NATIONAL SPACE GRANT FOUNDATION

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Moon to Mars eXploration Systems and Habitation (M2M X-Hab) Academic Innovation Challenge – FY22 Solicitation

on behalf of

NASA Headquarters
Human Exploration & Operations Mission Directorate

Sponsored by:

The Advanced Exploration Systems (AES) Division

Release Date:	March 1, 2021
Proposals Due:	April 23, 2021
Anticipated Award Date:	May 28, 2021
Program Website:	https://www.spacegrant.org/xhab/

X-Hab 2022 Academic Innovation Challenge Solicitation

1. Funding Opportunity Description - Synopsis

The Moon to Mars eXploration Systems and Habitation (M2M X-Hab) 2022 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. 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, 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 2022. Universities may form collaborations to perform as a single distributed project team.

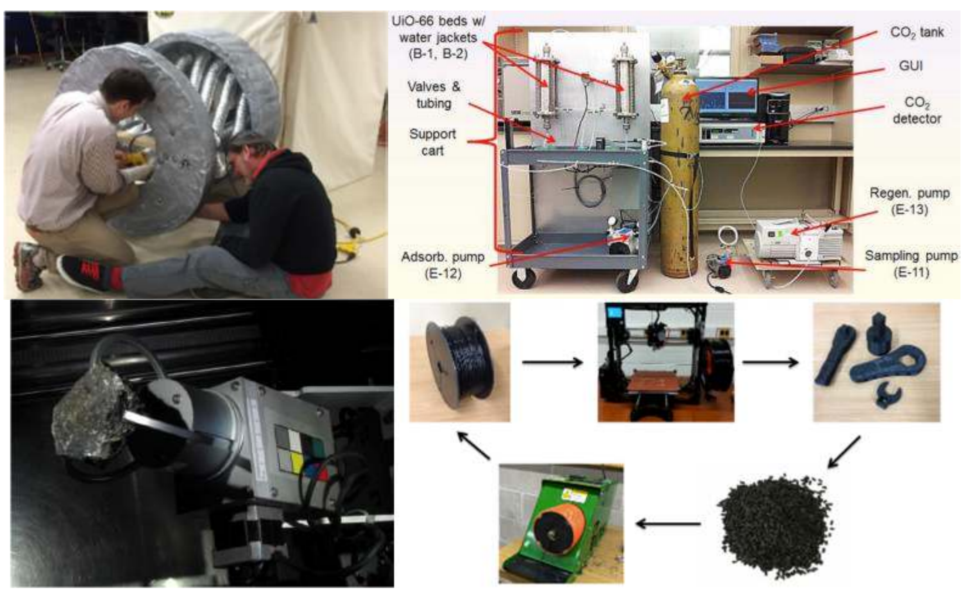


Figure 1: Previous X-Hab Projects (from top left, clockwise): Deployable Airlock, Closed Environment Air Revitalization System Based on Metal Organic Framework Adsorbents, Carbon-fiber/Fused Deposition Modeling Spacecraft Structural Fabrication System, Sample Handling System for GeoLab Glovebox (Image 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, multi-departmental, 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) 2022 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 2022 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 2021 and spring 2022 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-2016-6105 Rev2. 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 2021-2022 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 2021 – Requirements and System Definition Review (SDR)
- 11 Nov 2021 – Preliminary Design Review (PDR)
- 21 Jan 2022 – Critical Design Review (CDR)
- 11 Mar 2022 – Progress Checkpoint Review
- 06 May 2022 – 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: **Membrane Materials for High Temperature Ionic Liquid Regeneration**

Project Sponsor: AES Life Support Systems

- Project Title: **Move that Goo! Flow Limitations of High-Viscosity Fluids in Microgravity**

Project Sponsor: AES Life Support Systems

- Project Title: **Sub-scale Thermally Coupled Temperature Swing Adsorption and Compression (TC-TSAC) System Re-design**

Project Sponsor: Habitation Systems Development Project, Moon to Mars Planetary Autonomous Construction Technology (MMPACT) Project, In-Space Manufacturing (ISM project)

- Project Title: **Sub-scale Make It or Take It?: Approaches to Outfit an Inflatable Habitat**

Project Sponsor: Autonomous Systems and Operations

- Project Title: **Verification and Validation of Vehicle System Management Software**

Project Sponsor: AES Exploration Capability: NASA Platform for Autonomous Systems (NPAS) Project https://techport.nasa.gov/view/94884

- Project Title: **Strategies and Innovative Paradigms for Concepts of Operations Required for Implementing Hierarchical Distributed Autonomous Systems**

Project Sponsor: AES Crew Health Countermeasures

- Project Title: **Self-administered balance training gamification**

Project Sponsor: Crew Health & Performance (CHP) Extravehicular Activity (EVA) Future Capabilities Project

- Project Title: **Drones and/or Air Balloon Technologies to Enable 1/6-G Suited Testing in Field Environments**

Project Sponsor: Crew Health & Performance (CHP) Extravehicular Activity (EVA) Future Capabilities Project

- Project Title: **Treadmill walking in VR: Exploring a Lunar Virtual Reality Environment while Walking on a Treadmill Project Sponsor: AES Crew Health Countermeasures**

Project Sponsor: Crew Health & Performance (CHP) Extravehicular Activity (EVA) Future Capabilities Project

- Project Title: **Re-directed Walking in VR: Exploring a Lunar Virtual Reality Environment with re-directed walking while confined to a small play space**

3.3 Academic Innovation Challenge Background and Purpose

This announcement maps to NASA Budget Documents, Strategic Plans, and Performance Reports 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 to Mars 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

