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Integration Process for the Habitat Demonstration Unit

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The Habitat Demonstration Unit (HDU) is an experimental exploration habitat technology and architecture test platform designed for analog demonstration activities The HDU previously served as a test bed for testing technologies and sub-systems in a terrestrial surface environment in 2010 in the Pressurized Excursion Module (PEM) configuration Due to the amount of work involved to make the HDU project successful, the HDU project has required a team to integrate a variety of contributions from NASA centers and outside collaborators The size of the team and number of systems involved with the HDU makes integration a complicated process However, because the HDU shell manufacturing is complete, the team has a head start on FY11 integration activities and can focus on integrating upgrades to existing systems as well as integrating new additions To complete the development of the FY11 HDU from conception to rollout for operations in July 2011, a cohesive integration strategy has been developed to integrate the various systems of HDU and the payloads The highlighted HDU work for FY11 will focus on performing upgrades to the PEM configuration, adding the X-Hab as a second level, adding a new porch providing the astronauts a larger work area outside the HDU for EVA preparations, and adding a Hygiene module Together these upgrades result in a prototype configuration of the Deep Space Habitat (DSH), an element under evaluation by NASA's Human Exploration Framework Team (HEFT)

Scheduled activities include early fit-checks and the utilization of a Habitat avionics test bed prior to equipment installation into HDU A coordinated effort to utilize modeling and simulation systems has aided in design and integration concept development Modeling tools have been effective in hardware systems layout, cable routing, sub-system interface length estimation, and human factors analysis Decision processes on integration and use of all new subsystems will be defined early in the project to maximize the efficiency of both integration and field operations In addition a series of tailored design reviews are utilized to quickly define the systems and their integration into the DSH configuration These processes are necessary to ensure activities such as partially reversing integration of the X-Hab second story of the HDU and deploying and stowing the new work porch for transportation to the JSC Rock Yard and to the Arizona Black Point Lava Flow site are performed with minimal or no complications In addition, incremental test operations leading up to an integrated systems test allows for an orderly systems test program

For FY11 activities, the HDU DSH will act as a laboratory utilizing a new X-Hab inflatable second floor with crew habitation features In addition to the day to day operations involving maintenance of the HDU and exploring the surrounding terrain, testing and optimizing the use of

the new X-Hab, work porch, Hygiene Module, and other sub-system enhancements will be the focus of the FY11 test objectives The HDU team requires a successful integration strategy using a variety of tools and approaches to prepare the DSH for these test objectives In a challenging environment where the prototyping influences the system design as well as vice versa, results of the HDU DSH field tests will influence future designs of habitat systems

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Integration Process for the Habitat Demonstration Unit Deep Space Habitat

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I. Abstract

The Habitat Demonstration Unit (HDU) is an experimental exploration habitat technology and architecture test platform designed for analog demonstration activities. The HDU previously served as a test bed for testing technologies and sub-systems in a terrestrial surface environment in 2010 in the Pressurized Excursion Module (PEM) configuration. Due to the amount of work involved to make the HDU project successful, the HDU project has required a team to integrate a variety of contributions from NASA centers and outside collaborators. The size of the team and number of systems involved with the HDU makes integration a complicated process. However, because the HDU shell manufacturing is complete, the team began the Fiscal Year 2011 integration activities at full speed and can focus on integrating upgrades to existing systems as well as integrating new additions. To complete the development of the FY11 HDU from conception to rollout for operations in July 2011, a cohesive integration strategy has been developed to integrate the various systems of HDU and the payloads. The highlighted HDU work for FY11 will focus on performing upgrades to the PEM configuration, adding the eXploration Habitat, or X-Hab, as a second level, adding a new porch providing the astronauts a larger work area outside the HDU for EVA preparations, and adding a Hygiene module. Together these upgrades result in a prototype configuration of the Deep Space Habitat (DSH), an element under evaluation by NASA's Human Exploration Framework Team (HEFT).

Scheduled activities include early fit-checks and the utilization of a Habitat avionics test bed prior to equipment installation into HDU. A coordinated effort to utilize modeling and simulation systems has aided in design and integration concept development. Modeling tools have been effective in hardware systems layout, cable routing, sub-system interface length estimation, and human factors analysis. Decision processes on integration and use of all new subsystems will be defined early in the project to maximize the efficiency of both integration and field operations. In addition a series of tailored design reviews are utilized to quickly define the systems and their integration into the DSH configuration. These processes are necessary to ensure activities such as partially reversing integration of the X-Hab second story of the HDU and deploying and stowing the new work porch for transportation to the JSC Rock Yard and to the Arizona Black Point Lava Flow site are performed with minimal or no complications. In addition, incremental test operations leading up to an integrated systems test allows for an orderly systems test program.

