National Space Grant Foundation

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eXploration Systems and Habitation (X-Hab) 2018 Academic Innovation Challenge Solicitation

on behalf of

NASA Headquarters
Human Exploration & Operations Mission Directorate

Sponsored by:

The Advanced Exploration Systems (AES) Division

Release Date:	February 14, 2017
Proposals Due:	April 28, 2017
Anticipated Award Date:	May 26, 2017
Program Website:	https://www.spacegrant.org/xhab/

X-Hab 2018 Academic Innovation Challenge Solicitation

1. Funding Opportunity Description - Synopsis

The eXploration Systems and Habitation (X-Hab) 2018 Academic Innovation Challenge is a university-level challenge designed to develop strategic partnerships and collaborations with universities. It has been organized to help bridge strategic knowledge gaps and increase knowledge in capabilities and technology risk reduction related to NASA's vision and missions. *In 2016 the X-Hab Challenge scope was formally extended to include other areas of Exploration Systems as well as habitation topics*. The competition is intended to link with senior- and graduate-level design curricula that emphasize hands-on design, research, development, and manufacturing of functional prototypical subsystems that enable functionality for space habitats and deep-space exploration missions. NASA will directly benefit from the challenge by sponsoring the development of innovative concepts and technologies from universities, which will result in novel ideas and solutions that could be applied to exploration.

The Advanced Exploration Systems (AES) Division will offer multiple awards of $20k - $30k each to design and produce studies or functional products of interest to the AES Division (see Section 3.2, *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 X-Hab proposals which will be reviewed by technical experts; subsequent down-selection will determine which projects will be funded. X-Hab university teams will be required to complete their products for evaluation by the AES Division in May 2018. Universities may form collaborations to perform as a single distributed project team.

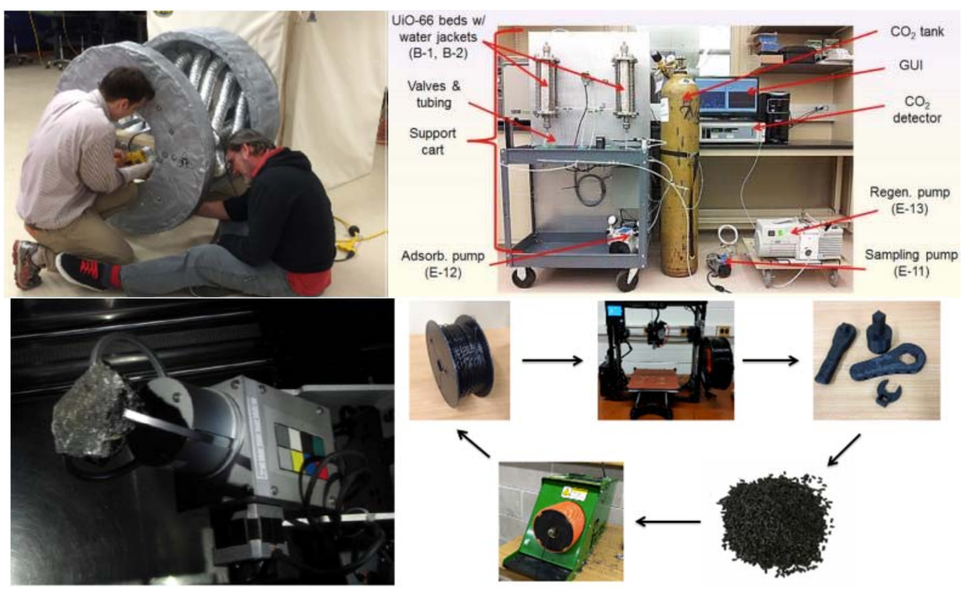


Figure 1: Previous X-Hab Projects (from top left, clockwise): Deployable Airlock, Closed Environment Air Revitalization System Based on Metal Organic Framework Adsorbents, Carbon-fiber/Fused Deposition Modeling Spacecraft Structural Fabrication System, Sample Handling System for GeoLab Glovebox (Image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

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

2. Eligibility

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

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

In order to fully comply with the United States Department of Commerce, Bureau of Industry and Security (BIS) Export Administration Regulations (EAR), *participation in the 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 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 eXploration Systems and Habitation (X-Hab) 2018 Academic Innovation Challenge. The 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 X-Hab 2018 challenge will 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 2017 and spring 2018 semesters. Applicants are required to apply a systems engineering approach in the design course. For reference please see the NASA Systems Engineering Handbook NASA SP-2007-6105. Further, all teams must provide proof that the course has been approved to be taught at their institution and the selected professor must be available for technical assistance to the implementing university team in 2017-2018 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):

- 9 Oct 2017 – Requirements and System Definition Review (SDR)
- 13 Nov 2017 – Preliminary Design Review (PDR)
- 22 Jan 2018 – Critical Design Review (CDR)
- 12 March 2018 – Progress Checkpoint Review
- 7 May 2018 – 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 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 Program*

- Project Title: *Mars Habitat Commonality*

Project Sponsor: *AES Resource Prospector Project*

- Project Title: *Reduced Gravity Airborne Mobility Testbed*

Project Sponsor: *AES Resource Prospector Project, RESOLVE Payload*

- Project Title: *Quantification of Condensed Water on Resource Prospector*

Project Sponsor: *AES Life Support Project*

- Project Title: *Humidity Management for CO_2 Sequestration through Deposition*
- Project Title: *Carbon Dioxide and Water Recovery System. (COHO)*

Project Sponsor: *AES Modular Power Systems (AMPS) Project*

- Project Title: *Robotic Replacement of Power System Modular Circuit Board*

Project Sponsor: *AES Logistics Reduction Project*

- Project Title: *Long Term Hygienic Trash Stowage System*

Project Sponsor: *AES In-Space Manufacturing (ISM) Project*

- Project Title: *3D Printing with Biologic Materials: Closing the Manufacturing Loop and "Greening" Additive Manufacturing*

Project Sponsor: *Space Life and Physical Sciences*

- Project Title: *Novel Steady-State Food Production System for Space*
- Project Title: *Fresh Produce Sanitation System for Use in Microgravity*
- Project Title: *3D Printed Plant Growth Substrate*

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

For specific Advanced Exploration Systems projects, visit here

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

3.3 Academic Innovation Challenge Background and Purpose

This announcement maps to NASA Strategic Plan Objective 2.3*: Optimize Agency technology investments, foster open innovation and facilitate technology infusion, ensuring the greatest national benefit.* 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. NASA 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 is pioneering new approaches for rapidly developing prototype systems, demonstrating key capabilities, and validating operational concepts for future human missions beyond Earth orbit. 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 five primary domain areas: Crew Mobility Systems, Habitation Systems, Vehicle Systems, Foundational Systems, and Robotic Precursor Activities. The purpose of the 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. Each of the topic areas is summarized below:

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.