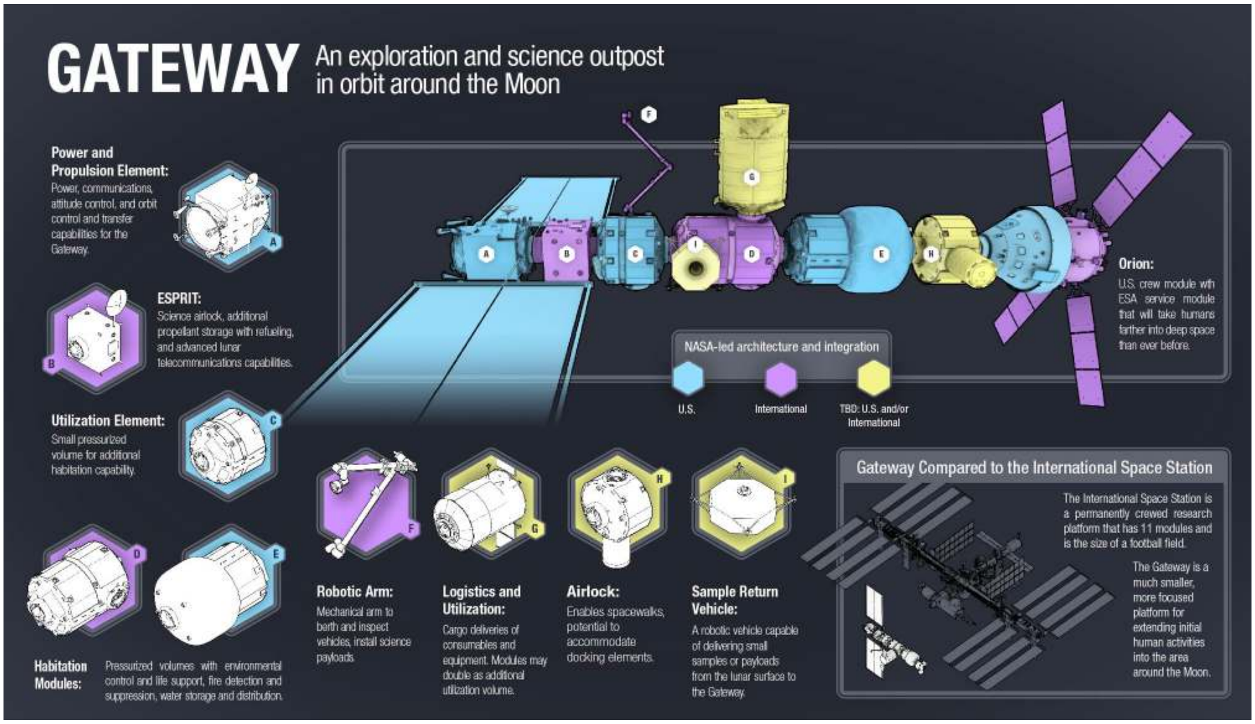
Foundational systems provide more efficient mission and ground operations and those that allow for more earth independence. These systems foster autonomous mission operations, *in situ* resource utilization, in-space manufacturing, communication technologies, and synthetic biology applications.

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, 2021.
Responses will be posted on April 8, 2021

3.5 Pertinent Dates

Proposal Phase

01 Mar	2021	Date of Announcement and Release of RFP
01 Apr	2021	Questions for online Technical Interchange due
08 Apr	2021	Responses to submitted questions published online
23 April	2021	Proposal due
28 May	2021	Award announcements

Award Phase

Summer - Fall 2021 — Design phase

Sept 2021		Kickoff meetings
08 Oct	2021	Requirements and System Definition Review
12 Nov	2021	Preliminary Design Review
21 Jan	2022	Critical Design Review
11 March	2022	Progress Checkpoint Review
06 May	2022	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 (using any one of a number of video teleconferencing tools) 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 be 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 be 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, 2021, to May 31, 2022. 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 2022 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 2021-22 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 2022 Academic Innovation Challenge will be implemented during the 2021-2022 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, 23 April 2021**. *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 28 May 2021.

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:
Membrane Materials for High Temperature Ionic Liquid Regeneration

Scope of the challenge:
Develop and test an air/liquid membrane designed to operate with heated ionic liquid

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, one alternative method currently being developed is CO_2 cold surface deposition. In order to maintain purity to feed to a downstream Sabatier reactor as well as to ensure efficiency of the CO_2 removal, cabin humidity must be removed prior to CO_2 deposition. The system utilizes hygroscopic ionic liquid to remove the humidity via an air/water hollow fiber membrane. To regenerate the ionic liquid, it is heated and swept with the dry, CO_2-free product air via another membrane. However, the majority of commercially available membranes oxidize when heated in air. Therefore, a new membrane material specific to this application needs developed.

Expected Product (delivery item/concept):
Determine existing or develop a new membrane material that has good materials compatibility with heated ionic liquid in air via testing and/or analysis. Design, build and test sub-scale membrane contactor to show both good permeability and selectivity to water vapor and successful operation in heated ionic liquid/air environment. Deliver experimental testing and analysis results and operational recommendations. Students will also provide design suggestions and/or alternative solutions.

Expected Result (knowledge gained):
A new membrane material can be utilized to build a full-scale contactor for the CO_2 Deposition system, aiding in its performance 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. Chemistry, thermal, fluid, and chemical 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, highly reliable 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 with other existing or new air revitalization subsystem segments. Technology Area TX06.01.01 Environmental Control and Life Support Systems Air Revitalization.

Level of Effort for student team:
Initial experiments and analysis to determine materials compatibility. Design and build of a sub-scale membrane contactor and testing in actual conditions to determine performance.

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

Suggestion for seed funding (~$10-$50k):
$50K for analysis, prototype fabrication, and testing.

Project Sponsor:
AES Life Support Systems

Project Title:
Move that Goo! Flow Limitations of High-Viscosity Fluids in Microgravity

Scope of the challenge:
Determine the maximum operable viscosity fluid that can be pumped through capillary-driven open channels

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, one solution takes inspiration from CO_2 scrubbing in power plants and submarines by utilizing liquid amines. Flowing the liquid through interior angles retains the liquid by surface tension, keeping it from floating away in microgravity. The liquid has a surface open to the air so that crossflow gas absorption and heated desorption can be performed.

