National Space Grant Foundation

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eXploration Systems and Habitation (X-Hab) 2017 Academic Innovation Challenge Solicitation

on behalf of

NASA Headquarters
Human Exploration & Operations Mission Directorate

Sponsored by:

The Advanced Exploration Systems (AES) Division

Release Date:	March 9, 2016
Notice of Intent Due:	April 4, 2016
Proposals Due:	April 29, 2016
Anticipated Award Date:	May 25, 2016
Program Website:	http://www.spacegrant.org/xhab/

X-Hab 2017 Academic Innovation Challenge Solicitation

1. Funding Opportunity Description - Synopsis

The eXploration Systems and Habitation (X-Hab) 2017 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 2017 the X-Hab Challenge scope is being formally extended not only to include habitation topics but other areas of Exploration Systems as well*. 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 $10k - $20k 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 2017. Universities may collaborate as a single project team.

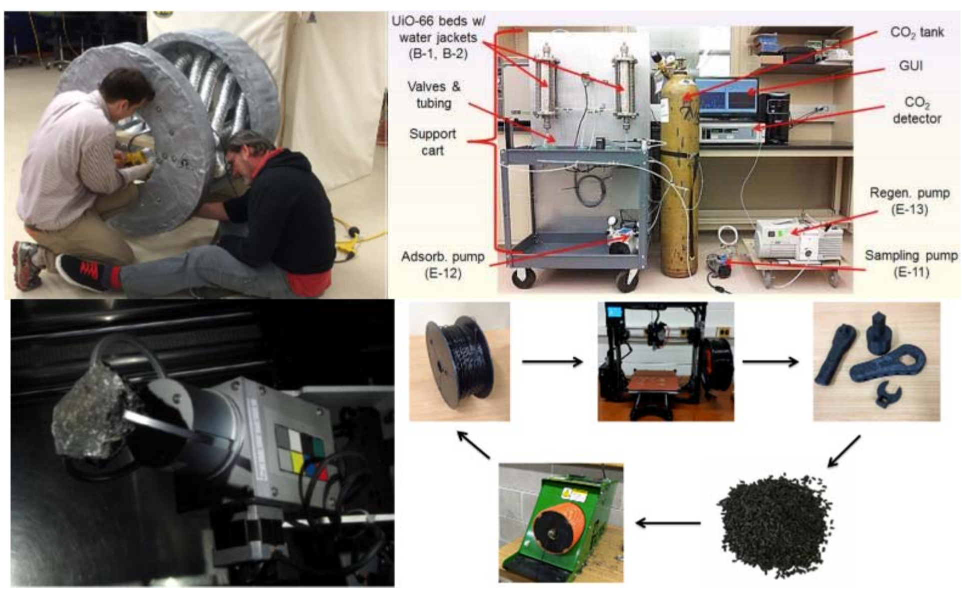

Figure 1: Previous X-Hab Projects (from top left, clockwise): Deployable Airlock , Closed Environment Air Revitalization System Based on Metal Organic Framework Adsorbents, Carbon-fiber/Fused Deposition Modeling Spacecraft Structural Fabrication System, Sample Handling System for GeoLab glovebox (Image 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, including a System Definition Review (SDR), a Preliminary Design Review (PDR), and a Critical Design Review (CDR) as for other NASA engineering products. 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. Multi-discipline, multi-departmental, and/or multi-institutional teaming collaborations are highly encouraged.

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

3. Funding Opportunity Description - Details

3.1 Description

NASA's multicenter AES Division is requesting proposals for the eXploration Systems and Habitation (X-Hab) 2017 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 2017 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 2016 and spring 2017 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 2016-2017 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 the universities are encouraged to seek additional, innovative sponsorships and collaborations (project teaming) with other universities and organizations (including institutional support, industry, space grant consortiums, 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):

- 7 Oct 2016 – Requirements and System Definition Review (SDR)
- 14 Nov 2016 – Preliminary Design Review (PDR)
- 18 Jan 2017 – Critical Design Review (CDR)
- 8 March 2017 – Progress Checkpoint Review
- 10 May 2017 – 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: AES In-Space Manufacturing (ISM) Project

