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X-Hab Challenge: Students in the Critical Path

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The eXploration Habitat (X-Hab) Academic Innovation Challenge follows a non-typical format for university student competitions. Rather than provide a realistic simulated mission for the students to perform, the X-Hab Challenge puts the student teams in the critical path of NASA's human space flight Exploration systems research and development, and expects them to deliver a product that will likely become heritage for eventual flight systems in the years to come. The added responsibility has two major benefits: the university teams are given real ownership in the NASA vision; students are given Principal Investigator (PI) status for their contribution and are looked upon as peers in the development process. This paper introduces the X-Hab Challenge and discusses the successes behind the program.

I. 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
GMWS	=	General Maintenance Work Station
HDU	=	Habitat Demonstration Unit
IVA	=	Intra-Vehicular Activity
PEM	=	Pressurized Excursion Module
PI	=	Principal Investigator
STEM	=	Science, Technology, Engineering, and Mathematics in education
X-Hab	=	eXploration Habitat Academic Innovation Challenge

I. Introduction

FROM the outset the Habitat Demonstration Unit (HDU) project team was charged with forming a rapid-prototyping "skunkworks" / tiger team environment for quickly designing and constructing a functional analog habitat (Kennedy, Tri, Gill, & Howe, 2010), that will eventually evolve into a flight-like unit. The HDU Management decided early on that it wanted to tie the project in with educational opportunities and provide a healthy atmosphere for student interns to participate in the project. Having previously been involved directly or

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indirectly with academia, members making up the management team understood that university students could provide two strengths to the team that otherwise might have had less emphasis. One strength the team wanted to draw upon was the ability for students to think “out of the box” and come up with innovative new ideas. The infusion of new ideas and their production could challenge standing cultures and “common sense”, given that students don’t yet know what is commonly thought to be impossible.

The second strength would come from deep roots into the educational system, with far-reaching influence on motivating a future generation of engineers and architects to make a worthy vision their own. The HDU team wanted to create an educational opportunity that would fit right into the curriculum of the universities involved, and allow those students to work on real concepts and hardware as part of their learning experience.

Figure 1: Habitat Demonstration Unit, 2011 D-RATS configuration with U. Wisconsin X-Loft (left), section (right)

The HDU project consisted of a multi-center team brought together in a rapid prototyping tiger-team approach to quickly build, test, and validate hardware and operations in analog environments. The project integrated operational hardware and software to assess habitat and laboratory functions in an operational prototype unit. The HDU project began in 2009, resulting in an analog of a Pressurized Excursion Module (PEM) laboratory for simulating a lunar habitat for the 2010 NASA Desert Research and Technology Studies (D-RATS) field analog. The initial elements included a 5-meter diameter hard shell vertically oriented one-story cylindrical module with four side hatches as docking ports for support modules, analog rovers, spacecraft, and other mission elements (Howe, Spexarth, Toups, Howard, Rudisill, & Dorsey, 2010). With a portable base configuration compatible with multi-mission architecture, various teams from all over NASA brought their technologies into the HDU shell to participate in a functionally integrated environment. Extra-Vehicular Activity (EVA), power, communications, Environmental Control Life Support Systems (ECLSS), dust management, avionics, human factors, and many other teams have contributed technologies that have been maturing in laboratories around NASA, but have heretofore not had a common portable platform that would allow them to come together in an integrated manner. For 2011 NASA built and tested a Habitat Demonstration Unit Deep Space Habitat (HDU-DSH) habitat/laboratory, using the 2010 configuration and technologies as a foundation, that was utilized to advance NASA's understanding of alternative mission architectures, requirements definition and validation, and operations concepts definition and validation (Figure 1). The HDU project has since become the Advanced Exploration Systems (AES) Habitation Systems project.

