NATIONAL SPACE GRANT FOUNDATION

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Moon to Mars eXploration Systems and Habitation (M2M X-Hab) Academic Innovation Challenge – FY23 Solicitation

on behalf of

NASA Headquarters
Human Exploration & Operations Mission Directorate

Sponsored by:

The Advanced Exploration Systems (AES) Division

Release Date:	February 25, 2022
Proposals Due:	April 22, 2022
Anticipated Award Date:	May 27, 2022
Program Website:	https://www.spacegrant.org/xhab/

X-Hab 2023 Academic Innovation Challenge Solicitation

1. Funding Opportunity Description - Synopsis

The Moon to Mars eXploration Systems and Habitation (M2M X-Hab) 2023 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 $13k - $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 2023. Universities may form collaborations to perform as a single distributed project team.

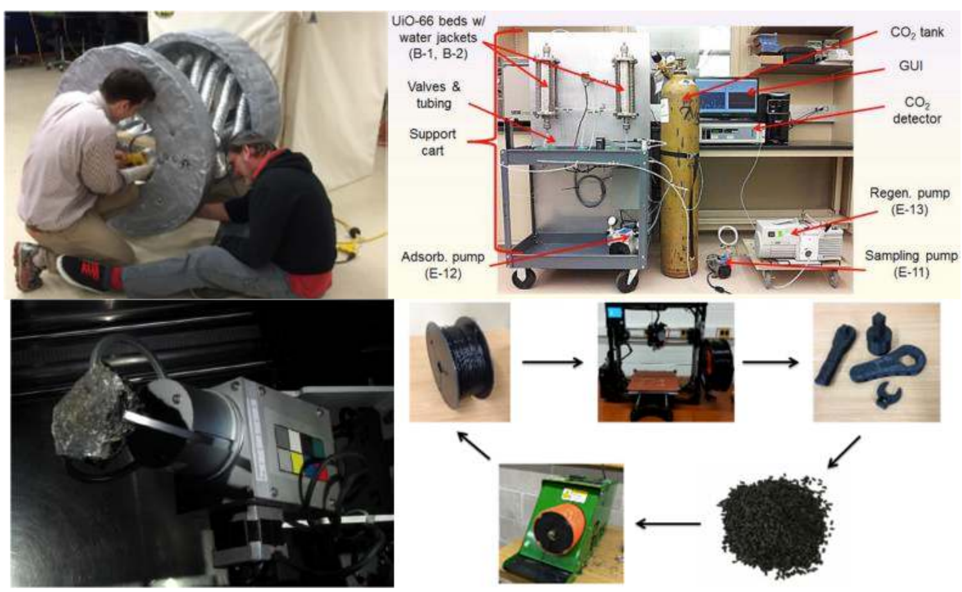


Figure 1: Previous X-Hab Projects (from top left, clockwise): Deployable Airlock, Closed Environment Air Revitalization System Based on Metal Organic Framework Adsorbents, Carbon-fiber/Fused Deposition Modeling Spacecraft Structural Fabrication System, Sample Handling System for GeoLab Glovebox (Image 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) 2023 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 2023 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 2022 and spring 2023 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 2022-2023 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):

- 07 Oct 2022 – Requirements and System Definition Review (SDR)
- 10 Nov 2022 – Preliminary Design Review (PDR)
- 20 Jan 2023 – Critical Design Review (CDR)
- 10 Mar 2023 – Progress Checkpoint Review
- 05 May 2023 – 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: Advanced Exploration Systems

- Project Title: Spaceflight Autonomous Multigenerational Microbial Sequencer (SAMMS) in Support of Plant-Growth Systems

- Project Title: Intelligent Devices/Equipment/Instruments (IDEI) for Enabling Crew Health and Performance on Mars

- Project Title: Regenerable Liquid Desiccants for High-Efficiency Humidity Control

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

- Project Title: Verification and Validation of Machine Learning for Safety Critical Autonomous Systems

- Project Title: Head and body monitoring sensorimotor assessment tool

- Project Title: Moon Supply: Logistics Transfer on the Lunar Surface

- Project Title: Autonomous Cargo Management & Distribution for Surface Logistics

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 (Artemis focused)

Gateway establishes a platform to mature necessary short- and long-duration deep space exploration capabilities through the 2030s. 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, 2022.
Responses will be posted on April 8, 2022

3.5 Pertinent Dates

Proposal Phase

25 Feb 2022	Date of Announcement and Release of RFP
01 Apr 2022	Questions for online Technical Interchange due
08 Apr 2022	Responses to submitted questions published online
22 April 2022	Proposal due
27 May 2022	Award announcements

Award Phase

Summer - Fall 2022	Design phase
Sept 2022	Kickoff meetings
07 Oct 2022	Requirements and System Definition Review
12 Nov 2022	Preliminary Design Review
20 Jan 2023	Critical Design Review
10 March 2023	Progress Checkpoint Review
05 May 2023	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, 2022, to May 31, 2023. 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 2023 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 2023 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 2023 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 2022-23 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 2023 Academic Innovation Challenge will be implemented during the 2022-2023 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. Proposals exceeding the allocated budget will not be considered. Soliciting NASA collaborators strictly on the basis of previous X-Hab management will result in disqualification pre-evaluation through post-award.

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 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, 22 April 2022**. *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 27 May 2022.