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 3, 2017.
Responses will be posted on April 10, 2017

3.5 Pertinent Dates

Proposal Phase

14 Feb 2017	Date of Announcement and Release of RFP
3 Apr 2017	Questions for online Technical Interchange due
10 Apr 2017	Responses to submitted questions published online
28 April 2017	Proposal due
26 May 2017	Award announcements

Award Phase

Summer - Fall 2017	Design phase
Sept 2017	Kickoff meetings
9 Oct 2017	Requirements and System Definition Review
13 Nov 2017	Preliminary Design Review
22 Jan 2018	Critical Design Review
12 March 2018	Progress Checkpoint Review
7 May 2018	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 (WebEx and telecon) through the project execution
3. Report on Educational Outreach activity prior to Project Completion
4. Demonstration articles for X-Hab developmental studies prior to Project Completion
5. Technical Final Report prior to Project Completion

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, 2017, to May 31, 2018. 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 X-Hab 2018 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 are 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 X-Hab 2018 Academic Innovation Challenge project, 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 X-Hab 2018 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 X-Hab prototype will be integrated and tested at the affiliated university in the 2017-18 academic year. Describe how the 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 X-Hab 2018 Academic Innovation Challenge will be implemented during the 2017-2018 academic year and will comply with all pedagogical requirements.

4.2 Proposal Evaluation Criteria

The X-Hab Challenge is divided into two phases. Phase 1 solicits proposals that will be evaluated for selection and Phase 2 is the project execution of the selected teams, the actual challenge. Both phases will be evaluated based on appropriate predetermined evaluation criteria.

Phase 1 Evaluation Criteria

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

Logistics
- Identify project title.
- Identify project team.
- Identify the principal investigator (PI).
- identify a vision, mission, and concept of operations.
- Identify the problem statement, functional and performance requirements.
- Identify a work plan, integration testing plan, milestone schedule, and experience.
- Identify faculty institution and provide confirmation of commitment in appendix.
- Identify a research assistant to provide leadership to the student project team (optional).
- Identify affiliated Space Grant Consortium (if applicable), sponsor, or affiliations.
- Identify NASA technical expert and provide signed statement of commitment in Appendix (optional).

- Identify manufacturing, assembly, and pretesting capabilities and facilities.
- Identify a preliminary notional concept of the demonstration article, with the understanding the final design will occur during the fall semester.

Merit

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

Contribution to NASA Strategic Goals

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

4.3 Proposal Submission

Electronic copies of proposals must be received no later than **midnight, Pacific Daylight Time, Friday, 28 April 2017**. *Late proposals will not be considered.* The proposal will be submitted online at https://spacegrant.net/proposals/xhab/

Applicants will be advised by electronic mail when selections are made. It is anticipated that the award will be announced on 26 May 2017.

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: X-Hab Topic Details

Project Sponsor:
Advanced Exploration Systems (AES) Program

Project Title:
Mars Habitat Commonality

Scope of the challenge:
A typical Mars mission sends a crew to Mars and back on a ~1000-day mission. This includes about 250 days outbound, 500 days on the surface, and 250 days on the return. The in-space transfer habitat is in ~0g unless it is rotated to generate an artificial gravity, and the surface habitat is on Mars at ~1/3g. This challenge is to create a habitation system that has commonality in both the in-space and surface habitat designs so the crew will be familiar with the layout, function, and location of everything in the surface habitat when they arrive on Mars.

Description:
General features of the habitation systems should include the following:

- Crew size: 4 to 6
- Utilities, including closed loop life support system
- Air lock for 2-person EVAs
- Logistics handling and refurbishment for reuse on multiple missions

In-space transfer habitat:

- Launched on SLS and fits within a 10-m diameter fairing
- Habitat design may assume ~0g up to 1/3g artificial gravity
- Two volumes so each can act as a safe haven for the other in the event of smoke, fire, or pressure loss in one of the pressure vessels
- 1000 days of logistics (4,000 kg to 5,000 kg per crew member)

Mars surface habitat:

- Launched on SLS with a lander and fits within a 10-m diameter fairing
- Sized to fit on a lander
- Concepts for connectivity to two pressurized rover
- Concepts for connectivity to logistics resupply
- Access method to a crew descent and ascent vehicle(s)
- 500 days of logistics (2,000 kg to 2,500 kg per crew member)
- Surface base growth options

Expected Product (delivery item/concept):
Habitat conceptual designs with full-scale mockup of primary habitat module and/or selected key demonstration elements and a fly through animation of the modules as a final product.

Expected Result (knowledge gained):
A challenge for the design of a habitat system is commonality between the in-space and surface system layouts. If the crew can arrive on the surface to live in a habitat that is like the one in which they traveled, then efficiency in increased as well as safety.

Relevance to Exploration:
Solving multiple design problems that works in an end to end habitat system is a challenge. This challenge will add to the knowledge gained from multiple single issue designs, leading to a more integrated approach. In-space habitats are at a very high Technology Readiness Level (TRL) due to the ISS experience. Surface Habitats and in-space habitats with artificial gravity are at a very low TRL since they do not yet exist. Continued exploration of designs and commonality

between in-space and surface systems will help close the knowledge gap and lead to the best solutions.

Level of Effort for student team:
Primary disciplines should be in the area of architecture, space architecture, industrial design, aerospace engineering, and other related branches of design and engineering. Research should be led at the graduate student level with support from undergraduates.

Level of effort for NASA team:
NASA habitation team consultation support available.

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

Project Sponsor:
AES Resource Prospector (RP) Project

Project Title:
Small-Scale Mobility Testbed for Reduced Flight Aircraft

Scope of the Challenge:
Create a test apparatus to enable rover wheel-soil interaction testing in a reduced gravity airplane.

Description:
The Resource Prospector mission will return NASA to the lunar surface in locations previously unexplored by anyone: the lunar poles. There, a rover will be deployed to investigate the in situ resource utilization (ISRU) potential of several volatiles, including water. Currently, the properties of lunar regolith at the poles and in permanently shadowed regions are unknown and present potential risk to the mission with respect to navigation and traversibility. Several scientific and observational theories exist to constrain the potential environment but physically characterizing the effect of reduced gravity would prove useful. NASA would like to test a small-scale rover wheel on lunar simulant in reduced gravity to help characterize the effect of this gravitational environment on wheel tractive performance.

The goal of this project is to design and build a small-scale wheel testbed that can be used on a reduced gravity aircraft. The testbed must be capable of driving a wheel across an inclined bin filled with lunar simulant and record wheel sinkage and wheel slip. The size of the testbed wheel should be able to be accommodated on a commercially available reduced gravity aircraft and allow the gravitational effects to be theoretically scaled up to full size wheels. One of the challenges is that the wheel must maintain relatively constant normal load throughout a test (assuming the gravity does not change) yet the wheel should be able to sink naturally in the soil. The design should also include a method for preparing the simulant to a loose condition while in flight (requires loosening and leveling). A reduced gravity flight typically consists of around 15 parabolic maneuvers in which there are 20-30 seconds of 1/6 g each. It is expected that changes in gravity will affect the soil condition so either both the soil preparation and wheel test will need to be carried out in the same 20-30 second period, or a method of maintaining the soil's loose condition during the gravity cycling will need to be determined.