II. The X-Hab Academic Challenge

Within the context of the HDU rapid-prototyping environment the eXploration Habitat (X-Hab) Academic Innovation Challenge (“X-Hab Challenge” for short) was born, embracing all the ideals for educational opportunities the HDU Management Team wanted to aspire to. The HDU Management Team wanted to establish a Science, Technology, Engineering, and Mathematics (STEM) educational program that could really leave an impact on both NASA and academia partners. After looking at various competitions and challenges, most of them appeared to offer a self-funded topic around which university teams could compete and win honors for the winning entry. However, the HDU Management Team wanted to create an opportunity for students to get involved with the mainstream NASA work, and leverage the excitement students have for creativity, vision, and out-of-the-box thinking that is often faded or encumbered with real-world "common sense" in long-time employees and engineers. It was thought that involving students in the mainstream NASA projects would provide opportunities of internship, allow NASA team members access to motivated students, energize the rest of the team, develop a relationship with like-minded faculty, and provide students with the opportunity to have their ideas be implemented in developmental applications that could become heritage technology in the next generation deep space flight systems. Rather than declare a topic that student teams could address, the X-Hab Challenge became a program where the NASA teams provided seed funding, and allowed the student teams to become full-fledged Principal Investigators (PI) part of the overall team, responsible for their subsystem under the direction of the faculty advisor. As of this writing, the X-Hab Challenge project has successfully completed its inaugural first year in 2011, is currently finishing up the second year 2012, and has released the third year 2013 solicitation under the direction of the HDU follow-on AES-DSH Project Management.

A. X-Hab Challenge Process and Timeline

Each year the X-Hab Challenge can take on a different form, depending on the needs of the NASA DSH team. The first project, begun in 2010 and completed in 2011, solicited proposals from various teams in a head-to-head competition to design and build an inflatable loft that could be mounted on top of the HDU module, the winner of which functioned as Principle Investigator (PI) for the "X-Loft subsystem" during field analog tests in NASA's Desert Research and Technology Studies (D-RATS) mission simulations in the Arizona desert – more on this later. Subsequent years have had a shotgun approach to X-Hab Challenge topics, where multiple teams work on single topics not in competition with other teams.

Figure 2: NASA X-Hab 2011 judges (astronauts, engineers, managers, etc) briefing on Oklahoma State's X-Loft concept

A typical X-Hab Challenge cycle begins in the spring with the release of the solicitation, managed by the National Space Grant Foundation, which allows us to utilize funding in one fiscal year to support the challenge execution in the following fiscal year. Utilizing the NSGF expertise also provides a fair and competitive environment similar to other grant processes for the applicant teams. In the solicitation, short project descriptions are provided by various DSH subsystem and technology teams, introducing some of the challenges the teams are up against in their developmental tracks toward DSH-related space hardware and subsystems. Proposals are 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 (if applicable) and Fellowship Program, or other US accredited university. Multi-discipline, multi-departmental, and/or multi-institutional teaming collaborations are highly encouraged. The solicitation contains a draft schedule that adheres to the NASA review process (discussed below).

In response to the solicitation, universities can choose among those suggested by the DSH subsystem teams, or propose similar projects on their own that match the expertise of the university faculty member and student teams. The sponsoring faculty member is required to set up a senior-level design course as the context within which the X-Hab Challenge topic can be addressed, and is required to identify a grad student that will be able to take responsibility of the project, even if other student team members join the project for specific tasks.

Once the university teams are selected, NASA domain managers and subsystem experts work tightly with the teams, going through various reviews and check points, as will be discussed later, before delivering the final products. In the 2011 head-to-head competition, various NASA experts, including managers, astronaut crew members, engineers, and designers were asked to perform as judges to select the winning X-Loft field test article (Figure 2).