Amines and other CO_2 liquid sorbent alternatives, such as ionic liquids, are or can become highly viscous when absorbing CO_2. An upper limit is reached both by the pump power and geometry of the manifolds feeding the wedge-shaped open channels. The viscosity may also change across the array of channels before exiting the system. A test is needed to determine the optimum manifold geometry to withstand high and changing viscosity conditions to minimize stress on the pump.

Expected Product (delivery item/concept):
Design and model different manifold geometries for a provided wedged channel shape. 3D print designs and build a benchtop test stand to pump viscous and variable viscosity fluids through designs and measure both flow and pump performance. 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 provide insight into the capability of using different sorbents in the Liquid Amine CO_2 removal system. The results will directly inform the design and operation of the system, which may influence the selection of an alternative air revitalization system for deep space transit to Mars. Mechanical, thermal, fluid, and chemical 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 liquid amine absorption as an alternative technology pathway to removing CO_2 from the cabin air environment. The system capitalizes on industry-standard materials used to remove CO_2, but approaches the microgravity fluid handling in a new and novel way to allow for the high-throughput flow required to remove sufficient CO_2. Technology Area TX06.01.01 Environmental Control and Life Support Systems Air Revitalization.

Level of Effort for student team:
Spec appropriate flow pump, CAD and flow model different manifold geometries, 3D print designs and build test stand to test high-viscosity and changing viscosity fluids, and analyze flow performance.

Level of effort for NASA team:
Requirements definitions/wedge geometry specifications, system design assistance, and data-sharing

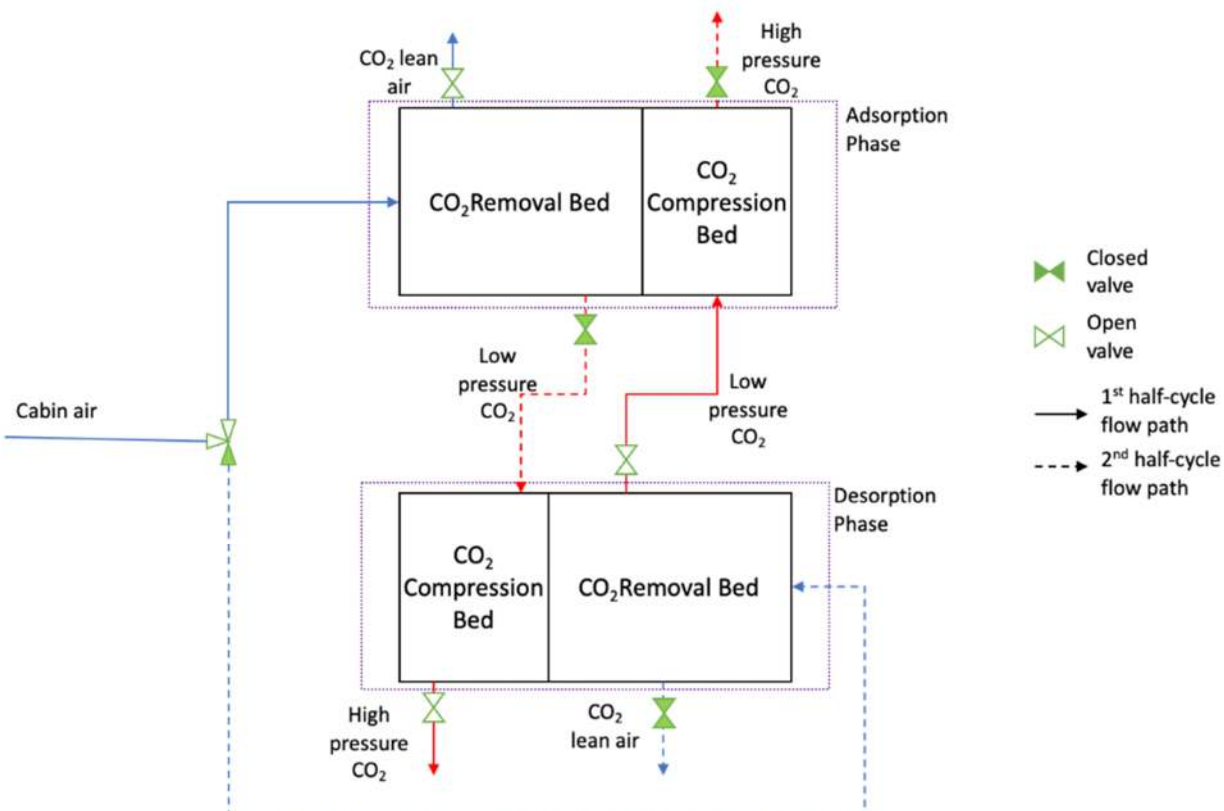
Suggestion for seed funding (~$10-$50k):
$50K for modeling, geometry printing/test stand fabrication, test and analysis

Project Sponsor:
AES Life Support Systems

Project Title:
Sub-scale Thermally Coupled Temperature Swing Adsorption and Compression (TC-TSAC) System Re-design

Scope of the challenge:
Design, build, and test a thermally coupled CO_2 removal and compression system for air revitalization.

Description:
To meet the challenges posed by deep-space manned exploration, innovative, reliable, and cost-effective solutions must be developed to close the loop in human life support. TC-TSAC is an alternative system that uses packed beds of regenerable bulk sorbents and heat cycles to simultaneously adsorb and compress CO_2 for downstream conversion to useful products.



A singular focus has been maintained on testing one geometry of coupling the adsorption and compression beds, but testing other geometries may show significant improvement in thermal efficiency. Therefore, a subscale redesign is warranted. This project aims to design, build, and test a new TC-TSAC geometry that can be scaled to meet the temperature and power requirements of a full-scale TC-TSAC system.

