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Moon to Mars eXploration Systems and Habitation (M2M X-Hab) Academic Innovation Challenge – FY21 Solicitation

on behalf of

NASA Headquarters
Human Exploration & Operations Mission Directorate

Sponsored by:

The Advanced Exploration Systems (AES) Division

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Proposals Due:	April 24, 2020
Anticipated Award Date:	May 26, 2020
Program Website:	https://www.spacegrant.org/xhab/

M2M X-Hab 2021 Academic Innovation Challenge Solicitation

1. Funding Opportunity Description – Synopsis

The Moon to Mars eXploration Systems and Habitation (M2M X-Hab) 2021 Academic Innovation Challenge is a university-level challenge designed to develop strategic partnerships and collaborations with universities. It has been organized to help bridge strategic knowledge gaps and increase knowledge in capabilities and technology risk reduction related to NASA's vision and missions. *In 2016, the X-Hab Challenge scope was formally extended to include other areas of Exploration Systems as well as habitation topics*. The competition is intended to link with senior- and graduate-level design curricula that emphasize hands-on design, research, development, and manufacturing of functional prototypical subsystems that enable functionality for space habitats and deep space exploration missions. NASA will directly benefit from the challenge by sponsoring the development of innovative concepts and technologies from universities, which will result in novel ideas and solutions that could be applied to exploration.

The Advanced Exploration Systems (AES) Division will offer multiple awards of $15k - $50k each to design and produce studies or functional products of interest to the AES Division (see Section 3.2, Moon to Mars (M2M) *X-Hab Proposal Topic List*) as proposed by university teams according to their interests and expertise. The prototypes produced by the university teams (examples of which are shown in Figure 1) may be integrated into existing NASA-built operational prototypes. Universities interested in participating will submit M2M X-Hab proposals, which will be reviewed by technical experts; subsequent down-selection will determine which projects will be funded. M2M X-Hab university teams will be required to complete their products for evaluation by the AES Division in May 2021. Universities may form collaborations to perform as a single distributed project team.

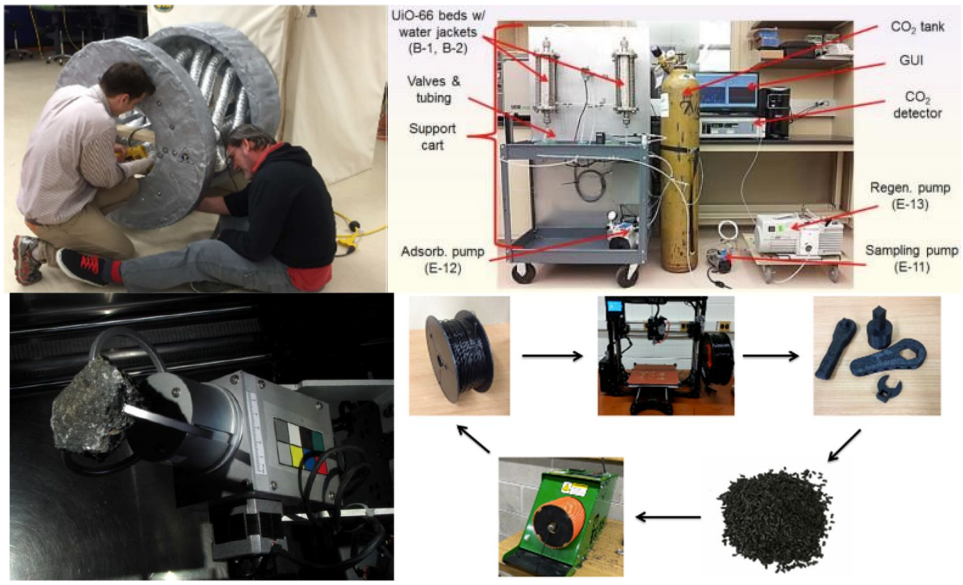


Figure 1: Previous X-Hab Projects (from top left, clockwise): Deployable Airlock, Closed Environment Air Revitalization System Based on Metal Organic Framework Adsorbents, Carbon-fiber/Fused Deposition Modeling Spacecraft Structural Fabrication System, Sample Handling System for GeoLab Glovebox (Image credit: NASA).

Students in the Critical Path: The M2M X-Hab Academic Innovation Challenge has a unique approach to student involvement, in that the student team is placed in the NASA mission critical path for the product or technology that they develop alongside NASA researchers. Teams are required to go through a series of NASA-standard assessments as other NASA engineering products, including a System Definition Review (SDR), a Preliminary Design Review (PDR), and a Critical Design Review (CDR). With this approach, NASA is putting a great deal of responsibility on the students. This in turn gives the students a bigger stake in the development of space technologies that likely will form the basis for future systems and technologies that will be flown in space.

2. Eligibility

Proposals will be accepted from faculty who are U.S. citizens and currently teach an Accreditation Board for Engineering and Technology (ABET)-accredited engineering senior or graduate design, industrial design, or architecture curriculum teaming course at a university affiliated with the National Space Grant College and Fellowship Program, or other US accredited university. Multidisciplinary, multidepartmental, and/or multi-institutional teaming collaborations are highly encouraged.

Historically Black Colleges and Universities, Tribal Colleges, and other minority-serving educational institutions are particularly encouraged to apply. Proposals from women, members of underrepresented minorities groups, and persons with disabilities are highly encouraged.

In order to fully comply with the United States Department of Commerce, Bureau of Industry and Security (BIS) Export Administration Regulations (EAR), *participation in the M2M X-Hab program by citizens of controlled countries, as defined in Part 768.1.d is prohibited*. This restriction applies to all faculty members, staff, students, consultants, and any other individual that participates in the M2M X-Hab program. For the current "Controlled Countries" list, reference EAR Part 768.1d

3. Funding Opportunity Description - Details

3.1 Description

NASA's multicenter AES Division is requesting proposals for the Moon to Mars eXploration Systems and Habitation (M2M X-Hab) 2021 Academic Innovation Challenge. The M2M X-Hab Challenge is a university-based challenge to provide real world, hands-on design, research and development opportunities to university teams. Teams will design, manufacture, assemble, test, and demonstrate functional prototypical subsystems and innovations that enable increased functionality for human space exploration missions. The projects and products of the challenge will be evaluated by NASA subject matter experts currently working in the topic area and may be integrated into prototypes for the purpose of operational and functional evaluation opportunities. Alternatively, the products of the challenge may be used in other NASA studies or analyses of exploration architectures. In previous X-Hab rounds, products have been tested and evaluated at NASA's Johnson Space Center (JSC), Marshall Space Flight Center (MSFC), Kennedy Space Center (KSC), NASA's Desert Research and Technology Studies (D-RATS) analog field tests, and school campuses. The products and technologies produced by the universities for the M2M X-Hab 2021 challenge may be improved upon for next-generation

exploration systems, and may eventually provide the basis for future flight demonstrations and exploration missions.

NASA's AES Division is inviting university faculty who teach design courses to submit proposals for a two-semester design course based on a topic that is congruent with the faculty members' interests and the topic list provided in Section 3.2. Design projects are intended to stimulate undergraduate and graduate research on current NASA exploration activities and to bring forth innovative ideas that can be used to complement those currently under development at NASA field centers. Additionally, such academic involvement will provide a hands-on space systems project development experience to enhance the scientific, technical, leadership, and project management and participation skills for the selected student teams, thereby improving the prospects for graduates to pursue additional studies and to seek careers in the space industry. The design courses should be related to existing or planned exploration systems and missions.

The selected project teams will implement the design course during the fall 2020 and spring 2021 semesters. Applicants are required to apply a systems engineering approach in the design course. For reference, please see the NASA Systems Engineering Handbook NASA SP-2007-6105. Further, all teams must provide proof that the course has been approved to be taught at their institution and the selected professor must be available for technical assistance to the implementing university team in 2020-2021 academic year.