Summary of test apparatus characteristics:
Wheel diameter: between 10-20 cm
Width: 0.4* diameter
Wheel speed: app. 2 RPM
Wheel normal load at 1/6 G: between 25-50 N
Soil type: lunar regolith simulant (TBD) in a loose condition
Inclination angles: 10, 15, and 20 deg
Soil bin dimensions: length = 1 wheel circumference, width = 3 X wheel width, depth = wheel diameter
Minimum measurements: Inclination angle, wheel normal load, wheel sinkage, and wheel slip

Expected Product (delivery item/concept):
Delivery of a test apparatus designed to be flown on one or more reduced gravity airplane platforms (example: https://www.gozerog.com/), with the capabilities listed above and any software required to operate and take measurements from the apparatus.

Expected Result (knowledge gained):
First steps toward implementing a test with both wheel and soil under reduced gravity environments.

Relevance to Exploration:
NASA includes *in situ* resource utilization in the critical path for future exploration. The system developed in this project directly addresses the Resource Prospector rover's ability to perform in an unknown lunar regolith environment by providing a platform to help characterize risk for the mission and understand any unexpected design drivers for the rover as a whole.

Level of Effort for Student Team:
The student team would be responsible for understanding the requirements given by the project and finding out what constraints and requirements would be imposed by different airborne platforms. They would then design and construct a test apparatus, which would be able to fly in the proposed platform, as well as any software needed to run tests and collect data.

Level of Effort for NASA Team:
The NASA team would provide any additional requirements needed by the student team, monitor progress and ensure the final design and capabilities are able to be used by the project team in future tests. Should NASA utilize the test apparatus built by the university, NASA would encumber the cost and planning associated with executing tests.

Suggestion for seed funding:
$20k from AES Resource Prospector team. Proposers are encouraged to seek additional funding or other contributions from their institutions, industry, space grant consortia, and others.

Project Sponsor:
Resource Prospector, RESOLVE Payload

Project Title:
Quantification of Condensed Water on the Resource Prospector

Scope of the Challenge:
Create a novel method for determining the quantity of a condensed fluid (water) on a cold finger

Description:
The Regolith and Environment Science and Oxygen and Lunar Volatiles Extraction (RESOLVE) payload and its Lunar Advanced Volatiles Analysis (LAVA) instrument are a part of the Resource Prospector (RP) mission. One demonstration planned for the RP mission is the Water Droplet Demonstration (WDD). The purpose of the WDD is to provide a demonstration of water capture from lunar regolith by imaging water that has evolved from the regolith. The WDD will be successful upon visible signs of water condensation on the WDD cold finger which will be photographed and relayed back to Earth. The water droplet demonstration chamber design for the Vacuum Demonstration Unit (VDU) is intended to accept sample effluent from the LAVA Fluid Subsystem, including a manifold with a 100 cubic centimeter volume called the surge tank. The LAVA surge tank is maintained at 150°C with pressures up to 100 psia. After gas analysis has been completed with other LAVA instruments, the remaining gas in the surge tank will be routed through the chilled WDD in order for condensing of water vapor to occur. The WDD includes a condensing chamber with a sapphire glass viewing area and camera with line of sight positioned normal to a cold finger condenser. The VDU WDD chamber is shown in Figure 1. The cold finger is cooled conductively using a heat exchanger mounted behind the wall of the sealed chamber. The cold finger is mounted against the inside wall of this chamber so that heat will flow outward from the cold finger to the heat exchanger. Sample effluent flows at constant velocity through the WDD chamber using a restriction on the vent outlet and the principle of choked flow. The sample effluent exits the WDD chamber through a thermally conditioned line back to the LAVA manifold where the isolation valve and aforementioned vent orifice are mounted. This is intended to mitigate any potential ice deposition which would otherwise clog the small vent orifice opening. While sample gas is flowing through the WDD out to a restricted vent line, the camera will repeatedly image the cold finger through the sapphire window. This will allow an understanding of how quickly the condensation is forming. The cold finger is illuminated by two LEDs that will remain on while the WDD is active.

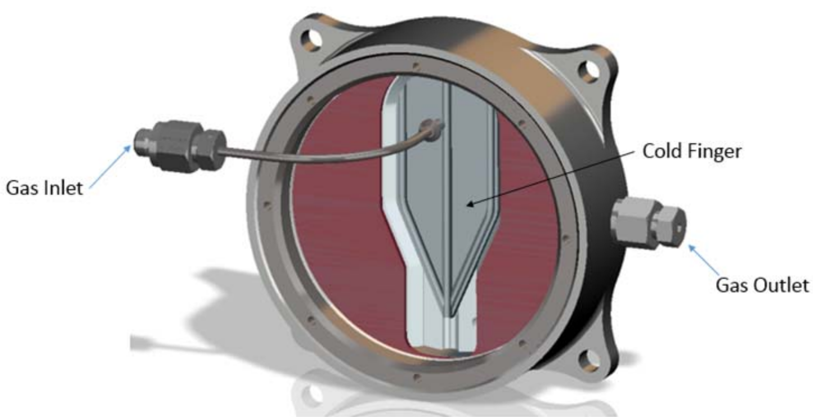


Figure 1 - The Water Droplet Demonstration Chamber (VDU Design)

Expected Product (delivery item/concept):
Demonstration of the method for quantification including concept of operations, software and/or imaging processing, component list, mass and power estimates, and prototype hardware.

Expected Result (knowledge gained):
The LAVA Subsystem includes a water droplet demonstration to condense the water released from heating lunar soil. Quantifying the amount of water condensed from a sample will provide insight into the feasibility of water capture for ISRU and help to inform future designs for resource capture on the lunar surface.

Relevance to Exploration:
NASA includes in situ resource utilization (ISRU) in the critical path for future exploration. The quantification of condensed water on the lunar soil will increase the knowledge gap that exists for processing lunar resources. The techniques developed on this project can be extended to other ISRU techniques as well as ground processing that involves quantifying a condensed liquid.

Level of Effort for Student Team:
The tasks include understanding the current water droplet demonstration hardware and creating a replicate of the critical interface in a laboratory setting. This would most likely involve designing a metal surface along with a way to cool the metal surface to condense water. The team would develop a way to create water droplets on the relevant surface with a similar configuration compared to the current system design. The team would evaluate different methods for water quantification based on the current design. This could involve optics and image processing (LED color choices, angles, etc.) and software for identification and quantification of the water or the use of sensors integrated onto the cold plate with minimal extraneous hardware for operations. After a design is chosen, the team would fabricate a prototype setup and test the concept of operations to demonstrate the quantification of the condensed liquid.

Level of Effort for NASA Team:
The RESOLVE-LAVA team has engaged numerous undergrad and graduate students in the design of the system using internships to support their work on the project. The NASA team would provide an overview of the current water droplet demonstration design and review the prototype setup from the team to ensure the appropriate interfaces and design choices are represented in the setup. The NASA team would also evaluate the demonstration of the prototype setup and work with the team to integrate the results into the design of the system for the lunar mission.

