# A Novel Approach for Engaging Academia in Collaborative Projects with NASA through the X-Hab Academic Innovation Challenge


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**The X-Hab Academic Innovation Challenge, currently in its sixth year of execution, provides university students with the opportunity to be on the forefront of innovation. The X-Hab Challenge, for short, is designed to engage and retain students in Science, Technology, Engineering and Math (STEM). NASA identifies necessary technologies and studies for deep space missions and invites universities from around the country to develop concepts, prototypes, and lessons learned that will help shape future space missions and awards seed funds to design and produce functional products of interest as proposed by university teams according to their interests and expertise. Universities propose on a variety of projects suggested by NASA and are then judged on technical merit, academic integration, leveraged funding, and outreach. The universities assemble a multi-discipline team of students and advisors that invest months working together, developing concepts, and frequently producing working prototypes. Not only are students able to gain quality experience, working real world problems that have the possibility of be implemented, but they work closely with subject matter experts from NASA who guide them through an official engineering development process.**


## Nomenclature

| | | |
|---|---|---|
| ABET | = | Accreditation Board for Engineering and Technology |
| AES | = | NASA Advanced Exploration Systems |
| D-RATS | = | NASA Desert Research and Technology Studies field analog tests |
| DSH | = | Deep Space Habitat |
| ECLSS | = | Environmental Control Life Support System |
| EVA | = | Extra-Vehicular Activity |
| HEOMD | = | Human Exploration Operations Mission Directorate |
| HDU | = | Habitat Demonstration Unit |
| NASA | = | National Aeronautics and Space Administration |
| NSGF | = | National Space Grant Foundation |
| PEM | = | Pressurized Excursion Module |
| STEM | = | Science, Technology, Engineering, and Mathematics in education |
| X-Hab | = | Exploration Habitat Academic Innovation Challenge |


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## I. Introduction

THE X-Hab Academic Innovation Challenge has a unique approach to student involvement, in that the student team is placed in the critical path for the product or technology that they develop in support of the National Aeronautics and Space Administration (NASA). The student team and the consulting professor(s) at the university are the lead for their particular project. They are required to go through NASA System Definition Review (SDR), Preliminary Design Review (PDR), and Critical Design Review (CDR) on a similar footing as other NASA engineered products. In doing so, the NASA team is putting a great deal of responsibility on the students, and in turn gives the students a bigger stake in the future development of space technologies that likely will become heritage to actual systems and technologies that will be flown in space in the years and decades to come. Although NASA's X-Hab Challenge started as a direct competitive challenge between multiple universities on one concept, it has evolved since then to include a diverse portfolio of projects each year to gain more from the agency investment.

The prototypes produced by the university teams may be integrated onto existing NASA-built operational prototypes, and they may be stand-alone demonstrations or studies. Examples of these efforts are shown in Figure 1 as represented by images from team final reports to NASA. The challenge is intended to link with senior and graduate level design curricula that emphasize hands-on design, research, development, and manufacture of prototypical subsystems that enable functionality for space habitats and deep space exploration missions. NASA directly benefits from the challenge by sponsoring the development of innovative concepts and technologies from universities, which result in innovative ideas and solutions that could be applied to exploration.

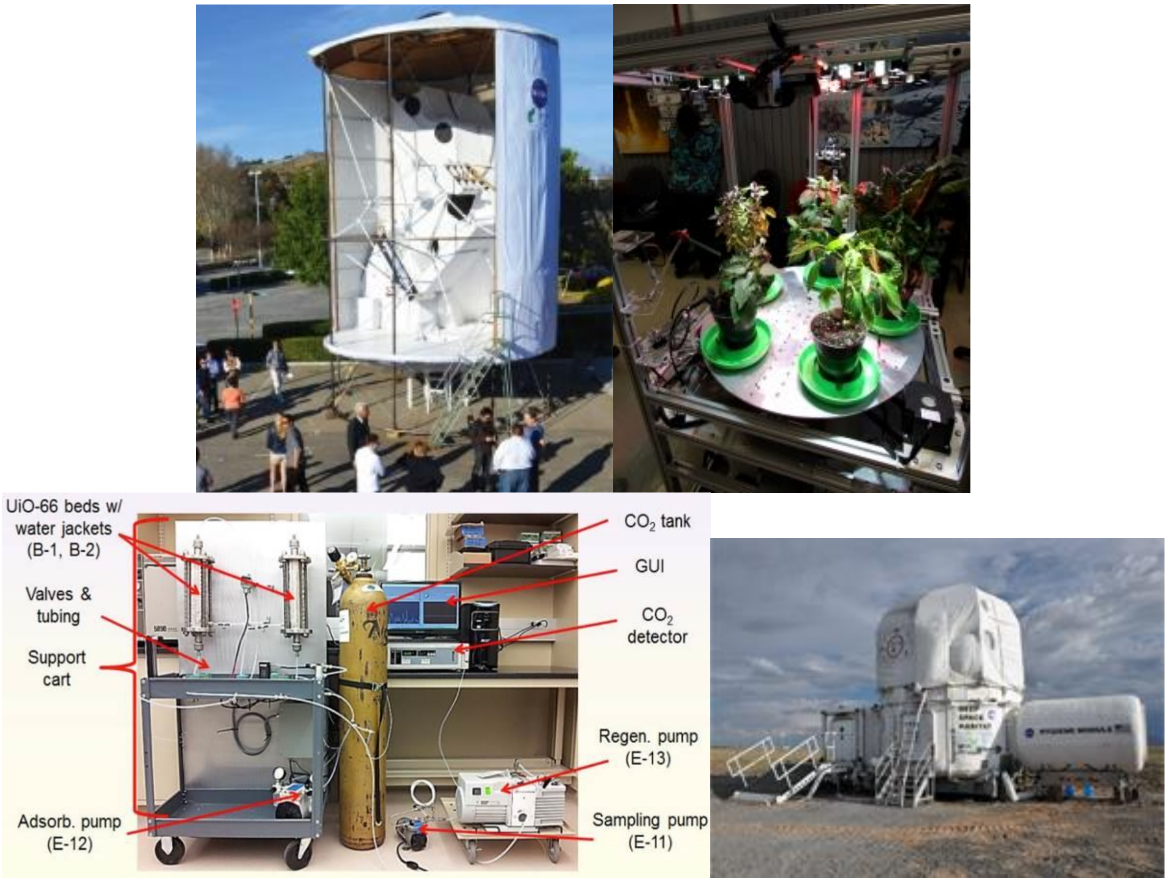


Figure 1: From top left clockwise - California Polytechnic State University: Vertical Habitability Layout and Fabrication Studies (2013), University of Colorado: Remote Plant Food Production Capability (2013), University of Wisconsin – Inflatable Habitat Loft (2011), University of South Alabama - Molecular Framework Absorbent Based Air Revitalization Unit (2014)

## II. Background

The Exploration Habitat (X-Hab) Academic Innovation Challenge started in 2010 as a mechanism to engage academia in the maturation of exploration habitat efforts. The challenge was started in the second year of the Habitat Demonstration Unit (HDU) project[1] as a means of augmenting the capabilities developed in the first year construction of the HDU. The HDU was fielded in its first year of existence as a mobile laboratory demonstration for a lunar exploration architecture, conceived under the Constellation program, in a configuration called the Pressurized Excurstion Module (PEM). In the second year, the team wanted to add crew accommodations to the HDU capability to overcome the necessity of the crew using the HDU as a laboratory but then having to use the capabilities of small camper-like pressurized rovers for hygiene and crew accommodations. The initial X-Hab solicitation released in 2010 called for proposals from academia to construct a loft on top of the HDU using inflatable technologies to provide those functions. The HDU had been designed to accommodate this construction, but the team decided it would be there would be several benefits from farming out the loft element of the new HDU configuration. It gave the team an opportunity to engage academia and benefit from their creativity and excitement in a low cost way, and it allowed parallel development that let the NASA HDU team continue to mature the existing systems and to add some new capabilities while the loft was being developed as part of the challenge. This initial X-Hab Academic Innovation Challenge was designed as a competitive challenge and three teams ultimately were selected for that head to head competition[2]. Though that initial year was successful, the following years brought some changes to the HDU project and to the X-Hab Academic Innovation Challenge. First, the HDU project, which was managed as an informal project team across 7 NASA centers with a variety of funding sources was rolled into the Advanced Exploration Systems (AES) program under the Human Explorations and Operations Mission Directorate (HEOMD) and was renamed the AES Deep Space Habitat (DSH) project under one funding code. After that change, the AES DSH project decided to modify the challenge from soliciting a head to head competition for one project to a call with a variety of projects where a suite of X-Hab projects could be selected that brought the most value to the DSH project goals. The AES Deep Space Habitat project ceased in 2013, but a new AES project called Exploration Augmentation Module (EAM) carried forward the sponsorship of X-Hab. The EAM project was focused on defining an architecture of capabilities that could augment the manned portion of the Asteroid Redirect and Rendezvous Mission (ARRM) concept under evaluation by NASA but providing capabilities such as an airlock as well as laboratory and habitation space.