For FY11 activities, the HDU DSH will act as a laboratory utilizing a new X-Hab inflatable loft with crew habitation features. In addition to evaluating the architecture for a Deep Space Habitat mission, day to day

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operations involving maintenance of the HDU and testing and optimizing the use of the new features of the X-Hab loft, work porch, Hygiene Module, and other sub-system enhancements will be the focus of the FY11 test objectives. The HDU team requires a successful integration strategy using a variety of tools and approaches to prepare the DSH for these test objectives. In a challenging environment where the prototyping influences the system design as well as vice versa, results of the HDU DSH field tests will influence future designs of habitat systems.

II. Background

A technique being utilized in NASA's exploration architecture analysis is analog testing in relevant environments such as desert locales. Running through potential "day in the life" scenarios at an outpost with prototype equipment allows designers insight into the utilization of the proposed systems and refines architecture and operations concepts. A series of Desert Research and Technology Studies (RaTS) have been held in locations such as Moses Lake, Washington and Black Point Lava Flow & SP Crater, Arizona, where the most recent tests in September 2010 were performed simulating a 14-21 day lunar mission. The NASA hardware demonstrated by Desert RATS 2010 included: Space Exploration Vehicles – a pair of rovers that astronauts lived in for 14 days at a time; Habitat Demonstration Unit/Pressurized Excursion Module – a simulated habitat where the rovers docked to allow the crew room to perform experiments or deal with medical issues; Tri-ATHLETEs, or All-Terrain Hex-Legged Extra-Terrestrial Explorer – two heavy-lift rover platforms that allowed transportation of large items; a Portable Communication Terminal Concept (PCT) to facilitate communication with mobile assets; Centaur 2 – a four-wheeled transportation option for NASA Robonaut 2; Portable Utility Pallets (PUPs) for short – mobile charging stations for equipment; and a suite of new geology sample collection tools, including a self-contained GeoLab glove box for conducting in-field analysis of various collected rock samples.

The 2011 session of Desert RaTS is planned again for Black Point Lava Flow where elements of architecture to visit a Near Earth Object (NEO) will be evaluated. For Desert RaTS 2011, two Space Exploration (SEV) Rovers will operate together to simulate Multi-Mission Space Exploration Vehicles (MMSEVs). The HDU will be configured as a full-scale habitat prototype, Deep Space Hab (DSH). The Habitat Demonstration Unit Deep Space Habitat (HDU-DSH) will be configured with an inflatable loft, from the X-Hab Academic Innovation Challenge, located as a second story loft on HDU, an Airlock/Dust Mitigation Module (A/DMM) that uses the HDU Airlock relocated 180 degrees from its 2010 location on the PEM, and a Microhab configured as the HDU Hygiene Module (HHM) for a series of test configurations during an analog mission. The DSH configuration represented by the 2011 HDU Project is depicted in Fig. 1. This DSH concept version shows a second level inflatable volume for additional habitation and stowage functions. The HDU version of the DSH will be applicable to deep space Near Earth Asteroid (NEA) missions or planetary surface exploration missions, the latter due to the 1-G orientation for Earth based tests and the evolution of the lunar gravity PEM configuration.