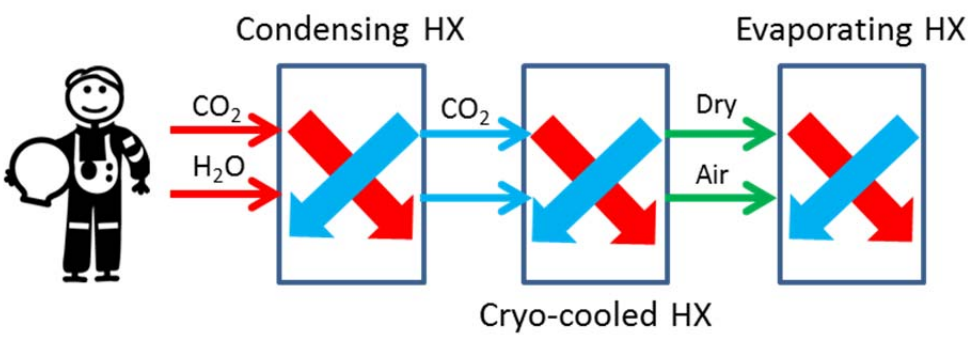
Seed Funding:
$10k from the Resource Prospector team at the Kennedy Space Center. Proposers are encouraged to seek additional funding or other contributions from their institutions, industry, space grant consortia, and others.

Project Sponsor:
AES Life Support Project

Project Title:
Humidity Management for CO_2 Sequestration through Deposition

Scope of the challenge:
Design, build, and characterize the operation of a humidity removal and recovery system for air revitalization for usage in conjunction with a cryocooled CO_2 removal system.

Description:
In order to meet the challenges posed by deep space manned exploration, innovative, reliable, and cost-effective solutions must be developed in order to close the loop in human life support. In the realm of air revitalization, the current sorbent-based architecture aboard the International Space Station (ISS) has proven to be sensitive to contaminants and mechanical failures. Cryo-cooling has demonstrated to be an effective method to remove CO_2 from process flow via deposition. However, 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. Once CO_2 has been removed from the airstream, the dry, clean air must then be re-humidified for cabin circulation. This project aims to design, build, and characterize a water removal and rehumidification system to meet the architecture of a cryocapture-based CO_2 recovery system. In the figure below, these two processes are performed via condensing and evaporating heat exchangers, but alternative solutions are encouraged.



Expected Product (delivery item/concept):
Design and build benchtop scaled dehumidifying and rehumidifying systems capable of integrating with the inputs and outputs of a cryoheat exchanger. The dehumidifying system will take an input of simulated cabin air and will produce dry air for CO_2 capture. The rehumidifying system will take an input of cryo-temperature dry air and produce cabin ready air. Condensation rates, evaporation rates, heat transfer properties, and heat exchanger designs are all project deliverables. Students will also provide design suggestions and/or alternative solutions.

Expected Result (knowledge gained):
Students will gain general knowledge of air revitalization techniques and heat exchange mechanisms, as well as requirements for environmental control and life support systems (ECLSS). Mechanical, thermal, fluid, and electrical engineering disciplines will work together to succeed in this project. Practical systems engineering and project management skills will be developed.

Relevance to Exploration:
This project will continue the exploration of cryocooling as an alternative technology pathway to removing CO_2 and other contaminants from the cabin air environment. In the past, cryocooling technology has been energy intensive and costly, but advancements in cooling technology have reopened the door for feasibility studies. This project specifically focuses on the humidity management segments of this system. An air revitalization system based on cryocooling can potentially operate as a full standalone system or can be integrated into other existing air revitalization subsystem segments for transit vehicle or planetary ventures.

Level of Effort for student team:
Design, build, and test a humidity management system for air revitalization using cryocapture CO_2 architecture. Possible involvement with 0-g test apparatus.

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

Suggestion for seed funding:
The AES Life Support Project will provide $30k toward this project. Proposers are encouraged to seek additional funding or other contributions from their institutions, industry, space grant consortia, and others.

Project Sponsor:
AES Life Support Project

Project Title:
Carbon Dioxide and Water Recovery System. (COHO)

Scope of the challenge:
To design, develop, fabricate, and test the integrated COHO system to recover carbon dioxide and water for use in deep space travel as well as in the Martian environment.

Description:
The COHO system is a forward osmosis (FO) amine-based water and $CO_{2(g)}$ recovery system. It is unique in that it integrates both water and $CO_{2(g)}$ removal into one system as it utilizes the carbon reduction necessities in the life support system on spacecraft to drive the water recovery process. The simplified diagram of the Switchable Polarity Solvent (SPS, a biphasic solution) and the COHO system are shown in Figure 1 and Figure 3, respectively. Brief descriptions of the system components are listed in Table 1. The FO process needs a strong osmotic agent (OA) to drive clean water across the FO membrane from the wastewater. The $CO_{2(g)}$ input into the SPS converts this organic from a water immiscible form into a water miscible solution. This water miscible organic has a much higher osmotic potential than sodium chloride (NaCl, a currently used OA solution). Higher water flux rates across the FO membranes lead to water recycling system that are smaller in size, lower in power requirements, and less in mass. At the same time, $CO_{2(g)}$ is captured and reconverted into usable components (e.g., oxygen and methane) in the life support closed-loop model. Idaho National Laboratory (INL) has been building both benchtop and full-sized systems to treat industrial wastewater (e.g., fractionation water). However, it has not been explored for spacecraft applications to date. The system has the potential to reduce launch cost as well as to close the life support loop in a uniquely integrated and simplified configuration.

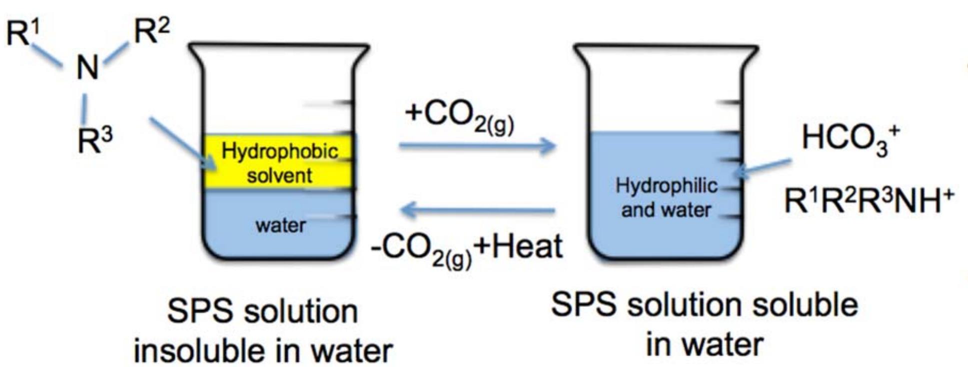


Figure 2: SPS in its non-polar water immiscible form can reversibly change to a polar, water-miscible form in 1 g.