Figure 3: X-Hab 2011 Oklahoma State University X-Loft concept CAD model (left), interior (right)

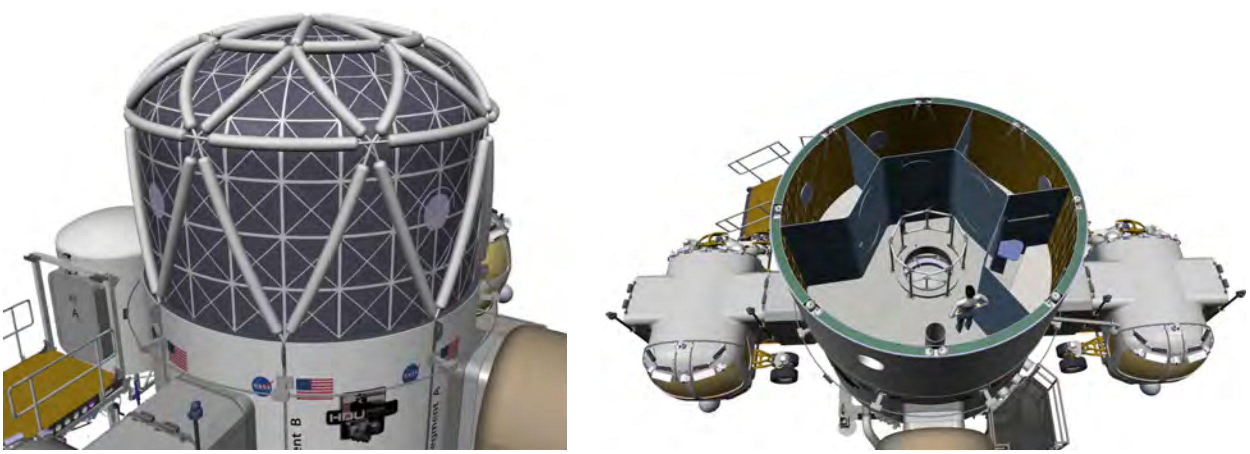

Figure 4: X-Hab 2011 U. Maryland X-Loft concept showing triangular structure (left), and crew quarter partitions (right)

B. X-Hab Challenge Projects: X-Hab 2011

The first X-Hab Challenge in 2011 was structured as a head-to-head competition and resulted in the design and manufacture of inflatable loft dome concepts that extended the HDU habitation functionalities. Since the HDU is not pressurized in itself, the dome was required to be self-standing without internal positive pressure. Three university teams were selected from University of Maryland, Oklahoma State University, and University of Wisconsin and were given seed funding that they extended through their own fund raising efforts. As will be discussed later, NASA DSH team members welcomed the three teams as equal PIs onto the team, following NASA protocol for reviews and safety. The teams were firewalled from each other during the competition, but each produced functional products and were given their own week at Johnson Space Center (JSC) to mount their X-Loft prototype and run a series of tests. Oklahoma State University used a bundled pneumatic tube approach for the barrel wall and dome. Figure 3 shows a CAD representation of the concept on the left, with instructor and students on the right during their week at JSC erecting their prototype on top of the HDU module.

University of Maryland developed a triangular pneumatic tube net structure (shown on the left in Figure 4 with outer cover removed in CAD model) and built a partitioned interior layout for crew quarters and communal space (Figure 4, right).

As will be discussed later, the University of Wisconsin team won the head-to-head competition with a dome supported by longitudinal pneumatic beams brought together at the crown (Figure 5).

C. X-Hab Challenge Technology Implementation

All three of the university products in the X-Hab 2011 competition had advantages and unique properties that the NASA team was able to digest and use as possible heritage on future inflatable pressurized module designs. For example, Oklahoma State University's bundled pneumatic tube design ended up being the strongest in the barrel section, even though it could not pass the overnight inflation test due to flaws in the inflation system. The University of Maryland concept for triangular pneumatic tubes was thought to have potential application for inflatable habitats with complex curves. The University of Wisconsin design had an inner sleep loft, innovative ventilation, and other features that were unique, and was selected as the winner due to practical reasons – it was brought out to the field for the one-month NASA D-RATS analog tests, and was able to keep its inflation and provide for weather protection in the field, with less maintenance than the others (even though flight versions of the three prototypes may have solved some of thos problems.