- Project Title: In-space Recycling/Reclamation

Project Sponsor: AES Resource Prospector, RESOLVE Payload

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

Project Sponsor: AES Life Support Systems Project

- Project Title: *CO2 Removal Bed Size and Shape Optimization Study*

Project Sponsor: *Space Life and Physical Sciences*

- Project Title: Wastewater to Plant Nutrient Solution

- Project Title: Microgravity plant watering system

- Project Title: A Microgravity Food Production System utilizing radial acceleration for water and nutrient delivery

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 https://techport.nasa.gov/view/85

For specific Space Life and Physical Sciences projects, visit https://techport.nasa.gov/view/103

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 to benefit the nation and humankind, generally. 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 advanced space suits, 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 April 4, 2016.
Responses will be posted April 11, 2016

3.5 Pertinent Dates

Proposal Phase

9 Mar 2016	Date of Announcement and Release of RFP
4 Apr 2016	Questions for online Technical Interchange due
11 Apr 2016	Responses to submitted questions published online
29 April 2016	Proposal due
25 May 2016	Award announcements

Award Phase

Summer - Fall 2016	Design phase
Sept 2016	Kickoff meetings
7 Oct 2016	Requirements and System Definition Review
14 Nov 2016	Preliminary Design Review
18 Jan 2017	Critical Design Review
8 March 2017	Progress Checkpoint Review
10 May 2017	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, 2016, to May 31, 2017. 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 2017 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 2017 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** (8 pages maximum)
   - *Proposal Synopsis* -- Description of the X-Hab 2017 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.
   - *Mechanisms for Integration* -- Description of how the X-Hab prototype will be integrated and tested at the affiliated university in the 2016-17 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 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 2017 Academic Innovation Challenge will be implemented during the 2016-2017 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 pre-testing 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.
- 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 in 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 engineering, industrial design, and architecture curricula.
- **Education Outreach:** Demonstrate effort 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, 29 April 2016**. *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 25 May 2016.

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, 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 relational 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:
AES In-Space Manufacturing (ISM) Project

Project Title:
In-space Recycling/Reclamation

Scope of the Challenge: *Address NASA's need for an integrated 3D Printer/Recycler that can manufacture and recycle polymer parts within a single unit to increase sustainability during long-duration space missions. This will require developing the performance requirements, designing the system itself, and formulating a sustainable in-space recycling utilization plan that addresses the form, fit, and function aspects of the parts being recycled throughout the part lifecycle. Material and performance characterization of the recycled parts is highly desirable, but not required.*

Description:
To reduce the quantity of resources taken on long-duration exploration missions to destinations such as Mars, NASA missions must include an integrated, multi-material fabrication laboratory ('FabLab'). This FabLab will ideally be the size of an ISS Express Rack (approximately the size of a refrigerator) and have capabilities to manufacture parts using multiple materials (including embedded electronics), recycle the parts into reusable filament, inspect the parts (internally and externally) to confirm that they meet specifications, and be highly autonomous, including part removal. This challenge focuses on the first critical step toward that FabLab, which is the capability to additively manufacture polymer parts as well as being able to recycle those parts into reusable filament (1.75 mm filament line). It is highly desirable that the recycler could also be able to accept items such as plastic bags, foam, water bottles, etc. for recycling into usable filament as well. These types of 3D printers and recyclers can already be found in today's commercial market, however, NASA would like to see these capabilities integrated into a single unit with as much automation as possible in order to reduce the amount of astronaut time required (remote commanding capability is highly desired). The form, fit, and function of the integrated 3D Printer/Recycler should not exceed 5ft^3, require as little power as possible, and be able to produce parts up to 6"x6"x6".

Additionally, identify candidate items that are often used once and thrown away and develop a method to reutilize these items as resources. A fully sustainable mission would not look at any item as waste, but everything as a potential resource for recycling/reclaiming/reuse.
These processes will ultimately lower mass to orbit and increase reliability and sustainability, which will lead to feasible, earth-independent space missions.