Because of the interdisciplinary nature of habitation technology evaluation, project concepts offered in the X-Hab Academic Innovation Challenge have spanned a variety of fields. The HDU, DSH, and EAM project teams that generated the project ideas in many cases had other discipline expertise than habitation and were members of other advanced technology and exploration architecture teams. Because of those varied background, the project concepts in past X-Hab solicitation have included habitation layout studies, power technologies, avionics advancements, robotic plant growth and food production capabilities, inflatable structure prototypes, environmental control system technologies, additive manufacturing systems, and specimen handling systems among others. When the X-Hab proposal assessment team would evaluate and rank the projects in line with the NASA team's priorities, occasionally, there were occasionally excellent projects that could not be funded under the original X-Hab budget. Because of the timeline of the X-Hab solicitation process toward the second half of the federal fiscal year (October-September) and the appeal of these project concepts to a variety of project teams around NASA, the selection cycle in May allowed the X-Hab proposal assessment team to seek funding for other NASA projects to fund additional X-Hab selections using available end of year funds. In 2015, the X-Hab team took this notion a step further and opened up the solicitation to open up the project concept generation to projects throughout HEOMD to gain their interest and investment at the beginning of the solicitation rather than the end to derive the most benefit for those teams from the X-Hab mechanism.

The grant mechanism for X-Hab has been run through the NASA's Kennedy Space Center through a contract with the National Space Grant Foundation (NSGF) and is currently planned through 2018. The National Space Grant Foundation hosts the solicitation website, manages the proposal process, provides a scoring rubric and web-based scoring tool, advises on the solicitation mechanism, and manages the contracts with the individual universities selected to participate each year. The NSGF X-Hab web site is at this location https://www.spacegrant.org/xhab and provides links to the most recent call as well as earlier solicitations. For the individual project concepts in the solicitation, the NASA mentoring team generates an estimate a minimal amount of seed funding for the project to be completed successfully, and the proposers are encouraged to bring in leveraged investments from their host institution, other institutions, industry, or local space grant consortiums to enhance the quality of the project. Suggested project seed funding amounts have ranged from $10k-$48k in previous solicitations because of the varied complexities of each project concept. Important factors in the evaluation of X-Hab projects have evolved as the NASA X-Hab team refines the process each year, but they include technical merit, academic integration, leveraged benefits, and outreach. Technical merit includes the quality of the concept as well as experience and capabilities of the proposing team. Academic integration includes how well his conduct of the X-Hab effort is incorporated into the course structure and among colleges and departments at the institution as well as the utilization of Accreditation Board for Engineering and Technology (ABET) standards. Leveraged benefits include investments from the proposers and their partners to enhance the quality and scope of the proposals. And outreach includes the quality of the planned efforts to communicate what the team is accomplishing to the general public, to their institutions, and to primary school audiences. A lead professor or team of professors at the proposing universities coordinates the detailed proposal responding to a solicitation area according to the solicitation guidelines, and then the NASA X-Hab team evaluates the proposals as described in the following section. Universities are encouraged to apply for one or more projects but not to tie the proposals together so the success or failure of one proposal does not affect another proposal.

Proposers are required to apply a systems engineering approach for the design course and are referenced to the NASA Systems Engineering Handbook NASA SP-2007-6105.

## III. Process and Timeline

There are two timelines that are relevant for the execution of the X-Hab Academic Innovation Challenge. The first is the solicitation schedule that includes solicitation release, the proposal process, and the award process.

Notional Solicitation Schedule

| | |
|---|---|
| February | Solicit for projects ideas and funding for projects in next FY |
| Early March | Release solicitation |
| Early April | Questions for online technical interchange due |
| Mid April | Responses for questions published online |
| Late April | Proposal due date |
| Late May | Award Announcements and announce Selections for start in the fall |
| June | Collect project funding and obligate to NSGF |

The solicitation gets released on the National Space Grant Foundation website and is promoted by NSGF through Space Grant Consortium network and by NASA via NASA Education Express Message and social media accounts. Informal distribution to interested peers in academia is performed by NASA stakeholders as well.

NASA collaborators are encouraged to work with university teams on their proposals to strengthen the proposal and ensure the content is aligned with NASA interests but then those collaborators cannot be engaged in the proposal selection process. For the proposal selection process, a core team of experienced X-Hab mentors, project sponsors, and other NASA stakeholders from HEOMD evaluate all proposals and score them. Scoring is performed on a website using a rubric tool from NSGF.

Once the proposals are received in May, scoring results are taken into consideration as an input in the selection decision. Project priorities can outweigh scoring, so scoring is simply a piece of information in the funding decision. If no proposals are received to address the priorities of a particular NASA funding source, that source has no obligation to commit the funding and may re-task the funding to another priority.

The second timeline of relevance is the project execution process. The following project review milestones take place with participation from the NASA mentoring team and the university project team:

Project Execution Schedule

| | |
|---|---|
| September | Project kickoff meetings for FY projects |
| October | Requirements and System Definition Review |
| November | Preliminary Design Review |
| January | Critical Design Review |
| March | Progress Checkpoint Review |
| May | Project Completion and Evaluation by NASA |

Additional meetings for more technical interchange can be requested by the teams but are not required as a milestone. Historically, some projects have carried additional testing into the summer period based on a request by either the NASA or the university teams, and those requests are negotiated on a case by case basis.

## IV. History

Fiscal Year 2016 will be the sixth year of the X-Hab Academic Innovation Challenge. This section will contain a brief summary of the projects for each year of the challenge.

### A. X-Hab 2011

University teams from Oklahoma State, Wisconsin-Madison, and Maryland were chosen for the finalist phase of the first X-Hab competition. This was the first and only challenge that was run as a competition. In June of 2011 at Johnson Space Center, the NASA-Habitat Demonstration Unit (HDU) Project evaluated three versions of an attachable inflatable habitat "Loft" concept, given a list of requirements for the design to provide crew accommodations and living space. The three designs were installed and evaluated as the second floor loft of the HDU in June of 2011 as seen in Figure 2. On July 1, 2011, the University of Wisconsin-Madison was announced as the winner of the 2011 X-Hab Academic Innovation Challenge.