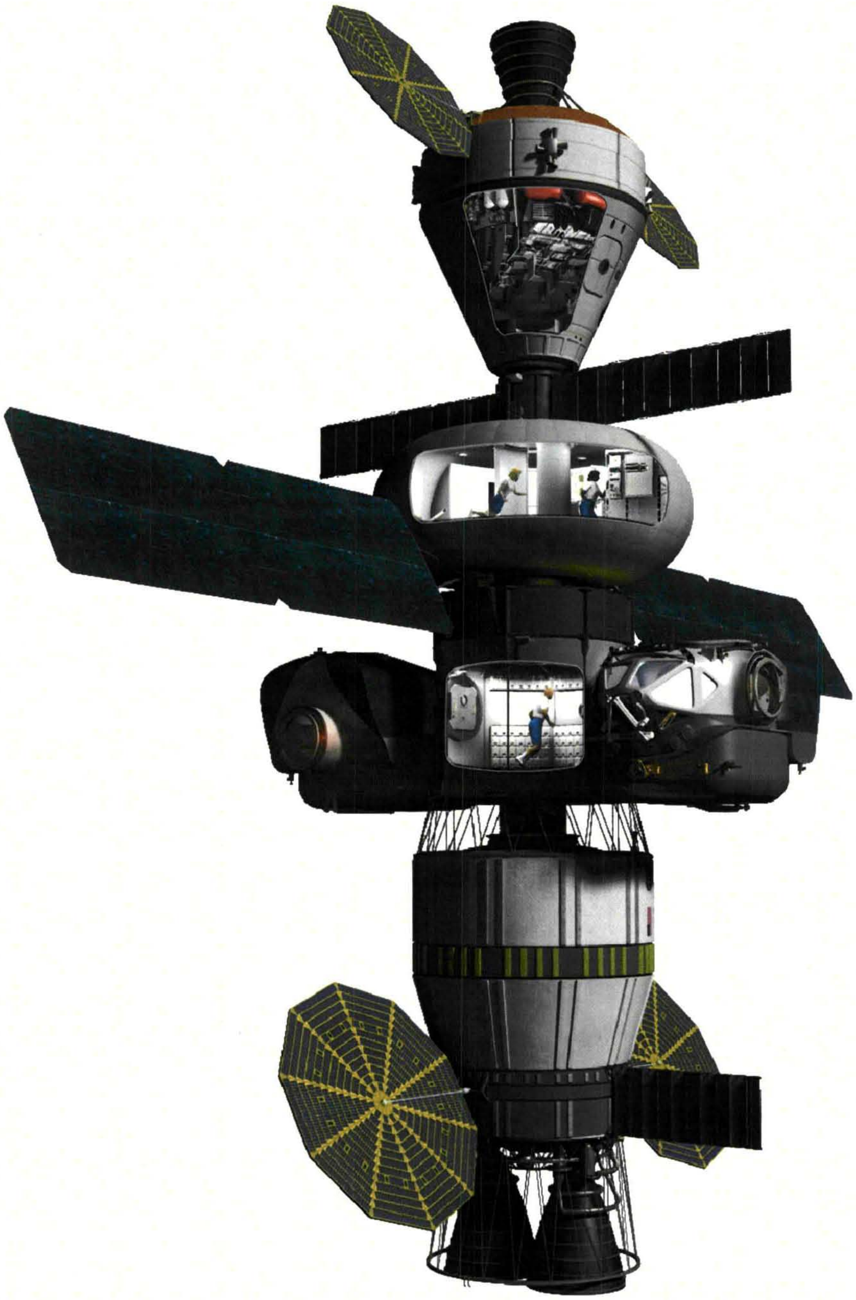

Figure 1. Example of a Near Earth Asteroid (NEA) architecture analyzed in the Desert RaTS 2011 campaign. The Deep Space Habitat with Inflatable loft is near the center with Multi-Mission Space Exploration Vehicles docked on either side.

III. Introduction

The human exploration design reference missions (DRMs) defined by NASA's Human Spaceflight (HSF) Architecture Team (HAT) have identified a deep space habitat as a critical element within the capability driven framework strategy. Simulating mission scenarios with rapid prototype hardware and systems enables engineers, architects, and scientists insight into the utilization and characterization of the proposed systems. The analog simulation testing refines mission architectures and operations concepts during the early definition phase. The Habitat Demonstration Unit (HDU) Project is a unique project from a multi-center team of NASA architects, scientists, and engineers working together to develop sustainable living quarters, workspaces, and laboratories for next-generation space missions. The HDU Project utilized a variety of tools in an integration strategy tailored to enable the rapid prototyping approach of the NASA's analog test environment to be able to successfully field and demonstrate an operations habitat test bed for technology demonstration and architecture validation.

IV. Integration Strategy

The HDU project built upon the infrastructure developed during the initial campaign[1] of 2010 and evolved to the DSH configuration by continuing to integrate a variety of contributions and upgrades from NASA centers and outside collaborators. Though the HDU shell manufacturing was complete, giving the team a head start on FY11 integration activities, upgrades to the existing systems and the new additions posed a challenge in integrating these various efforts into a cohesive architecture. The integration work was primarily performed at Building 220 at the Johnson Space Center (JSC). The HDU-DSH has performed upgrades to the PEM configuration, added the X-Hab loft as a second level, utilized the existing Airlock with additional dust mitigation to form the A/DMM, and added a Health and Hygiene Module. The X-Hab loft has been integrated directly on top of the HDU and the A/DMM is integrated directly to the HDU at a location compared to the 2010 configuration. A partial reversal of this integration will need to be performed to allow transportation of the HDU-DSH to the Arizona Black Point Lava Flow site for field tests. The HDU-DSH is a first generation of a notional space habitat reflecting both technology demonstrations and an operational architecture. The integration activities combining these two elements require flexible planning and an understanding of the objective of deploying an operational test-bed in a cost-effective manner. Results and analysis of the HDU-DSH field tests will influence future designs of Exploration habitats.

A. Integration Process

The integration strategy involved upgrading the existing HDU core systems into the existing fully assembled HDU shell. The layout of HDU-DSH Systems, is seen in Figure 2 – HDU-DSH Layout.

