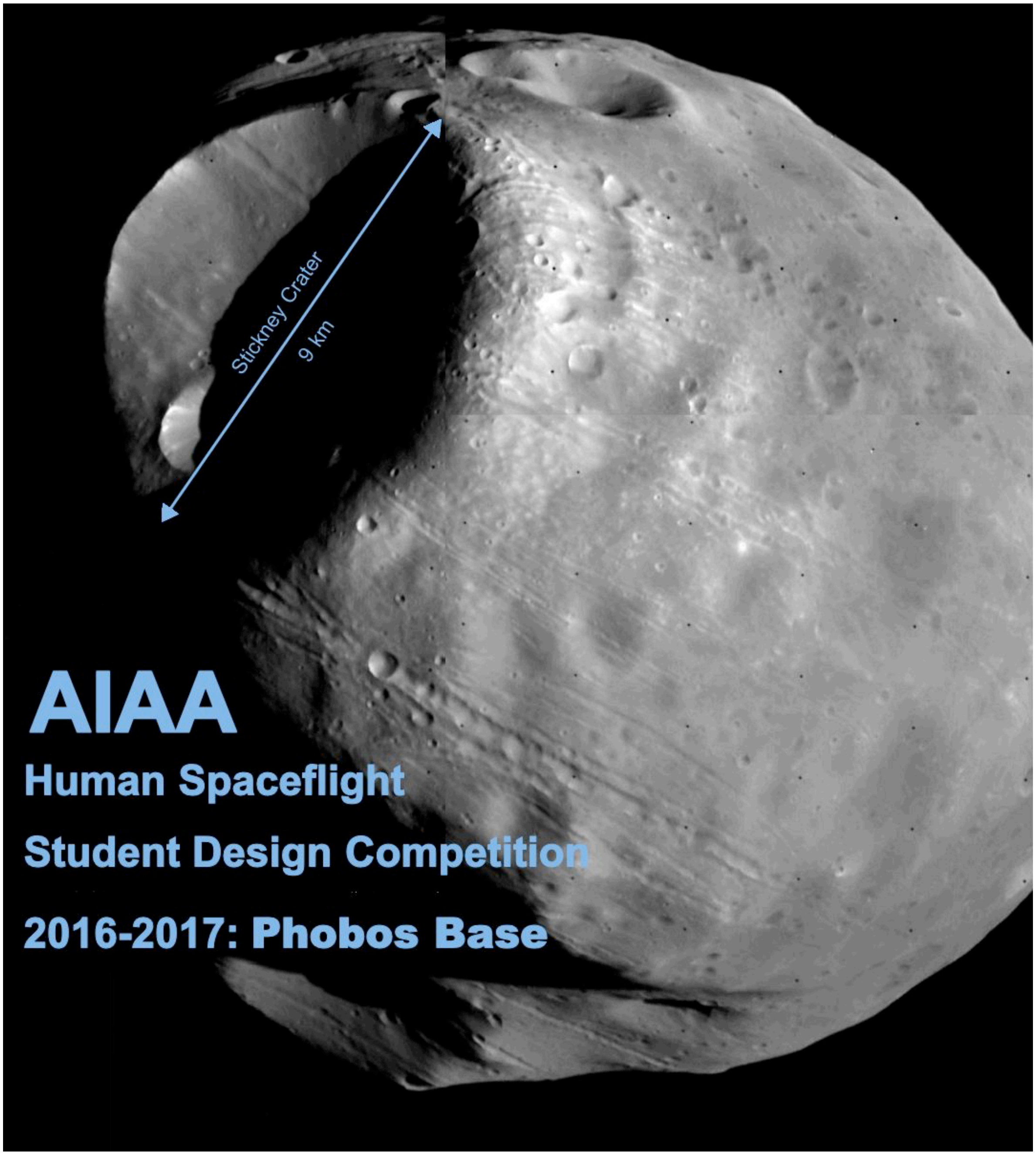
This process of coordination and collaboration was very fruitful for the participants. It gave them a rare opportunity to see the priorities of the other discipline(s), and to hear how the “other side” articulates it perspectives and objectives. In the end, the design brief constitutes a consensus between Space Architecture and Life Sciences and Systems as to what are the important parts of planning and designing a human mission to Phobos, and beyond Phobos to Mars.