Expected Product (delivery item/concept):

- *Develop performance requirements for and design of an integrated In-space 3D Printer/Recycler that can print and recycle/reclaim polymer materials into useable filament/feedstock for reuse based on the parameters defined in the above description. A prototype is highly desirable, but not required.*
- *Formulate a sustainable in-space recycling utilization plan that addresses the form, fit, and function aspects of the parts being recycled throughout the part lifecycle, including how to track the parts/materials thru multiple recycles. This should include identifying*

any and all candidate items (based on ISS data and/or terrestrial examples) that could be ideal for recycling/reclaiming and 3D Printing if common-use materials are utilized. Lifecycle analysis will need to be performed to show that there is a reduction in mass delivered to orbit for any particular long duration space exploration mission (such as Mars).

- *Terrestrial Uses: This is a prime area for terrestrial growth and commercialization. While it is not required to identify terrestrial partners from industry, it is desired. For example, in today's world of throw-away water bottles and to your door delivery of any and everything, bottling, packaging, and 3D printing industries are all prime targets for this application.*
- *Material and performance characterization of the recycled parts is highly desirable (such as degradation studies), but not required.*

Expected Result (knowledge gained):
New mechanism or process that utilizes available material and reduces waste thereby reducing the total mass of payload that has to be launched to orbit. Payload delivered to low Earth orbit will cost ~$10k per pound. Re-utilizing/re-claiming waste will reduce the total mass required in orbit and will greatly increase the sustainability of long-duration space missions. Ultimately, this could enable a long duration mission with less advanced propulsion systems or allow more payload space for critical system that enables a long duration space exploration architecture.

Relevance to Exploration:
Currently, NASA relies on the 4 R's (resupply, replace, redundancy, retreat) for Low Earth-Orbit (LEO) missions to ISS. This model will not be feasible for long-duration space missions. The In-space Manufacturing Initiative under NASA's Advanced Exploration Systems (AES) Office is identifying and developing the capabilities needed for on-demand manufacturing and repair for parts and systems. For this approach to be sustainable, common use materials must be utilized for packaging, storage, parts,etc. that can serve the function needed at the time and then be recycled/reclaimed for other use. This will ultimately decrease mass and risk, while increasing reliability and sustainability.

- *NASA Roadmaps TA12 (Materials, Structures, Mechanical Systems, & Manufacturing) and TA07 (Human Exploration Destination Systems)*

Level of Effort for Student Team:
Broad based multi-disciplinary team is warranted – structures, manufacturing, material characterization, chemistry, experimental methods and analysis, etc.. It is expected that the University Point of Contact (POC) will be able to help determine the degree of scope in the context of resources provided joint by NASA and those which are University derived.

Level of Effort for NASA Team:
This is a function of determined scope, but expect this level of effort to be at typical levels associated with previous X-Hab activities. Requirements development, mentoring, progress assessment

Seed Funding:
$20k from AES In-space Manufacturing Project. Proposers are encouraged to seed additional funding from their institutions, industry, space grant consortiums, and others.

Project Sponsor:
Resource Prospector, RESOLVE Payload

Project Title:
Quantification of condensed water on 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 100psia. 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 is flowed 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 be imaging the cold finger through the sapphire window repeatedly. 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.

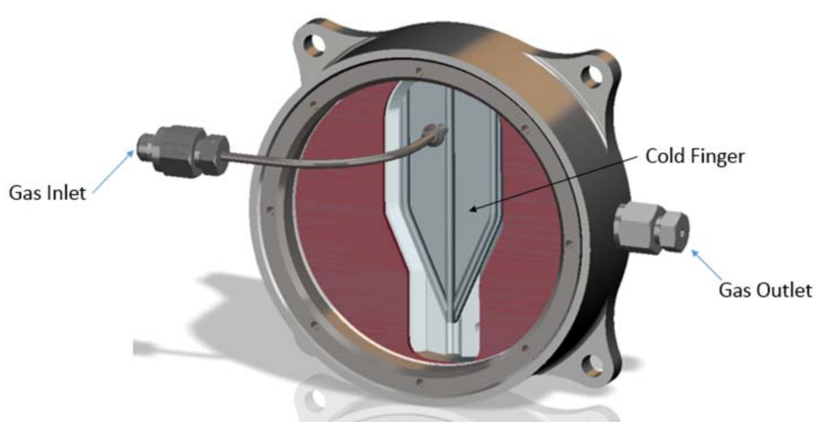

Figure 1 - The Water Droplet Demonstration Chamber (VDU Design)

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 design of resource capture on the lunar surface.