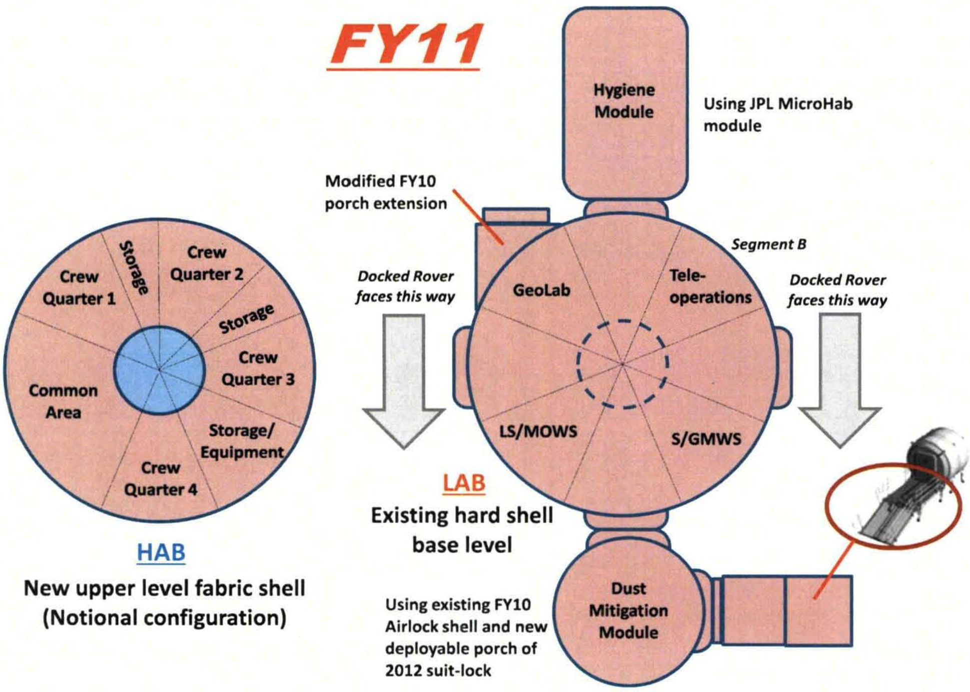

Figure 2. HDU-DSH Outfitting Top View

There are four quadrants in the lower level of the DSH in the HDU hard shell lower level. The four quadrants are the General Maintenance Work Station (GMWS), the Medical Operations Work Station (MOWS), the Tele-Robotics Work Station (TRWS), and the Geology Laboratory (Geo-Lab) area. Three of the four quadrants are basically the same as the 2010 configuration of the HDU hard shell. One lesson learned from the 2010 campaign that dedicating two sections to maintenance, with one for Extra-Vehicular Activity (EVA) Suits and the other for general maintenance, was excessive, so those two work stations were combined to make room for the new TRWS that enables human-robotic interaction with the MMSEV and its crew.

The same airlock structure that was utilized in 2010 was evolved to the Airlock/Dust Mitigation Module (A/DMM) by adding additional features and instrumentation and will be utilized for dust mitigation as the operational entrance to the DSH configuration. One other new and notable feature of the HDU DSH 2011 configuration is the EVA work platform attached to the A/DMM.

A Jet Propulsion Laboratory (JPL) asset used in earlier Desert RaTS campaigns, known as the Microhab, has been internally reconfigured as the Health and Hygiene Module, and it will re-utilize the interface panels developed in 2010 for the original airlock since it will be integrated in ~~he~~the position utilized by the HDU airlock in 2010.

The HDU integration process followed the basic process below shown in the high level overview of the DSH integration schedule for fiscal year 2011 is depicted in Figure 3.