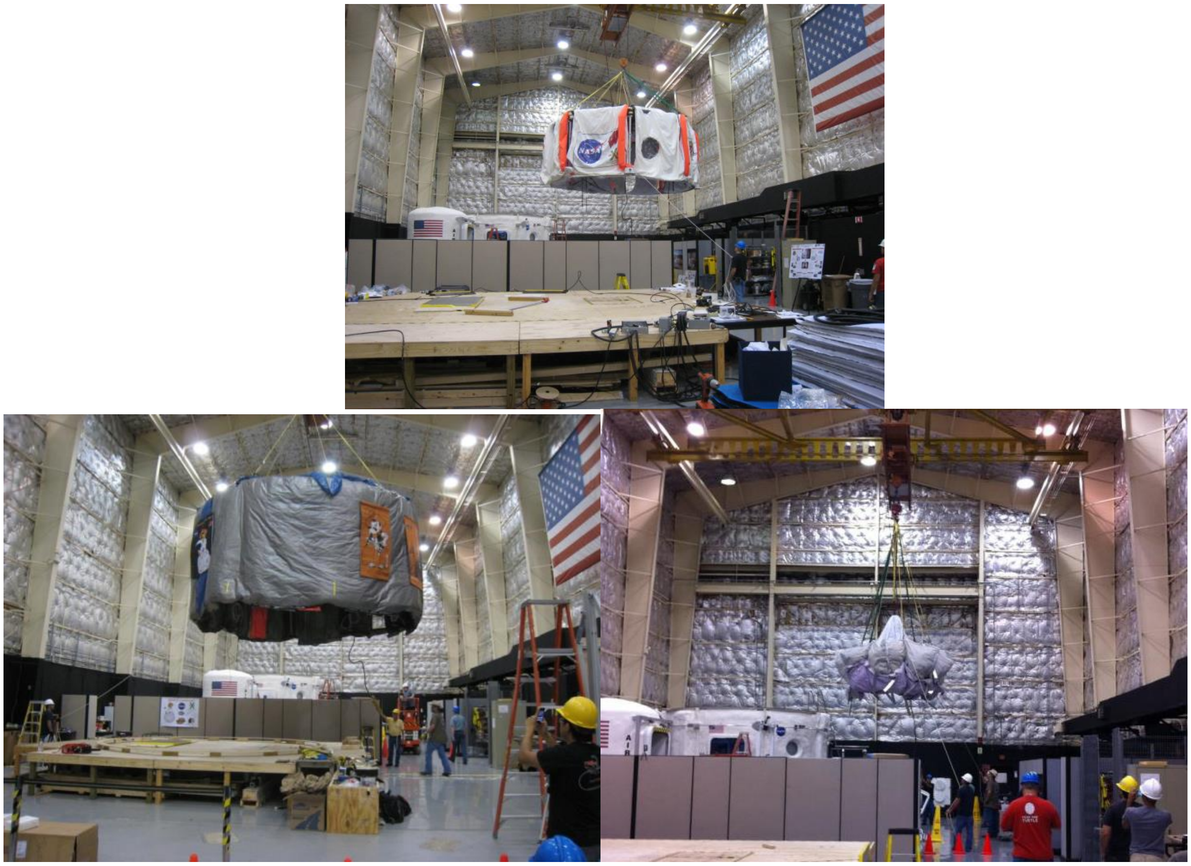

Figure 2: Attachable Inflatable Habitat Loft Concepts being attached to the HDU.  From the top clockwise – University of Wisconsin, University of Maryland, and Oklahoma State University (Credit: NASA)

**B.  X-Hab 2012**

On July 22, 2011 NASA announced the selection of four teams to compete in the 2012 challenge, from Oklahoma State University; University of Maryland, College Park; Ohio State University; and University of Bridgeport, Conn. The undergraduate students designed, manufactured, assembled and tested their concepts and hardware. A panel of engineers and scientists assessed their progress at each stage of the competition. The X-Hab Challenge funded the cost of the teams' design, development, and their participation in testing in summer 2012 at NASA's Johnson Space Center, Houston, Texas.

**Oklahoma State University: Horizontally Oriented Deep Space Habitat**

Oklahoma State University (OSU) students developed a concept and worked with a constructed mock-up of a horizontally oriented habitat, Figure 3. They finalized and tested the design, which included space for research, sleeping, and storage.

The "Highly Expandable Module" was designed with a crew of 4 in mind and all of the necessary cargo for a long duration space flight. Inflatable supports allow minimal storage space for launch and easily expand to create fixed shaped spaces to live and work.

In addition to their own work on the project, the OSU team enlisted the help of high school students around the country to develop their own designs with similar constraints and goals. OSU conducted a challenge open to all Oklahoma high school students and participants in the NASA Interdisciplinary National Science Project Incorporating Research and Education Experience (INSPIRE), which is a year-round project designed for students in ninth to 12th grade who are interested in science, technology, engineering and mathematics (STEM) education and careers . The winning team was rewarded with a trip to Johnson Space Center for a tour and to see the previous year's work on the Habitat Demonstration Unit (Figure 4) [3].

Figure 3: From top left then clockwise: Concept for Oklahoma State University's expandable habitat prior to being expanded; Concept for expandable habitat after being expanded; Demonstration prototype of the expandable habitat after expansion; Demonstration prototype of OSU's expandable habitat before expansion. (Credit: Oklahoma State University)

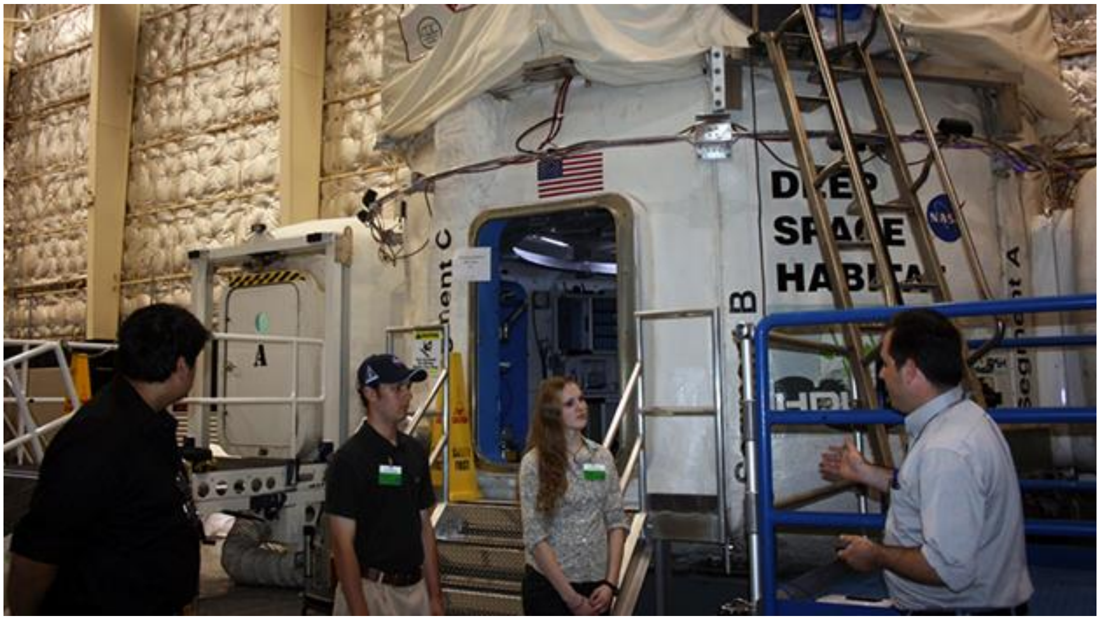

Figure 4: High school students who won the competition facilitated by Oklahoma State University to design an expandable habitat taking a tour of Johnson Space Center. (Credit: NASA)

**University of Maryland, College Park: Vertically Oriented Habitat Demonstration Unit**

University of Maryland students, designed and constructed a vertically oriented space habitat that is suitable to support a crew of four for up to 900 days, Figure 5. They gave the name "Crew Habitat Evaluator for Long-Duration Orbital, Near-earth, and Interplanetary Applications" (CHELONIA) to their project, planning for a variety of missions.

The scope of the finished design was a living space of no less than 42 cubic meters (1482 cubic feet) and the capability to stack modules, and connect them side-by-side. Modularity and accessibility are two of the greatest considerations for a successful habitat with research capabilities. Other requirements considered in the design process included storage, software, personal space for the crew, safety and production techniques.  The student team then spent time evaluating their design for livability, Figure 6.

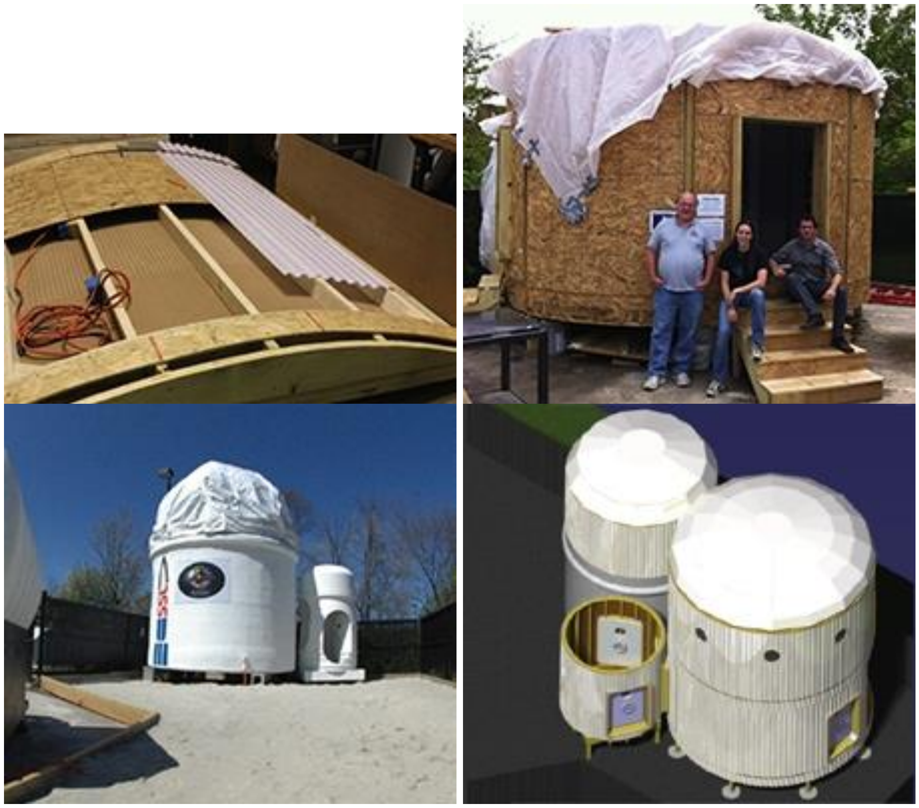

Figure 5: From top left, clockwise: A wall of the vertical habitat prototype by University of Maryland students; Early prototype built for living simulations at the University of Maryland, College Park; Concept for stacking of multiple vertically oriented modules; Prototype built for living simulations at the University of Maryland, College Park. (Credit: University of Maryland)

Figure 6: Students at the University of Maryland, College Park testing their prototype for livability (Credit: University of Maryland).