Figure 5: HDU-DSH with X-Hab 2011 U. Wisconsin inflatable X-Loft dome

Figure 5 shows the completed HDU-DSH with the University of Wisconsin "Badger" X-Loft on top, at the Black Point Lava Flow in Arizona during the 2011 D-RATS mission simulations. The elements in Figure 5 include the Deployable Extra-Vehicular Activity Platform (DEVAP) ramp on the left attached to the “Dust Module” airlock. In the center the main HDU module functioned as the laboratory deck, and to the right is the Hygiene Module. The Wisconsin X-Loft on top was fitted as the habitation element in the DSH, with an electric cargo / personnel lift in the center for circulation between the two levels. The X-Loft was designed with a lightweight, deployable, overhead sleeping loft (Figure 6), with galley, communal meeting space, exercise functions, and Intra-vehicular Activity (IVA) workstation.

During the D-RATS field tests, the University of Wisconsin team was invited to participate as PIs for the X-Loft subsystem, and University of Maryland and Oklahoma State teams also were involved in the D-RATS activities, even though their prototypes were not attached to the HDU during the exercise. The X-Loft was occupied by astronaut crews for multiple days at a time as part of the field tests, and valuable data was gathered from the crews via feedback. The DSH team also was able to put together several one-night “designer” crews, which included University of Wisconsin students, to allow the designers to give feedback on their own creations.