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

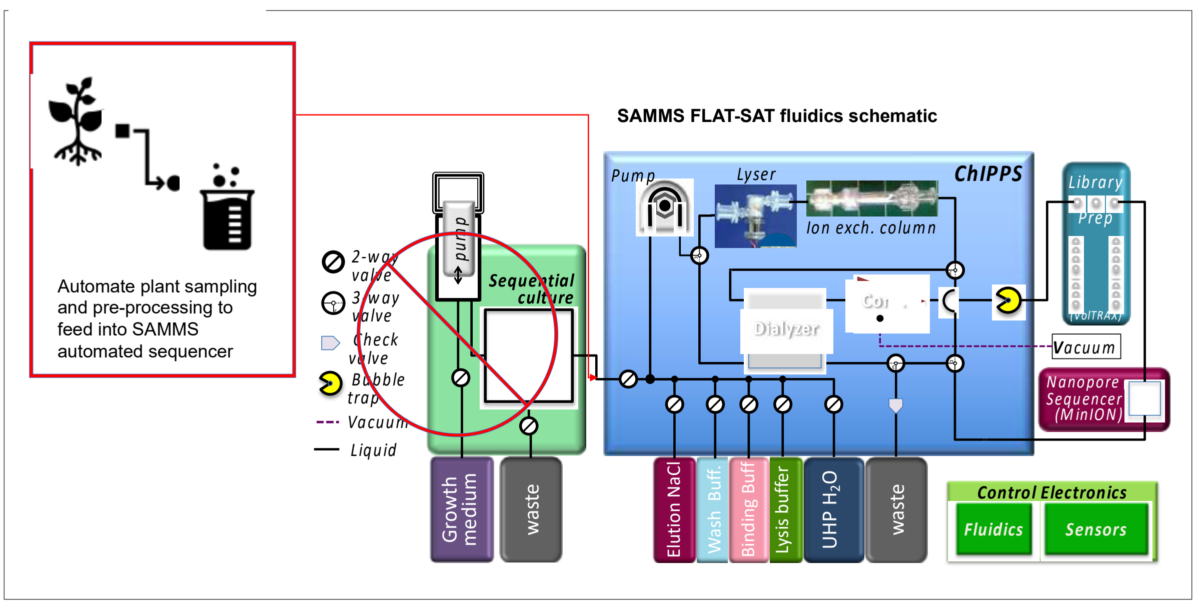
Project Sponsor:
AES Polaris

Project Title:
Spaceflight Autonomous Multigenerational Microbial Sequencer (SAMMS) in Support of Plant-Growth Systems

Scope of the challenge:
To automate a plant sampling process that can feed into an automated genomic sequencing device.

Description:
A microbiology and molecular biology team from Kennedy Space Center and Johnson Space Center is working in collaboration with Ames Research Center to fully automate a genomic sequencing device for use off-planet to assess the effect of the spaceflight environment on Earth-evolved genomes. The current process includes a microbial culturing component that will feed microbes to the DNA extraction component, the Charged Information-storage Polymer Preparation System (ChiPPS), and is followed by library preparation and sequencing. While microbes are easier to grow and sample than plants and are a starting point, the device will be used to sample and evaluate the genomic change of plants and animals in the future.

PROJECT POLARIS Spaceflight Autonomous Multigenerational Microbial Sequencer (SAMMS) in Support of Plant-Growth Systems



The university team is tasked with designing and building a prototype to sample and preprocess plants material to feed into the DNA extraction component (ChiPPS) to be followed by genomic sequencing (Figure 1). ChiPPS is meant to be earth-based polymer agnostic for astrobiology purposes (eg characterize a polymer from another planet). In earth terms, a charged polymer example is DNA, and ChIPPS, is a DNA extraction method. Commercial DNA extraction kits follow the same extraction principles.

Plants are harder to extract from due to cell walls, lignin, and secondary metabolites which interfere with the chemistry of the DNA extraction and so the team would need to find a way to build something that can feed into a DNA extraction protocol like ChIPPS.

A brief introduction to ChiPPs is included and the NASA sponsor will be available to mentor and guide the X-Hab team.

Expected Product (delivery item/concept):
The deliverable will be an automated growth and plant sampling device that preprocesses plant material to feed into the ChiPPS DNA extraction device. The use of mechanical methods such as bead-beating or freezing by liquid nitrogen to break down plant cell walls and organic material is expected to access nucleic acids, however other methods might be employed. A trade study should be completed to understand the various plant commercial DNA extraction approaches and a hybrid approach that is most amenable to automation and spaceflight shall be built. The prototype hardware will be delivered to Kennedy Space Center for evaluation and use.

Expected Result (knowledge gained):
The plant sampling prototype would allow for the extended use of the currently funded DNA processing and sequencing device (SAMMS). Inclusion of autonomous plant genomic sequencing capability would greatly increase the science driving future space crop selection.

Relevance to Exploration:
The ability to monitor plant and associated microbial genomes overtime will allow for the selection of plants with the necessary genetically encoded space traits, founding a basis for a robust food system for space exploration. It will allow for monitoring of potential mutations and overall crop health.

Level of Effort for student team:
It is expected the team will consist of biology, chemistry, and engineering students. The team will need members with an understanding of plant and microbial genetics and molecular biology techniques. Access to guidance in such topics as DNA extraction, and nanopore sequencing is a must. The Universities are highly encouraged to team with technical experts within and outside the university to cover the needed skill sets.