NASA understands that the funding awarded to manufacture some test articles may not be sufficient; thus, NASA may require teams to obtain supplemental sponsored or leveraged funding from university sources or industry partners in order to design, manufacture, assemble, test, and demonstrate a functional and operational test article. Any savings from reducing or waiving overhead costs at universities may count as leveraged funding in the proposals. Additionally, the supplemental funding may enable the teams to enhance the quality or scope of the proposed work. As part of this solicitation, universities are encouraged to seek additional, innovative sponsorships and collaborations (project teaming) with other universities and organizations (including institutional support, industry, space grant consortia, etc.) to meet the design requirements and test objectives. Each proposal must include a signed letter of commitment from the university faculty, collaborators, and their potential sponsor(s) to ensure their commitment to the project.

The following project review milestones will take place with participation from the NASA Project Team, for the awarded university projects (dates are approximate):

- 08 Oct 2020 – Requirements and System Definition Review (SDR)
- 11 Nov 2020 – Preliminary Design Review (PDR)
- 21 Jan 2021 – Critical Design Review (CDR)
- 11 Mar 2021 – Progress Checkpoint Review
- 06 May 2021 – Project Completion and Evaluation by NASA

Additional information on the listed reviews is found in Appendix E: *NASA Review Requirements and Checklists*

Interactions with NASA personnel are not limited to these meetings. Additional meetings for more technical interchange can be requested by the teams but are not required as a milestone.

3.2 M2M X-Hab Proposal Topic List

Proposals addressing the following topics will be given priority consideration. Proposals that address other areas in direct support of the Advanced Exploration Systems Division will also be considered. Detailed topic descriptions are located in Appendix B.

Project Sponsor: AES Life Support Systems

- Project Title: Thermal Radiator for CO2 Deposition in Deep Space Transit

Project Sponsor: Space Life and Physical Science Research and Applications

- Project Title: Volume Optimization and Thermal Control for Food Product During Deep Space Exploration

Project Sponsor: AES NASA Platform for Autonomous Systems (NPAS) Project

- Project Title: Voice Interactions Management of Gateway

Project Sponsor: Near Earth Asteroid (NEA) Scout project, which is a solar sail mission to explore a Near Earth Asteroid

- Project Title: High-efficiency, Low-Mass, Low-Cost Mars Propulsion Technology for X-Hab

For reference information on the sponsoring projects at NASA, please refer to the NASA Techport database at http://techport.nasa.gov.

For specific Advanced Exploration Systems projects, visit here

For additional information on Space Life and Physical Sciences, visit here

For additional information on Strategic Knowledge Gaps to improve human and robotic exploration, visit here.

3.3 Academic Innovation Challenge Background and Purpose

This announcement maps to NASA Strategic Plan Goal 3 to *Address National Challenges and Catalyze Economic Growth* in attracting students to enter STEM fields and Objective 4.1 to *Engage in Partnership Strategies* where NASA identifies, establishes, and maintains a diverse set of partnerships to enable collaborations of mutual benefit to NASA and academia. NASA is dedicated to creating a capability-driven approach to technology and foundational research that enables sustained and affordable off-Earth human and robotic exploration. It has a long history of working with universities in pursuit of joint-interest research and technology development efforts. Drawing on talent from industry and academia, NASA delivers innovative solutions that dramatically improve technological capabilities for its missions, thereby benefiting the nation and humankind. Using innovative approaches to problem solving—such as challenges and collaborations—NASA seeks to stimulate innovators, thereby creating diverse pools of problem solvers that address NASA problems and advance technology development in a flexible way for technological breakthroughs.

The AES Division has five main objectives for the Academic Challenge:

1. Teams will learn by putting into practice the knowledge and skills they have gained throughout their years at their respective universities.
2. Teams will analyze and solve complex design and integration issues from an interdisciplinary perspective, exercising their innovation skills and initiative as they deal with conflicting requirements and make appropriate trade-offs.
3. Teams will develop skills in project planning, teamwork, leadership, critical thinking, and decision-making in an academic environment, but with an eye toward integration with NASA activities.
4. Teams will produce a test article and a final report that will be made widely available to space agencies, aerospace companies, and universities.
5. Teams' support under this program will adhere to NASA's commitments in its *Strategic Plan* to "maintain strong partnerships with academia" and to "engage and inspire students."

Pursuant to these objectives, NASA's AES Division focuses on advanced design, development, and demonstration of exploration capabilities to reduce risk, lower life cycle cost and validate operational concepts for future human missions to deep space. AES leads development of new approaches to project and engineering management, such as rapid systems development or alternative management concepts, open innovation, and collaboration. Specifically, AES Division activities are uniquely related to crew safety and mission operations in deep space, and are strongly coupled to future vehicle development. The activities fall under six primary domain areas: Crew Mobility Systems, Habitation Systems, Vehicle Systems, Foundational Systems, Robotic Precursor Activities, and Human Spaceflight Architecture Development. NASA is also extending human presence deeper into space with the Moon for long-term exploration and utilization by first establishing a Lunar Gateway in cislunar space. The purpose of the M2M X-Hab Academic Innovation Challenge is to leverage funding, capabilities, and expertise within and outside of NASA to overcome technology barriers and advance technology in these areas. Topic areas are summarized as follows:

Crew Mobility Systems

Systems to enable the crew to conduct “hands-on” surface exploration and in-space operations, including portable life support systems, and extravehicular activity tools.

Habitation Systems

Habitation systems provide a safe place for astronauts to live and work in space and on planetary surfaces. They enable crews to live and work safely in deep space, and include integrated life support systems, radiation protection, fire safety, and systems to reduce logistics and the need for resupply missions.

Vehicle Systems

Vehicle systems include human and robotic exploration vehicles, including advanced in-space propulsion, extensible lander technology, modular power systems, and automated propellant loading on the ground and on planetary surfaces.

Foundational Systems

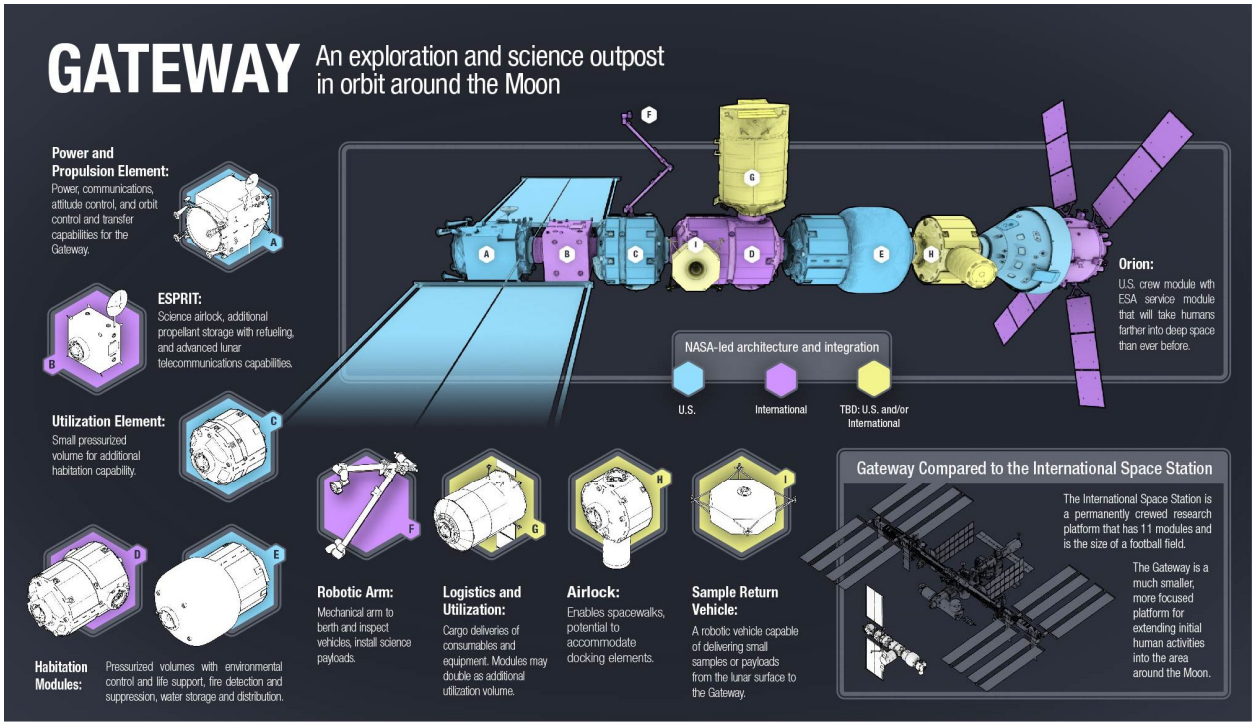
Foundational systems provide more efficient mission and ground operations and those that allow for more earth independence. These systems foster autonomous mission operations, *in situ* resource utilization, in-space manufacturing, communication technologies, and synthetic biology applications.