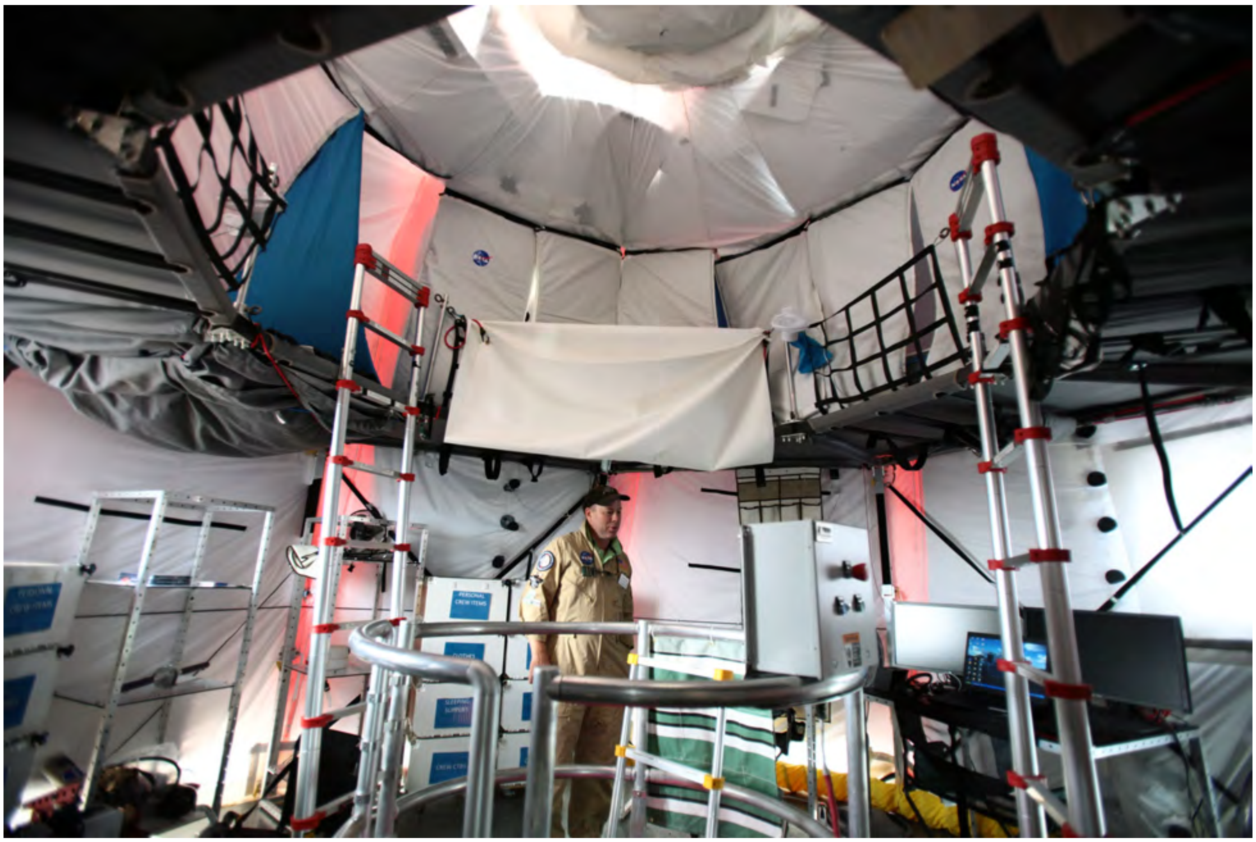

Figure 6: X-Hab 2011 U. Wisconsin inflatable X-Loft habitation deck interior (photo courtesy of James W. Young)

III. Students in the Critical Path

In contrast to many other university-level competitions, the X-Hab Challenge was initiated from within NASA for the purpose of assisting with the development of flight-heritage technology, hardware, and subsytems. The HDU-DSH, and subsequently the AES-DSH Management Team, some of whom had experience in academia, realized the contribution students can make to NASA efforts. Students are often quite knowledgeable but lacking in experience. Where experienced engineers shy away from certain solutions or are tied to certain approaches due to tradition or habit, students are often uninhibited in their design and exploration of various concepts.

From the NASA side, giving students free reign to develop and explore ideas provided insights in directions the more experienced engineers were either too constrained by management to do themselves, or had too much “common sense” to even begin to think in those directions.

From the university side, the X-Hab Challenge projects stimulate university students with a responsibility and ownership of the future space programs, more than forcing them to inherit solutions that have already been developed. Indeed, the students were invited to participate in the NASA critical path, as equal peers and PIs of their own subsystems. The NASA DSH team risked failure of several aspects of the DSH technology should the students fail to perform in a satisfactory manner. Trusting the students in this manner made all the difference in the world – the students realized the tremendous responsibility in their hands a rose to the challenge.

Another advantage given to the students teams as project PI was the exposure to NASA experts, including astronaut crew members that have experience living and working in space. Students were able to demonstrate and get real-time feedback from crew members who would eventually be the ones that would use the habitat (Figure 7).

Figure 7: U. Maryland X-Loft interior (left), student team getting pointers from astronaut crew (right)

A. NASA Review Process

The X-Hab Challenge follows NASA review protocol in the NASA Systems Engineering Handbook, including various reviews to make sure the project stays on schedule and is matured in a timely manner. The X-Hab project holds three major reviews during the design cycle, with NASA experts in attendance either in person or via virtual teleconferences, and two progress check points that follow the manufacture and production of the deliverables.

The first major review is the System Definition Review (SDR) where the university team introduces their team members, set the vision, goals, objectives, establish work breakdown structure and preliminary functional baseline, and provide preliminary risk assessments and test plans. The second review is the Preliminary Design Review (PDR), where the university team expands on the various trades, designs, specifications, and development introduced during the SDR. Finally, the Critical Design Review (CDR) is where the university teams present their completed design, including analaysis, parts list, and fabrication drawings.

Thereafter the NASA experts will help the team during the fabrication and assembly process via major progress check points and other meetings. The NASA DSH integration team begins to hold regular weekly or bi-weekly meetings with the university teams to make sure the product will be ready to install into the Deep Space Habitat prototype.

At the end of the one-year X-Hab Challenge, the university team hand-carries the final product to NASA Johnson Space Center and spends several days to a week integrating the system into the DSH. Overall, the students are treated as equals, and without exception the students have risen to the challenge.