## Appendix A

### The Phobos Base Design Brief

The Phobos Base Design Brief as submitted to the AIAA, February 10, 2016. For the current version, please go to the AIAA website:

In the event of any disagreement in the text, the RFP on the website above governs the student design competition.
https://www.aiaa.org/DesignCompetitions/




**Mars Reconnaissance Orbiter (MRO) view of Phobos, featuring the Mars-facing Stickney Crater. Although black and white, this photo gives a good approximation of the dark gray color of the Phobos surface.**

## 1. Opportunity Description

One of the greatest challenges for designing a human mission to Mars and sustaining it from the Earth over many varying synodic cycles is how to deploy and stage the lander descent and ascent modules and overall logistics from Mars orbit. For the human exploration of the Mars surface to become reliably repeatable, an orbital platform would be ideal. Fortunately, Mars boasts two moons, Phobos and Deimos, each with the potential to serve as the "gateway to Mars." As the USA and other countries contemplate the design of human missions to Mars, the best first step may prove to be establishing an exploration, transportation, and logistical support base on Phobos.

This Competition addresses how to advance human life support capabilities, space architecture, life science countermeasures, transportation system support, and the engineering for all these disciplines for the exploration of Phobos and the cis-Mars system. The Phobos infrastructure can then serve as the jumping-off point for the eventual human exploration of the Martian surface.

Phobos is believed by some planetary scientists to be a captured carbonaceous chondrite asteroid that may contain as much as 13 percent water by mass. The design of the Phobos Base and its systems may consider the possibility of obtaining consumables and materials through the in situ resource utilization (ISRU) potential there. The potential to exploit these in situ resources may create a profound impact upon the design of Phobos Base.

## 2. Project Objective

The objective of this project is to produce an integrated, multidisciplinary design solution for a base on Phobos to enable the human exploration of the cis-Mars System, including arrival from Earth and return to Earth plus routine descent to the Mars surface and return to Phobos.

## 3. General Design Requirements And Constraints

The student team (class) shall design a Phobos Base for astronaut crews to meet the following objectives:

### 3.1 Site

The construction site for Phobos Base is Stickney Crater.

### 3.2 Spaceflight Assumptions

The Phobos Base architecture, operations, and timeline shall assume that spacecraft may arrive from Earth at every potential launch window for every class of mission (e.g. conjunction class, opposition class, Aldrin cycler class, etc.) for lowest energy (Hohmann) transfers and other possibly higher energy transfers.

### 3.3 Crew and Crew Protection

Phobos Base can accommodate 12 crewmembers at any time, given the assumed NASA Mars Design Reference Architecture 5.0 for a crew of six to land eventually on the surface and a potential replacement crew in transit.
The skill mix of the crew includes pilots, mission specialists, payload specialists, scientists, engineers and medical doctors. Cross-training among the crewmembers will be essential. The crew that may consist of any mixture of men and women of any adult age, size, and weight within the nominal anthropometric range from the "5$^{th}$ percentile Japanese female" to the "95th percentile "American Male", as described in http://msis.jsc.nasa.gov/, and the NASA Anthropometric Source Book, NASA Reference Publication **1024.**

The crew skill mix will require more varied and perhaps more complex skills than on ISS. Operating rovers on the surface in real time and building parts in the workshop will be new vocations requiring new skills and more crewmembers.

The Phobos Base will provide a safe haven for the crew against all credible risks, reducing the hazards "as low as reasonably achievable" on the ALARA principle. At a minimum the base should be capable of protecting a crew to keep them healthy, productive, and safe for the longest conjunction class mission in an Earth-Mars synodic cycle. Ideally, the base will protect the crew through one missed return window to the next return opportunity.