Level of effort for NASA team:
The NASA team is available for consulting on the design of the subcomponent and working to advise on the methods needed to integrate the subcomponent to the downstream extraction and sequencing component.

Suggestion for seed funding:
AES Polaris project will provide $13K to this effort from Kennedy Space Center allocated funds.

CHIPPS: CHARGED INFORMATION-STORAGE POLYMER PREPARATION SYSTEM. K.F. Bywaters[1], A.J. Ricco[2], T.D. Boone, T. Hoac, R.C. Quinn[2], K. Zacny[1] [1]Honeybee Robotics, 2408 Lincoln Ave, Altadena, CA 91001 [KFBywaters@honeybeerobotics.com; KAZacny@honeybeerobotics.com], [2]NASA Ames Research Center, Moffett Field, CA 94035 [antonio.j.ricco@nasa.gov; trinh.hoac@nasa.gov; travis.d.boone@nasa.gov; richard.c.quinn@nasa.gov]

Introduction: The search for life beyond Earth should incorporate technologies capable of detecting an array of potential biomarkers: this increases the chances of unambiguous results for autonomous missions to Ocean Worlds, such as Europa and Enceladus as well as Mars. Charged polymers comprised of multiple block types are biological systems' means to store and transfer information; life on other worlds may use different polymers than those of terrestrial biology. The examination and characterization of both mineralogical and biological charged particles ranging in size from 20 nm – 5 µm would detect a range of potential biomarker particles as one relevant part of an overall life-search instrumentation suite. The successful development of a synthetic nanopore Coulter Counter sample processing system will further detection capabilities for biomarkers beyond Earth.
Technological advances are required to achieve principal science objectives of a proposed Europa lander mission and multiple proposed Enceladus missions that will search for biosignatures of past or extant life. For life-detection missions, detection sensitivity and reliability are of particular concern due to small sample sizes (2 µL – 1 mL) and the extraordinary import of the results. The preparation and processing of small samples can constrain limits of detection (LoDs), as on the Viking [1] and Phoenix [2] landers and Mars Science Laboratory rover [3]. As we prepare to explore ocean-world environments, technological advances in autonomous sample processing will add new classes of reliably detectable biosignatures while simultaneously improving their LoDs.

Concept: The Charged Information-storage Polymer Preparation System (ChIPPS) will integrate a monolithic, microfluidic sample processor that prepares (simulated) icy-world samples for use with two complementary nanopore-based analyzers: 1) Oxford Nanopore's MinION - a charged-polymer sequencer that characterizes chain size, shape, and charge vs. chain position [4]; 2) Ontera's nano/microparticle sizer-and-counter, i.e. a Coulter counter, which characterizes the relative abundance of charged polymer chains (including fragments thereof) and other particles according to their hydrodynamic diameter, length, and charge [5-6]. Such measurements will reveal the nature and abundance of charged polymers that could be used by biological systems to store and transfer information—much as DNA and RNA are used terrestrially—without limitation to those terrestrial examples, given that life elsewhere may utilize different information store-and-transfer moieties. This key component of a search-for-life strategy must enhance the concentrations of target polymers sufficiently according to the platform: 400 ng DNA/equivalent for Oxford Nanopore's MinION (per manufacture's recommendations), 1 – 5 nM of DNA/equivalent for Ontera's polymer sizer/counter (per manufacture's recommendations). It must also adjust sample salt concentration to attain scientifically useful LoDs. These functions are particularly critical for an Enceladus fly-by sample capture, expected to be just a few µL of ice plume particles [7].

Technology Overview: Two critical functional processes to attain adequate LoDs for small volumes of likely-dilute ocean-world samples will be concentration of the extracted sample and the removal of excess salt. Our previous work focused on combining sample concentration via water vapor removal through a hydrophobic membrane [8, 9] with osmosis driven dialysis to remove salt, both functions imple-

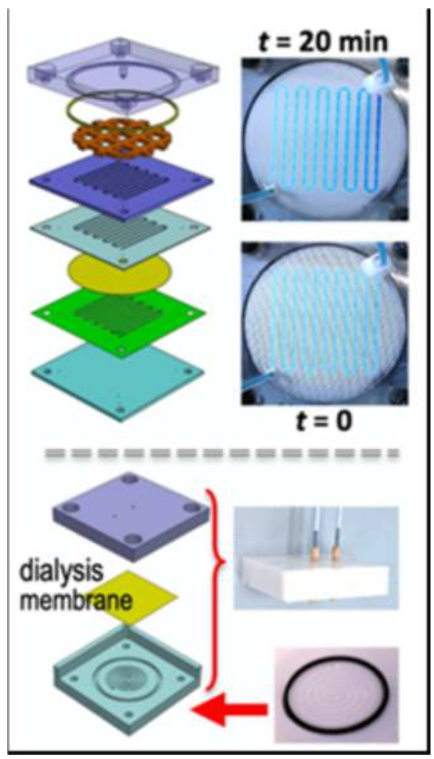


Figure 1. Top: Concentrator exploded diagram (left) and photos of concentration of blue dyed solution (right). **Bottom:** Dialyzer exploded diagram (left); photo of spiral microchannel (below right) and assembled dialyzer unit.

mented in fluidic-manifold-compatible format. Figure 1 shows that system's key components.