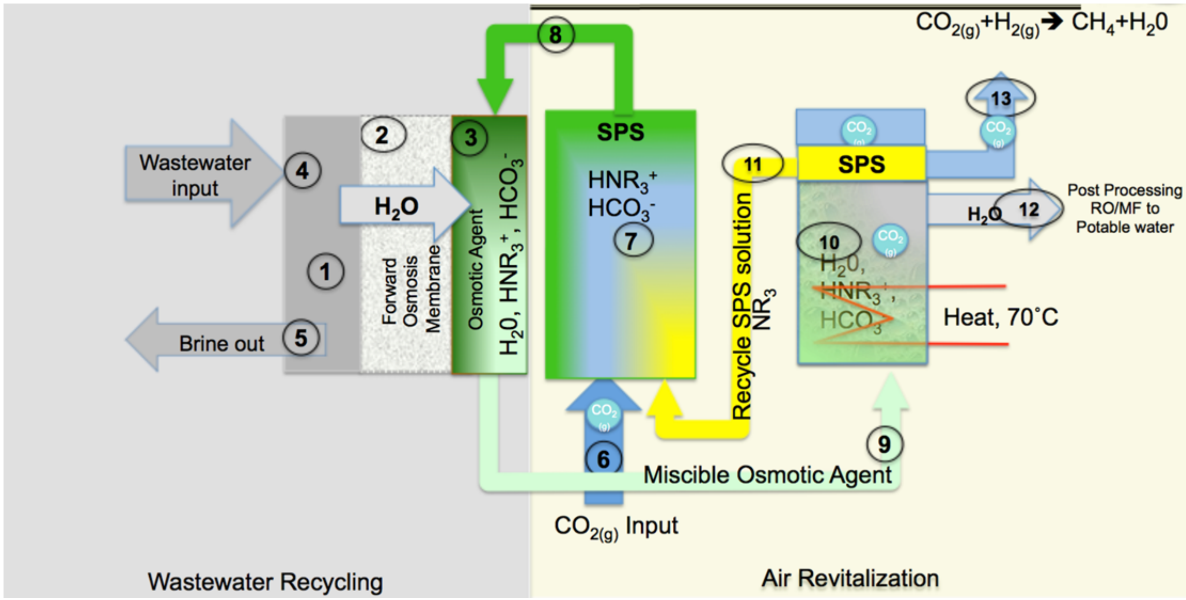


Figure 3: A simplified diagram of the COHO process.

Table 1. COHO system components

Wastewater Recycling

① Wastewater input tank
② Forward osmosis (FO) membrane allow clean water to diffuse through the membrane via an osmotic potential
③ Osmotic agent tank. Osmotic Agent (OA) is the driving force for the water to pass through the membrane. When $CO_{2(g)}$ is added to the organic SPS solution, the solutions convert to a salt solution with high osmotic potential.
④ Wastewater input
⑤ Brine Output

$CO_{2(g)}$ capture

⑥ $CO_{2(g)}$input from the cabin or the Martian atmosphere
⑦ SPS solution mixed with $CO_{2(g)}$ allow for water be soluble in the salt solution.
⑧ Dilute miscible OA with water.
⑨ Water-miscible SPS solution
⑩ SPS, water, $CO_{2(g)}$ is heated to separate all the components.
⑪ Recycled SPS solution is feed back into the OA tank to be reuse
⑫ Processed water for further conversion to potable water via multifiltration systems
⑬ $CO_{2(g)}$ output to the Sabatier system for further processing.

Expected Product (delivery item/concept):

The expected product is a bench top prototype COHO system using a SPS solution that is compatible for spacecraft. The system will recycle spacecraft wastewater and remove $CO_{2(g)}$ from cabin air. The delivered system will be similar to the process described in Figure 3. All design, fabrication, and experimental findings will be delivered to the AES community for feedback on a regular basis. Final deliverable will be all design and test data with recommended parameters for a scaled up system.

Expected Result (knowledge gained):

The COHO system has been demonstrated successfully in terrestrial applications through the INL research[1]. However, spacecraft applications have not been explored even though the potential for an integrated water and $CO_{2(g)}$ recovered system could lead to an unexplored concept of combining and utilizing the waste product ($CO_{2(g)}$) itself as the driving force to enhance/drive another system (FO). Therefore, collaborative efforts at the university level is needed to encourage more research into this integrated concept for a life support system in spacecraft.

Relevance to Exploration:

Improving the knowledge and capability in this area will introduce and improve NASA's capacity for space exploration systems conceptually from a one system for every function into an integrated system of multiple functions. The integrated recovery process may offer simplicity and reduce ESM parameters. This model mimics the waste recovery process model that is similar to how nature recovers its valuable resource here on Earth. The system is at TRL 2 based on research already completed by INL. The SPS organics used at INL may not be appropriate for space travel. Part of the next level is to identify SPS components that are compatible with space travel.

The FO process has been thoroughly researched at NASA ARC since 2006. NASA ARC has extensively explored different FO membranes to improve water recovery. However, the osmotic potential of NaCl is not high enough to enhance the FO process. Therefore, researchers in government and educational institutions as well our commercial partners globally and domestically have been exploring alternative OA solutions. One of those solutions is offered in the COHO system as developed at INL and Porifera LLC, a FO-membrane manufacturer. Taking what has already been done terrestrially and applying it to space travel would be beneficial to NASA since the initial basic research has already begun at INL and by other researchers within the FO community.

Level of Effort for student team:

In order to research, design, develop, fabricate, build, assemble and test the COHO bench top prototype, the team should have some variations of the skill set listed below, **Error! Reference source not found.**. These are preferred skills and knowledge set. It is important that the group is open to exploring and being involve in a first generation prototype, one of a kind, with

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[1] Wilson, A., Orme, C., Jones, M., Hrbac, C., Adhikari, B., Wendt, D., Mines, G., « Switchable Polarity Solvent Forward Osmosis Process Development. » June 2016. Aaron Wilson ; personal presentation by Idaho National Lab to Ames Research Center.

potential to be a Master Thesis or PhD thesis topic with relevance to NASA outreach as well as contributing to the NASA closed loop Life Support System. One of the main tasks would be to conduct SPS candidates for use in spacecraft system. The NASA ARC team will be working very closely with the university.

Table 2 The COHO team minimum skill sets.

TASK	MAJOR	Minimum Degree Aspiration
Identify the SPS to be used in spacecraft	**Chemistry**	**M.S./PhD preferred**
Design, build, fabricate, assemble, build, and test a bench scale system	**Chemical, Mechanical, Aerospace, Engineer**	**M.S.**

Level of effort for NASA team:

The NASA team, especially the ARC team, will be hold a weekly telecon with the research team at the university to consult, collaborate, and evaluate the project demonstration/presentation on both sides. The university team is expected to present to the AES communities at each major milestone, to be agreed upon.

Suggestion for seed funding:

The AES Life Support Project will provide $30k toward this project. Proposers are encouraged to seek additional funding or other contributions from their institutions, industry, space grant consortia, and others.