### 3.4 Delivering Payloads

Although the mission design is not the primary focus of the Phobos Base competition, the design team needs a clear concept for delivering payloads to Phobos and how to accomplish the base construction consistent with the crew and robotic capabilities. The mission design integrates with both Space Architecture and Engineering, while fitting within several broad constraints. These constraints include mass to LEO; launch frequency, trajectory, and arrival at the Mars system. Each payload mass may range from 70 to 130 metric tonnes launched to LEO. Mission design relates closely to the External Functions that provide many of the capabilities needed to perform the mission objectives.

**3.5 External Environment**

The base connects to the external environment through a variety of interfaces and instruments. These connections encompass the physical, structural connection between Phobos Base and the Phobos surface, the operational connections for Extravehicular Activity (EVA), proximity operations, and local flight, and the instrumentation installed in situ. The operations include exploration, set-up of external utilities and equipment, plus resource extraction and refinement processes.

**3.6 Life Support**

A regenerative environmental control and life support system (RECLSS) is central Phobos Base. It is essential to maintaining:

1. A healthy and safe atmosphere,
2. Potable water supply,
3. Waste recovery and treatment processes,
4. Contaminant control detection and for air and water,
5. Humidity control,
6. Thermal control and waste heat rejection,
7. Clothes washing, and
8. Fresh food production for 50 percent of the crew's diet.

The remaining food shall arrive from Earth in freeze-dried or other preserved forms. Incorporate trade and analysis studies to explain and justify the choice of technologies and subsystems in the context of their integration and operation.

**3.7 Life Science Provisions**

Life Science provisions include microgravity countermeasures, radiation protection, dust and other contaminant exclusion and control, and planetary protection (forward and backward) throughout the crew tour of duty.

**5. Space Architecture Design Criteria.**

Space Architecture encompasses the living and working functions, habitation provisions, and crew operations of the Phobos Base. Habitability design means that the living and working environment supports crew health, productivity, teamwork, and overall well-being.

**5.1 Quality of the Living and Working Environment**

The design of habitable modules and other IVA sections of the base should support the crew by providing a comfortable, pleasant, visually interesting, and easily readable environment.

**5.2 Habitability and Habitation**

The Space Architecture of the base organizes the habitability accommodations and functions. It makes distinctions among "public" areas (galley, wardroom, gymnasium, workplaces, etc.) and private areas (sleep quarters, hygiene facilities, etc.) and any rooms or functions that may fall in between public and private.

**5.3 Functional Space Planning**

Space Architecture organizes the arrangement of functions based upon needs for proximity, separation, crew activities, and work process flows.

**5.4 Physical Integration**

Space Architecture integrates the RECLSS and utility systems (power, data, water, thermal loops, etc.) into the living and working spaces in a consistent, unobtrusive, and visually compatible manner.

| TABLE 1: Phobos Base Pressurized Volume Requirements | | |
|---|---|---|
| **Required Function** | **Gross Volume, $m^3$** | **Remarks** |
| 1a. Regenerative ECLSS physical/chemical | 25 to 50 | Includes redundancies |
| 1b. Regenerative ECLSS, bioregenerative. | 400 | Includes growing food |
| 2a. EVA airlock system, including docking to a pressurized roving vehicle to explore the Phobos surface (x2) | 100 | For Both EVA Airlocks. Includes all spacesuit checkout, maintenance, repair, and spare parts. |
| 2b. 2 Docking systems for the Interplanetary Vehicle (IPV) & Descent/Ascent Vehicle | 400 | Access, and bulk cargo in addition to crew. |
| 3. Operation stations to control rovers on the Mars surface in real time. | 20 | Includes a virtual reality display system (not just headsets). |
| 4. Astrobiology lab to analyze samples returned from the Mars surface. | 120 | Includes Bio isolation Level 4 and decontamination capability. |
| 5. Astronomical observation station | 10 | Operate telescopes, instruments on Phobos or in Mars Orbit. |
| 6. Mars direct observation station(s) | 20 | Meteorology, geology, hydrology, etc. |
| 7. Group Activities Area | 150 | |
| 7a. Galley | Included in 7 | Food preparation and storage, “dish washing.” |
| 7b. Wardroom (dining and meeting) | Included in 7 | Dining and meeting area. |
| 7c. Recreation | Included in 7 | Quiet |
| 7d. Exercise | Included in 7 | Acoustical separation from other rooms |
| 8. 12 Private Crew Quarters, with access/ circulation. | 70 | Acoustical isolation and additional radiation protection. |
| 9. Hygiene, sanitary, waste management, and laundry facilities | 60 | Includes showers, toilets, and hand washing. |
| 9a. 3 Toilets | Included in 9 | Acoustical isolation. One associated with EVA support. |
| 9b. 4 hand washing stations | Included in 9 | At least one associated with lab and workshop. |
| 9c. 2 showers w/ dressing area | Included in 9 | One associated with EVA support systems. |
| 9d. Laundry | Included in 9 | Acoustical isolation. |
| 10. Medical Facility with outpatient and inpatient accommodations. | 35 | Includes telemedicine equipment, including surgical robot. |
| 11. Workshop | 150 | Fabrication and Repair |
| 12. Microgravity Countermeasures | 100 to 250 | Design team’s choice |
| 12. Optional/Discretionary, Circulation | 400 | Allocate as desired |