Expected Product (delivery item/concept):
Design, build, and test a benchtop thermally coupled CO_2 removal and compression system. Model its performance to predict performance and scalability for up to 4kg CO_2/day. 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, chemical, 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 combining the CO_2 removal and compression units into a single system. Proving out and developing an air revitalization system based on thermally coupling a solid-state compressor to a CO_2 removal bed can potentially improve mass, volume, and energy requirements, providing a viable alternative to existing air revitalization subsystem segments.

Level of Effort for student team:
Design, thermal-flow modeling, build, and test of a sub-scale TC-TSAC to determine its capability to integrate CO_2 removal and compression into a single system.

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.

Project Sponsor:
Habitation Systems Development Project
Moon to Mars Planetary Autonomous Construction Technology (MMPACT) Project
In-Space Manufacturing (ISM project)

Project Title:
Make It or Take It?: Approaches to Outfit an Inflatable Habitat

Scope of the challenge:
This challenge seeks new and novel approaches to inflatable habitat outfitting for long endurance, long duration space missions where current logistics support strategies may prove insufficient. The challenge asks teams to consider the use of rapidly emerging technologies in manufacturing and robotics for habitat outfitting and the overall benefits of a "make it" approach in reducing the amount of initial mass required and enabling Earth independent operations.

Description:
NASA's Habitation Systems Development project is looking to leverage inflatable habitation solutions for long duration space missions as it provides larger habitable volumes at lower mass penalties than conventional full metallic habitats. This in turn however creates a unique and more complex outfitting challenge due to the habitat being stowed for launch and transit in an uninflated, small diameter package and deployed to its full inflated volume on the lunar surface, requiring additional stowing and/or prepositioning of logistics and more extensive crew involvement in system installation. Habitat outfitting generally refers to the supplies and equipment which provide crew with a livable, safe environment during a mission and enable the performance of mission tasks. Outfitting can include hardware (such as environmental control and life support systems, science equipment), internal structures (such as walls, partitions, furniture, storage space, and crew quarters), personal items for the crew (food utensils, clothing, etc.), and utilities (lighting, ventilation, electrical systems). This opportunity seeks novel approaches to inflatable habitat outfitting which consider trades in volume, mass, risk, and crew time. NASA's In-Space Manufacturing (ISM) and Moon to Mars Planetary Autonomous Construction Technology (MMPACT) projects are developing technologies to enable on-demand manufacturing of spare parts and large structures, respectively, on a planetary surface. By using indigenous resources for manufacturing feedstock (such as launch packaging materials and lunar regolith), the upmass required for a mission can be significantly reduced. Both projects have an interest in leveraging additive manufacturing (AM) technologies to reduce logistics for future missions beyond low Earth orbit, where supply chains are constrained and resupply opportunities are more limited.

In the course of the academic year, teams will undertake concept studies and potentially prototyping/demonstration efforts which consider some aspects of the following with regard to inflatable habitat outfitting:

- Identifying items for habitat outfitting and considering which could be manufactured at the point of use versus prepositioned versus installed/stowed in the launched habitat package.
- Approaches to additive manufacturing which can operate in a crewed, pressurized environment and have potential for on-demand habitat outfitting applications.

- Ancillary robotic technologies and features/systems for autonomous integration which will be required to assist with installation of systems on uncrewed precursor missions.
- Trades in autonomous installation of systems in habitat outfitting prior to crew arrival versus installation by crew.
- Developing a queueing strategy and associated prioritization for habitat element manufacturing and installation (i.e. which elements are manufactured prior to launch, order/prioritization of elements in a launch cadence, which elements can be manufactured and/or installed prior to arrival of crew, and which are manufactured and/or installed after crew arrival at the habitat).
- Tasking and crew time required for habitat outfitting activities in partial gravity; includes considerations for potential hazards, accessibility, and strenuousness associated with the tasking.
- Potential sources of in situ resources and how they can be used in habitat outfitting (for example, repurposing or conversion to manufacturing feedstock); includes launch packaging and polymer waste streams, lunar regolith, and parts/elements of the habitat which have exceeded their useful life and represent nuisance material/waste.

Expected Product (delivery item/concept):

The primary outcome of the academic year effort is a trade study report on approaches to inflatable habitat outfitting which considers and presents trades in launch mass, crew time, safety, volume, and risk. In doing so, teams should seek to accomplish the following objectives:

1) Considering the baseline traditional approach to habitat outfitting (which assume crew involvement in installation of systems and prepositioning of habitat elements), generate alternative approaches which may incorporate technologies such as advanced robotics and on-demand manufacturing (In-Space Manufacturing) and describe the advantages and disadvantages of those approaches.
2) Consider task assessments to determine impacts to crew performing the outfitting task in partial gravity, including time required, hazards, accessibility and stress.
3) Make recommendations on method for components to outfit the habitat. For example, recommendations could categorize items that should be a) installed/stowed in habitat prior to launch, b) deployed by the inflation action of the habitat, c) reconfigured by autonomous or remote-controlled robotics, d) installed by crew, or other means identified by the students.
4) Make recommendations on phasing of manufacture. For example, recommendations could categorize what point in the mission profile the item should be made, e.g. a) prior to launch, b) after launch using In-Space Manufacturing, c) after landing and expansion of the habitat using In-Space Manufacturing, or d) after crew arrival.

Universities are also encouraged to create simulations and prototypes to demonstrate concepts/approaches generated through this activity. If a team has access to manufacturing systems which could potentially be used for habitat outfitting (such as larger scale robotic 3D printing technologies, for example), they may be able to produce and test prototype articles of habitat elements which could be manufactured at the “point of use” in the course of the effort.