Robotic Precursor Activities

Robotic missions and payloads acquire strategic knowledge about potential destinations for human exploration. They inform systems development, including prospecting for lunar ice, characterizing the Mars surface radiation environment, radar imaging of near-Earth asteroids, instrument development, and research and analysis.

Human Spaceflight Architecture Systems (Gateway focused)

Gateway establishes a platform to mature necessary short- and long-duration deep space exploration capabilities through the 2020s. It will be assembled in a lunar orbit where it can be used as a staging point for missions to the lunar surface and destinations in deep space, providing a flexible human exploration architecture. Gateway can be evolved for different mission needs (exploration, science, commercial and international partners). Initial functionality will include several main elements: a Power and Propulsion Element (PPE), habitation elements, two airlock elements (one to enable human Extra-Vehicular Activities (EVA), one to pass science hardware and experiments), utilization, and required logistics element(s). The element containing a science airlock will also house additional propellant storage and advanced lunar telecommunications capabilities.



3.4 Online Technical Interchange Forum

Prior to the proposal submission deadline, an online Technical Interchange will be posted for NASA AES Division representatives to answer questions about the project. Questions pertaining to this effort shall be submitted to xhab@spacegrant.org no less than four days prior to the deadline to have them included in the response. Answers will be published on the solicitation website.

Schedule:

Questions are due by April 1, 2020.
Responses will be posted on April 8, 2020

3.5 Pertinent Dates

Proposal Phase

19	Feb	2020	Date of Announcement and Release of RFP
01	Apr	2020	Questions for online Technical Interchange due
08	Apr	2020	Responses to submitted questions published online
24	April	2020	Proposal due
26	May	2020	Award announcements

Award Phase

Summer - Fall 2020			Design phase
Sept 2020			Kickoff meetings
08	Oct	2020	Requirements and System Definition Review
12	Nov	2020	Preliminary Design Review
21	Jan	2021	Critical Design Review
11	March	2021	Progress Checkpoint Review
06	May	2021	Project Completion and Evaluation by NASA

3.6 Documentation and Deliverables

3.6.1 Project Documentation

For successful project completion, award recipients will provide the following deliverables:

1. Work Plan and Implementation Schedule by the SDR. milestone
2. Participation in Milestone Progress Reviews (Vidyo, Skype, WebEx and telecon) through the project execution
3. Report on Educational Outreach activity prior to Project Completion
4. Demonstration articles for M2M X-Hab developmental studies prior to Project Completion
5. Technical Final Report prior to Project Completion.
    1. Third party content will not be included in the final report, including materials protected by copyright or trademark. Third party content is any content created by an entity other than the awardee or NASA.
    2. Photos or videos included in the final report featuring the authors must include written permission to publish the photos/videos in any medium. Photos/videos featuring individuals other than the authors will not be incorporated into this final report.
    3. Any financial information included, as deemed necessary to the final report by the authors, will be incorporated into a separate appendix.
    4. Any included software code will incorporated into a separate appendix.
    5. Universities must comply with the U.S. export requirements by submitting their final presentation/report to their University Export Control Office (ECO) for review prior to submission to NASA.

6. If determined export controls do not apply, the ECO will note the outcome and recommend the final presentation/report be approved/accepted.
7. After ECO approval, the M2M X-Hab coordinator will file a Scientific and Technical Information/Document Availability Authorization (STI/DAA) form NG1676B using the NASA Electronic Forms site (https://nef.nasa.gov/) to formally archive the report.
8. Project teams/advisors are expected to provide a list of authors and brief abstract in support of the Document Availability Authorization process.
9. No personal contact information will included in the final report.

3.6.2 Formal Review Activities and Requirements

As noted elsewhere, submitted projects will undergo formal NASA review and assessment. Descriptions of the individual review components, their purposes, and checklists to help teams prepare for the reviews are found in Appendix E: *NASA Review Requirements and Checklists.*

3.7 Period of Performance

The period of performance for this award will be August 1, 2020, to May 31, 2021. The contract for the awarded teams may be extended to facilitate participation in testing as appropriate.

3.8 Facilities and Equipment

Facilities and equipment needed to conduct this M2M X-Hab 2021 Academic Innovation Challenge are the responsibility of the proposing project team and respective universities. No unique facilities, U.S. Government-owned facilities, industrial plant equipment, or special tooling is required.

4. Proposal and Submission Information

4.1 Proposal Format and Content

Proposals should be single-spaced, formatted to fit on standard 8½" x11" paper, no smaller than 12-point font, with one-inch margins throughout. All proposals must be prepared in the following sequence of sections:

A. **Title Page** (not included in the page count) - Title of the M2M X-Hab 2021 Academic Innovation Challenge project, university name, name and contact information of proposing faculty member(s) (address, university affiliation, email address, and phone number), and the local Space Grant Consortium faculty affiliation (if applicable).
B. **Body of Proposal** (12 pages maximum)
   - *Proposal Synopsis* – Description of the M2M X-Hab 2021 Academic Innovation Challenge work plan, design challenge to the students, and scope of the proposed effort.
   - *Significance* – Description of the need and relevance of the proposed design project for NASA, and how this course will benefit the university.
   - *Content* – Description of the course outline, framework, and the faculty outline. Applicants should describe the involvement of appropriate computer-aided tools in

their design and analysis solutions. Applicants should describe how a systems engineering process will be applied. Applicants should propose a preliminary notional concept for the proposed study or test article with the understanding that the design should occur during the fall semester.

- *Administration* – Description of project administration approach including the facilitation of cross-campus or other partnership collaborative efforts.
- *Mechanisms for Integration* – Description of how the M2M X-Hab prototype will be integrated and tested at the affiliated university in the 2020-21 academic year. Describe how the M2M X-Hab work will be performed during regular courses. Describe the feasibility of implementing the project team with other universities, if applicable.
- *Diversity* – Demonstrate efforts to attract a diverse group of student participants, including underrepresented and underserved minorities, women, and students with disabilities, along with multiple academic disciplines. Some applicable disciplines include engineering, industrial design, and architecture curricula.
- *Educational Outreach Plan* – Provide a plan to engage K-12 students from the local community though presentations, team involvement, mentoring, etc. Note that NASA also has public relations specialists that will be available for assistance.
- *Assessment Plan* – Provide a plan that describes the evaluation approach for the design course, lessons learned, and potential impacts.
- *Past Performance* – Demonstrate successful implementation of design courses that have met ABET quality standards. Demonstrate experience with a systems engineering process.
- *Resources (Sponsors)* – Include sponsorships, leveraging opportunities, unique capabilities, matching funds, and in-kind support. Also may include collaborations with other universities.

C. **Schedule** (not included in the page count) – Present a one-page overview of the proposed schedule. This should include the deliverables, expected dates of tangible outcomes, travel dates, and date of final report to NASA.