## 6. Engineering Criteria

In addition to evaluating how completely and consistently the submitted designs fulfill the requirements of the Design Brief; the judging panel will evaluate the quality of the design engineering. The design engineering criteria apply to nearly all aspects of the Phobos Base design. The Major design engineering criteria include:

### 6.1 Safety Strategy

Articulate a safety strategy that ensures a highly reliable and fault tolerant system.

### 6.2 Payload Compatibility

Explain and document launch vehicle selection and compatibility with the Phobos Base payloads,

### 6.3 Assembly

Designate the Location of Assembly, based on a trade study of the assembly process and where best to conduct it to assemble the payload components of Phobos Base (e.g. LEO vs. EML2 vs. Mars orbit vs. on Phobos).

### 6.4 Critical Life Support Functions

The RECLSS maintains critical life support functions through any two failures.

### 6.5 EVA Systems

The EVA systems integrate with the RECLSS. EVA Systems provide access to all external portions of Phobos Base and its Spaceport, and a means for exploring Phobos.

### 6.6 Structural Systems

The design of the Base and habitat structures for primary pressure vessels, trusses, connections, anchorage to the surface, and any secondary structures shall accommodate the appropriate design loads within a margin of safety consistent with the safety strategy.

### 6.7 Micrometeoroids

Micrometeoroid protection: achieve 99.9% or higher probability of no penetration by micrometeoroids during the mission and to assure crew safety to perform a repair after such a penetration occurs.

### 6.8 Logistics

Logistics and resupply: Estimate the amount and type of logistics and consumables resupply needed. Correlate these logistics to the launch opportunities and capacity.

### 6.9 Crew Transfer

Crewmember transfer among all the modules and sections of the base shall be safe and supported by pressurized systems (RECLSS or EVA). However, the need for EVA transfer between pressurized environments should be kept to a minimum.

## 7. Elements and Subsystems

The Phobos Base Project includes the following elements and subsystems:

### 7.1 Pressurized Modules

Habitat and laboratory pressurized modules to accommodate the functions in TABLE 1, including docking or berthing systems, nodes, connectors, and their mechanisms as needed to arrange the base ensemble.

### 7.2 Spaceport

The Spaceport provides the Mars docking system for interplanetary vehicles and descent/ascent vehicles. Includes a propellant depot and fueling systems that may be refilled from tankers from elsewhere or from ISRU. Provide a means for crew to move safely from the habitat to the spaceport docking and logistics areas.

**7.3 RECLSS**

The Regenerative Environmental Control and Life Support System is a central organizing function for the base.

**7.4 EVA Systems**

The EVA systems include airlocks, suits, portable life support systems (PLSS), and pressurized or unpressurized mobility systems.

**7.5 Power and Utility**

Power generation systems and utility connections to the base and spaceport comprise part of the site plan. Estimate electrical power demand and distribution requirements.

**7.6 ISRU**

In Situ Resource Utilization from Phobos or elsewhere can contribute consumables to the RECLSS and materials for other base systems.