Multiple channel layouts, membrane areas, and internal support structures were developed and optimized for the concentrator; multiple types of dialysis membrane, pressures, flow rates, and channel depths were characterized for the dialyzer. Ultimately, both components functioned successfully, the former concentrating samples 10- fold in 60 min and the latter reducing salt concentration 10-fold in 75 min. Our results for model DNA samples are in preparation for publication [10]. These components will be optimized and integrated into the ChIPPS manifold.

Technical Approach: We build on our foundation of successful biology CubeSat payloads [11-18] and *BioSentinel* (delivery 2021) [19], along with WetLab-2 on the International Space Station [18] and experience with FLuidics for Ocean Worlds (FLOW) [11], to design, build, integrate components, and test the ChIPPS manifolded fluidic system. Fluidic components are selected from those flown in CubeSat and other missions [11-20], as well as those developed in the past three years by six NASA-funded projects that included manifold-based fluidic systems and interfaces for icy-world biomarker analysis [8 -9; 20]. Manifold design will apply lessons learned from those projects for component layout, tolerancing, mechanical fastening, and leak-tight sealing.

An abbreviated operational sequence begins with pre-evacuation of the manifold and priming with ultra-high-purity water; reconstituting the various dried reagents; preparing the binding column for charged polymers by rinsing/conditioning with salt solutions; drawing in sample, delivering it to the lyser, adding lysis buffer, then physically disrupting it; filtering (0.45 μm) sample lysate, mixing in binding buffer, then pumping to the ion-exchange column. The first elution of charged polymers is delivered to the dialyzer to reduce salt to ~ 0.05 M; it is then sent to the concentrator (~20x). About 100 μL of processed sample, matching analysis volume without waste, is sent via bubble trap to the nanopore analytical instruments. The second fraction is similarly eluted from the column and processed, followed by the third. With the configuration of Figure 2, all three eluted fractions can be concentrated ~20x without risk of NaCl precipitation.

The ChIPPS project will evaluate a modified configuration to provide improved desalination, yielding 100 μL for nanopore analysis without exceeding the solubility limit of NaCl, whether for sequencing or sizing, to measure the lowest possible starting charged polymer concentrations.

Acknowledgments: This research is funded by a NASA Ames Internal Research and Development Award.

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

Project Title:
Intelligent Devices/Equipment/Instruments (IDEI) for Enabling Crew Health and Performance on Mars

Scope of the challenge:

The scope of this challenge focuses on devices/equipment/instruments (DEI) for Crew Health and Performance (CHP) necessary for crew living on Mars for extended periods of time (longer than one Earth year). CHP aligns under the NASA Human Research and Program (HRP) which is working to improve astronauts' ability to collect data, solve problems, and remain healthy during and after extended space travel, and help address the challenges and demands that astronauts will face. If systems do not accommodate for human capabilities and limitations, disconnect can occur between inputs and outputs of systems and what humans can manage and/or provide, which could result in system failure and potentially loss of life. Incorporating these considerations as part of the systems engineering process is referred to as Human Systems Integration (HSI). A key principle of HSI is that all humans within the system, must be considered.

On Mars, crew will be kept alive by artificial life support systems (LSS), either inside habitats or within a space suit while outside of the habitat. The LSS will need to coordinate systems with resource management systems (RMS) and Crew Health and Performance Managers (CHPM) for each crew member. CHPM will provide, in real-time, complete awareness to the crew about the individual's health and performance, as well as provide this same awareness to the RMS and LSS to ensure required consumables are available and are provided to the crew. Because exercise is important to crew health, a very important element of CHP are the intelligent devices/equipment/instruments (IDEI) that support crew exercise activities. Additionally, IDEI should embody autonomous behavior that is capable of interacting with crew, CHPM, RMS (all of which may require resources to function and/or support maintenance). Figure 1 represent the various systems that could be involved in supporting CHP on the surface of Mars.

Therefore, this project seeks to focus on developing a paradigm for implementing IDEIs, in conjunction with an ontology, architecture, and concept of operations for autonomous IDEIs in the context described above (to support CHP). This should involve the development one or more autonomous IDEIs that serve as an analog for DEIs that are used on Earth to train for hanging and/or rock-climbing.

Description

Hanging and rock-climbing are activities that exercise the human body in a manner that optimizes muscle strength needed to have excellent control of one's body. It is also an activity that can be adapted with virtual reality or immersion content. The weight of a person on Mars is 0.375 times the weight on Earth (a little more than one third). The project can investigate creative ways to explore beyond what is normally done on Earth, that would serve as an analog for types of stress that humans would experience on Mars. This idea has 3 challenges: (1) to develop an IDEI prototype that is an analog to DEIs for hanging and rock-climbing activity (HARC) DEI on Earth; (2) the IDEI should operate autonomously, and (3) the IDEI should have the ability to integrate with other systems that support CHP, including LSSs, RMSs, and CHPMs as described in the Scope Section (Figure 1).

The autonomous IDEI, that could be inspired by hangboards (Figure 2), should provide quantitative information regarding the exercise activity it is used for, which would be used to support the functions of the CHPM, LSS, and RMS. For example, in the case of the HARC IDEI, forces on fingers, kinematic movement, energy spent, and other data would be provided to the systems. The autonomous IDEI should also have the capability of operating autonomously and establish state of health, report faults and maintenance needs, as well as report performance quality.