Expected Result (knowledge gained):
The knowledge gained from this trade study will assist NASA in planning for future missions which require sustained habitats on a planetary surface. While this study is focused on lunar surface inflatable habitats, the results and recommendations generated may also be extensible to Mars architectures. The current paradigm for surface habitats assumes that all elements will be launched from Earth and installed by crew. This trade study will help to identify alternative approaches to habitat outfitting which may leverage technologies (such as large scale additive manufacturing, polymer recycling, and robotic systems) already in development by NASA for other applications such as spare part manufacturing and planetary surface construction. This work will provide a benefits assessment for integrating these technologies into habitat outfitting approaches.

Relevance to Exploration:
As NASA undertakes sustained missions beyond low Earth orbit, the agency must look at alternative approaches to outfitting and logistics. The International Space Station approach for habitat outfitting relies on large amounts of storage space, prepositioning of all elements and spares, a frequent launch and return cadence, and dedicated crew involvement in system installation, operation, and maintenance. This approach will be difficult to adapt to long duration, long endurance missions where large diameter inflatable habitats are launched and transported in pre-deployed packaging and cargo resupply opportunities and overall launch mass become more limited. Results of this study could inform future mission planning and generate new ideas/approaches for habitat outfitting to enable sustained Artemis missions in the 2030s.

Level of Effort for student team:
The study team will complete the effort during the course of an academic year (September to May). A team of students will consistently engage with NASA stakeholders and mentors from Habitation Systems Development, ISM, and MMPACT projects. Students will participate in reviews with NASA personnel, including a kickoff meeting, system requirements review, preliminary design review, checkpoint review, critical design review, and final review, consistent with the X-Hab program requirements. The team's products will include a trade study. Teams are also encouraged to develop supporting simulations and/or produce manufacturing demonstration articles for habitat outfitting (depending on facilities and equipment the team has access to).

Level of effort for NASA team:
The NASA team will provide subject matter experts to mentor the students within key technical areas. For the trade study and concept development, NASA will assist the team by providing background information on habitat outfitting, manufacturing technologies, and in situ resource utilization. NASA will also help the team with defining high level requirements, ground rules and assumptions, objectives, and figures of merit.

Suggestion for seed funding (~$10-$50k):
$20k from NASA. Proposers are encouraged to seek additional funding from their institutions, industry, space grant consortiums, and others.

Project Sponsor:
Autonomous Systems and Operations

Project Title:
Verification and Validation of Vehicle System Management Software

Scope of the challenge:
NASA's Gateway will develop a Vehicle System Manager (VSM) to autonomously operate Gateway while crew is not present, reducing the burden on Mission Control. The VSM consists of numerous planning, plan execution and fault management capabilities, integrated with lower level managers and flight software. There is a critical need for automated Verification and Validation (V&V) for software to ensure quality and safety of the Gateway VSM without lengthy test campaigns. There is a lack of V&V techniques for software for autonomous systems of the scale and complexity envisioned for Gateway.

Description:
Automated V&V can help increase quality while respecting accelerated timelines. NASA has an interest in tools that work well with model-based development process. Many autonomous systems are model-based as well, although the modeling paradigms differ from model-based software development tools such as SysML. V&V tools have proven to scale well when using a divide-and-conquer approach to V&V, in which V&V on components demonstrate respect of local behavioral contracts which are used to demonstrate assurance at the system level. This approach also allows for mixing formal methods, traditional testing, and probabilistic reasoning for autonomy algorithms, including planning, plan execution and fault management.

While robotic space missions have similar autonomy software capabilities, human spacecraft typically do not, and thus the V&V effort for an autonomous system of this scale requires new ideas and new investments.

Expected Product (delivery item/concept):
Specific technology elements of the solution may include:

- Requirements Analyzer: formalize requirements to check for inconsistencies, ambiguities, missing requirements.
- Autonomy Technology Verifiers: validation of planning and fault model requirements using formal analysis, automated planner and fault management test case generation, verification of autonomous system models (including planning, plan execution and fault management) against requirements.
- Compositional V&V / Integration: Verify and Validate integration of autonomy components (planning, fault management, execution, and lower level systems)

Expected Result (knowledge gained):
Demonstrate the ability to V&V individual autonomy components (e.g. an automated planner or scheduler model and/or software).
Demonstrate the ability to V&V a VSM using divide and conquer techniques. Leverage V&V of two or more components and demonstrate V&V of the integration of those two components.
Evaluation of either test case coverage, time saved, or other metrics.
Recommendations and lessons learned.

Relevance to Exploration:

- VSM Requirements and Test and Verification development and analysis for Gateway is ongoing; provides entry points for infusion.

- Existing AES projects developing a variety of autonomy technology for Gateway and Orion (as proxy for other Artemis elements) to provide use cases for verification and validation.
- Development now will position technology for use in later Gateway phases, and beyond.
- While not specifically designed for autonomous robotics software, similar efforts will have relevance to V&V of autonomous robotics.

Level of Effort for student team:

- Automated planning and scheduling technology
- Fault management technology
- Plan Execution technology
- Model checking
- Theorem proving
- Static analysis

Level of effort for NASA team:

Consulting on VSM design and autonomy components.
Consulting on autonomy component flight software integration.
Consulting on available NASA and commercial V&V tools.

Suggestion for seed funding (~$10-$50k):

$20-$30K.

Project Sponsor:
AES Exploration Capability: NASA Platform for Autonomous Systems (NPAS) Project
https://techport.nasa.gov/view/94884

Project Title:
Strategies and Innovative Paradigms for Concepts of Operations Required for Implementing Hierarchical Distributed Autonomous Systems

Scope of the challenge:

Develop conceptual/theories, principles, ontology, and concepts of operation, that enable implementation of hierarchical distributed autonomous systems (which may include graphic interfaces as needed to enable conceptual awareness -use Gateway as a reference system).

Description:

The future of "true" autonomous systems requires independent (on-board) thinking in order to eliminate the need for 1- persistent updates and 2- accounting for unforeseen oversight made by humans. A "Thinking System" encompasses the following capabilities: Reason, Intellect, Understanding, Decision, Presentation, Sensory, and Will; and a language founded on a sound ontology; ontology being a set of concepts and categories in a domain or subject area that enables a systematic and comprehensive development of capabilities and technologies.