## 8. Data Requirements

The final proposal report shall provide an overall engineering description of the design concept and detailed design information for major components and subsystems. The Design Team shall submit a report that provides a narrative describing the project that tells the story of the Phobos Base design, giving the reasons for each significant aspect of the design. Describe the risks, advantages, and potential disadvantages of design decisions. Where the team considered alternative solutions, describe them and explain the selected solution. Each section from 6 through 12 should include a trade and analysis study. The report shall follow this outline and include the following sections in this order.

1. Abstract
2. Brief Introduction to the Project.
3. Requirements analysis and interpretation.
4. Concept key features including Architecture, Engineering Systems, Infrastructure, Life Science Provisions, Regenerative Life Support, Timelines, and Trajectories.
5. Interplanetary Transfer:
    - 6.1 From Earth to the Mars System,
    - 6.2 Approach to Phobos,
    - 6.3 Arrival at Phobos.
    - 6.4 Delivery and landing of payloads.
6. Base assembly and construction process (assuming a role for robotics).
7. Space Architecture of the Base including airlocks, connectors, modules, nodes, structures utility routing. Provide schematic site plan, plans, sections, elevations, and renderings.
8. RECLSS Engineering schematics, mass flow estimates, equivalent system mass calculations, and subsystem selection and design. Include estimates for resupply of all consumables and ISRU potential contribution.
9. Life Science Countermeasures:
    - 10.1 Microgravity,
    - 10.2 Radiation,
    - 10.3 Dust and contaminants,
    - 10.4 Planetary Protection.
10. Arrival of the crew.
    - 11.1 Crew transfer from the Interplanetary Vehicle (IPV) to the habitat,
    - 11.2 Process by which the crew activates and verifies the base,
    - 11.3 Further assembly, construction, and outfitting under crew supervision.
11. Concept of Operations for completed Phobos Base, including the Spaceport. Systems that are unique to the proposed design should be addressed in considerable detail. Subsystems that are not the focus of this project do not require as much attention.

12. Other/Optional
13. Critical technologies and their current Technology Readiness Level (TRL).
14. Conclusion: Summary of the design with a concise review of the outcome.
    - 14.1 What does the team's design achieve?
    - 14.2 What were they unable to achieve? Why?
    - 14.3 What should space mission designers do differently in the future?
    - 14.4 What exploration program should follow the successful implementation of Phobos Base?
    - 14.5 What opportunities does the team see for future research?

## 9. Additional Contacts

All technical questions pertaining to this RFP should be directed to Donna Rodman, oceanspirit@telus.net or her alternate Nancy Hall. nancy.r.hall@nasa.gov. Any updates to this RFP will be posted on the AIAA Space Architecture Technical Committee web site, which can be accessed directly at http://spacearchitect.org.

## 10. References:

Full references will be posted to http://www.spacearchitect.org.

**General References** (download links at http://spacearchitect.org/pubs/pub-biblio.htm):


C. Stoker, C. Emmart (Eds.), *Strategies for Mars: A Guide to Human Exploration* (American Astronautical Society, Science and Technology Series, Vol. 86, p. 465-512). San Diego, California, USA: Univelt, Inc.

Cohen, Marc M. (2009 April). Testing the Celentano Curve: An Empirical Survey of Predictions for Human Spacecraft Pressurized Volume (SAE 2008-01-2027). In, *SAE International Journal of Aerospace* (vol. 1, no. 1, p. 107-142). Warrendale, Pennsylvania, USA: Society of Automotive Engineers.

Drake, Bret G. (2009 February). *Human Exploration of Mars: Design Reference Architecture 5.0 (NASA-SP-2009-566).* Houston, Texas, USA: Johnson Space Center, National Aeronautics and Space Administration.

Häuplik-Meusburger, Sandra (2011). *Architecture for Astronauts: An Activity-Based Approach.* New York, New York, USA: Springer.

Hoffman, Stephen J.; Kaplan, David L. (Eds.) (1997 July). *Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team* (NASA SP-6107). Houston, Texas, USA: Johnson Space Center, National Aeronautics and Space Administration.