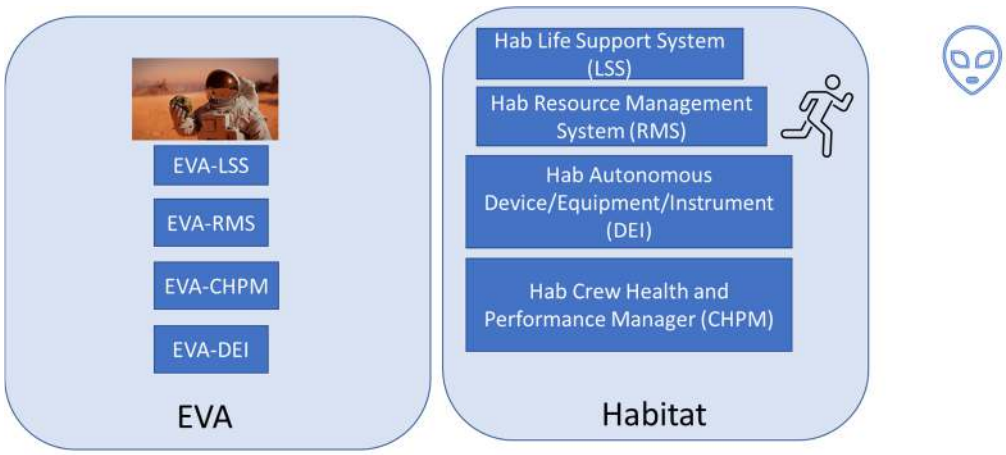

Figure 2. Autonomous IDEI in the context of systems for CHP inside a Habitat and during EVA

Figure 3. Typical Hangboard used for rock-climbing training

Expected Product (delivery item/concept):

- Develop a paradigm for implementing autonomous IDEIs in conjunction with an ontology, architecture, and concept of operations for autonomous IDEIs in the context described in the sections above
- Develop and build a prototype of one or more autonomous IDEIs that represent an analog of DEIs used on Earth to train for hanging and/or rock-climbing

Expected Result (knowledge gained):

The AES NPAS project is developing technologies and capabilities to enable autonomous operations of systems, and decision support, for developing and testing capabilities that will ensure crew health and performance during exploration EVA on Mars. The idea proposed will address how DEI may operate autonomously and integrate with software that monitors, evaluates, and manages CHP autonomously. In addition, the prototype will add a class of IDEI that has not yet been conceived and that will encompass autonomous operations capability. The products expected will add to knowledge and technology needed to fill current CHP HEOMD Tier 1 gaps identified by Artemis.

Relevance to Exploration:

The project will address the following HEOMD-405 v2 Tier 1 technology gaps:

Gap ID	Capability Gap Title
06-22	EVA Crew Capabilities and Constraints
06-26	EVA Bioinformatics & Decision Support
06-107	Semi-autonomous Behavioral Health and Performance Technologies

Level of Effort for student team:

Student teams will benefit from participation of members in a variety of disciplines, including topics such as engineering, computer science, intelligent systems, autonomous systems, exercise devices/equipment/instruments, exercise physiology, health and performance, immersive environments, as well as graphical user interfaces, and other associated technologies.

Tasks include research as well as development of a unique hardware prototype with autonomous behavior.

Level of effort for NASA team:

The NASA team will provide knowledge and expertise related to the primary topic areas represented in this idea.

Suggestion for seed funding:

$30K. Proposers are encouraged to seek additional funding or other contributions from their institutions, industry, space grant consortium and others.

Project Sponsor:
AES Life Support Systems

Project Title:
Regenerable Liquid Desiccants for High-Efficiency Humidity Control

Scope of the challenge:
Determine and test an optimal liquid desiccant for drying spacecraft cabin atmosphere

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. Ideally, a liquid desiccant is used to remove humidity, as it may also be used as a coolant fluid elsewhere in the system. The optimal liquid desiccant would be highly efficient at removing humidity while also limiting toxicity. Additionally, the desiccant must be regenerable to continuously remove humidity. The system in which the desiccant interacts with cabin atmosphere also affects its efficiency, so a complete liquid humidity removal system must be developed.

Expected Product (delivery item/concept):
Select a regenerable liquid desiccant that has high water adsorption capability at low partial pressures. Design, model, build, and test a subscale air-desiccant contactor to show performance, selectivity to water vapor, and successful regeneration. Deliver experimental testing and analysis results and operational recommendations. Report on methods used to minimize toxicity. Students will also provide scaling, design suggestions, and/or alternative solutions.

Expected Result (knowledge gained):
An optimal liquid desiccant can be utilized to build a full-scale humidity control system 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. Mechanical, material, 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 optimal desiccant. Design, model, and build of a sub-scale system 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:
$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 optimal manifolding and pumping method to drive high-viscosity fluids 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 concurrent flow gas absorption and heated desorption can be performed.

Amines and other CO_2 liquid sorbent alternatives, such as ionic liquids, have a wide range of viscosities and miscibilities with water. They can also become highly viscous when absorbing CO_2. Therefore some liquid sorbents, although highly effective at capturing CO_2, may not be useable to the inability to be pumped through a manifold to an open array of wedge channels. The viscosity may also change across the array before exiting the system. Above a viscosity of about 100 cP, typical pumping and manifolding methods begin to fail. A manifold geometry and accompanying pump system need to be designed to allow for use of high and changing viscosity systems, while also minimizing the liquid volume required to fill the system not actively absorbing or desorbing CO_2.