Project Sponsor:

AES Modular Power Systems (AMPS)

Current spacecraft power systems are custom designed, each with their own set of individual components to perform power distribution and control functions. As we move toward long duration exploration missions, often with multiple vehicles, the development of multiple different power converters, power regulators, and switchgear becomes expensive. Additionally, providing an inventory of spare components is logistically unreasonable for long missions. The goal of the AMPS project is to identify and develop a set of modular power components, along with associated standards, to provide power system commonality across a variety of exploration applications. Modularity enhances reusability, in that components can be interchanged between multiple platforms and missions or scavenged from retired platforms. It also allows for flexibility in the power system architecture, and increases system reliability, since failures will more likely result in reduced capability instead of a complete loss of use.

Project Title:

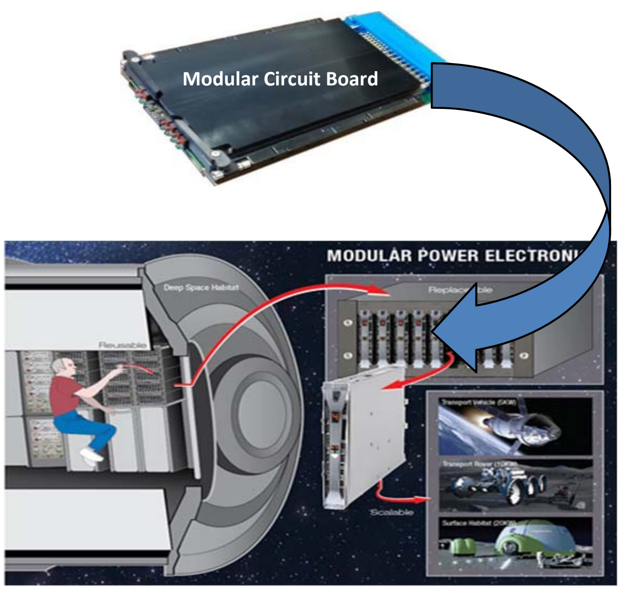
Robotic Replacement of Power System Modular Circuit Board

Scope of the challenge:

Modify the mechanical design of a modular circuit board and its chassis to allow a robot to remove a failed board and replace it with a spare.

Description:

The scenario for use of this concept is brought into play when a critical electrical solid-state switch has failed on a modular circuit board in an unmanned spacecraft and needs to be replaced. A robot is available and has the capability to perform the operation.



On command, a robot must be used to locate a specific circuit board within a spacecraft rack and chassis, unfasten the failed board, remove it from the chassis, grasp a replacement, install it in the failed board's original position, and fasten the new board into place. Human intervention is not allowed during the process. A modular circuit board and its chassis will be supplied by the AMPS project as an example of the existing design.

Expected Product (delivery item/concept):
A written report with a video showing a robot removing and replacing the modular circuit board.

Expected Result (knowledge gained):
The expected benefit from the demonstration is confirmation that the power system's modular circuit board concept will permit robotic replacement without the need for crew members involvement.

Relevance to Exploration:
Exploration missions force spacecraft systems to have high reliability since spare parts cannot be supplied from Earth as easily as when in low-Earth orbit, due to the distances traveled. The modular power system concept permits key components to have common spares and to be easily replaced. If it can be shown that a robot is able to perform the simple task of replacing a failed circuit board and returning the spacecraft to a fully operational condition, then sending unmanned craft with a robot will increase the probability of mission success. In addition, for manned missions, performing maintenance tasks should not detract from crew time needed to accomplish science goals.

Level of Effort for student team:
Students will have to have mechanical, computer science and electrical knowledge and skills.
The modular circuit board will have to be redesigned to enable fastening and handling by the robot taking into consideration the physical limitations of the unit. The robot will have to have the intelligence and dexterity to perform the operation, which includes unfastening, removing, aligning and replacing the modular circuit board. This task could be expanded to include recognition of the board location, retrieval of the spare unit from a different location, and installation of the replacement board into the correct slot.

Level of effort for NASA team:
The AMPS project will supply personnel to aid in design, construction, and review of the project up to five hours per month. In particular, modifications to the circuit board retaining unit will have to be coordinated with the appropriate NASA designers.

Seed funding:
$20k from AES Modular Power Systems (AMPS) project. Proposers are encouraged to seek additional funding or other contributions from their institutions, industry, space grant consortia, and others.

Project Sponsor:
AES Logistics Reduction Project

Project Title:
Long-Term Hygienic Trash Stowage System

Scope of the challenge:
Develop a prototype Long Term Hygienic Trash Stowage System that includes trash stowage container, volume reduction, long-term odor control, and a long-term hygienic trash stowage arrangement. Odor, gas evolution, and microbial control from trash stored inside the space vehicle are key issues. Microbial activity on food residues and other wet trash is a major odor source. Techniques to stabilize the wet trash may include air drying, heat, and vacuum exposure. The effectiveness of stabilization over wet trash needs to be quantified. The challenge should include the container (using either soft or hard materials) and volume reduction and stabilization equipment. The prototype should occupy less than one-half of an ISS rack. Assume power consumption to be less than 150 watts, and that ventilation, cooling, and a vacuum connection are available from the vehicle; however, the impact of using any of these resources must be considered.

Description:
Long-Term Hygienic Trash Stowage System Concept:

1. Crew members separate trash into separate wet and dry trash containers or bags.
2. Wet trash is stabilized.
3. Crew members periodically reduce the volume with compaction or other means, such as mechanical, shredding, vacuum compression, etc.
4. When trash container is full and compacted into an acceptable size and shape, crew member prepares the container for long-term, odor controlled, hygienic stowage.
5. Crew member transfers trash container to designated area for long-term hygienic stowage (2-12 months). Compacted trash stowage containers should fit efficiently in an empty Cargo Transfer Bag (CTB for long-term stowage. Internal dimensions of CTB are 19.5 inches x 16.25 inches, x 9.5 inches. Number of sealed compacted trash stowage containers that fit inside of a CTB is determined by the system design. The CTB can also be used for odor control.
6. Crew member transfers trash container to vehicle air lock for disposal (container must be compatible with exposure to vacuum) or departing logistic vehicle (under atmospheric conditions)

Expected Product (delivery item/concept):
Full-scale, functional prototype of the Long-Term Hygienic Trash Stowage System that includes trash container, trash compaction system, odor control, and long-term hygienic trash stowage arrangement. It expected that a multidisciplinary team will address both the mechanical design, human factors, chemistry/microbial aspects (i.e., aerobic vs. anaerobic effects) of odor control. Design should quantify trash stabilization technique. Determine frequency of operation and if additional trash sorting is recommended to enhance processing and stabilization. Any gases or air movement through trash should be directed and contained so that if odor treatment (e.g., adsorption or catalytic) is required it could be added later. Testing of prototype system to demonstrate functionality. Final report should include findings and recommendations. At end of project prototype will be delivered to NASA's JSC for further testing and evaluation. Request that the university reserve travel funding to NASA's JSC in their budget plan.