Howe, A. Scott; Sherwood, Brent (Eds.) (2009). *Out of This World: The New Field of Space Architecture*. Reston, Virginia, USA: American Institute of Aeronautics and Astronautics.


**Standards** (to be posted to www.spacearchitect.org)**:**


Hanford, Anthony J. (Ed.) (2004 August). *Advanced Life Support Baseline Values and Assumptions Document* (NASA CR-2004-208941). Washington, DC, USA: National Aeronautics and Space Administration.

Levri, Julie A. et al (2003). Advanced Life Support Equivalent System Mass Guidelines Document (NASA TM-2003-212278) Moffett Field CA: NASA Ames Research Center.

Mankins, John C. (1995). Technology Readiness Levels, A White Paper. Washington DC: NASA HQ. https://www.hq.nasa.gov/office/codeq/trl/trl.pdf.

McPhee, Jancy; Charles, John B. (2009). Human Health and Performance Risks of Space Exploration Missions (NASA SP-2009-3405). Washington DC: National Aeronautics and Space Administration.

NASA (2010, Jan 27). Human Integration Design Handbook (HIDH) NASA/SP-2010-3407. Washington DC: National Aeronautics and Space Administration.

NASA (1995 July). *Man-Systems Integration Standards* (NASA STD-3000, Revision B). Washington, DC, USA: National Aeronautics and Space Administration.

NASA (2006, December 15). Constellation Program Human Systems Integration Requirements (HSIR). (NASA-CxP 70024), Houston TX: Johnson Space Center.

## 11. Rules and Guidelines

**11.1 General Rules**

1. There are two divisions for this competition: undergraduate and graduate. A School may submit undergraduate or graduate proposals or both, however undergraduate and graduate students may not serve on the same team. All AIAA student branches or at-large Student Members are eligible and encouraged to participate.

2. Teams will be groups of not more than ten AIAA or at-large Student Members per entry.

3. The report in Adobe PDF format must be submitted online to AIAA Student Programs. Total size of the file(s) cannot exceed 60 MB, Projects should be no more than 100 (total) double-spaced pages and typeset should be no smaller than 10pt Times (including graphs, drawings, photographs, and appendices). Up to five of the 100 pages may be foldouts (11"x17" max).

The file title should include the team name and university. A "Signature" page must be included in the report and indicate all participants, including faculty and project advisors, along with their AIAA member numbers. Designs that are submitted must be the work of the students, but guidance may come from the Faculty/Project Advisor and should be accurately acknowledged. Graduate student participation in any form is prohibited.

4. Design projects that are used as part of an organized classroom requirement are eligible and encouraged for competition.

5. More than one design may be submitted from students at any one school.

6. If a design group withdraws their project from the competition, the team chairman must notify AIAA Headquarters immediately.

7. Final monetary awards will be determined pending funding availability. It is estimated that the minimum prizes shall be: First place-$500; Second place-$250; Third place-$125 (US dollars). Certificates will be presented to the winning design teams for display at their university and a certificate will be presented to each team member and the faculty/project advisor.

**11.2. Copyright**

All submissions to the competition shall be the original work of the team members.
Any submission that does not contain a copyright notice shall become the property of AIAA. A team desiring to maintain copyright ownership may so indicate on the signature page but nevertheless, by submitting a proposal, grants an irrevocable license to AIAA to copy, display, publish, and distribute the work and to use it for all of AIAA's current and future print and electronic uses (e.g. "Copyright © 20__ by _____. Published by the American Institute of Aeronautics and Astronautics, Inc., with permission.).
Any submission purporting to limit or deny AIAA licensure (or copyright) will not be eligible for prizes.