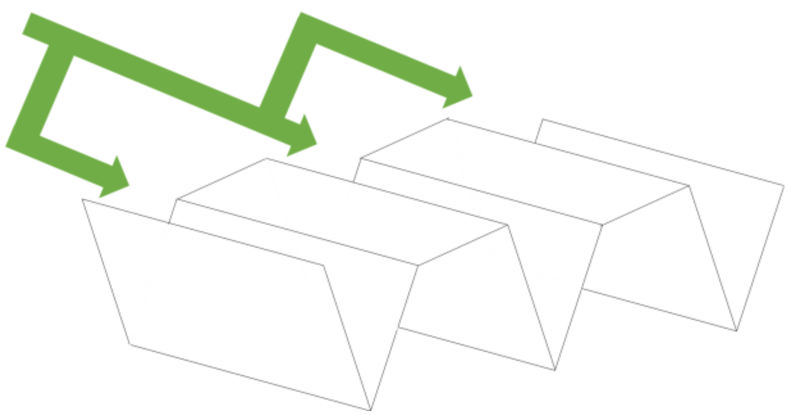

Figure 4. Liquid sorbent wedge geometry and arrows designating needed liquid feed manifold.

Expected Product (delivery item/concept):
Design and model different manifold geometries for a provided wedged channel shape and determine optimal pumping method. Optimal design also minimizes liquid volume. Manufacture and/or 3D print designs and build a benchtop test stand to pump fluids that simulate the viscous and variable viscosity sorbents through optimal design 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, manufactured/3D printed 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:
$50K for modeling, geometry printing/test stand fabrication, test and analysis

Project Sponsor:
Autonomous Systems and Operations (ASO)

The NASA Autonomous Systems and Operations (ASO) project has developed and demonstrated numerous autonomy enabling technologies employing Artificial Intelligence (AI) techniques. Our work has employed AI in three distinct ways to enable autonomous mission operations capabilities. Crew Autonomy gives astronauts tools to operate space vehicles or systems without assistance from Mission Control. Vehicle System Management uses AI techniques to turn the astronaut's spacecraft into a robot, allowing it to operate when astronauts are not present, or to reduce astronaut workload. AI technology also enables Autonomous Robots to act as crew assistants or proxies when the crew are not present.

A survey of prior work done by ASO can be found here:
https://arxiv.org/abs/1910.03014

Project Title:
Verification and Validation of Machine Learning for Safety Critical Autonomous Systems

Scope of the challenge:

Development and demonstration of verification and validation methods to either prove or assess the safety of safety critical machine learning applications for human spaceflight autonomous systems.

Description:
Future human exploration missions to the Moon and Mars will require increasing amounts of spacecraft and astronaut autonomy. The Gateway spacecraft will feature four crew instead of 6 (or more), and will be occupied for only a few months out of the year. Small crews cannot take on all functions performed by ground today, and so Gateway must be more automated to reduce the crew workload for such missions. In addition, both near-term and future missions will feature significant periods when crew is not present; Gateway shall provide for autonomous operations for up to 21 days, independent of ground communications, when crew are not present.

Machine learning is used in numerous applications ranging from image detection to fault management. For human spaceflight applications, performance guarantees are critical to ensure spacecraft and astronaut safety, but methods to provide such guarantees for machine learned classifiers are in their infancy. Techniques include, but are not limited to, 'robustness testing', in which inputs prone to misclassification are generated. It should be difficult to create an 'adversarial' input indicating a spacecraft fault that is 'too close' to one of the training inputs.

Expected Product (delivery item/concept):

A successful project proposal will:

- Describe a human spaceflight safety critical application that potentially benefits from machine learning; examples include spacecraft system fault detection or prognostics. NASA has collected many datasets for different fault management and prognostics applications:
    - https://ti.arc.nasa.gov/tech/dash/groups/pcoe/prognostic-data-repository/

- Describe a machine learning approach selected by the student team to this application; examples include decision trees, Bayesian networks, or neural networks.
- Describe a verification and validation approach for the machine learning system selected by the student team. Such V&V approaches include, but are not limited to: coverage testing, robustness testing, explainability of machine learning outputs. Describe the results of implementing it for the selected machine learning system.
- Deliver a final report describing the above elements.

Expected Result (knowledge gained):
The benefits of this project include:
- Ease of use in V&V of machine learning applications for human spaceflight
- Metrics for suitability of machine learning applications for human spaceflight
- Pros and cons of specific application of machine learning for human spaceflight

Relevance to Exploration:
This project is relevant to:
- TX10.2: Reasoning and Acting
- TX10.4:Verification and Validation of Autonomous Systems
- TX11.1: Verification and Validation of Software Systems

Level of Effort for student team:
The successful project does not require creating new datasets, machine learning approaches, or new verification and validation approaches. However, the successful project should:
- Choose a human spaceflight safety critical application area, and explain the benefits and risks of using machine learning for this application.
- Explore a novel V&V approach to a machine learning application (i.e. not repeat a prior exploration of V&V to machine learning.)
- Deliver a conclusion regarding whether or not machine learning should be used for this application as though the decision maker were responsible for investing in this application for a human space mission to Mars. Justify this conclusion with enumeration of limitations and advantages of that approach.