**Ohio State University: Plant Monitoring and Control Network**

Students from the Ohio State University developed plant growth containers in unused storage space on the Habitat Demonstration Unit (HDU), Figure 7 and 8. In addition to the growth containers, a system was developed for automated monitoring of the plants. The system was able to keep track of irrigation, temperature, lighting, and harvesting of plants and was able to be monitored by the HDU avionics system.

This type enhancement to a space habitat can allow oxygen to naturally be produced on long-duration space travel, or during exploration of celestial bodies, and can provide a supply of fresh foods for the crew.

Figure 7: 3D rendering of plant growth atrium sensor system built by students from the Ohio State University. (Credit: Ohio State University)

Figure 8: Implementation of containers, lighting, and sensor system for HDU atrium. (Credit: NASA)

**University of Bridgeport: Reduced Gravity Sample Holder**

The University of Bridgeport (UB) team designed and created a prototype robotic arm that was integrated into the GeoLab glove box test bed located within the HDU Deep Space Habitat, Figure 9 and 10.

The goal was to produce a product that would be able to properly hold and flexibly handle geological samples during analytic processes in a microgravity environment on long duration space flight missions. Their robotic system had six axes of motion and could hold geological samples for lab examination and testing. Included in the system wee one 3-D motion slider, one rotary table, and several step motors.

The prototype of this remote controlled Geo-Lab reduced gravity sample holders/manipulator tool system was delivered to the Johnson Space Center in May 2012 for testing and system integration.

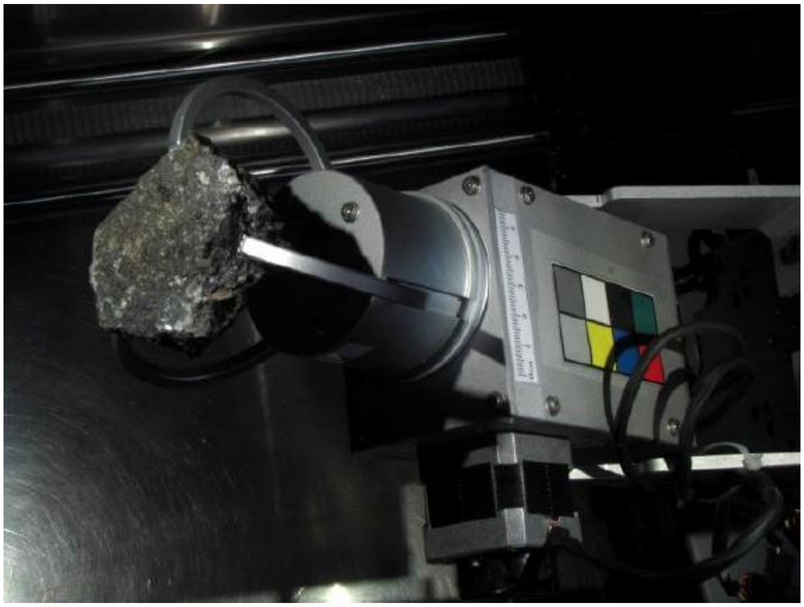

Figure 9: Reduced gravity sample holder for the GeoLab glovebox built by the University of Bridgeport[4].

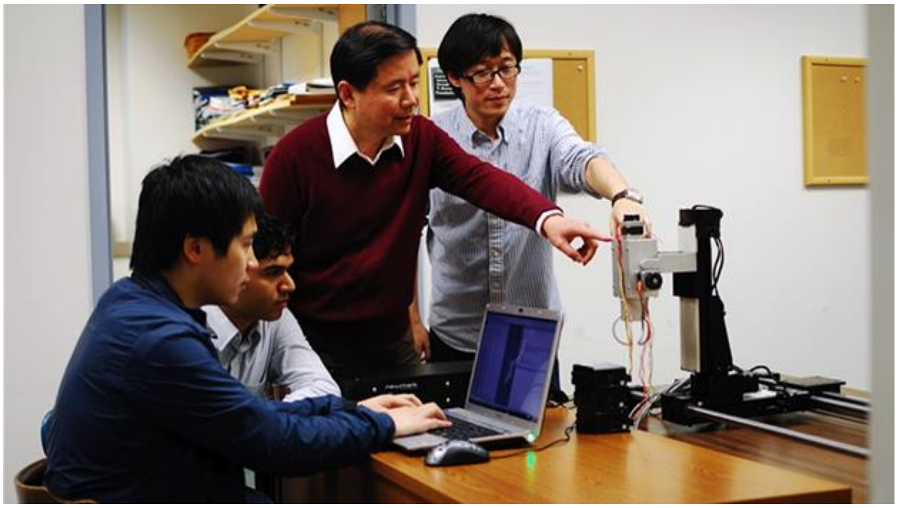

Figure 10: The entire team from the University of Bridgeport, Connecticut tests their prototype robotic arm (Credit: University of Bridgeport).

**C. X-Hab 2013**

On March 20, 2012, NASA released a call for proposals for the 2013 challenge, inviting students to design, manufacture, assemble and test systems for use on NASA's deep space habitat prototype. NASA announced on May 30, 2012 that five teams were selected to participate in the 2013 X-Hab Challenge: California State Polytechnic University, Oklahoma State University, Texas A&M University, University of Alabama in Huntsville, and University of Colorado at Boulder. In this year, projects included a plant growth chamber, vertical and horizontal habitats, a universal power controller, and dynamic storage systems.

**University of Alabama, Huntsville: Microgravity Random Access Stowage & Rack System**

A team from the University of Alabama, Huntsville developed a unique modular storage system, Figure 11, for long duration spaceflight. The prototype system was actually installed in a habitat concept demonstrator at NASA's Marshall Space Flight Center, in Huntsville, Alabama.

The system was designed to minimize mass, be scalable to accommodate various sizes and sustain launch conditions. The team interviewed experts around NASA and performed a detailed engineering assessment to develop their design from concept to implementation.

The UAH students worked with common, commercially available parts, including 80/20 hardware and Velcro, to complete the task efficiently and effectively in conjunction with the team at Marshall.

Figure 11: The University of Alabama, Huntsville team developed a modular storage system, seen here installed in a demonstrator at Marshall Space Flight Center (Credit: NASA)

**California Polytechnic State University: Vertical Habitability Layout and Fabrication Studies**

The student team from California Polytechnic State University (Cal Poly) created a comprehensive Building Information Model (BIM) assessing workspaces, functions and subsystems. They used a three stage trade and analysis cycle and a suite of analysis tools to create the BIM. The students created innovative designs for crew systems and workstations, even down to footholds and windows. The Cal Poly project culminated by implementing the design concept in an impressive, full-size mockup in a parking lot on campus, Figure 12.

Figure 12: The Cal Poly Team preparing to demonstrate their mockup of a vertically oriented habitat system (Credit

**Oklahoma State University: Horizontally Oriented Inflatable Deep Space Habitat**

The team from Oklahoma State University (OSU) participated again and matured concepts based on a horizontally oriented habitat concept. The team performed a detailed digital design to layout the design and implementation of subsystems and crew work stations within this concept. And finally, they designed and built a full-size functional mockup for demonstration purposes, Figure 13. The OSU team ontinued their excellent outreach efforts with a miniature X-Hab challenge for high schools within their region.

Figure 13: A demonstration of Oklahoma State University's horizontal habitat concept using International Space Station derived elements (Credit: Oklahoma State University).