B. Testing and Analysis

Another way the university team is involved in the critical path is through testing and analysis. The products produced by the teams are required to be put through the strict standards NASA holds to contractors, which requires the students to research material strengths, flammability, temperature resistance, and outgassing. Though the products that are built for integration into the prototype are not required to be space-rated, the students are required to go through the process of designing a space-rated system, and then to figure out how to actually build an analog of that system. The product they produce is well-designed as a functional subsystem, but also maintains analog characteristics of the proposes flight system with a variety of "hooks" for using the system to gain more knowledge on how a further evolve the system toward a more flight-like version. Figure 8 shows an example where University of Maryland used wind tunnels and scale membrane models of their dome design to find the right structure (left). The structure shown on the left is an orthogonal net of pneumatic tubes, but the wind tunnel testing gave them insight into a triangular net that they built into their final product. The various fabric samples were tested for strength and failure as well (Figure 8, right). Figure 9, left, shows how Oklahoma State University created custom frames and weight systems (sometimes the students themselves!!) to test the compressive strength of their pneumatic bundled tube design.

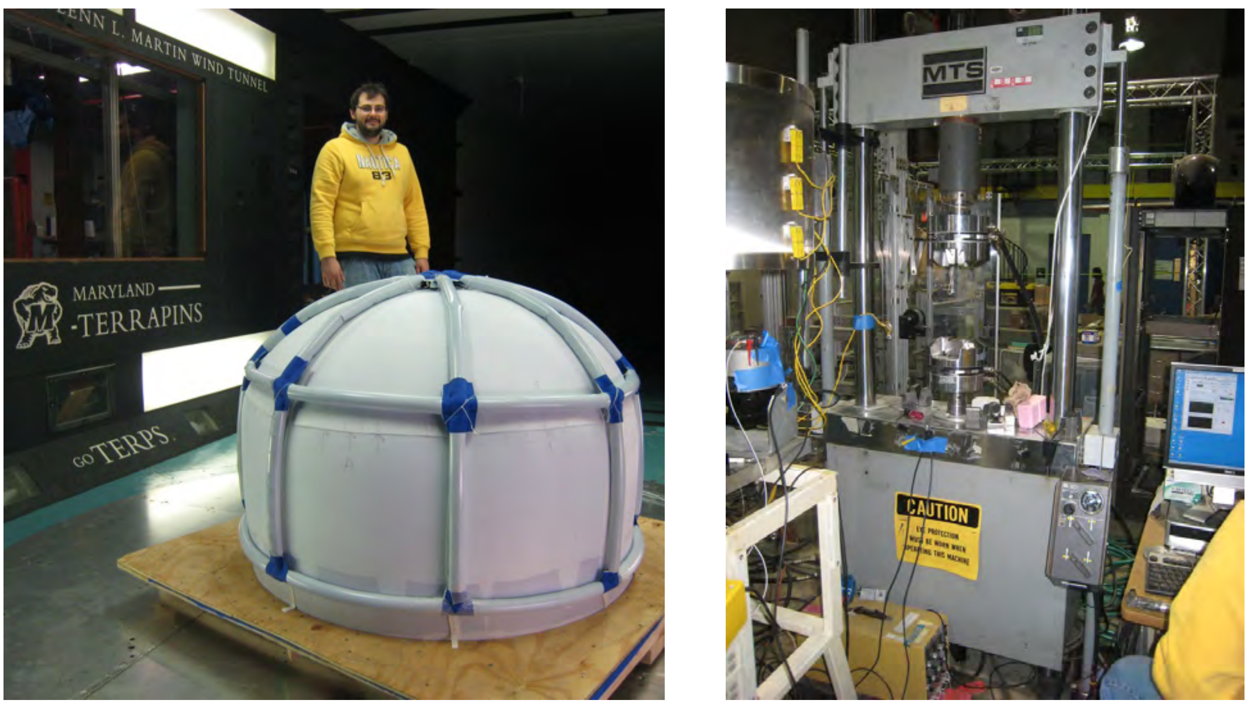

Figure 8: U. Maryland students building scale mockups (left), and testing material strengths (right)

C. Public Outreach

The teams were required to participate in public outreach, to give their program a boost and also to help improve the image of space research and NASA activities. Of exemplary note were the efforts by Oklahoma State University, who initiated a sub-competition for high-school and younger students, to design a space habitat, with OSU students as mentors. The Oklahoma State University outreach efforts have gained national attention, and students from all over the country came together in virtual teams to design habitats, such as the one shown in Figure 9, right, which already shows some sophisticated CAD modeling by the younger students. To support the outreach efforts, NASA engineers and experts participated in online lectures and chat rooms to interact with the enthusiastic younger students.