Relevant skills include but are not limited to:
- Use of machine learning toolkits such as Pytorch, Keras, TensorFlow
- Use of machine learning V&V tools such as
- Familiarity with mathematical programming environments such as Matlab
- Teamwork, writing and communication skills
- Software engineering skills

Level of effort for NASA team:
The NASA team will provide assistance in the following areas:
- Selecting appropriate mission critical human spaceflight applications
- Selecting appropriate machine learning technology
- Selecting appropriate machine learning V&V technology
- Requirements engineering
- Design feedback
- Teamwork, writing and communication skills feedback

Suggestion for seed funding:
$25K

Project Sponsor:
AES Crew Health Countermeasures

Project Title:
Head and body monitoring sensorimotor assessment tool

Scope of the challenge:
The purpose of this project is to develop unobtrusive assessments of sensorimotor fitness for duty by monitoring head and body motion

Description:
Exposure to microgravity alters sensorimotor function which manifests as motion sickness and decrements in spatial orientation, postural control and locomotion. During descent and early recovery activities, head movements can be provocative. During the early phase of post-flight recovery, crewmembers tend to restrict head movements, especially one involving tilts relative to gravity or head turns relative to their torso. However, continuing to restrict motion may delay adaptation. One medical guideline, therefore, is to encourage crewmembers to initially limit head movements to minimize motion sickness, but gradually increase the amplitude of their movements to promote adaptation while staying within a range of motion that is well tolerated.

Unobtrusive monitoring of head and body motion as crewmembers perform their mission tasks can provide an objective assessment of their recovery progress. This type of an assessment tool could also potentially provide objective criteria of fitness for duty for more complex tasks during exploration missions, e.g., extravehicular activities (EVAs). This could be performed from image processing of their movements from cabin camera views, having crewmembers don wearable motion sensors (e.g., inertial measurement units, or IMUs) on their head and torso, or some combination of the two. The goal of this project will be to develop metrics that characterize the range and type of head movements over an extended time, and/or when the crewmember performs specific tasks that involve movements to targets of interest. The metrics can be further refined by comparing values from healthy subjects to either clinical populations, subjects exposed to a spaceflight analog, or simply restricting movements with a neck brace. The utility of this monitoring tool will need to be validated by establishing thresholds of head and body motion that relate to performance on operationally relevant tasks, e.g., surrogate EVA tasks.

Expected Product (delivery item/concept):
The expected deliverable will be a data capture and analysis platform using wearable small head and body motion sensors (e.g., inertial measurement units) and/or image processing of head and body movements. The analysis tool should deliver simple metrics that characterize head and body motion with visual reports that can track progression over time and are easily interpreted by the crewmember to guide their self-assessment of readiness.

Expected Result (knowledge gained):
The sponsoring project will benefit from development of unobtrusive head and body monitoring can be used to track sensorimotor adaptation following G-state transitions, e.g., during planetary landings or return to Earth.

Relevance to Exploration:
This capability will specifically address the Human Safety Risk for Sensorimotor Alterations, and the Crew Health Countermeasures capability gap for sensorimotor countermeasures.

Level of Effort for student team:
This effort will ideally involve an integrated team involving a biomedical engineering discipline focus to develop the assessment tool along with a sports medicine or complementary clinical discipline (e.g., physical therapy) to help define the most appropriate metrics and validation steps.

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:
Depending on the complexity of the proposal, up to $30K will be available for selected proposals. Additional funding through university sources and space grant consortiums is highly encouraged.

Project Sponsor:
Habitation Systems Development Office, NASA Marshall Space Flight Center

Project Title:
Moon Supply: Logistics Transfer on the Lunar Surface

Scope of the challenge:
This challenge focuses on logistics transfer on the lunar surface to enable outfitting of inflatable and constructed habitats for long endurance, long duration space missions. The challenge seeks novel approaches for design of outfitting elements which enable movement and storage of logistics within or external to a habitat and support capabilities for transfer of logistics between surface assets (for example, a surface habitat and pressurized rover).

Description:
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.), utilities (lighting, ventilation, electrical systems), and logistics.

Previous spaceflight endeavors have used metallic structures where most core systems launch pre-integrated (an example is an International Space Station module). NASA may rely on softgoods inflatable habitation solutions, which are multi-layer material systems that house the crew and protect them from the space environment, for long duration space missions to the lunar surface. One advantage of inflatables is that they provide larger habitable volumes at lower mass than conventional fully metallic habitats. However, inflatables create a unique and more complex outfitting challenge since the habitat is stowed for launch in an uninflated, small diameter package and deployed to its full inflated volume at the point of use, requiring additional stowing and/or prepositioning of logistics and more extensive crew involvement in system installation.

Vertically constructed habitats, which are built in-situ on a planetary surface through processing of primarily indigenous resources, require full outfitting as they contain no pre-integrated systems. Constructed habitats can be made using large scale 3D printing technologies such as those being developed under the Moon to Mars Planetary Autonomous Construction Technology (MMPACT) Project at NASA Marshall Space Flight Center.

A lunar base will require a substantial amount of logistics delivery (food, water, repair items, tools, gas, etc.) for outfitting. Logistics are typically stored in cargo transfer bags, tanks, or pressurized containers which must be offloaded from a lander, transported across the lunar surface to a habitat or a pressurized rover, and then loaded by crew/robotics into the habitat for storage or use. Carriers and habitat elements for transfer of logistics represent enabling capabilities. The focus of this project is on designs and concepts which facilitate movement of logistics between surface assets and also within the habitat. In the course of the academic year, teams will perform concept studies, prototyping/demonstration activities, and potentially human factors studies on logistics transfer in support of outfitting.