D. **Budget** (not included in the page count) –Note that total requested NASA funding cannot exceed the funding level associated with the project title. Specific information should be given for salary, detailed expenses for supplies and materials for the course and for the project, and expenses for workshops and travel. Specific information should be given pertaining to supplemental funding by sponsors.

E. **Collaboration** – Showing estimated expenditures. Reduction or full waiver of indirect costs are encouraged and may be considered to be a university contribution to the project.

F. **Appendix** (not included in the page count):

- *Mandatory* – Confirmation of support for the proposal must include signed documents from the university faculty, collaborators, and their potential sponsor(s) to ensure their respective commitment to the project.
- *Mandatory* – Include a signed confirmation from the university, stating that the M2M X-Hab 2021 Academic Innovation Challenge will be implemented during the 2020-2021 academic year and will comply with all pedagogical requirements.

4.2 Proposal Evaluation Criteria

The M2M X-Hab Challenge is divided into two phases. Phase 1 solicits proposals that will be evaluated for selection and Phase 2 is the project execution of the selected teams, the actual

challenge. Both phases will be evaluated based on appropriate predetermined evaluation criteria.

Phase 1 Evaluation Criteria

The following criteria will be used in the Phase 1 proposal evaluation process:

Logistics

- Identify project title.
- Identify project team.
- Identify the principal investigator (PI).
- Identify a vision, mission, and concept of operations.
- Identify the problem statement, functional and performance requirements.
- Identify a work plan, integration testing plan, milestone schedule, and experience.
- Identify faculty institution and provide confirmation of commitment in appendix.
- Identify a research assistant to provide leadership to the student project team (optional).
- Identify affiliated Space Grant Consortium (if applicable), sponsor, or affiliations.
- Identify NASA technical expert and provide signed statement of commitment in Appendix (optional).
- Identify manufacturing, assembly, and pretesting capabilities and facilities.
- Identify a preliminary notional concept of the demonstration article, with the understanding the final design will occur during the fall semester.

Merit

- Demonstrate alignment with NASA Human Exploration and Operations Mission Directorate objectives.
- Describe work plan to implement and integrate project into university activities.
- Demonstrate alignment with ABET quality standards.
- Include systems engineering process in the course.
- Include appropriate computer-aided design and analysis tools in the course.
- Provide evidence of past performance of design courses that meet ABET quality standards.
- Provide feasibility of project teaming implementation with other universities.

Contribution to NASA Strategic Goals

- **Content:** Demonstrate ability to develop a meaningful, challenging, realistic hands-on Human Exploration and Operations Mission Directorate-relevant design project.
- **Continuity:** Demonstrate ability to create interest within NASA while connecting and preparing students for the workforce.
- **Diversity:** Demonstrate effort to attract a diverse group of student participants, including underrepresented and underserved minorities, women, and students with disabilities, along with multiple academic disciplines. Disciplines could include (but are not limited to) engineering, industrial design, and architecture curricula.
- **Education Outreach:** Demonstrate efforts to engage K-12 students in the local community.
- **Evaluation:** Provide assessment plan, including appropriate quantitative metrics and qualitative outcomes.
- **Budget:** Provide adequate, appropriate, reasonable, and realistic budget.

4.3 Proposal Submission

Electronic copies of proposals must be received no later than **midnight, Pacific Daylight Time, Friday, 24 April 2020**. *Late proposals will not be considered.* The proposal will be submitted online at https://spacegrant.net/proposals/xhab/

Applicants will be advised by electronic mail when selections are made. It is anticipated that the award will be announced on 26 May 2020.

Appendix A: Budget Summary

From _____ To _____ *(performance period)*

	Funds Requested from Sponsor	Proposed Cost Sharing (if any)
1. Direct Labor	$ _____	_____
2. Other Direct Costs:		
a. Subcontracts	$ _____	_____
b. Consultants	$ _____	_____
c. Equipment	$ _____	_____
d. Supplies	$ _____	_____
e. Travel	$ _____	_____
f. Other	$ _____	_____
3. Indirect Costs	$ _____	_____
4. Other Applicable Costs	$ _____	_____
5. Total	$ _____	_____
6. Total Estimated Costs	$ _____	

Budget Narrative

If the proposal contains cost sharing separate budget narratives should be included for the funds requested from the sponsor and the proposed cost sharing.

1. **Direct Labor** (salaries, wages, and fringe benefits): List numbers and titles of personnel, number of hours to be devoted to the grant, and rates of pay.

2. **Other Direct Costs**:
   a. **Subcontracts** - Describe the work to be subcontracted, estimated amount, recipient (if known), and the reason for subcontracting this effort.
   b. **Consultants** - Identify consultants to be used, why they are necessary, the number of hours they will spend on the project, and rates of pay (not to exceed the equivalent of the daily rate for Level IV of the Executive Schedule, exclusive of expenses and indirect costs.)
   c. **Equipment** - List separately and explain the need for items costing more than $1,000. Describe basis for estimated cost. General-purpose equipment is not allowable as a direct cost unless specifically approved by the sponsor.
   d. **Supplies** - Provide general categories of needed supplies (*e.g.,* office supplies, lab supplies, etc.), the method of acquisition, and estimated cost.
   e. **Travel** - List proposed trips individually and describe their purpose in relation to the award. Also provide dates, destination, and number of people where known. Include where appropriate airfare, hotel, per diem, registration fees, car rental, etc.)
   f. **Other** - Enter the total direct costs not covered by 2.a through 2.e. Attach an itemized list explaining the need for each item and the basis for the estimate.

3. **Indirect Costs** - Since the project is related to academic course work and not research, the indirect cost rate should not exceed your university's negotiated rate for that category. Waived indirect cost is encouraged.

4. **Other Applicable Costs** - Enter the total of other applicable costs with an itemized list explaining the need for each item and basis for the estimate.

5. **Total** – The sum of lines 1 through 4.

6. **Total Estimated Costs** – The sum of the funds requested from the sponsor and the proposed cost sharing (if any).

Appendix B: M2M X-Hab Topic Details

Project Sponsor:
AES Life Support Systems

Project Title:
Thermal Radiator for CO_2 Deposition in Deep Space Transit

Scope of the challenge:
Design, build, and test a thermal radiator to generate a cold surface for air revitalization utilizing the CO_2 deposition method.

Description:
In order to meet the challenges posed by deep-space manned exploration, innovative, reliable, and cost-effective solutions must be developed in order to close the loop in human life support. In the realm of air revitalization, the current sorbent-based architecture aboard the ISS has proven to be sensitive to contaminants and mechanical failures. It has been demonstrated that use of cryogenic coolers can be an effective method to remove CO_2 from process flow via deposition. For Mars missions, the transit through deep space offers an environmental temperature close to 4 Kelvin. As the cryogenic coolers are energy-intensive, a thermal radiator could be used either in conjunction with or instead of the coolers to generate the cold surface for CO_2 deposition. This project aims to design, build, and test a thermal radiator that can be scaled to meet the temperature and power requirements of a full-scale CO_2 deposition system.

Expected Product (delivery item/concept):
Design, build, and test a benchtop scaled thermal radiator capable of rejecting heat at 130K. Model its performance to predict performance and scalability to 1kW of heat rejection. Deliver modeling results, experimental testing results, and operational recommendations. Students will also provide design suggestions and/or alternative solutions.

Expected Result (knowledge gained):
This project will aid in designing the full-scale system as a candidate for future deep space exploration air revitalization. The results will influence the selection of an alternative air revitalization system for deep space transit to Mars. Mechanical, thermal, fluid, and electrical engineering disciplines will work together to succeed in this project. Practical systems engineering and project management skills will be developed.

Relevance to Exploration:
This project will continue the exploration of deposition onto a cold surface as an alternative technology pathway for removing CO_2 and other contaminants from the cabin air environment. Proving out and developing an air revitalization system based on deposition can potentially operate as a full standalone system or can be integrated into other existing air revitalization subsystem segments.