The X-Hab Challenge has inspired many articles in local and national media outlets, and the X-Hab 2011 Challenge was covered in video podcast produced by award winning The NASA Edge podcast team.

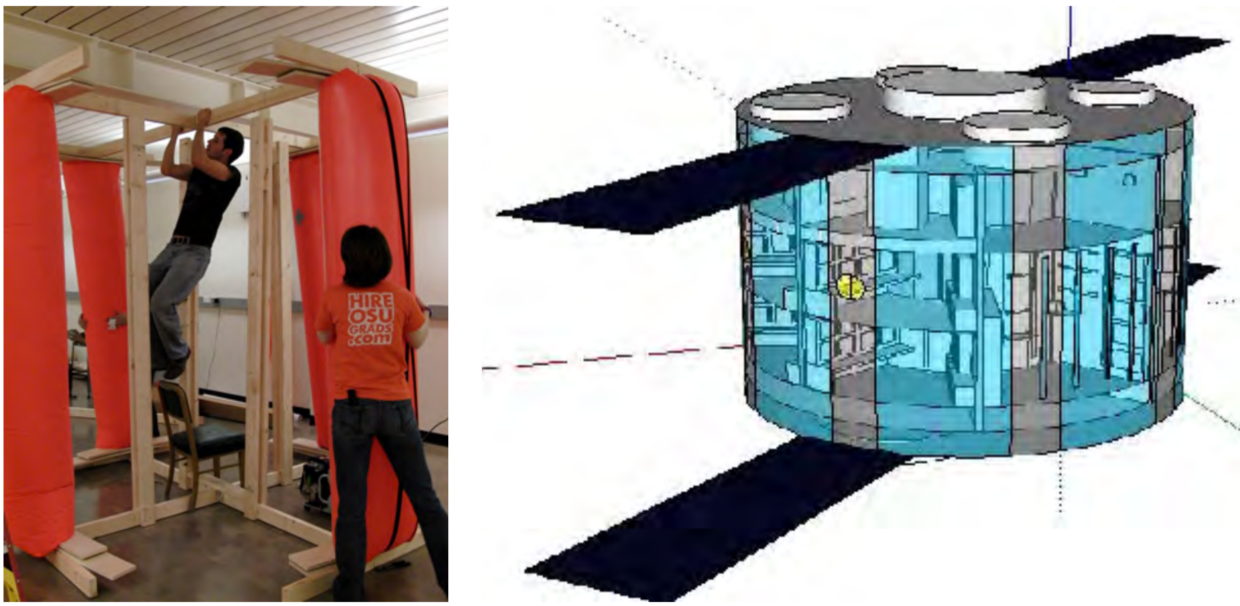

Figure 9: X-Hab 2011 Oklahoma State prototype testing (left), and high school outreach (right)

IV. Conclusion

In times where space spending is tight, and the public is losing the vision of what the advantages and benefits of space exploration potential could be, the X-Hab Challenge project establishes a tight, well-organized program that draws children from the youngest ages and sets them on a journey toward more STEM-based careers. A clear road is established as high school students get excited about the work the universities are doing, and look forward to join the same departments. The university teams are welcomed into the NASA mainstream work as peers, on the critical path for NASA missions in human spaceflight. Already we have seen students from the university teams come to our NASA centers as interns, and expect some of them to be hired on as career civil servants and contractors. The space program is their future, and now they own it.

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