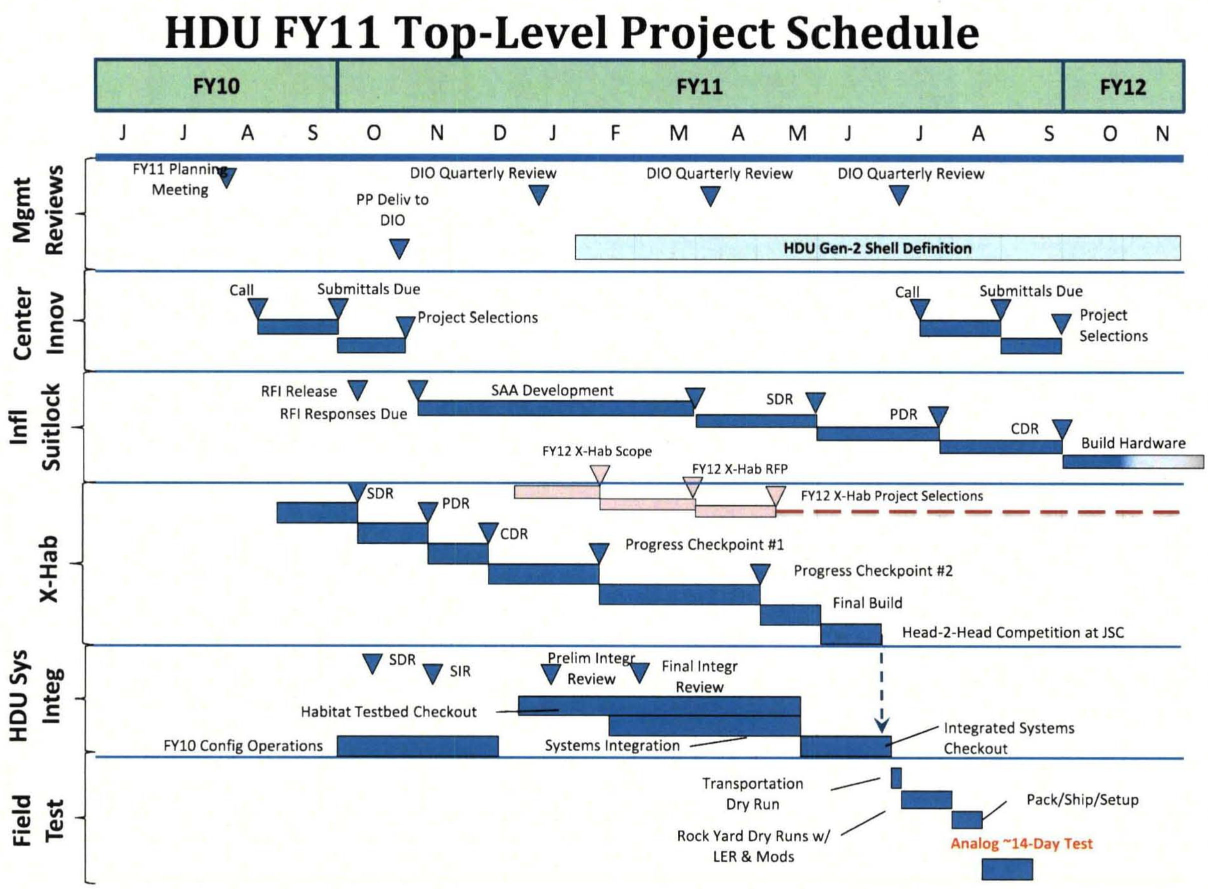

Figure 3. HDU Top Level Project Schedule for FY11

During the execution of the integration plan, the HDU team utilized a system engineering process tailored to the rapid prototyping nature of an analog test project resulting in the series of reviews shown below.

October – System Definition Review (SDR)

This review defined the basic concepts for the systems that would constitute the HDU Deep Space Habitat. This included the systems, the workstations, and the technology demonstrations.

November – System Implementation Review (SIR)

Each subsystem identified the hardware being designed or selected and defined a preliminary plan for integration into or on the HDU-DSH

January – Preliminary Integration Review (PIR)

This review is close in function to a Preliminary Design Review (PDR). At this review, each subsystem began to finalize their system designs and delivered their contribution to the DSH Master Equipment Lists (MEL) and the integrated electrical schematic.

February – CAD Integration Review (CIR)

During this review, the team discussed how the hardware systems would be populated within the HDU DSH. By importing the model into a simulation tool, the team could manipulate and move elements to show their operations and use operability as a design consideration.

March – Final Integration Review (FIR)

This review is close in function to a Critical Design Review (CDR) and included a final general system overview, hardware deliverables, and test objectives for each subsystem.

May – Test Configuration Review (TCR)

The TCR defined the final configuration of the HDU PEM that would be tested during field test operations. This review gave a brief review of previously covered areas, identified any changes that occurred during the integration process, and provided a brief description of the materials to be used to develop training and operations material

June – Integrated Systems Test Readiness Review (TRR)

This is the formal review for all systems, facilities, procedures, protocols, and personnel involved to validate readiness to begin test operations for integrated systems test to verify system performance prior to analog test operations

July – Field Test Readiness Review (TRR)

Formal review for all systems, facilities, procedures, protocols, and personnel involved to validate readiness to begin analog mission test operations

During this review process, the HDU project team took advantage of collaboration tools such as an integrated schedule, integrated system schematics, a master equipment list, a powered equipment list as well as the 3-D integrated CAD model, to be discussed later, using online data repositories and a project wiki to share data. Partial deintegration work of the primary elements of the DSH configuration will be performed to allow for transportation to the Arizona Desert RaTS location and then back to JSC. This involves disconnecting the A/DMM and the EVA platform from the hard shell of the HDU. The X-Hab will be collapsed as transported on top of the HDU. When the HDU DSH completes its Desert RaTS 2011 campaign, it will be transported back to JSC for long-duration test opportunities in the fall of 2011 and for future evolution of the DSH concept in 2012.

B. New Elements to DSH Configuration

EVA Work Platform

The EVA Work platform is a prototype deployable ramp for EVA that can be collapsed for transportation and deployed for operational use. In the analog test environment for HDU DSH, it provides access between the A/DMM and the outside environment. The HDU project intends in the future to develop an inflatable suitlock[2] which is planned to be developed independently with industry partners. The EVA work platform was designed to interface with the future inflatable suitlock, but the project team also designed it to be compatible with the existing HDU A/DMM. This element was designed and built during FY11 by the NASA Prototype Shop at the Kennedy Space Center (KSC) working in conjunction with teams at JSC and JPL, and it is discussed in more detail in the CAD integration portion of this paper.