Level of Effort for student team:
Design, thermal-flow modeling, build, and test of a thermal radiator to determine its capability to generate a cold surface for air revitalization via CO_2 deposition.

Level of effort for NASA team:
Requirements definition, system design assistance, and data-sharing.

Suggestion for seed funding (~$10-$50k):
$50K to perform modeling, prototype fabrication, and testing. Proposers are encouraged to seek additional funding or other contributions from their institutions, industry, space grant consortium and others.

Project Sponsor:
Space Life and Physical Science Research and Applications

Project Title:
Volume Optimization and Thermal Control for Food Product During Deep Space Exploration

Scope of the challenge:
Development of a system that provides optimum volume conditions for plant growth will significantly reduce mission cost while providing a healthy diet for crew members. Plants will be needed during Exploration missions lasting more than one year to provide nutrients and some calories to flight crews. Volume requirements change over the lifecycle of most plants grown for food and systems need to be developed to support plant needs while making the best use of available volume. Thermal conditions within specific ranges (warm temperature crops and cold temperature crops) are a critical consideration in optimized plant growth. The balance between these environmental variables and optimum volume is a critical design consideration.

- Development of a modular, scalable infrastructure to support food production using as little volume as possible while delivering optimal thermal conditions
    - Development of a fault tolerant architecture that can be reused multiple times and supports plant size changes over its life cycle.
- Develop a system that optimizes total volume, controls thermal conditions, and minimizes hands on crew time requirements.

Description:
Deep Space Exploration by humans, e.g., Mars Missions, will require plant growth systems to produce food, both nutrients and calories for periods of three to five years. The time frame will dictate the reuse of this plant growth system many times, while consistently providing the expected output. The need for continuous production over time could require multiple independent volumes or coordinated use of a common volume to accommodate different crops and stages of growth. Thermal conditions within a controlled range will deliver optimum crop production within known volumes and are an important consideration. The use of automation and AI should also be considered to reduce hands on crew requirements. Developing a system that produces the maximum output per unit volume will significantly reduce system mass. The system needs to include lighting, water and nutrient delivery, and air flow management, and hence should also consider mass and energy constraints.

Expected Product (delivery item/concept):
NASA would expect to see an operating system concept and an operating model of the proposed end product.

Expected Result (knowledge gained):
Students would become familiar with NASA's project management process, the issues of producing food in space, and the development of operating models. NASA would be training the next generation of space system developers and be reviewing ideas from a fresh perspective.

Relevance to Exploration:
The capability to produce a continuous supply of fresh food is critical to exploration. The system configuration needed to produce this desired output is wide open to new ideas. If we get three

or four good proposals and can get an equal number of end products, we will be closer to an end product which is critical to Exploration

Level of Effort for student team:
The team will need expertise in structures and mechanical systems, electrical and electronic systems, software development, plant growth, micro biology, and the integration of those systems into an operating product.

Level of effort for NASA team:
The NASA team will support five 2-hour telecom with the University team including kickoff meeting, SDR, PDR, CDR, and completion presentation and a site visit of one day for two team members.

Suggestion for seed funding (~$10-$50k):
The sponsor will provide up to $25K for this project which needs to support a demonstration visit to KSC for at least 2 members of the team. Proposers are encouraged to seek additional funding or other contributions from their institutions, industry, space grant consortium and others.

Project Sponsor:
AES NASA Platform for Autonomous Systems (NPAS) Project
https://techcport.nasa.ov/view/94884

Project Title:
Voice Interactions Management of Gateway

Scope of the challenge:
Explore technologies, develop conceptual/theoretical frameworks, and design voice interfaces that enable voice querying ('by crew' and 'to crew' by Gateway) and commanding required to manage Gateway. For efficient operations, the voice interfaces shall be accompanied by corresponding graphic interfaces, as needed, and to enable enhanced and effortless comprehension.

For example, crew may ask "what is the charge of the batteries?" or "how long can the gateway operate with current energy resources?" or "what is the current temperature and humidity?" and/or make requests like, the following: "set the lights for sleeping" or "maintain a cabin temperature of 25 degrees centigrade" or "prepare for docking."

Description:
The NASA Gateway will consist of multiple modules, as described in Figure 1 below.

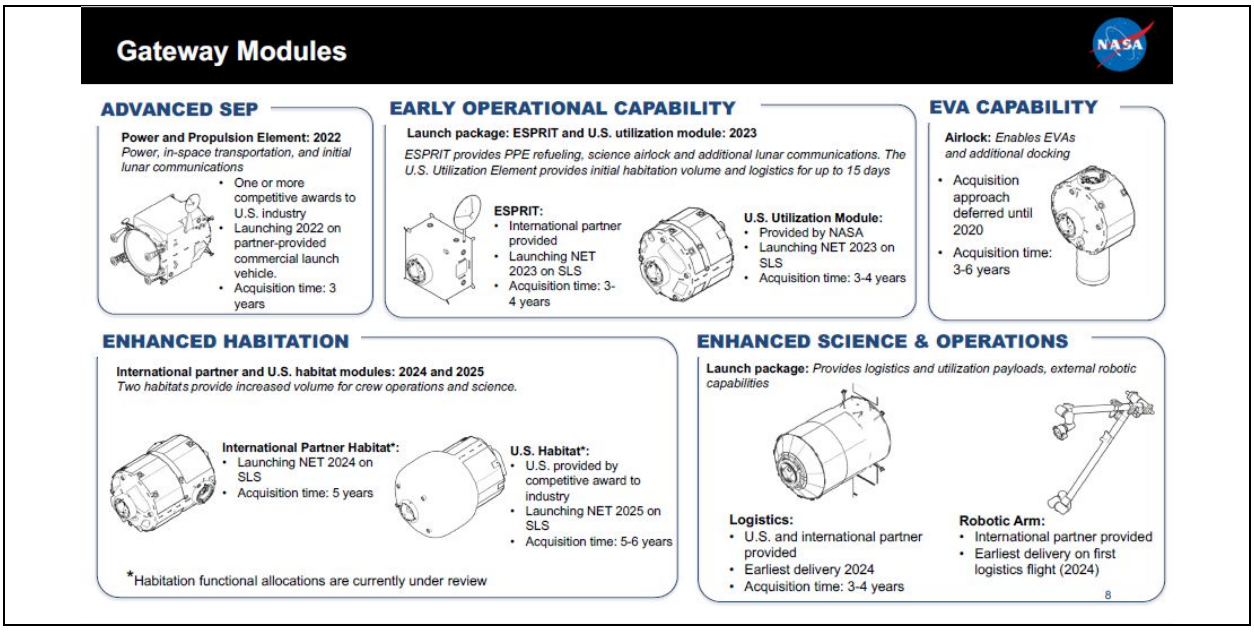


Figure 2. Gateway Modules (W Gerstenmaier, AA Crusan – 2018, NASA Technical Report, Cislunar and Gateway Overview. HEO Committee of the NASA Advisory Council Meeting- Mountain View, CA: Ames Research Center)

Additional information regarding Gateway design and purpose is provided at

https://www.nasa.gov/topics/moon-to-mars/lunar-gateway

While in lunar orbit, Gateway is being designed to operate autonomously; there will be both periods of time when the spacecraft is crewed, and other often long periods of time un-crewed.

Gateway is expected to operate autonomously when un-crewed; share autonomy with the crew, when crewed; and also share autonomy with ground support as needed.

Gateway must provide user interfaces to enable crew and ground-support to conduct nominal operational functions while Gateway operates with the highest possible level of independence. The user interfaces must provide complete awareness in an efficient and intuitive manner, while enabling crew or ground-support access to control for circumstances when needed. Additionally, user interfaces must address all modules in the Gateway. A prototype graphical user interfaces for a Vehicle Manager (operating the entire vehicle), a Power System, and an Avionics System developed using SSC's NASA Platform for Autonomous Systems (NPAS) are shown in Figure 2.