Relevance to Exploration:
NASA includes in situ resource utilization 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. Proposers are encouraged to seed additional funding from their institutions, industry, space grant consortiums, and others.

Project Sponsor:
Space Life and Physical Sciences

Project Title:
Wastewater to Plant Nutrient Solution

Scope of the Challenge:
Develop a urine processing system that can retrieve and deliver nutrients (fertilizer) for plant food production system.

Description:
A spacefaring crew will generate liquid waste that can be recovered and processed to create nutrients for a plant food production system. Primarily, urine is a waste product that can potentially be utilized. The sodium in urine is of particular concern due to its potential buildup in the system as a result of the crew's expected diet. Sodium in not useful as a plant fertilizer and can stress plants at high concentrations. In addition, high levels of total organic carbon in the waste stream might be a challenge for direct use of waste urine as fertilizer. Sodium is needed in the human diet, however, so finding a way to separate and retrieve this is critical for long duration missions.

Expected Product (delivery item/concept):
A functional microgravity or partial gravity urine converter sized for a crew of four that can recover a large portion of water and nutrients suitable for feeding to plants. Other waste streams may be considered in addition to urine, such as graywater from washing both humans and clothes. An exploration in methods shall be done in removing sodium from urine salts to hinder buildup in plant systems and for reuse in human systems. A list of key science questions and engineering challenges that have an impact on success.

Expected Result (knowledge gained):
The ability to apply critical thinking skills to existing hardware. Conducting trades and identifying areas where small changes can have larger impacts. Reverse engineering of external designs might be involved.

Relevance to Exploration:
The recovery of urine from a crew of four for water recovery and fertilizer for food production can greatly reduce the amount of overall mission mass, and could eliminate the need for harsh chemicals currently utilized for treating urine prior to processing.

Level of Effort for Student Team:
Design, modeling, prototype development, construction, assembly, testing and reporting of one or more systems.

Level of Effort for NASA Team:
Advising, plant growth information, development of a workspace to show the prototype.

Seed Funding:
$15k. Proposers are encouraged to seed additional funding from their institutions, industry, space grant consortiums, and others.

Project Sponsor:
Space Life and Physical Sciences

Project Title:
Microgravity plant watering system

Scope of the Challenge:
Develop a plant watering or nutrient delivery system that works in microgravity. System should be passive or use very little energy, should be reusable, and require little crew involvement

Description:
For space food production, watering plants in microgravity has been the biggest challenge, since plant roots require both water and oxygen. Most successful microgravity plant watering systems have been active, requiring power for pumps, solenoids and moisture sensors. Systems have also been planted on Earth, and used rooting modules have to be returned for cleaning or refurbishment and replanting. Ideally we would like a system that is reusable under microgravity conditions and requires little or no energy and little crew time and low launch mass. Using capillary wicking and vanes may be a desirable way to distribute water or a nutrient solution. 3-D printing technologies in space could be used to print root systems optimized for microgravity. Roots or inedible plant biomass could be used as a substrate for future crops, potentially broken down and printed into a new matrix. Mechanical energy (e.g. springs, flywheels, etc.) that can be utilized for determining the mass of water in the root zone would be acceptable reasons for periodic crew involvement or electrical energy usage (e.g. accelerometers, microcontrollers, displays, etc.).

Expected Product (delivery item/concept):
One or more functional microgravity or gravity independent plant watering/nutrient delivery systems. Students might propose to test their system or a scale model in the parabolic flight opportunities program. A list of key science questions and engineering challenges that have an impact on success.

Expected Result (knowledge gained):
Novel solutions to plant watering in microgravity.

Relevance to Exploration:
Reducing mass, volume, power, cooling and crew time is an important goal for transitioning technologies beyond low Earth orbit. Food production capabilities are currently being tested on ISS and expanding these will be important as humans live off Earth for longer durations and travel farther.

Level of Effort for Student Team:
Design, modeling, prototype development, construction, assembly, testing and reporting of one or more systems.