Expected Result (knowledge gained):
The sponsoring project would like to receive a prototype of the Long-Term Hygienic Trash Stowage System for testing and evaluation that would provide data and information to determine whether to proceed with a similar system design for the Orion Program and for future long duration missions to Mars. CAD model, stress analysis to prove its safely designed, estimated consumables for a one-year mission, operations manual, example of compacted trash, define what future work should be done to address unknowns and risks.

Relevance to Exploration:
Currently there is no trash management system for long duration missions. On long duration missions trash cannot be managed in the same manner as for the ISS, where it is temporarily stowed until it is transferred to a non-returning cargo vehicle which burns up on re-entry. Month long or greater crewed missions will require a new concept for trash management and stowage since the trash cannot be stowed for the duration of the mission that does not utilize re-entry cargo vehicles. Typically, unacceptable odors diffuse through storage bag in the storage areas. For transit missions to Mars, the trash that is generated but not stabilized and stored will create odor, microbial, and hygiene issues for the crew. Technologies that reduce the trash volume for storage inside the space vehicle or eventual jettisoning via an air lock or disposable logistics vehicle are needed. Technology Area: TA6: Human Health, Life Support, and Habitation Systems, TA6.1.3 Waste Management, TA6.1.3.3 Trash Management System, Technology Readiness Level: 1-4.

Level of Effort for student team:
Skills needed: Knowledge of design process, general systems engineering, mechanical design, environmental engineering, knowledge of materials (metallic and non-metallic), collaboration with disciplines other than engineering, such as microbiology, chemical engineering, and industrial engineering design.

Level of effort for NASA team:
NASA personnel will be available for consultation, collaboration, and project demonstration/presentation. NASA will provide requirements and reference documents that include trash processing system requirements, reference publications from the International Conference of Environmental Systems (ICES) on the Heat Melt Compactor, Logistics Reduction, and the Waste Model for Space mission Trash.

Suggestion for seed funding:
Sponsoring project will provide $20K funding. Proposers are encouraged to seek additional funding or other contributions from their institutions, industry, space grant consortia, and others.

Project Sponsor:
AES In-Space Manufacturing Project

The In-space Manufacturing (ISM) Project is responsible for developing the manufacturing capabilities that will provide on-demand, sustainable operations during NASA Exploration Missions (in-transit and on-surface). This includes testing and advancing the desired technologies, as well as establishing the required skills and processes (such as certification and characterization) that will enable the technologies to become institutionalized.

The key capabilities being developed in ISM to support this "Make it, Don't Take It" approach include developing a Fabrication Laboratory (Fab Lab) for the International Space Station (ISS), which can manufacture parts in space using several materials, as well as the ability to embed printed electronics, in-space recycling of printed parts and other materials such as packaging in order to reduce mass and waste, and manufacturing structures externally in space. ISM has also developed, in conjunction with Tethers Unlimited, an integrated 3D printer and feedstock recycler (which can recycle a printed part back into plastic filament that can be used for additional printing operations). This payload, known as the ReFabricator, will be operational on ISS in 2018. The ISM project made history in 2014 by sending the first 3D printer (built by Made in Space) to ISS and manufacturing. This was a critical first step in demonstrating additive manufacturing in microgravity.

https://www.nasa.gov/mission_pages/station/research/experiments/1115.html

Project Title:
3D Printing with Biologic Materials: Closing the Manufacturing Loop and "Greening" Additive Manufacturing

Scope of the challenge:
Use plant mass or other biologically derived materials to make filament feedstock for 3D printing.

Description:
As mission durations increase and move beyond low Earth orbit (reducing the frequency of resupply opportunities), crew will need to grow plants to provide a sustainable source of fresh food. Plant growth on the International Space Station has been demonstrated through the Veggie Production System (Veggie), a deployable plant growth unit capable of producing salad-type crops. Veggie and similar systems developed for long duration, long endurance missions, will produce a substantial amount of inedible plant mass that would otherwise be discarded.

This project seeks to evaluate the feasibility of using inedible plant mass or other biologically derived materials to make filament feedstock blends for 3D printing. The outcome is to demonstrate an end-to-end process that uses raw plant mass (or compounds extracted from plant mass, such as cellulose and lignin) alone or in combination with other materials/additives to produce filament feedstock that can subsequently be used in an extrusion-based additive manufacturing processes. Materials testing of plant-based feedstocks and/or printed parts should be undertaken to understand the link between chemical composition of filament blends and resulting mechanical material properties. Preferred feedstock materials include Acylonitrile Butadiene Styrene (ABS) blends, polylactic acid (PLA) blends, or polyhydroxyalkanoate (PHA) blends, but this is by no means a comprehensive list and teams are encouraged to be creative in materials selection provided the primary constituents of the filament have a biological basis.

Ideally, teams would be able to demonstrate printing of substrates for further plant growth from biologically-derived/plant-based feedstock formulations. Other suggested applications/candidate printed components include cellulose structures for conductive films and textiles.

Expected Product (delivery item/concept):
Expected outcome of project is to repurpose inedible plant matter that would otherwise be discarded into usable feedstock for 3D printing applications. Teams should demonstrate: a process for making filament from biologically-derived materials and the capability to print with a a developed plant-based feedstock blend and produce polymeric components therefrom. Materials testing data from feedstock blends considered (based on chemical composition, mechanical properties) should be provided to the extent possible. Teams should evaluate scalability of processes to human space operations and whether extraction, blending, and filament production processes are capable of operating in reduced gravity (e.g. non-terrestrial planetary surface) or microgravity environments. Yield of process (amount of feedstock produced per unit of raw material) should also be reported.

Expected Result (knowledge gained):
The ISM philosophy is "Make it, Don't Take it!" ISM is committed to investigating the feasibility of repurposing materials that would otherwise be discarded as feedstock for manufacturing processes. In this way, waste material could be used to produce components that fulfill identified crew needs or find other use in exploration hardware and supporting systems. Reclaiming waste and reusing it as feedstock for manufacturing is critical to closing the manufacturing loop and changing the current logistics paradigm of launching all space-based infrastructure from Earth, bringing NASA closer to the vision of "massless exploration." This work helps NASA address the feasibility of one piece of this puzzle.

Relevance to Exploration:
Explain the context for how improving the knowledge and capability in this area will improve NASA's capacity for space exploration. Identify strategic knowledge gap, Technology Area, and/or Technology Readiness Level.

Closing the manufacturing loop, specifically recycling of waste materials, is essential to realizing the benefits of in-space manufacturing and creating a more favorable logistics scenario for long duration, long endurance missions. Plant growth will be essential for missions where resupply opportunities are infrequent. In these mission scenarios plant mass (and materials extracted from it) can potentially be harnessed to produce usable parts for other space applications and mission needs.

Level of Effort for student team:
Student teams will be responsible for creating biologically derived feedstock formulations, producing and testing feedstocks, demonstrating 3D printing with feedstock(s), and delivering parts that could be used to enable further plant growth (e.g. water delivery system, substrates) or find other use in exploration applications.

Level of effort for NASA team:
NASA will provide consultation and collaboration in an insight/oversight role. NASA will help to calibrate team efforts to best serve NASA needs and address identified technology gaps.