Health and Hygiene Module

One of two existing Microhab modules from JPL has been reconfigured into the Health and Hygiene Module (HHM) to support long-duration habitation studies in the HDU. The HHM provides areas to perform hygiene functions as well as additional stowage locations. The module will be divided into 3 areas: a waste collection area (camper toilet), a wet bath and general hygiene area, and a general stowage area. This asset was designed and built during 2011 by teams at JSC and JPL and contributes to giving the HDU team an overnight stay capability for long duration studies.

A general layout of the Hygiene Module areas can be seen in Figure 4, while Figure 5 depicts scenes from the outfitting of the Microhab to transform it into the HHM.

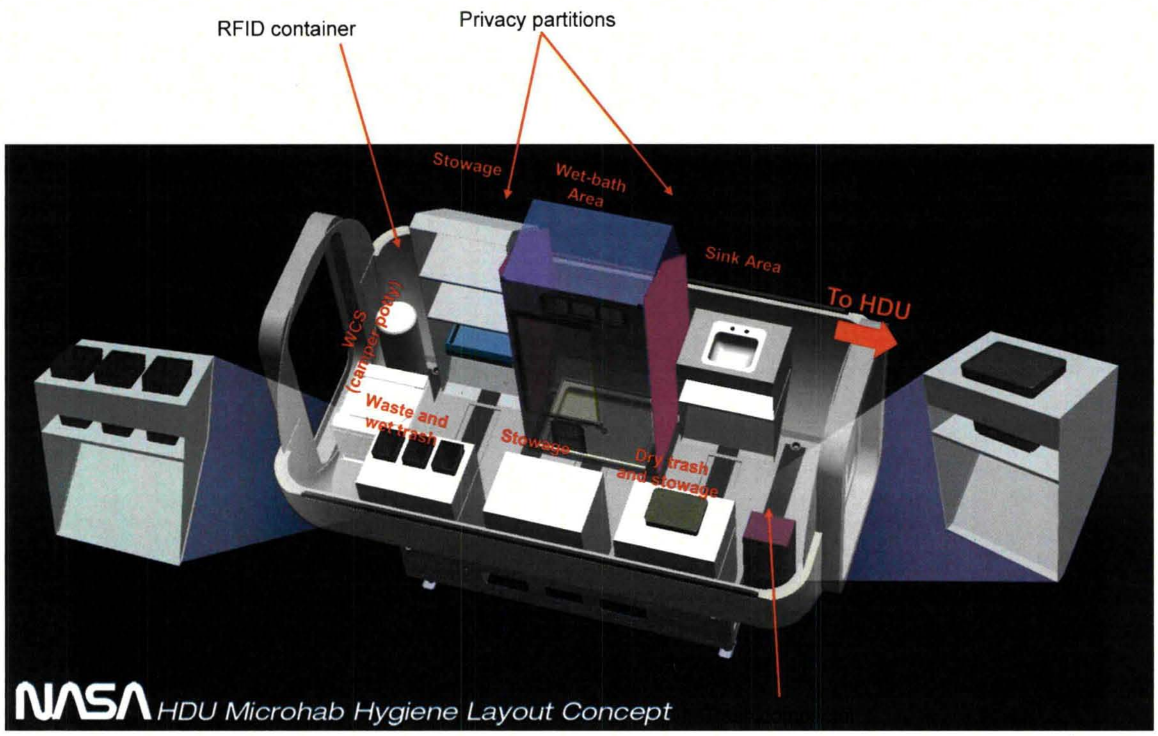

Figure 4. Hygiene Module Concept Layout

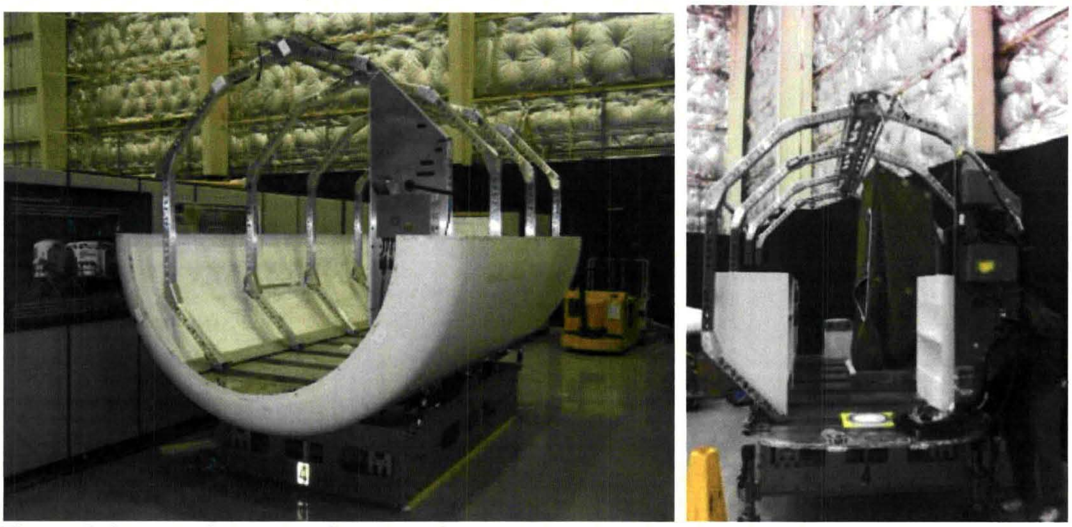

Figure 5. Scenes of the reconfiguring of the Microhab into the Health and Hygiene Module

X-Hab Inflatable Loft

The HDU project ran a competition known as the X-Hab Academic Innovation Challenge to supply an inflatable loft with habitation functions for the HDU DSH configuration in FY11. For additional information on the X-Hab challenge, reference http://www.spacegrant.org/xhab/. In August 2010, initial proposals were received from university teams, and three winners of that initial competition were chosen to compete during the fall 2010 and spring 2011 academic year. Those winning teams were led by the University of Maryland, the University of Wisconsin-Madison, and Oklahoma State University. Each of these three teams followed the schedule outlined below and delivered their version of a loft to the HDU team in Houston at JSC. These reviews were held separate from the HDU system reviews described earlier to dedicate an appropriate level of effort and feedback for each of the student teams, but the discussions and agreements made in these reviews were enveloped into the larger HDU system reviews.

Fall Semester 2010: Design
- Sept 2010: Concept and System Definition Review
- Oct 2010: Preliminary Design Review
- Dec 2010 - Jan 2011: Critical Design Review
- Feb 2011: Progress Checkpoint Review #1
- April 2011: Progress Checkpoint Review #2

Spring Semester 2011: Manufacture and Assembly
June 2011: Head-2-Head Competition @ JSC
June 2011: Select Winner:
July-August 2011: Integration with HDU
August-September 2011: Field Testing

Each of the lofts was checked out offline, integrated on top of the HDU, outfitted, evaluated, and then removed within a one week window. The University of Wisconsin team, pictured in Figure 7, was selected as the winning team for the 2011 Academic Innovation Challenge. The University of Wisconsin loft, known as the Badger eXploration Loft (BXL) was reinstalled onto the HDU after the competition and has become a piece of the DSH configuration for Integrated Systems Testing, Dry Run Test Support, the Desert RaTS 2011 campaign, and future HDU DSH test operations.

Figure 7. The 2011 X-Hab Academic Innovation Challenge Winners and provider of the X-Hab inflatable loft - University of Wisconsin