Figure 3. Prototype user interfaces for an autonomous habitat.

This X-Hab project concept addresses the addition/combination of voice-based interaction with graphical interfaces for enhanced autonomous operation management of Gateway.

Expected Product (delivery item/concept):
The project will deliver 3 products:

1. A formal study, results will be used to develop concepts, frameworks, and paradigms to implement voice management for Gateway.
2. Tools and associated implementation of a pilot capability to demonstrate crew-Gateway interaction by voice. The expectation is to incorporate voice interaction with the NASA

Platform for Autonomous Systems (NPAS) to manage an autonomous space habitat module.

3. A final report describing (1) the theory and concepts, (2) the technologies, (3) the processes, (4) the concepts of operations, and (5) description of the pilot implementation of a voice interaction system. Also, the report should include a developer guide that includes (1) the approach and (3) the methodology developed to create the user interfaces that were associated with the demonstrations. This document will establish guidance for design and implementation of voice user interfaces for autonomous systems.

Expected Result (knowledge gained):
Results from this project will help accrue knowledge and technology to successfully design voice user interfaces for implementation of autonomous operations on Gateway and/or other autonomous spacecrafts, as well as systems that are expected to have some degree of autonomous operation, operating on planetary surfaces including for example, In-Situ-Resource-Utilization (ISRU).

Relevance to Exploration:
NASA, for the first time, is developing a spacecraft, Gateway, which must function with an elevated degree of autonomy. User interfaces for autonomous systems is a technology area where knowledge, implementations, and associated concepts of operations are lacking. This shortcoming is now in the critical path for Gateway, Moon activities, and exploration of Mars and beyond.

Level of Effort for student team:
Student teams will benefit from participation of members in a variety of disciplines, including topics such as human-machine interaction, human behavior, engineering, computer science, voice as well as graphical and other technologies for human-machine interaction.

Level of effort for NASA team:
The NASA team will provide knowledge and expertise related to Gateway, Gateway concepts of operation, and autonomous systems and operations.

Suggestion for seed funding (~$10-$50k):
$30K. Proposers are encouraged to seek additional funding or other contributions from their institutions, industry, space grant consortium and others.

Project Sponsor:
Near Earth Asteroid (NEA) Scout project, which is a solar sail mission to explore a Near Earth Asteroid.

https://www.nasa.gov/content/nea-scout

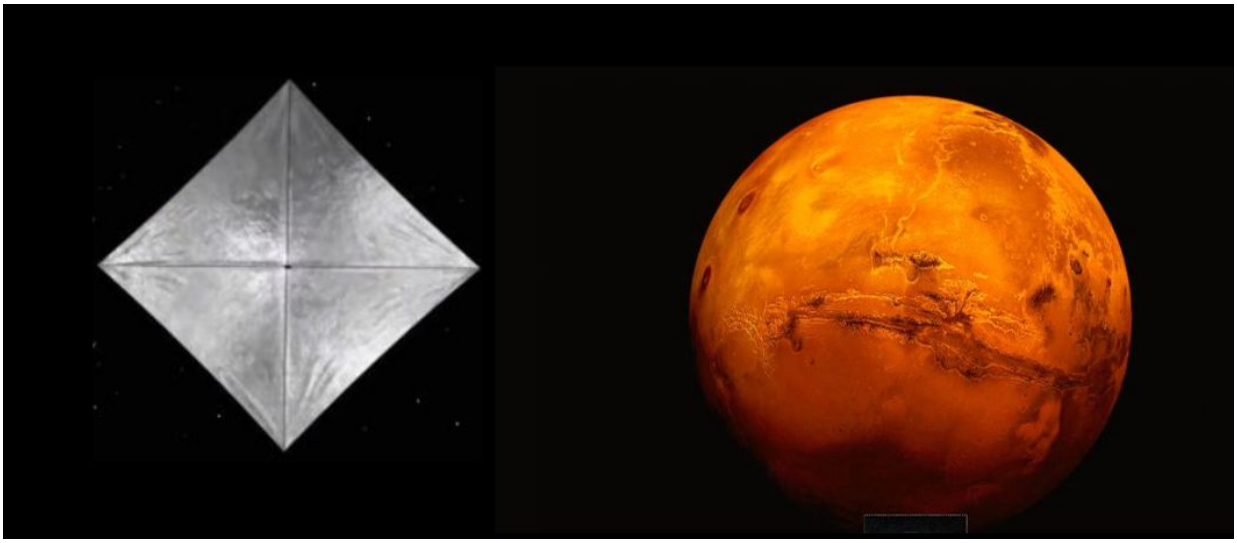
Project Title:
High-efficiency, Low-Mass, Low-Cost Mars Propulsion Technology for X-Hab

Scope of the challenge:
Lower costs for X-Hab Transportation with Solar Sail Propulsion

Description:
Current solar sail missions such as NEA Scout, and LightSail-2 use boom-stabilized solar sails, and future sail missions, such as Solar Cruiser, are planning to do the same. The booms are quite long, 7 meters for NEA Scout (Solar Cruiser is looking at boom lengths of about 29 meters) and must be stored in a limited volume during launch and prior to sail deployment. Solar Sail boom technology is thought to be nearing a practical limit.

Future sail technology will use spin to create a centripetal force to deploy the sail membrane in place of booms. Booms or tethers may be used to augment the spin-stabilized sail structure but will be secondary. There will be limits to the size of a sail that can be created using spin stabilization and there will be a tradeoff between sail size, spin rate, and the tensile strength of the membrane used.

A large performance factor for solar sails is mass, the lighter the sail, the better the performance. So the trade space will also include the possibility of using thinner, lighter membranes (with an expected reduction in tensile strength). Current sail membrane thickness for NEA Scout is 2.5 micrometers, but there is 0.9 micrometer sail material available commercially, so the study should factor in mass savings from thinner membrane material as well.



Expected Product (delivery item/concept):
Delivery products include 1) analysis and trade studies to determine limits of sail size based on spin rate and material properties limits; 2) a prototype device to test sail membrane tensile strength limits; and 3) potentially, a prototype, lightweight mechanism to induce sail spin, including an associated analysis product to select among potential prototypes/methods of inducing spin.

Expected Result (knowledge gained):
Robust analysis and investigation of sail size upper limit based on spin rate and tensile strength properties of sail material, including materials test results.

Relevance to Exploration:
This effort will improve NASAs capacity for in-space transportation considerably, and particularly for Mars Cargo missions. In general, larger more efficient solar sails offer a low-cost option for transporting cargo in space. More specifically to X-Hab, solar sail propulsion could help transport the X-Hab or parts of the X-Hab itself, transfer supplies and replacement supplies such as food, oxygen, water, in-space manufacturing material, and any other cargo needs of X-Hab. Ideally solar sail technology development can lead to large cost savings in cargo transportation to Mars, making the mission more feasible and shortening the timescale.

Level of Effort for student team:
The student effort should be rigorous but reasonable. General tasks include analysis and trade studies to determine upper sail size limit based on sail membrane material properties and sail spin rate. Disciplines needed for these analysis tasks include materials knowledge, structural analysis capability, insight and understanding of flexible spacecraft body dynamics and spacecraft attitude control, and systems engineering. Prototypes constructed to test aspects of the sail rotation (such as sail tensile strength and/or a spinning deployment mechanism) will also need mechanical engineering and manufacturing skills. The NASA Subject Matter Experts (SMEs) can help guide the students in all disciplines required.

Level of effort for NASA team:
The NASA team will be available to establish project requirements, supply necessary data and inputs, set constraints, define the analysis needed and also help with suggestions of hardware that can be tested. The NASA team will also serve as SME (Subject Matter Expert) advisers to the students, suggesting analysis techniques and tools, and offering advice on all aspects of the project. The NASA team will also maximize the applicability of the project to NASAs needs.