**Texas A&M University: Wireless Smart Plug**

The team from Texas A&M developed a NASA Wireless Smart Plug (NWSP) that allows for wireless transmission of current draw for a system power feed. This current draw information is fed to a master control unit to enable automated management of power systems. This type of capability is critical for long duration spaceflight to maximize available resources.

Extensive hardware and software development effort led to the creation of five operational test units, Figure 14. The team traveled to NASA's Johnson Space Center to test the units with the habitat avionics test bed and characterized their performance.

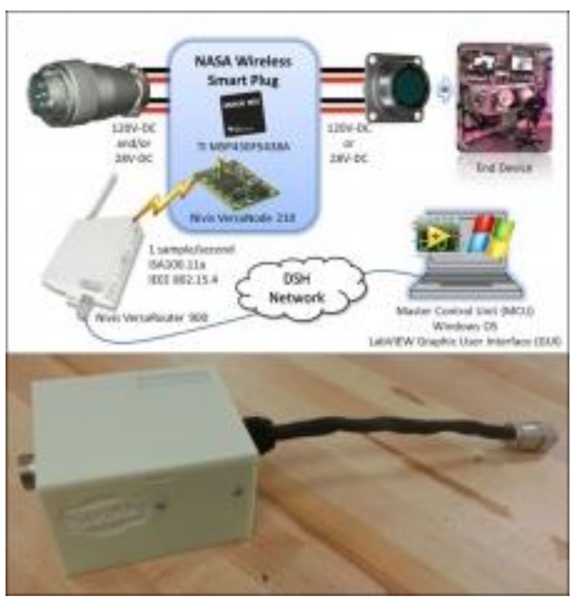


Figure 14: Concept Diagram and Working Prototype of Wireless Smart Plug Developed by Texas A&M University.

**University of Colorado: Remote Plant Food Production Capability**

The team from University of Colorado developed a complete system for robotically growing, nurturing and maintaining plants on space missions. The system was designed to allow for robotic maintenance of the plants by a remote operator while also allowing a user to interface and interact with the plant system in a way that does not disrupt autonomy provided by the robotic systems. A complete robot arm, solid state lighting system, watering system, operational turntable and graphical user interfaces were among the systems provided in the demonstration system, Figure 15.

The system was deployed and demonstrated at both Johnson Space Center and Kennedy Space Center. The Colorado team produced a survey to collect from end users to further mature their system concept.

Figure 15: University of Colorado's robotic plant growth is demonstrated at the Kennedy Space Center (Credit: NASA)

## D. X-Hab 2014

In 2014, the forward progress of NASA's new Space Launch System and emphasis on future deep space missions, drove a breadth of technology required to successfully complete such long duration flights. The challenges that exist, from producing food on the journey to effectively recycling breathable air to utilizing every last resource available, create opportunities for groundbreaking innovation.

The 2014 selected partners and areas of emphasis were:

- University of Wisconsin, Madison: Badger Compartmentalized Onboard Material Extrusion Technology
- University of South Alabama, Mobile: Closed Environment Air Revitalization System Based on Metal Organic Framework Adsorbents
- Rice University, Houston: SpaceRing: a Versatile, Scalable Power-Generation and Cooling System
- University of Colorado at Boulder: Plant Anywhere: Plants Growing in Free Habitat Spaces
- University of Maryland, College Park (2 projects): Vertical Habitability Layout Studies, Neutral Buoyancy/Parabolic Flight Habitat Studies
- Oklahoma State University, Stillwater: Horizontal Habitability Layout Studies

**University of Colorado Boulder**

A successful prototype has been completed of a smart pot for plant growth. One of the main focuses for the team from the University of Colorado was to have a system built with easily replaced parts. The team successfully investigated and provided recommendations for operational surface requirements, arm limitations, appropriate batteries, distance sensors, cameras, control systems, and charging dock for the Remotely Operated Gardening Robot, Figure 25. A fully functional user interface was also been developed.

Figure 16: University of Colorado’s Remotely Operated Gardening Robot (Credit: NASA).

**University of Maryland**

Spending significant time underwater, Figure 17, University of Maryland students conducted a plethora of studies to increase the research body of knowledge on space habitats. The testing was done to compare and contrast various activities that would be taking place in microgravity, on the lunar surface and on the Martian surface. The evaluation included multi-level access (use of ladders and ramps), posture (with and without gear), mobility and human-robot interactions, and workstations. In addition to the underwater testing, the team also did virtual reality testing on the space management and accessibility of their conceptualized habitat.


Figure 17: University of Maryland students conducting studies underwater (Credit: University of Maryland).

**Oklahoma State University**

After completing construction of their habitat mockup, the team from Oklahoma State University was able to create a variety of module options, Figure 18. Among expected tests are deciding upon bedding options, identifying minimal habitable volume, and interactions between participants during hours of consecutive testing. The walls of the lower level are module to allow for testing to occurring with varying volumes and square footage.

Figure 18: Oklahoma State University Habitat Module Mockup (Credit: Oklahoma State University).

**Rice University**

The team from Rice University successfully constructed a prototype of the heat exchange system, Figure 19. The concept allows the placement of a thermoelectric generator between pipes that transfer fluid of drastically different temperatures. The temperature difference allows the generator to gather energy which is then stored in batteries for future use. For space missions, there are existing systems that use fluids with similar temperature differences. By installing systems such as this one, it is possible gather additional energy through existing systems.

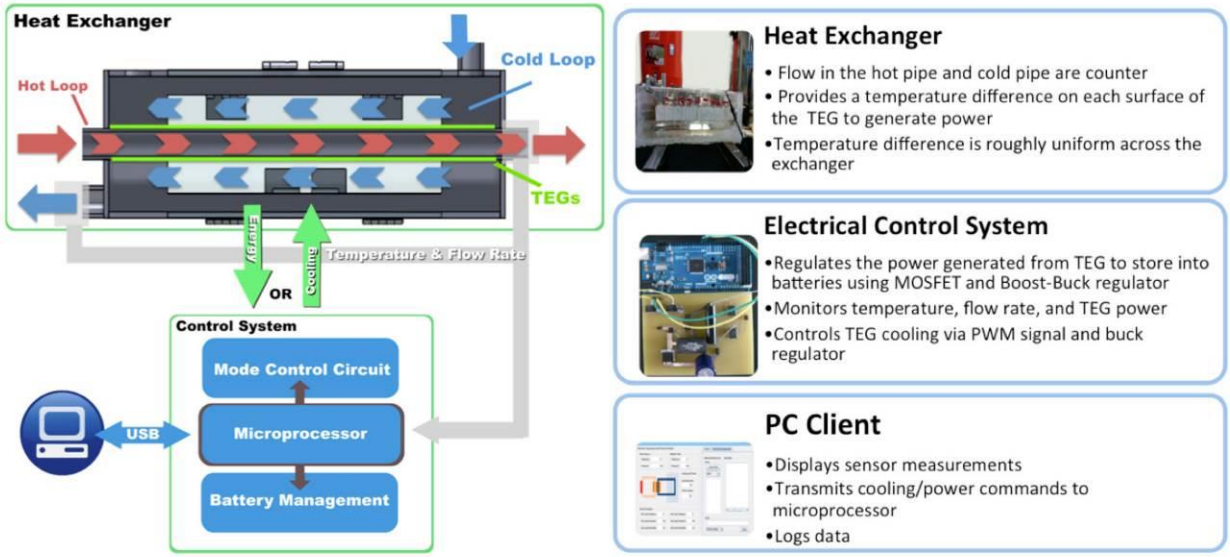


Figure 19: Rice University heat exchange system concept (Credit: Rice University).

**University of South Alabama**

The South Alabama team succeeded in creating their air revitalization system, Figure 20, gaining experience in systems engineering and learning valuable lessons about planning for long and short term projects. The system has was successfully tested for the full capability of a system using metal organic framework adsorbents. Even with some unexpected delays in manufacturing and delivery of various parts, the team was able to avoid a large number of risks and obstacles because of the systems engineering approach and deemed the project a success.