In order to implement autonomous systems, the ability of a system to personify intelligence is required. The approach and technologies associated with "Thinking Autonomy" (TA) enable the "thinking" to be done on-board, as opposed to by expert teams off-line, trying to anticipate exponentially combinatorial possible use cases. With TA implementation, the code itself transfers to the system the "thinking" capabilities of human experts. That is, self-awareness, self-directedness, and self-sufficiency, are not hard-coded off-line; they are exercised on-board, using generic and systemic knowledge of a true autonomous system. Then, hierarchical distributed autonomy occurs when an overall system is defined as a collection of autonomous systems, where there is a hierarchy that reflects default command authority relationships.

Implementation of hierarchical distributed autonomous systems, must include the following:

1. Autonomy and authority: the objective is to establish theories, principles, and ontology to implement autonomy and authority; and then, to develop a concept of operations that will make viable hierarchical distributed autonomy capability that meets NASA's mission requirements; system members behave autonomously, initially with a default authority according the hierarchy level where they are placed, however, the authority level may be exchanged when distributed autonomy is implemented; leverage Gateway as a reference system
2. Concepts of Operation: the objective is to execute tasks by each autonomous element and/or system that constitutes the spacecraft; leverage Gateway functions; example activities conducted by autonomous systems should include the following:
    - *Autonomous spacecraft functions include*
        - Ensure safety and survivability
        - Resource management: availability, need, replenishment, generation, disposal
        - Fault management: fault detection, failure modes and effects, prognostics.
        - Mission objectives management: e.g. maintaining orbit, docking

- *Tasking and task priority negotiation*: how tasks are managed to satisfy priorities/needs of the mission and of the autonomous elements across hierarchy levels
  - Tasks have constraints of time, resources, states, and conditions that must be met in order to be scheduled and executed
- *Task execution processes:* how tasks are scheduled creating timelines; the aim is to achieve the spacecraft objectives safely (i.e. scheduled tasks are executed)
  - Scheduling and execution of tasks require processes that implement task execution while ensuring crew safety and spacecraft integrity
- *Autonomy in cooperation with crew members and/or ground control*: occurs when, for instance, operational challenges exceed the autonomous system's capabilities, and/or to make humans aware of decisions made by the autonomous system

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 hierarchical distributed autonomous systems
2. Tools and associated implementation of a pilot capability of a hierarchical distributed prototype system. The expectation is to enable an infrastructure to implement hierarchical distributed operations as part of the NASA Platform for Autonomous Systems (NPAS).
3. A final report describing a design for hierarchical autonomous operations that includes (1) the theory and concepts, (2) the technologies, (3) the processes, and (4) the concepts of operations that addresses items described in the Description section. This document will establish guidance for design and implementation of operations of an overall autonomous system architected as a collection of individual autonomous systems hierarchically organized.

Expected Result (knowledge gained):

Results from this project will help accrue knowledge and technology to successfully implement hierarchical distributed autonomous systems, focusing on deep space habitat as reference objective.

Relevance to Exploration:

NASA is currently developing Gateway, which must function with some degree of autonomy, and has plans for spacecraft and assets to travel beyond low earth orbit for deep space exploration, and habitation on both Moon and Mars which will require "true" autonomous operation. The ability to implement a hierarchical distributed autonomous system is required, and this is an area where knowledge, capability and associated concepts of operations are significantly lacking. The Technology Readiness Level is approximately 3. This shortcoming is now in the critical path for Gateway, and deep space exploration as well as Lunar and Mars habitation activities.

Level of Effort for student team:

Student teams will benefit from participation of members in a variety of disciplines, including topics such engineering, computer science, intelligent systems, theories associated with implementing artificial intelligence (AI), as well as graphical user interfaces, and other associated technologies.

Level of effort for NASA team:

The NASA team will provide knowledge and expertise related to implementation of hierarchical distributed autonomous systems, 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:
AES Crew Health Countermeasures

Project Title:
Self-administered balance training gamification

Scope of the challenge:
The purpose of this project is to develop computerized balance training exercises in a gaming format with minimal equipment that can be self-administered to promote sensorimotor conditioning.

Description:
Exposure to altered gravity leads to changes in sensorimotor function that results in decrements in postural control and locomotion. The risk of sensorimotor deconditioning is mitigated in part during preflight, inflight and postflight sessions supervised by Astronaut Strength, Conditioning & Rehabilitation (ASCR) specialists. There is a need to enhance our capabilities to optimize the proprioceptive training on-orbit, especially during exploration missions where the resources for exercise facilities will be more constrained. As longer exploration missions require more crew autonomy, the appropriate informatics tools need to be incorporated into these training systems to enable crewmembers to self-administer any changes to pre-planned programs based on performance metrics.

A gamified environment for proprioceptive training will help improve motivation while enhancing autonomy for the crewmember. Real-time visual biofeedback displays will enable interactive games to keep the training more engaging and challenge improvement across sessions. The gaming environment allows the integration of proprioception (e.g., leaning towards virtual targets) with spatial memory and other cognitive functions. A shared platform across users can encourage team interactions and improve compliance over the course of long-duration missions.

Expected Product (delivery item/concept):
The expected deliverable will be a prototype training platform using portable motion sensors (e.g., force plate, inertial measurement unit, accelerometers) to quantify performance, and a visual display with a variety of training games and assessment routines that can target proprioceptive function and/or eye-hand coordination. The visual display can utilize tablet or virtual reality formats. This prototype will ideally be delivered to Johnson Space Center for a demonstration with the ASCR and crew health countermeasure community.

Expected Result (knowledge gained):
The sponsoring project will benefit from understanding how participation in the proprioceptive gaming routines relate to improvements in balance assessments, and which types of routines were the most engaging over time.