C. Utilization of CAD Modeling and Simulation

The use of three dimensional (3-D) Computer Aided Design (CAD) modeling has provided the ability for engineers to not only create individual 3-D models for all unique components, but it has allowed engineers to use those models to fit check components, perform material and load analysis, and finally put together final assemblies. The utilization of 3-D modeling during the each of the first two years of deployment of the HDU for subsystem development and integration enabled the team to identify and fix problems that would have affected schedule, thus delaying planned test activities. The team made efforts to identify where all the individual subsystems would be installed during the CAD design, but there were still lessons to be learned from the physical integration that informed the overall system design. The CAD model developed for HDU DSH was of moderate fidelity to plan integration activities and did not include the cabling, for example, to reduce the level of effort in a rapid prototyping effort, allowing for some field engineering decisions by an experienced integration team. Thus the HDU team used CAD modeling at a level of effort deemed cost effective for a rapid prototyping effort rather than develop a more detailed model that might be utilized for a flight hardware project.

Two areas will be discussed that demonstrate the value of the use of modeling and simulation tools during the HDU DSH development effort. The first area was the integration of multiple new systems around the upper hatch of the HDU to both provide translation between the lower level and the new loft and to better take advantage of under-utilized space in the ceiling of the HDU lower level. As seen in Figure 8, the HDU team designed a lift platform to translate personnel and equipment between the two levels, but in addition to the support structure for the lift platform, the design team also incorporated an atrium surrounding the upper hatch to incorporate the food production aspect of a Deep Space Habitat. Surrounding the atrium was a material handling system with a trolley hoist mounted between inner and outer rails and overhead stowage compartments. And interfacing with the material handling system were the Solid State Lighting Modules that had to be relocated from their original mounting locations on the ribs that were now blocked by the atrium and material handling system. And these new elements had to be compatible with the existing work stations, sensors, and thermal ducting in the area as well as the structural loading limits of the HDU ribs and shell. To complicate matters, the lift platform was designed by JSC, the material handling system was designed by a team at the University of Michigan on a grant from JPL, and the atrium and the SSLMs were designed by personnel at the Kennedy Space Center (KSC). The forum of the integrated 3-D CAD model allowed all these teams to work together fairly rapidly during the planned review processes and minimize problems during the installation process.