Level of Effort for NASA Team:
Advising, plant growth information, development of a workspace to show the prototype.

Seed Funding:
$20k. Proposers are encouraged to seed additional funding from their institutions, industry, space grant consortiums, and others.

Project Sponsor:
Space Life and Physical Sciences

Project Title:
A Microgravity Food Production System utilizing radial acceleration for water and nutrient delivery

Scope of the Challenge:
Design and prototype a rotating plant growth system for food production in microgravity with the long term vision of expanding the artificial gravity technology for simplifying fluid systems and crew health.

Description:
Plant food production for microgravity missions is challenging to implement due to the physics of delivering water and nutrients in a microgravity environment. Microgravity makes supplying adequate moisture and oxygen in the root zone difficult, and plant growth will be hindered by conditions of anoxia, hypoxia or insufficient moisture. This proposal asks for ideas on how to have an "artificial gravity" to improve the technology readiness of higher order plant production in a microgravity long duration mission. The prototype system should be able to utilized for ground testing by incorporating way to minimize dripping water, brace typical plants from moving while they rotate around the wheel, and be scaled to a size for practical transport (fit through a doorframe). Technical demonstrations of simple artificial "gravity" system can help mission architects better utilize the space environment to mitigate the challenge of that environment. Plant food production is an appropriate analog to test new advanced life support concepts.

Expected Product (delivery item/concept):
Develop a prototype plant food production system that utilizes a rotating system for water and nutrient delivery to plants. Automation of an on-board plant root moisture monitoring and nutrient delivery system that can be remotely monitored and controlled is highly desired. A list of key science questions and engineering challenges which have an impact on success.

Expected Result (knowledge gained):
Better understanding of the threshold level of gravity needed to adequately distribute water/nutrient solution; the feasibility of a rotating plant growth system for microgravity.

Relevance to Exploration:
A stable water delivery system for plants in microgravity is very challenging and having a gravity-like acceleration could increase the reliability and technology readiness of bioregenerative systems. This could be used in transit missions and orbital habitats.

Level of Effort for Student Team:
Design, modeling, prototype development, construction, assembly, testing and reporting of one or more systems.

Level of Effort for NASA Team:
Advising, plant growth information.

Seed Funding:
$10k. Proposers are encouraged to seed additional funding from their institutions, industry, space grant consortiums, and others.

Project Sponsor:
AES Life Support Systems Project (http://www.nasa.gov/directorates/heo/aes)

Project Title:
CO_2 Removal Bed Size and Shape Optimization Study.

Scope of the challenge:
Build a minimalistic breakthrough test stand to test basic bed flow characteristics across a number of bed dimensions and shapes.

Description:
CO_2 sorbent beds are designed to desorb gas with a pressure and/or temperature swing. The transfer of heat or conduction of vacuum through a bed is intrinsically linked to the dimensions of the bed. Study of bed aspect ratios and alternative flow arrangements would guide better system designs by reducing pressure drop and improving CO_2 removal.

Expected Product (delivery item/concept):
Prototype beds (new or representative configurations) and the flow performance of the bed (based on tracer migration through the bed).

Expected Result (knowledge gained):
Unique ideas for bed designs and quantified performance.

Relevance to Exploration:
Improved bed flow and/or thermal characteristics would enable smaller and/or more effective systems.

Level of Effort for student team:
Procurement, assembly, design, and fabrication of prototype beds will require graduate student time and effort, unless facilities already exist for this purpose. Prototype beds require 3D modelling skills and collaboration with machining or 3D-printing experts.

Level of effort for NASA team:
Support includes providing current example and performance of our test articles and assistance with scale-down and scale-up of different design proposals.

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

Appendix C: Standard Education Grant or Cooperative Agreement

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

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

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

Unless otherwise specified, the terms and conditions in 2 CFR 1800.900 to 1800.918 and the requirements in 2 CFR 170, 175, and 182 apply and are incorporated by reference. To view full text of these requirements 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

____
Signature Date

____
Printed Name of Principal Investigator/Program Director

____
Proposal Title

CERTIFICATION REGARDING LOBBYING

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

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

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

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

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

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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.