**11.3. Schedule & Activity Sequences**

Significant activities, dates, and addresses for submission of proposal and related materials are as follows:

**A. Letter of Intent – February 10, 2017**
**B. Student Teams Submit Proposals to AIAA Design Competition Office April 10, 2017**
**C. The AIAA Design Competition Office submits deliverables to the Space Architecture Technical Committee and the Life Sciences & Systems Technical Committee for Evaluation April 30, 2017**
**D. Winners Announced – June 1, 2017**
**E. Presentation of Awards at the 47th International Conference on Environmental Systems in Charleston, SC – July 10 to 14, 2016. https://www.ices.space/**

**11.4 Proposal Requirements**

The technical proposal is the most important criterion in the award of a contract. It should be specific and complete. While it is realized that all of the technical factors cannot be included in advance, the following should be included and keyed accordingly:

1. Demonstrate a thorough understanding of the Request for Proposal (RFP) requirements.

2. Describe the proposed technical approaches to comply with each of the requirements specified in the RFP, including phasing of tasks. Legibility, clarity, and completeness of the technical approach are primary factors in evaluation of the proposals.

3. Particular emphasis should be directed at identification of critical, technical problem areas. Descriptions, sketches, drawings, systems analysis, method of attack, and discussions of new techniques should be presented in sufficient detail to permit engineering evaluation of the proposal. Exceptions to proposed technical requirements should be identified and explained.

4. Include trade and analysis studies performed to arrive at the final design.

5. Provide a description of automated design tools used to develop the design.

**11.5. Basis for Judging**

*1. Technical Content (35 points)*

This concerns the correctness of theory, validity of reasoning used, apparent understanding and grasp of the subject, etc. Are all major factors considered and a reasonably accurate evaluation of these factors presented?

*2. Organization and Presentation (20 points)*

The description of the design as an instrument of communication is a strong factor on judging. Organization of written design, clarity of the language, and inclusion of pertinent information are major factors.

*3. Originality (20 points)*

The design proposal should avoid standard textbook information, and should show independence of thinking or a fresh approach to the project. Does the method and treatment of the problem show imagination? Does the approach show an adaptation or creation of automated design tools?

*4. Practical Application and Feasibility (25 points)*

The proposal should present conclusions or recommendations that are feasible and practical, and not merely lead the evaluators into further difficult or insolvable problems.

# APPENDIX B

## Additional References

Le Maistre S., Rosenblatt P., Rambaux N, Castillo-Rogez J.C., Dehant V, and Marty J.C. Phobos interior from librations determination using Doppler and star tracker measurements. Planetary and Space Science, 85, 106-122, DOI: 10.1016/j.pss.2013.06.015.

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Interior', Rings and satellites Workshop).

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# APPENDIX C

## SETI Institute Lectures Online

Race, Margaret (2015, Sept. 15). Very long term planning integrating planetary protection for human missions, a lecture at the SETI Institute.
http://www.seti.org/weeky-lecture/very-long-term-planning-integrating-planetary-protection-human-missions

Despite decades of experience with human missions in low Earth orbit (LEO), we have only scant, outdated information applicable to human missions to planetary surfaces, where contamination concerns and planetary protection requirements raise unusual challenges. It has been over 40 years since the Apollo program dealt with the challenges of humans living, exploring and returning from the surfaces of celestial bodies.

Dr. Margaret Race discusses how changes in science, technology and policies are impacting future human exploration plans. Developing the necessary infrastructure, habitats, spacesuits, rovers, operations and plans for human missions beyond LEO is a very long term process, and the identification of strategic knowledge gaps in science and technology is an important part of the incremental path forward.

Lee, Pascal (2014, June 3). Mission to Phobos and Deimos: Exploring the Moons of Mars, A lecture at the SETI Institute.
http://www.seti.org/weeky-lecture/mission-phobos-and-deimos-exploring-moons-mars-0

After five decades of spacecraft exploration of the Solar System, the origin of two moons of Mars, Phobos and Deimos, remains a perplexing mystery. Are they a) captured asteroids, b) remnants of Mars's formation, or c) reaccreted impact ejecta from Mars? These small bodies lie at the crossroads of a wide range of outstanding issues in solar system research, and elucidating their origin tests our understanding of planet formation and solar system evolution, including the question of how water and organics became available on Earth. Meanwhile, Phobos and Deimos are emerging as key stepping stones in the future human exploration of Mars. Dr. Lee's talk will cover the history of our efforts to understand Phobos and Deimos, and new prospects in their exploration.

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