Suggestion for seed funding (~$10-$50k):
The NEA Scout project is willing to fund $20K to help this effort. Proposers are encouraged to seek additional funding or other contributions from their institutions, industry, space grant consortium and others.

Appendix C: Standard Education Grant or Cooperative Agreement

This award is made under the authority of 51 U.S.C. 20113 (e) and is subject to all applicable laws and regulations of the United States in effect on the date of this award, including, but not limited to 2 CFR Part 200 and Part 1800.

The following provisions of the Federal Code of Regulations are incorporated by reference

Location	Title	Date
Appendix A to 2 CFR Part 170	Reporting Subawards and Executive Compensation	Dec. 26, 2014
2 CFR 175.15	Trafficking in persons.	Dec. 26, 2014
2 CFR 182	Government-wide requirements for Drug-Free Workplace	Dec. 26, 2014
1800.900	Terms and Conditions	Dec. 26, 2014
1800.901	Compliance with OMB Guidance on Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal awards.	Dec. 26, 2014
1800.902	Technical publications and reports.	Dec. 26, 2014
1800.903	Extensions.	Dec. 26, 2014
1800.904	Termination and enforcement.	Dec. 26, 2014
1800.905	Change in principal investigator or scope.	Dec. 26, 2014
1800.906	Financial management.	Dec. 26, 2014
1800.907	Equipment and other property.	Dec. 26, 2014
1800.908	Patent rights.	Dec. 26, 2014
1800.909	Rights in data.	Dec. 26, 2014
1800.910	National security.	Dec. 26, 2014
1800.911	Nondiscrimination.	Dec. 26, 2014
1800.912	Clean air and water.	Dec. 26, 2014
1800.913	Investigative requirements.	Dec. 26, 2014
1800.914	Travel and transportation.	Dec. 26, 2014
1800.915	Safety.	Dec. 26, 2014
1800.916	Buy American encouragement.	Dec. 26, 2014
1800.917	Investigation of research misconduct.	Dec. 26, 2014
1800.918	Allocation of risk/liability.	Dec. 26, 2014

Unless otherwise specified, the terms and conditions in 2 CFR 1800.900 to 1800.918 and the requirements in 2 CFR 170, 175, and 182 apply and are incorporated by reference. To view full text of these requirements, terms, and conditions go to https://prod.nais.nasa.gov/pub/pub_library/srba/index.html

Provisions listed above are contained in the Code of Federal Regulation (14 CFR Part 1260). The CFR can be accessed electronically at: http://www.gpoaccess.gov/cfr/index.html or copies are available in most libraries and for purchase from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402. Provisions incorporated by reference have the same force and effect as if they were given in full text. The full text provision can be found via the NASA Grant and Cooperative Agreement Handbook web site: http://prod.nais.nasa.gov/pub/pub_library/grcover.htm. OMB Circulars referenced in the provisions can be assessed electronically at: http://www.whitehouse.gov/omb/circulars/ or may be obtained from the Office of Administration, Publications Unit, New Executive Office Building, Washington, D.C. 20503. An index of existing OMB Circulars is contained in 5 CFR 1310.

Appendix D: Certifications and Assurances

CERTIFICATION REGARDING DEBARMENT, SUSPENSION, AND OTHER RESPONSIBILITY MATTERS PRIMARY COVERED TRANSACTIONS

This certification is required by the regulations implementing Executive Order 12549, Debarment and Suspension, 34 CFR Part 85, Section 85.510, Participants' responsibilities. The regulations were published as Part VII of the May 28, 1988 Federal Register (pages 19160-19211). Copies of the regulations may be obtained by contacting the U.S. Department of Education, Grants and Contracts Service, 400 Maryland Avenue, S.W. (Room 3633 GSA Regional Office Building No. 3), Washington, D.C. 20202-4725, telephone (202) 732-2505.

A. The applicant certifies that it and its principals:

(a) Are not presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency;
(b) Have not within a three-year period preceding this application been convicted or had a civil judgment rendered against them for commission of fraud or a criminal offense in connection with obtaining, attempting to obtain, or performing a public (Federal, State, or Local) transaction or contract under a public transaction; violation of Federal or State antitrust statutes or commission of embezzlement, theft, forgery, bribery, falsification or destruction of records, making false statements, or receiving stolen property;
(c) Are not presently indicted for or otherwise criminally or civilly charged by a government entity (Federal, State, or Local) with commission of any of the offenses enumerated in paragraph A.(b) of this certification; and
(d) Have not within a three-year period preceding this application/proposal had one or more public transactions (Federal, State, or Local) terminated for cause or default; and

B. Where the applicant is unable to certify to any of the statements in this certification, he or she shall attach an explanation to this application.

C. Certification Regarding Debarment, Suspension, Ineligibility and Voluntary Exclusion - Lowered Tier Covered Transactions (Subgrants or Subcontracts)

(a) The prospective lower tier participant certifies, by submission of this proposal, that neither it nor its principles is presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from participation in this transaction by any Federal department of agency.
(b) Where the prospective lower tier participant is unable to certify to any of the statements in this certification, such prospective participant shall attach an explanation to this proposal.

_____
Organization Name

_____
Printed Name and Title of Authorized Representative

_____
Signature Date

_____
Printed Name of Principal Investigator/Program Director

_____
Proposal Title

CERTIFICATION REGARDING LOBBYING

As required by S 1352 Title 31 of the U.S. Code for persons entering into a grant or cooperative agreement over $100,000, the applicant certifies that:

(a) No Federal appropriated funds have been paid or will be paid by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, in connection with making of any Federal grant, the entering into of any cooperative, and the extension, continuation, renewal, amendment, or modification of any Federal grant or cooperative agreement;

(b) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting an officer or employee of any agency, Member of Congress, an or an employee of a Member of Congress in connection with this Federal grant or cooperative agreement, the undersigned shall complete Standard Form - LLL, "Disclosure Form to Report Lobbying," in accordance with its instructions.

(c) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers (including subgrants, contracts under grants and cooperative agreements, and subcontracts), and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by S1352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

Organization Name

Printed Name and Title of Authorized Representative

Signature Date

Printed Name of Principal Investigator/Program Director

Proposal Title

Assurance of Compliance with the National Aeronautics and Space Administration Regulations Pursuant to Nondiscrimination in Federally Assisted Programs

The _____
(Institution, corporation, firm, or other organization on whose behalf this assurance is signed, hereinafter called "Applicant.")

HEREBY AGREES THAT it will comply with Title VI of the Civil Rights Act of 1964 (P. L. 88-352), Title IX of the Education Amendments of 1972 (20 U.S.C. 1680 et seq.), Section 504 of the Rehabilitation Act of 1973, as amended (29 U.S.C. 794), and the Age Discrimination Act of 1975 (42 U.S.C. 16101 et seq.), and all requirements imposed by or pursuant to the Regulation of the National Aeronautics and Space Administration (14 CFR Part 1250) (hereinafter called "NASA") issued pursuant to these laws, to the end that in accordance with these laws and regulations, no person in the United States shall, on the basis of race, color, national origin, sex, handicapped condition, or age be excluded from participation in, be denied the benefits of, or be otherwise subjected to discrimination under any program or activity for which the Applicant receives federal financial assistance from NASA; and HEREBY GIVES ASSURANCE THAT it will immediately take any measure necessary to effectuate this agreement.

If any real property or structure thereon is provided or improved with the aid of federal financial assistance extended to the Applicant by NASA, this assurance shall obligate the Applicant, or in the case of any transfer of such property, any transferee, for the period during which the real property or structure is used for a purpose for which the federal financial assistance is extended or for another purpose involving the provision of similar services or benefits. If any personal property is so provided, this assurance shall obligate the Applicant for the period during which it retains ownership or possession of the property. In all other cases, this assurance shall obligate the Applicant for the period during which the federal financial assistance is extended to it by NASA.