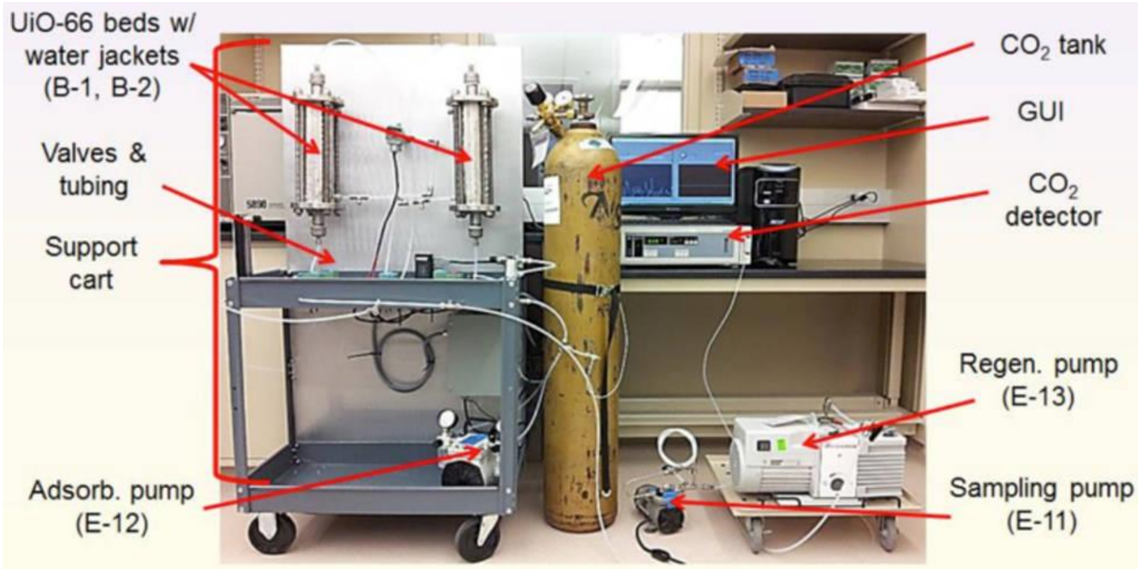


Figure 20: University of South Alabama Air revitalization system (Credit: University of South Alabama).

**University of Wisconsin - Madison**

As production for their collapsible 3D printer, Figure 21, progressed, the team from the University of Wisconsin-Madison identified some much more efficient and effective means to construct the machine. A total redesign took place, resulting in a lighter, more reliable device that consisted in much fewer custom parts, allowing for easier repair and replacement as needed. The team's overall goals remained constant, producing a 3D printer that is safe, functional, capable of producing parts to industry standards, and able to collapse and reduce at least 50% of its volume. The design would lead to an improvement in the state of the art for 3D printers in microgravity for volume and for product size.

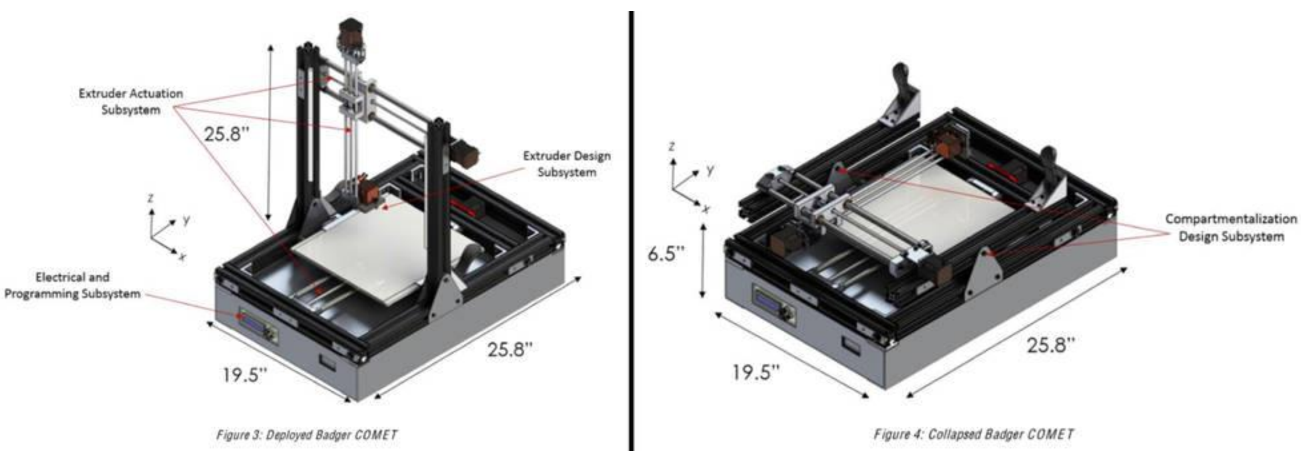


Figure 21: University of Wisconsin Collapsible 3D printer (Credit: University of Wisconsin - Madison).

**E. X-Hab 2015**

X-Hab 2015 continued to press a variety of technology challenges to enhance the capabilities for deep space exploration. The X-Hab Academic Innovation Challenge 2015 teams and projects were:

- University of Colorado at Boulder: Deployable Greenhouse for Food Production
- Oklahoma State University: Deployable Greenhouse for food production on long-duration exploration missions
- University of South Alabama: Development of a Volumetric Absorption System for CO2 and H2O Multicomponent Isotherm Measurements
- University of Vermont: Design of a "Smart-Structure" Deployable Airlock
- University of Wisconsin - Milwaukee: Design of a Carbon-fiber/Fused Deposition Modeling Spacecraft Structural Fabrication System

**University of Colorado - Boulder**

After completing a conceptual design for a pre-deployable Martian greenhouse, the University of Colorado-Boulder team designed and constructed a prototype to identify science concepts and engineering challenges, Figure 22. Further prototype development opportunities include supporting a variety of food-producing plants over multiple growth cycles to investigate topics such as utilization of in-situ $CO_2$ while minimizing atmospheric contamination, water recycling and reduction of losses through the system, and replacement of consumables.

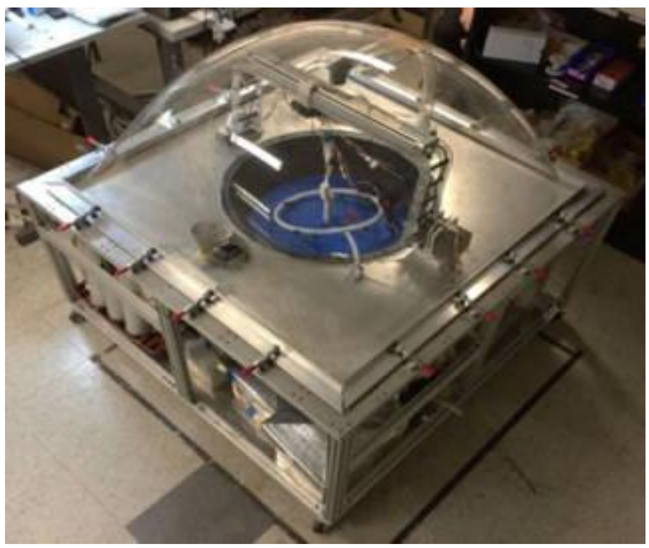

Figure 22: The University of Colorado's pre-deployable Martian greenhouse prototype. (Credits: University of Colorado)

**Oklahoma State University**

Students from Oklahoma State University designed a module for use as an Organics and Agricultural Sustainment Inflatable System (OASIS) to grow plants autonomously on Mars before astronaut arrival. A full-scale model of one of the module’s “greenwings,” or growth chambers that extend from the OASIS central hub, was built and outfitted with a deployable plant growth system and an aeroponics system. In addition, the team also built a smaller scale model of a greenwing to test how greenwings could inflate and deploy from the central hub of the module, Figure 23.

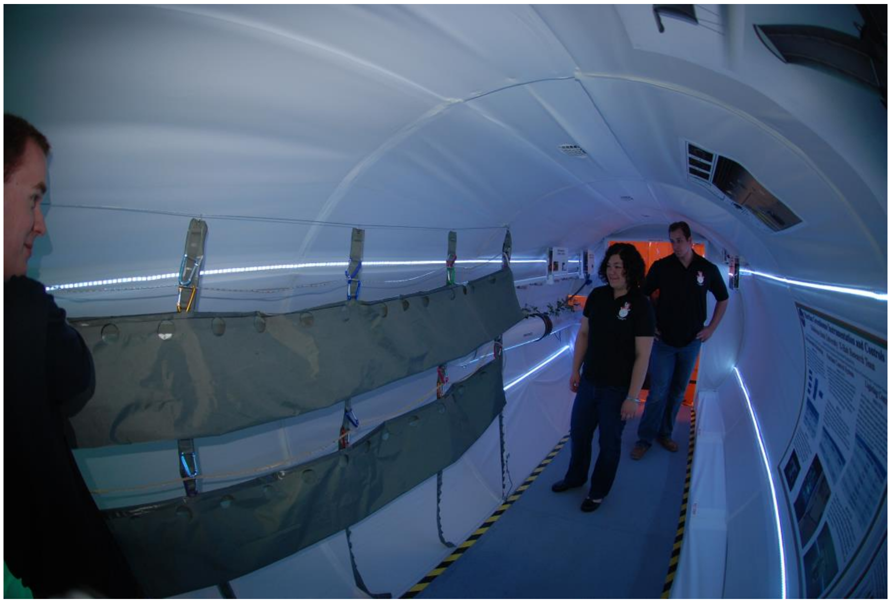

Figure 23: Students evaluate the "greenwings" of the Oklahoma State deployable greenhouse concept. (Credit: Oklahoma State University).