Relevance to Exploration:
This capability will specifically address the Human Safety Risk for Sensorimotor Alterations, and the Crew Health Countermeasures capability gap: inflight sensorimotor and neurovestibular countermeasures and assessment systems for exploration missions are required to provide capability for landing and post-landing activities.

Level of Effort for student team:

This effort will ideally involve an integrated team involving students from physiological, behavioral, sports medicine, as well as biomedical and software engineering disciplines.

Level of effort for NASA team:
Subject matter experts from the Crew Health Countermeasures integrated product team will be available for consulting throughout and for the project demonstration at completion.

Suggestion for seed funding (~$10-$50k):
Depending on the complexity of the proposal, up to $50K will be available for selected proposals. Additional funding through university sources and space grant consortiums is highly encouraged.

Project Sponsor:
Crew Health & Performance (CHP) Extravehicular Activity (EVA) Future Capabilities Project

Project Title:
Technologies to Enable 1/6-G Suited Testing in Field Environments

Scope of the challenge:
This project aims to develop and validate methods for offloading a suited subject to simulate the reduced gravity of the moon or Mars byoffloading the suited subject's weight while safely attached to the system and performing a range of activities (walking, kneeling, etc.).

Description:
One primary task for astronauts during EVA is walking and navigating to various geological sites of interest to perform geological sampling, such as craters on the South Pole of the Moon, that for example could be about 2-km away from the Lunar lander. Field environments, such as geologic sites in Arizona, provide realistic terrain for simulating astronaut Extra-vehicular Activities (EVAs) on the surface of the Moon. However, NASA does not currently have the capability to simulate 1/6-G in field environments that would be required to provide integrated training of both navigating and working in Lunar-like terrain while in an offloaded space suit to simulate partial gravity. To achieve a long ambulation in a field environment at the appropriate physical workload for what it will be like on the Moon, the goal of this project is to offload a portion of the weight necessary to simulate Lunar or Martian gravity. For prototype development it is not necessary to offload a person in an actual spacesuit, but extensibility of the concept to a suited subject should be demonstrated. Similarly, the specific offloading forces achieved are less important than the proof of concept, but must be scalable to achieve offloading forces of at least 100 lbf. The NASA sponsor is particularly examining drone or balloon concepts to address this challenge, but other concepts could be considered.

Expected Product (delivery item/concept):
Deliverables include 1) detailed documentation on the testing setup and instrumentation (including any additional sensors required), 2) documented code for reproducing the methods that are developed, 3) a report on testing data to show the accuracy of the methods at offloading and enabling natural movements for a range of activities (walking, kneeling, etc.), 4) hardware or prototypes developed.

Expected Result (knowledge gained):
This project is an opportunity to develop capabilities for performing high fidelity 1/6-G EVA simulations in field environments, such as the JSC Rockyard or geologic sites in Arizona.

Relevance to Exploration:
H-3PO conducts feasibility testing to inform plans for evaluating EVA Suit Design for exploration-class missions to the Moon and Mars (EVA Gap 89: Suit Design) and developing and improving analog environments for simulating 1/6-G operations on the Moon.

Level of Effort for student team:
The sponsor prefers students have some experience with drones and/or air balloon technologies and with biomechanics to offload suited subjects while still enabling mobility (walking, kneeling, etc.), however other concepts will be considered.

Level of effort for NASA team:

The NASA team will be available for consultation and meetings as needed to provide guidance, status updates, and feedback for the duration of the project. The team would also welcome student participation in weekly project meetings that occur every Monday on Microsoft Teams as a venue for reporting on progress and asking questions as needed.

Suggestion for seed funding (~$10-$50k):
$35k

Project Sponsor:
Crew Health & Performance (CHP) Extravehicular Activity (EVA) Future Capabilities Project

Project Title:
Re-directed Walking in VR: Exploring a Lunar Virtual Reality Environment with re-directed walking while confined to a small play space

Scope of the challenge:
This project aims to develop and validate methods for redirected walking to allow users to explore a large-scale hybrid/virtual reality environment while being confined to a small 300-400 square foot area through 1) tracking users locations in the physical space and 2) re-directing the user by perturbing the visual scene to the user to stay within the small play space.

Description:
The APACHE project has a Lunar hybrid/virtual reality environment for simulating astronaut Extra-vehicular Activities (EVAs) on the surface of the Moon. One primary task for astronauts during EVA is walking and navigating to various geological sites of interest, such as craters on the South Pole of the Moon, that for example could be about 2-km away from the Lunar lander. To achieve a long ambulation in a virtual reality environment, the APACHE (Assessments of Physiology and Cognition in Hybrid-reality Environment) project has a need for re-directed walking to perturb visual scene in order to induce users to stay within in a 300-400 square foot play space. The play space is 15x20 currently but could be expanded to 20x20 if needed to achieve the re-directed walking capability (Figure 1).

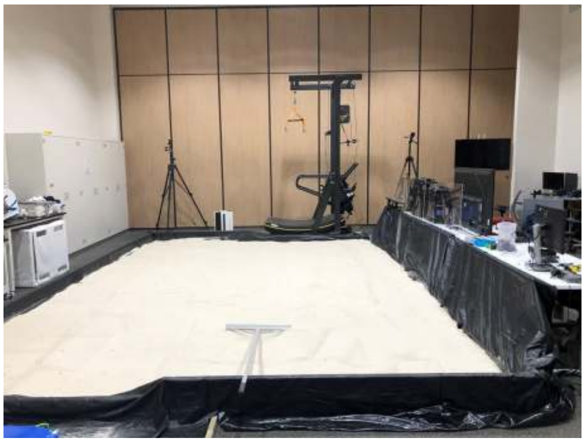


Figure 1. Existing APACHE play space.

As a secondary objective, development of high-fidelity realistic lunar VR scenes or terrains within which test subjects can walk or even conduct EVA tasks (e.g., exploration, geology, payload deployment, inspection, maintenance, repair, etc) is also of value.