- Students will design habitat elements for moving logistics within a habitat or externally. These elements could include ladders, stairs, or even elevators. Designs would seek to optimize space and maximize capability. Human factors studies to assess the safety and efficiency of designs can also be undertaken. Students may also consider vertical versus horizontal habitation layouts in relation to outfitting and logistics transfer.

- Students should also design support capabilities and develop a concept of operations for moving logistics between surface assets (for example, between a surface habitat and a pressurized rover or lander).

Teams are required to create simulations and/or prototypes to demonstrate concepts/approaches.

Expected Product (delivery item/concept):
The primary outcome expected would be a study report covering a concept of operations, requirements, design, and feasibility assessment for the tasks identified above. Universities are required to deliver simulations and/or prototypes to demonstrate concepts/approaches generated through this activity to NASA. Human factors studies are also desired to evaluate aspects of crew interaction with the system and efficiencies achieved relative to baseline concepts. If applicable to the scope, teams may use existing habitat mockup facilities at their university for this project or create new facilities using X-Hab funding. It may also be possible to test or integrate elements designed by student teams into a habitat mockup at a NASA facility.

Expected Result (knowledge gained):
The knowledge gained from this study will assist NASA in planning for future missions which require sustained habitation on a planetary surface. While the effort should focus primarily on lunar surface inflatable habitats or constructed habitats, the results and recommendations generated may also be extensible to Mars architectures. These studies will help to develop novel approaches for logistics transfer and movement in support of outfitting. Human factors considerations will be at the forefront of any effort. The work will provide a benefits assessment for integrating approaches or designs into lunar surface outfitting activities.

Relevance to Exploration:
As NASA undertakes sustained missions beyond low Earth orbit, the agency must look at alternative approaches for logistics and outfitting. The International Space Station approach for logistics and outfitting relies on large amounts of storage space, prepositioning of all elements and spares, pre-integration of systems, a frequent launch and return cadence, and dedicated crew involvement in any system installation, operation, and maintenance. This approach will be difficult to adapt to long duration, long endurance missions where 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 movement of logistics 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 2022 to May 2023). A team of students will consistently engage with NASA stakeholders and mentors from the Habitation Systems Development office. 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 study report. Teams are also encouraged to develop supporting prototypes, simulations, and/or conduct human factors studies.

Level of effort for NASA team:
The NASA team will provide subject matter experts to mentor the students within key technical areas, including materials, structures, systems engineering, and human factors. For trade studies and concept development, NASA will assist the team by providing background information on logistics, habitat outfitting needs, and technology gaps. Ground rules and assumptions for future habitation platforms will also be provided.

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

Project Sponsor:
Deep Space Logistics Project Office, Kennedy Space Center
https://www.nasa.gov/content/about-gateway-deep-space-logistics

Project Title:
Autonomous Cargo Management & Distribution for Surface Logistics

Scope of the challenge:
Develop a concept for automated cargo handling for logistics at Gateway and on the Lunar Surface.

Description:
The current state-of-the-art for supply chains beyond Earth's Atmosphere is limited to our experience with Commercial Resupply Services (CRS). This has allowed NASA to develop effective cargo packing and storage strategies for humans to interact with and access, but a need for internal vehicle robotics at Gateway and the Lunar surface due to infrequent human occupancy brings up many questions. This task seeks to answer some of those questions, namely

"What would an automated cargo management system look like in space?"

The key driver of this is to minimize crew time and maximize the level of automation at the lunar surface. This also plays a key role in our ambitions to put a person on Mars, which would require extensive autonomous cargo storage and management in the establishment of a sustainable colony on the red planet. This technology also has clear benefits to the logistics industry here on Earth, enabling a greater degree of autonomy and improved efficiency in our delicate supply chain.

Expected Product (delivery item/concept):
A demonstration of the fundamental technology that enables automated cargo handling for assets of various sizes, masses, and shapes. This would notionally look something like a more flexible and lightweight vending machine for the purposes of moving cargo from inside the logistics module to a waiting astronaut or robot. Future applications would apply this to extracting pressurized cargo from a pressurized volume.

Expected Result (knowledge gained):
A scalable, vending-machine-like demonstration of automated cargo handling.

Relevance to Exploration:
Every link in the chain for automated supply chain management reduces the need for crew time and frees up astronauts to pursue other tasks that are less monotonous and require the human touch. Furthermore, current state-of-the-art for retrieving supplies from a pressurized chamber requires two astronauts – one on the inside to deposit the item into a notional airlock, and another to retrieve it outside. If this process could be automated without impeding astronaut operations, then it would free up considerable crew time.

Level of Effort for student team:
Students will develop and demonstrate a concept that:

- Is autonomous
- Is lightweight
- Can handle cargo of various sizes and shapes

- Is reliable

Level of effort for NASA team:
The NASA team will:
- Provide physical constraints on object size, mass, and shape
- Provide physical constraints of spacecraft/habitat
- Provide guidance and instruction on NASA systems NASA needs

Suggestion for seed funding:
$13k for University design and development during Phase I.

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

____
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.