**University of South Alabama**

The team from the University of South Alabama designed and built a multi-component adsorption recirculation system to measure adsorption of carbon dioxide and how water vapor affects the adsorption. This technology would be able to be used on spacecraft to purify air.

**University of Vermont**

After designing an inflatable airlock system that could be used on deep space missions, University of Vermont students built a one-third scale model to test how the airlock could be deployed, repacked, and reused multiple times, Figure 24. The team tested multiple folding methods, fabric connection points and methods, and multiple air inflation systems.

Figure 24: University of Vermont students work on a third-scale model of their inflatable airlock system (Credit: University of Vermont)

**University of Wisconsin – Milwaukee**

The team from the University of Wisconsin - Milwaukee studied 3-D printing technology applications for creating and recycling tools on long-term space missions, Figure 25. They had the goal of creating high-strength, reliable components produced using carbon fiber reinforcements in acrylonitrile butadiene styrene (ABS) during

Fused Deposition Modeling, an additive manufacturing technology that deposits the materials in layers. They tested to optimize for strength, weight, and then separation of the materials and recyclability of the ABS. Using this method, they designed a ratcheting wrench, crowfoot adapter, locking pliers, and modular tools.

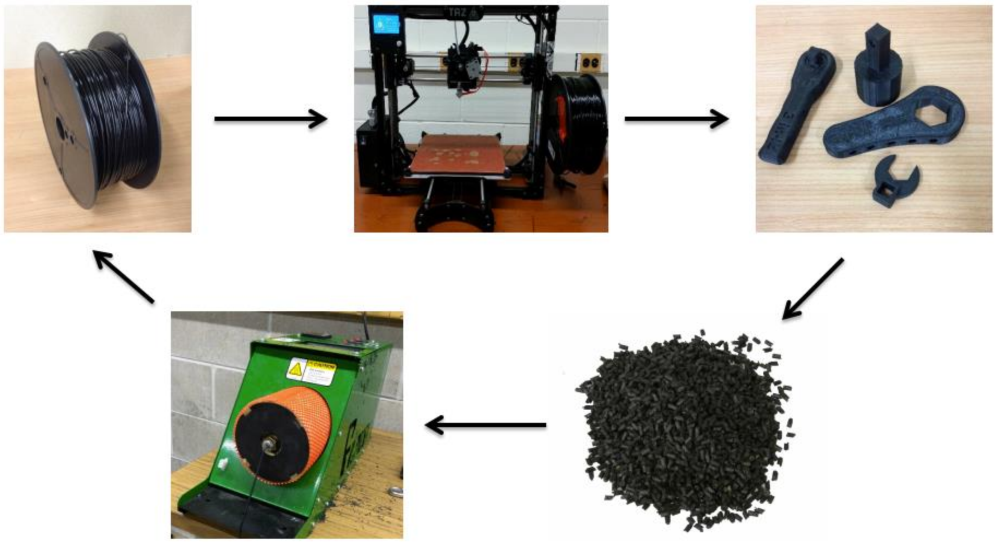

Figure 25: The recycling concept of the University of Wisconsin-Milwaukee carbon fiber reinforced additive manufacturing system. (Credit: University of Wisconsin-Milwaukee).

**F. X-Hab 2016**

NASA recently announced the 2016 X-Hab design challenge selectees, which include some returning universities. The X-Hab Academic Innovation Challenge 2016 teams and projects are as follows:

**University of Maryland, College Park, Md. - Inflatable/Deployable Airlock Structures**

The project team will develop sub-scale and full-scale inflatable/deployable structures for a two-person airlock, applicable to use on either a long-term space habitat or a crewed transport vehicle, Figure 26. The study will focus on airlock concepts for both microgravity and planetary surface operations, with systems design studies to determine the degree of commonality desirable between the two applications.

Figure 26: University of Maryland - Cutaway of inflatable airlock highlighting doors, support structures and suit ports.

**Pratt Institute, Brooklyn, N.Y. - Human Centered – Designs for Mars Transit Habitat**

The project will strengthen and extend the current design of the mission systems and build upon their success from a specific human factors function in support of crew health and wellbeing living over extended periods of time in the microgravity environment of space. Given the human physiologic and psychological standards established in NASASTD-3001, the team will develop physical and spatial designs and prototypes than can be used to determine the essential baseline needs for the crewmembers, identify and validate effective design methods for modifying the habitat/vehicle environment to mitigate the psychological and behavioral effects of psychological environmental stressors (e.g., isolation, confinement, acoustics, reduced sensory stimulation) likely to be experienced in long-duration, deep-space missions.

**Oklahoma State University, Stillwater, Oklahoma - Deep Space Mars Transit Habitat Layout Studies**

The project will continue efforts to design, build and evaluate components for horizontally and vertically oriented habitats for deep space missions. The team will work to build a complete habitat mockup for use in research and education, namely the Stafford Deep Space Habitat (SDSH) developed around the MPLM, the Martian Reconfigurable Habitat (ReHAB), and the Organics and Agricultural Sustainment Inflatable System (OASIS), Figure 27. To compliment these modules, the student team will design a construct an advanced crew transport system analog based around the Orion.

Figure 27: Organics and Agricultural Sustainment Inflatable System (OASIS) Habitat Interior
Credits: Oklahoma State University

**University of South Alabama, Mobile, Alabama - Development of a Concentration Swing Frequency Response Device**

Project for the development of a concentration-swing frequency response (CSFR) device for the measurement of diffusion rates of $CO_2$ in 13X zeolite, Figure 28. The device will provide diffusion parameters that can be used in the development of mathematical models of adsorption systems that examines the use of adsorbent materials for closed air revitalization for long-term duration space flight. The efficiency of air revitalization needs to be improved while at the same time increasing reliability and reducing power and mass of the revitalization system.

Figure 28: CSFR adsorbent bed containing silica gel that was used in a set of diffusion measurements. Credits: University of South Alabama

**University of Puerto Rico at Mayagüez, Puerto Rico - Technology Development of Low-Power Required Manufacturing of Metals for the Zero Gravity Environment Project**

The project will improve current 3D printing capabilities to allow space metal manufacturing by optimizing current techniques in subtractive and additive manufacturing of metallic parts for the development of hand tools, metallic components for actuators, and structures in zero-gravity environment. It will be developed with a reduction of volume and power consumption while using automated processes.

**Utah State University, Logan, Utah - Student Experimental Microgravity Plant System (SEMPS)**

The objective of this project is to design a Student Experimental Microgravity Plant System utilizing radial acceleration for water and nutrient delivery. The prototype plant food production system will be approximately 0.3 meters in diameter and 0.5 meters in length and, will allow experiments and models to be developed to better understand the challenges and physics of delivering water and nutrients to plants in a microgravity environment.

**The Ohio State University, Columbus, Ohio - Water Assurance: Improve water delivery of a modular vegetable production system**

The project will improve the performance of a vegetable production unit (VEGGIE) that uses a passive watering system for multiple crop production in a microgravity environment. The team will implement: a better pressure regulation of the water reservoir; a more robust and effective water transport interface between the water reservoir and the plant rooting media; and a sensing system to monitor water status of the plant-root zone-water reservoir continuum.

**University of Colorado-Boulder, Boulder, Colo. - Performance Characterization and Enhancement of the MarsOASIS Space Plant Growth System**

The project will characterize and enhance the performance of the MarsOASIS deployable greenhouse developed in X-Hab 2015, from both engineering and plant growth perspectives. The team will generate and attempt to answer key science and engineering questions that will be challenges for designers of future Mars crop production systems and lay the groundwork for future intra- and inter-university research in bio regenerative Environmental Control and Life Support Systems (ECLSS).