Suggestion for seed funding:
$20k from the In-Space Manufacturing Project. Proposers are encouraged to seek additional funding or other contributions from their institutions, industry, space grant consortia, and others.

Project Sponsor:
Space Life and Physical Sciences

Project Title:
Novel Steady-State Food Production System for Space

Scope of the challenge:
Develop a novel, steady-state microgravity plant food production system for a crewed environment that dampens out the effects of crop growth on the vehicle/habitat Environmental Control and Life Support System (ECLSS).

Description:
The lighting and transpiration of a plant food production system increases the sensible and latent heat load for the overall ECLSS system of the vehicle or habitat. For diurnal plant systems, ECLSS systems have to adjust with the lighting transitions. In these closed systems, the oxygen will only be created during photosynthesis, CO_2 will increase at night, and the pressures will change if there are temperature changes. Also, the transpiration rate of the plant will change with diurnal factors and it will increase as crops grow, increasing the water load on the humidity removal system. This challenge is to design a system that adjusts to have a steady-state atmosphere. The challenge will design a microgravity food production system that can achieve a near steady state (adjustable with plant growth) with respect to carbon dioxide removal, oxygen output, power input, and transpiration. Crop scheduling might play an important role. In addition, a novel aspect shall be incorporated such as: growing multiple plants with shared lighting, monitoring and controlling hardware; utilization of mechanisms to move the plants to create accelerations for water delivery to roots; waste lighting heat to circulate air or to move mechanisms for water delivery; or addition of a plant-based crew interactive game or exercise. These novel aspects could incorporate Stirling engines, springs, centripetal accelerations, robots, Peltier generators, or other devices whose use may not be efficient for growing a few plants but, when scaled up to hundreds of plants, could provide increased efficiencies and reliability. Any acceleration can be used to determine mass or move fluid. Traditional pumps and conductive water sensors should not be the focus of the novel ideas.

Expected Product (delivery item/concept):
A functional food production system will be delivered that improves NASA's ability to grow plants while damping out its effects on the overall ECLSS system. In additional, a novel aspect prototype shall be demonstrated to evaluate its feasibility. It is recommended that funding be included in the proposal’s budget for travel to NASA’s Kennedy Space Center for a demonstration.

Expected Result (knowledge gained):
The expected result establishes a capability to grow plants to in a flexible and expandable manner to ease their integration into habitats while minimizing crew time. The capability to grow thousands of plants in space could benefit from some of the smaller scale novel designs that are being explored.

Relevance to Exploration:
Plants systems with steady state inputs and outputs are easier to integrate into an overall ECLSS system.

Level of Effort for student team:

The students will utilize a system engineering approach to research the challenge, design and develop the prototype, and present to NASA.

Level of effort for NASA team:

Advising, plant growth information, and workspace to show the prototype

Suggestion for seed funding:

$20k. Proposers are encouraged to seek additional funding or other contributions from their institutions, industry, space grant consortia, and others.

Project Sponsor:
Space Life and Physical Sciences

Project Title:
Fresh Produce Sanitation System for Use in Microgravity

Scope of the challenge:
Design and prototype a fresh produce sanitation system functional in microgravity. System should be highly sustainable, require minimal crew time, and not foul fresh food.

Description:
Growing fresh produce in space will be essential to deep space exploration, as it minimizes upmass, supplements key nutritional aspects of the astronauts' diet, provides psychological benefits, and supports regenerative life support systems. Food sanitation is a critical aspect of growing and consuming food in space, as crew vehicles are not sterile environments and foodborne illness can have potentially disastrous consequences for mission success. Current state of the art in sanitizing produce in microgravity uses sanitary Pro-San wipes to treat produce prior to consumption; however, this is not a sustainable option for prolonged missions. Chemical, UV, and plasma are possible avenues to consider, though there are many other solutions to consider. An ideal system would minimize the physical footprint, mass, and power consumption for incorporation into transit vehicles and space stations.

Expected Product (delivery item/concept):
Develop a prototype fresh food sanitation system that effectively manages microbial levels of fresh grown produce to levels deemed safe by the NASA Human Research Program. System should function in microgravity, and exhibit a high degree of sustainability, minimize crew time, and not foul fresh food in any way that would discourage astronauts from using the sanitation system.

Expected Result (knowledge gained):
Critically conduct trades of various food sanitation options to identify those most applicable to the microgravity space environment. Understanding of microbial aspects of food safety and plant propagation.

Relevance to Exploration:
Effective and sustainable sanitation of produce grown in microgravity enables greater independence from Earth for deep space explorers while also reducing upmass and improving crew health.

Level of Effort for student team:
Design, modeling, prototype development, construction, assembly and reporting.

Level of effort for NASA team:
Advising, information pertaining to plant growth and crop choice, development of a workspace to show the prototype.

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

Project Sponsor:
Space Life and Physical Sciences

Project Title:
3D Printed Plant Growth Substrate

Scope of the challenge:
Design and prototype a plant growth substrate that utilizes 3D printing to achieve effective plant growth in microgravity.

Description:
Growing fresh food in space will be essential to deep space exploration, as it minimizes upmass, supplements key nutritional aspects of the astronauts' diet, provides psychological benefits, and supports regenerative life support systems. Reliable delivery of water and oxygen to plants root zones has been a foremost challenge of growing plants in microgravity. Priority should be given to materials that are reusable and capable of passively wicking nutrient solution. An ideal substrate will account for all aspects of the plant growth cycle, to include achieving high germination success and measures to ensure that plant stems are not girdled nor suffer salt stress.

Expected Product (delivery item/concept):
3D printed substrate that effectively wicks water and nutrients in a microgravity environment. Metrics of reusability and reprintability of chosen substrate.

Expected Result (knowledge gained):
Understanding of the types of materials available for creating 3D printed plant substrate and their application to growing plants in microgravity.

Relevance to Exploration:
Sustainable food production in microgravity is essential for a continuous human presence beyond low Earth orbit.

Level of Effort for student team:
Design, modeling, prototype development, construction, assembly and reporting.

Level of effort for NASA team:
Advising, information pertaining to plant growth, development of a workspace to show the prototype.

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

Appendix C: Standard Education Grant or Cooperative Agreement

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

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

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

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

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

Appendix D: Certifications and Assurances

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

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

A. The applicant certifies that it and its principals:

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

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

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

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

____

Organization Name

____

Printed Name and Title of Authorized Representative

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Signature Date

____

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.

____
Organization Name

____
Printed Name and Title of Authorized Representative

____
Signature   Date

____
Printed Name of Principal Investigator/Program Director

____
Proposal Title

Appendix E: NASA Review Requirements and Checklists

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

System Design Review (SDR)

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

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

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

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

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

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

Preliminary Design Review (PDR):

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

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

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

PDR Objectives:

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

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

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

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

PDR Success Criteria:

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

Post-PDR, Pre-CDR Activities

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

Critical Design Review (CDR)

The team should finalize all their designs for the CDR, after having selected a preferred alternative among the trade studies. The intent of the CDR during the 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.