THIS ASSURANCE is given in consideration of and for the purpose of obtaining any and all federal grants, loans, contract, property, discounts or other federal financial assistance extended after the date hereof to the Applicant by NASA, including installment payments after such date on account of applications for federal financial assistance which were approved before such date. The Applicant recognizes and agrees that such federal financial assistance will be extended in reliance on the representations and agreements made in this assurance, and that the United States shall have the right to seek judicial enforcement of this assurance. This assurance is binding on the Applicant, its successors, transferees, and assignees, and the person or persons whose signatures appear below are authorized to sign on behalf of the Applicant.

_____
Organization Name

_____
Printed Name and Title of Authorized Representative

_____
Signature Date

_____
Printed Name of Principal Investigator/Program Director

_____
Proposal Title

Appendix E: NASA Review Requirements and Checklists

NASA follows a strict adherence to a formal review process, as described earlier. The SDR, PDR, and CDR activities are further explained below, providing rationale, objectives, the information to be provided, and success criteria.

System Design Review (SDR)

The SDR examines the proposed system architecture/design and the flow down of Level 1 requirements to all functional elements of the system. SDR is conducted to prepare for, and assess readiness for the Preliminary Design phase.

SDR Objectives:

1. Ensure a thorough review of the team, processes, and products supporting the review.
2. Ensure the products meet the success criteria.
3. Ensure issues raised during the review are appropriately documented and a plan for resolution is prepared.

SDR Results of Review

As a result of successful completion of the SDR, the system and its operation are well enough understood to warrant proceeding to PDR. Approved specifications for the system, interfaces, and preliminary specifications for the design of appropriate functional elements may be released.

SDR Agenda (each academic team to present):

1. Identify Team Members.
2. Review Vision, Mission, Goal and Objectives of Project.
3. Review System Architecture (includes system definition, concept and layout).
4. Review Level 1 Requirements.
5. Review Traceability of requirements “flow down”.
6. Review Work Breakdown Structure (WBS).
7. Review preferred system solution definition including major trades and options. CAD model of physical components of system if available.
8. Review preliminary functional baseline.
9. Review draft concept of operations.
10. Review preliminary system software functional requirements.
11. Review risk assessment and mitigations approach.
12. Review analysis tools to be used.
13. Review Cost and schedule data.
14. Review software test plan (approach).
15. Review hardware test plan (approach).

SDR Success Criteria:

1. Systems requirements (based on mission as described by NASA) are understood, defined, and form the basis for preliminary design.
2. All requirements are allocated, and the flow down (subsystems, etc.) is adequate.
3. The requirements process is defined and sound, and can reasonably be expected to continue to identify and flow detailed requirements in a manner timely for development of project, post SDR.
4. The technical approach is credible and responsive to the identified requirements.
5. Technical plans have been updated, as necessary, from initial proposal.

6. Trades have been identified, and those planned prior to PDR/CDR adequately address the trades/options.
7. Any significant development or safety risks are identified, and a process exists to manage risks.
8. The ConOps is consistent with any proposed design concepts and is aligned with the Level 1 requirements.
9. Review demonstrates a clear understanding of customer and stakeholder needs.

Preliminary Design Review (PDR):

The PDR should demonstrate the establishment of a functionally complete preliminary design solution (i.e., a functional baseline) that meets project goals and objectives. It should define the project in enough detail to establish an initial baseline capable of meeting the project needs.

During the PDR, the team should demonstrate that activities have been performed to establish an initial project baseline, which includes a formal flow down of the project-level performance requirements to a set of system and subsystem design specifications. The technical requirements should be sufficiently detailed to confirm schedule and cost estimates for the project are being met. While the top-level requirements were baselined at SDR, the PDR should identify any changes resulting from the trade studies and analyses since SDR.

In general, teams should devote significant effort to discussing interface requirements and operational requirements (including test support, training products, repair products). The team should thoroughly define design and production requirements (if possible) during the PDR. PDR products should include comprehensive system and element requirements documentation, interface documentation, and technology validation.

PDR Objectives:

1. Ensure a thorough review of the team, processes, and products supporting the review.
2. Ensure the products meet the success criteria.
3. Ensure issues raised during the review are appropriately documented and a plan for resolution is prepared.

PDR Results of Review
As a result of successful completion of the PDR, the system and its operation are well enough understood to warrant proceeding to CDR. Approved specifications for the system, interfaces, and specifications for the design of appropriate functional elements may be released.

PDR Agenda (each academic team to present):
1. Review and updates of any documents developed and baselined since SDR.
2. Review a matured ConOps.
3. Review of any updates to any engineering specialty plans.
4. Review risk management plan.
5. Review cost and schedule data.
6. Review top-level requirements and flow down to the next level of requirements since SDR.
7. Review any design-to specifications (hardware and software) and drawings, verification and validation plans, and interface documents at lower levels. A CAD model is required at PDR stage for all physical components of the system.
8. Review any trade studies that have been performed since SDR and their results.

9. Review any performed design analyses and report results.
10. Review any engineering development tests performed and report results.
11. Review and discuss internal and external interface design solutions (and any interface control documents needed). This includes interface information provided by NASA since SDR.
12. Review system operations.
13. Review any potential safety issues (or data) including test identification and test readiness criteria as applicable.
14. Select a baseline design solution.

PDR Success Criteria:

1. Systems requirements (based on mission as described by NASA) are understood and defined and form the basis for preliminary design.
2. All requirements are allocated, and the flow down (subsystems, etc.) is adequate.
3. The requirements process is defined and sound, and can reasonably be expected to continue to identify and flow detailed requirements in a manner timely for development of project, post PDR.
4. The technical approach is credible and responsive to the identified requirements.
5. Technical plans have been updated, as necessary, from the System Design Review.
6. Trades have been identified and executed, and those planned for PDR have been completed with appropriate rationale.
7. Any significant development or safety risks are identified, and a process exists to manage risks.
8. Plans are defined to address Test Readiness Criteria if applicable.
9. The ConOps is consistent with any proposed design concepts and is aligned with the Level 1 requirements.
10. Review demonstrates a clear understanding of customer and stakeholder needs.

Post-PDR, Pre-CDR Activities

Design issues uncovered in the PDR should be resolved so that final design can begin with unambiguous design-to specifications. From this point on, almost all changes to the baseline are expected to represent successive refinements, not fundamental changes.

Critical Design Review (CDR)

The team should finalize all their designs for the CDR, after having selected a preferred alternative among the trade studies. The intent of the CDR during the M2M X-Hab milestone process is to finalize the products seen in the SDR and PDR products and to reflect the changes and maturation since the earlier reviews but not to repeat the content seen earlier.

CDR Agenda (each academic team to present):

1. Review and updates of any documents developed and baselined since PDR.
2. Review a finalized ConOps.
3. Review of finalized engineering specialty plans.
4. Review finalized risk management plan.
5. Review finalized cost and schedule data.
6. Review top-level requirements and flow down to the next level of requirements since PDR.
7. Review finalized design-to specifications (hardware and software) and drawings, verification and validation plans, and interface documents at lower levels. A CAD model is required at CDR stage for physical components of the system.

8. Review finalized design analyses and report results.
9. Review finalized engineering development tests performed and report results.
10. Review and discuss finalized internal and external interface design solutions (and any interface control documents needed). This includes interface information provided by NASA since PDR.
11. Review finalized system operations.
12. Present the finalized baseline design solution that will be built.

Once the CDR is completed, the majority of the design work should be over and the teams will concentrate on testing, building, procuring, and assembling the finalized system. The Checkpoint Review is a progress discussion to help the team along with the assembly and construction of the product. As noted earlier, teams may request additional meetings for technical interchange, but they are not required as a milestone.