Expected Product (delivery item/concept):
Deliverables include 1) detailed documentation on the testing setup and instrumentation (including any additional sensors required), 2) documented code for reproducing the methods that are developed for re-directed walking technology, and 3) a report on testing data to show the accuracy of the methods at a range of walking rates with various individuals. If applicable, 4) software and documentation associated with any additional scenes created.

Expected Result (knowledge gained):
This project is an opportunity to improve the simulation quality and task acceptability of walking in virtual reality and for adding capability for the user to self-navigate and explore the large-scale virtual environment while confined to a small play space.

Relevance to Exploration:
This project is evaluating EVA concepts of operation for exploration-class missions to the Moon and Mars (EVA Gap 92: ConOps) and developing operationally-relevant performance measures for inferring the physiological status of crew, including fatigue, situational awareness, and other cognitive domains (EVA Gap 91: Physiological Inputs and Outputs).

Level of Effort for student team:
Students will need some experience with VR programming and need to be capable of analyzing sensor data for motion tracking or gait monitoring. Students will need to have access to a VR headset. The NASA sponsor has experience with the Unreal Engine and Vive Pro Headset and can provide some technical assistance in this area, however other solutions will be considered.

Level of effort for NASA team:
The NASA team will be available for consultation and meetings as needed to provide guidance, status updates, and feedback for the duration of the project. The team would also welcome student participation in weekly APACHE project meetings that occur every Wednesday on Microsoft Teams as a venue for reporting on progress and asking questions as needed.

Suggestion for seed funding (~$10-$50k):
$30K

Project Sponsor:
Crew Health & Performance (CHP) Extravehicular Activity (EVA) Future Capabilities Project

Project Title:
Treadmill walking in VR: Exploring a Lunar Virtual Reality Environment while Walking on a Treadmill

Scope of the challenge:
This project aims to develop and validate methods for exploring a hybrid/virtual reality environment while walking on a treadmill through 1) gait monitoring to accurately track the user's steps while on a passive treadmill (e.g. walking speed), 2) directional controls for the user to choose the direction in which the user intends to move in the virtual reality environment, and 3) combine the gait monitoring and directional choices to control movement in the virtual reality environment.

Description:
The APACHE project has a Lunar hybrid/virtual reality environment for simulating astronaut Extra-vehicular Activities (EVAs) on the surface of the Moon. One primary task for astronauts during EVA is walking and navigating to various geological sites of interest, such as craters on the South Pole of the Moon, that for example could be about 2-km away from the Lunar lander. To achieve a long ambulation in a laboratory environment, the APACHE (Assessments of Physiology and Cognition in Hybrid-reality Environments) project has a passive, non-motorized treadmill with a safety harness attached to an overhead suspension system to enable subjects to safely walk on a treadmill while wearing a virtual reality headset (Figure 1).

Figure 1. Passive treadmill with fall-restraint system.

Currently, the APACHE project is needing an improved solution for tracking a user's gait on the treadmill and using that data to control movement in the virtual reality environment. The existing gait monitoring system has an algorithm that processes data from the user wearing virtual reality pucks on each ankle to track when each step is occurring and approximates stride length. However, the accuracy of this gait monitoring approach is needing improvement as user feedback has shown that the movement in virtual reality is mis-matched with the actual movement on the treadmill (e.g. some users feel the virtual reality scene is moving too fast or too slow compared to their actual step rates on the treadmill). Another limitation of the existing system is that it limits the user's movement to a pre-determined direction and does not allow the user to choose the direction to walk toward.

As a secondary objective, development of high-fidelity realistic lunar VR scenes or terrains within which test subjects can walk or even conduct EVA tasks (e.g., exploration, geology, payload deployment, inspection, maintenance, repair, etc) is also of value.

Expected Product (delivery item/concept):
Deliverables include 1) detailed documentation on the testing setup and instrumentation (including any additional sensors required), 2) documented code for reproducing the methods that are developed for controlling the direction and speed of movement in the virtual reality scene while a user is walking on a passive treadmill. and 3) a report on testing data to show the accuracy of the methods at a range of walking rates with various individuals (e.g. validate with a range of different stride lengths and step rates). If applicable, 4) software and documentation associated with any additional scenes created.

Expected Result (knowledge gained):
This project is an opportunity to improve the simulation quality and task acceptability of walking on a treadmill while in virtual reality and for adding capability for the user to self-navigate and explore the virtual environment. The project may also provide additional high-fidelity virtual areas within which subjects can operate.

Relevance to Exploration:
This project is evaluating EVA concepts of operation for exploration-class missions to the Moon and Mars (EVA Gap 92: ConOps) and developing operationally-relevant performance measures for inferring the physiological status of crew, including fatigue, situational awareness, and other cognitive domains (EVA Gap 91: Physiological Inputs and Outputs).

Level of Effort for student team:
Students will need experience with VR programming and need to be capable of analyzing sensor data for motion tracking or gait monitoring. Students will need to have access to a VR headset and a passive, unmotorized treadmill to conduct testing of their solutions. The NASA sponsor uses the Unreal Engine and the Vive Pro Headset and will be able to provide some technical support, however other solutions will be considered.

Level of effort for NASA team:
The NASA team will be available for consultation and meetings as needed to provide guidance, status updates, and feedback for the duration of the project. The team would also welcome student participation in weekly APACHE project meetings that occur every Wednesday on Microsoft Teams as a venue for reporting on progress and asking questions as needed.

Suggestion for seed funding (~$10-$50k):
$30K

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.

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Organization Name

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Printed Name and Title of Authorized Representative

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Signature Date

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Printed Name of Principal Investigator/Program Director

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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.

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Organization Name

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Printed Name and Title of Authorized Representative

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Signature Date

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Printed Name of Principal Investigator/Program Director

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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.

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Organization Name

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Printed Name and Title of Authorized Representative

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Signature Date

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Printed Name of Principal Investigator/Program Director

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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 Lunar 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.