## V. Benefits

There are a variety of benefits that have resulted from the X-Hab Academic Innovation Challenge, and these benefits extend beyond just the reports and prototypes produced by the team. They also include outreach, financial flexibility for the sponsoring projects, and the student experience.

### A. Reports and Prototypes

The two primary outputs from the conduct of an X-Hab project are typically divided into two categories. First are the reports associated with the milestones in the Systems Engineering process including, importantly, the final report delivered at the conclusion of the project. NASA provides definition of the content for the Requirements and

Systems Definition Review, the Preliminary Design Review, and the Critical Design Review while the universities are given more latitude for the Progress Checkpoint Review and the Final Report. This approach allows the later milestones to be tailored to products that may already be planned by the university for other purposes such as conference papers or required curriculum products. The second output may be a prototype product. Depending on the project design, a prototype may not be included if the project was set up simply to provide a topical report, but most X-Hab projects included prototype systems to encourage a hands-on experience. The projects have been split between standalone prototypes produced at the universities that may stay with the university and projects that are delivered to NASA for demonstration and/or utilization. Most of the early X-Hab projects were designed to deliver products that were to be delivered to NASA at Johnson Space Center for integration with the Habitat Demonstration Unit, but many others have been delivered to other centers for demonstration purposes as well. Through the contract mechanism between the National Space Grant Foundation and the universities, the NSGF actually maintains the rights for any prototype systems produced by X-Hab projects and defers the decision to NASA on whether NASA wants to accept the prototype or allow the university to keep the prototype for further utilization or other purposes. Several universities have been able to leverage investments from previous X-Hab projects in future proposals and have further matured their prototype systems.

### B. Outreach

The NASA X-Hab team ensures that press releases and/or web features are produced for the annual X-Hab selections as well as a year-end summary on a an official NASA public web page for the X-Hab Challenge. There is a National Space Grant Foundation website that hosts the solicitation each spring and contains references to past solicitations. There is also a NASA Deep Space Habitat Facebook page on which solicitation information is posted along with articles on X-Hab projects and space habitation themes.

A listing of the official X-Hab web pages are listed below for future reference on past projects. Future solicitations and updates will be posted to these sites as well.

NASA X-Hab Academic Innovation Challenge Public Page
http://www.nasa.gov/exploration/technology/deep_space_habitat/xhab/#.VYHw1PlViko

NASA Deep Space Habitat Facebook page
https://www.facebook.com/pages/NASA-Deep-Space-Habitat/303267556447857?ref=bookmarks

National Space Grant Foundation X-Hab site
https://www.spacegrant.org/xhab

Because the university teams are encouraged to perform outreach related to their projects, the most publicity for X-Hab projects derives from the university efforts. Over the first 5 years of execution, there have been a wealth of media articles on X-Hab projects, websites and social media accounts established to update project status, and many conference papers as prestigious events such as Space Symposium, International Astronautics Congress, and AIAA Space and AIAA International Conference on Environmental Systems (ICES). An excellent compilation of published papers was produced that were associated with the Habitat Demonstration Unit for an AIAA Space 2013 paper[5] that included many X-Hab papers. A simple internet search of the terms "NASA" and "Xhab" will produce countless web links of magazine articles, social media pages, press coverage, paper publications, web articles, and more.

### C. Financial Flexibility

As previously mentioned, having a range of disciplines in the project concepts in each solicitation allows the X-Hab challenge to not only access planned funding from primary sources of funding in the Habitation community but also a range of other funding sources within the NASA community. The list of previous investors in X-Hab includes HEOMD Strategic Integration, AES Deep Space Habitat, AES Exploration Augmentation Module, AES Logistics and Resupply, AES Life Support, AES In-space Manufacturing, Human Research Program, and Space Life and Physical Sciences.

Secondly, the timing of the solicitation and the mechanism with the National Space Grant Foundation allows money from the current fiscal year to be obligated to the National Space Grant Foundation to be expensed in the following fiscal year in which the bulk of the challenge activities occur. However, the start of the academic year is typically August or September which the kickoff meetings happen with each team. This could make for a difficult start each year if the plan was to rely on current fiscal year money to run this challenge because of historical problems in having the federal budget approved for the start of the fiscal year. Thus the timing and the mechanism of the X-Hab academic Challenge divorce the challenge from waiting to start with the arrival of funds each fiscal year.

### D. Student Experience

The X-Hab challenge is executed around a modified NASA systems engineering process, and the university teams follow the schedule through the review and implementation process under the guidance of their mentors at the university and at NASA. They work in a team environment, making procurements, managing risk, solving problems, and documenting their work. The experience of these projects serves as valuable, practical work experience for the students participating in the projects. Many X-Hab students continue on into the aerospace workforce and are currently employed by companies like Boeing, Ball Aerospace, and Google Lunar X Prize Foundation.

## VI. Future Plans

Instead of running X-Hab under just one NASA project and reaching out to other NASA projects if there are excellent candidates for additional funding, X-Hab is now being a run as a service to HEOMD for Advanced Exploration Systems (AES) projects or other interested projects. The call for X-Hab project ideas is distributed to points of contact across AES to generate potential project concepts and to commit the availability of current fiscal year funds. These project concepts are vetted with potential funding source managers and then incorporated into the solicitation. There may be an advantage in managing all of the funding resources for X-Hab within one project budget rather than assembling piecemeal budgets by cobbling together various funding sources, and that option is being evaluated as well. The advantage would be that the highest quality projects overall may be selected rather than the highest quality projects within certain funding categories.

Collaborative efforts between NASA and academia are becoming more and more commonplace across NASA to be able to maximize the value of investments in architecture and technology development activities. Not only is it difficult for NASA teams to be able to perform the type of work performed in X-Hab projects within the budget allocations for X-Hab projects, but this partnering with academia gives the student teams practical work experience and gives NASA the benefit of the creativity of academia. The competitive nature of this call ensures NASA gets a selection of proposals that maximize the value of the investments as well as the opportunity to bring in academic partners that may be non-traditional. The X-Hab Academic Innovation Challenge has become a valuable tool that benefits both NASA and its academic partners in this effort.

## VII. Conclusion

The X-Hab Academic Innovation has evolved and matured as it enters its sixth year of operation. This model can serve as an excellent mechanism to engage academia in research and technology efforts not only within NASA but any government agency. The model benefits government with creative, low cost focused research through academic partners while the universities can tailor the curriculum to give their students a good systems engineering experience guided by the expertise of the agency.

## Acknowledgments

The founder of the Exploration Habitat Academic Innovation Challenge is Kriss Kennedy at Johnson Space Center. Without his efforts is beginning the X-Hab challenge as well those in building a community of practice with the Habitat Demonstration Unit, the X-Hab challenge would not exist. Special mention should also be made to Scott Howe of the Jet Propulsion Laboratory and Larry Toups of Johnson Space Center for their efforts in working with the early X-Hab efforts. Finally, thanks to the many NASA and contractor mentors for the university projects who took interest in these efforts of the students and their professors to give them the benefit of their experience and insight to enable the projects to succeed and for the students to have a quality experience in working with NASA.

## References

[1] Kennedy, K. J., T.R. Gill, T. O. Tri, and A. S. Howe. The Habitat Demonstration Unit Project Overview ASCE Earth & Space 2010 , Honolulu, HI, March 14-17, 2010

[2] Howe, A. S., K. J. Kennedy, T. O. Tri, S. Liolios, L. Toups, R. L. Howard, T. R. Gill. X-Hab Challenge: Students in the Critical Path. Global Space Exploration Conference (GLEX 2012), Washington, DC, May 22-24, 2012.

[3] Student Team FireFly! Wins Space Habitation Innovation Challenge, URL: https://www.nasa.gov/directorates/heo/education/2012-habitat-innovation-challenge.html#.VZrzjvlVhBc [Cited July 14, 2015].

[4] Robotic Sample Manipulator for Handling Astromaterials Inside the GeoLab Microgravity Glovebox. URL: http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20130001877.pdf [Cited July 14, 2015].

[5] Howe, A. S., K. J. Kennedy, T. R. Gill., et al. NASA Habitat Demonstration Unit (HDU) Deep Space Habitat Analog. AIAA Space 2013 Conference & Exhibition. San Diego, CA, Sep 10-12, 2013.

[6] Exploration Habitat Academic Innovation Challenge, URL: http://www.nasa.gov/exploration/technology/deep_space_habitat/xhab/#.VYHw1PlViko [Cited July 14, 2015].