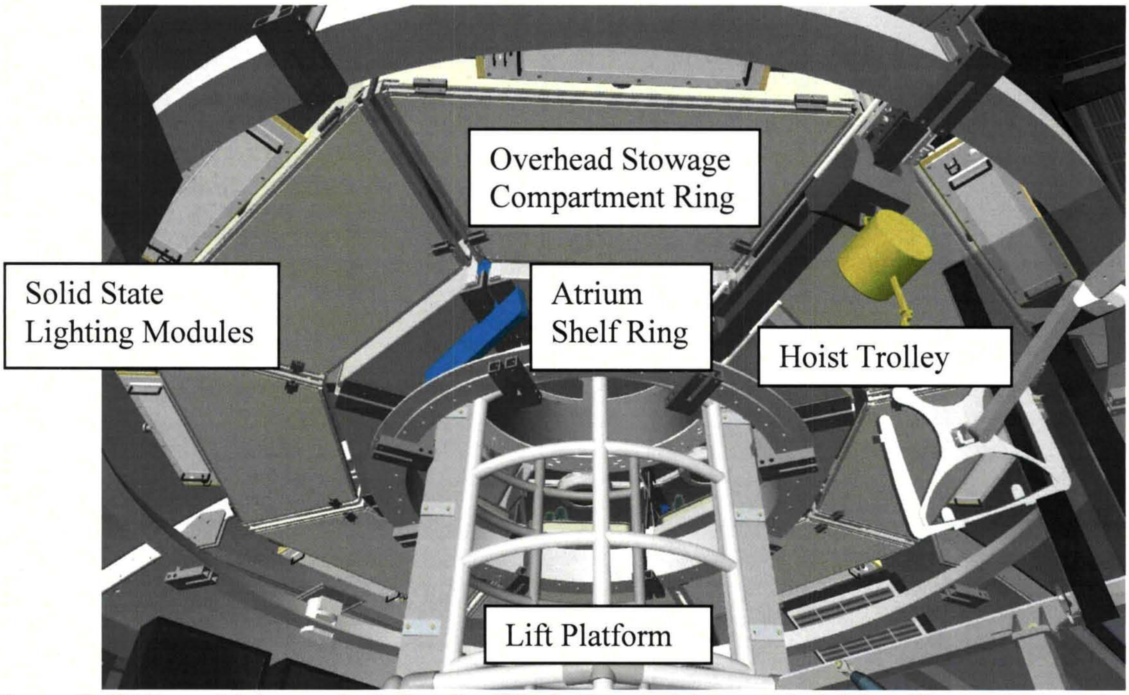

Figure 8. CAD model image depicting the lift platform, atrium, material handling system, and solid state lighting modules all integrated around the upper hatch of the HDU DSH.

The second area to discuss that yields insight into the value and application of 3-D CAD modeling, as well as the tailored review process of the rapid prototyping approach of the HDU project, is the new Extra Vehicular Activity (EVA) Work Porch. During the Desert RaTS 2010 activities, the HDU configuration included a very steep ramp with minimal working area that astronauts could use when entering or exiting the airlock. Originally for the 2011 DSH configuration, the team was going to include a new inflatable suitlock and an EVA Work Porch that would be easily deployed and stowed. Due to budget limitations, the inflatable suitlock was not developed, so this new EVA porch had to be adapted to work with the existing Airlock/Dust Mitigation Module (A/DMM). The EVA Porch was to deploy and stow to provide the crew with a staging/work area outside the airlock before walking down the ramp to the surface. This collapsible work porch concept is a prototype of an element for a surface exploration architecture taking advantage of the ability to collapse the porch as needed for launch packaging or for convenience in transportation between areas on the Lunar or Martian surface. Of course, for the HDU team, the ability to stow the porch is used during transportation on a truck to the analog mission test site.

The HDU team provided basic requirements, which consisted of employing weight-relief measures to enable stowing and deploying manually by two people without exceeding human factors limits, having lifting lugs to permit lifting of the porch assembly by crane, employing suitable gratings on the main deck and ramp to permit sand, dirt, and dust to fall freely to the ground beneath, being constructed to the dimensions of 16 ft L x 6.25 ft W x airlock door height, and being able to withstand a support load of 100 lb/ft^2. After some initial analysis of the first 3-D model, the design team determined that the overall weight of the porch would decrease dramatically if the support load was decreased by 50% to 50 lb/ft^2, which was still strong enough to support the expected activities that would take place on the porch. This proposed change was analyzed, and once concurrence was received, the design team moved forward.

The first concept of the porch met all the basic design requirements but left plenty of room for improvement. To deploy the ramp, the base support structure would be deployed first. Once locked into position, an electronic hoist would proceed to lower the assembly until in fully deployed position. After deployment, the handrails would be lifted and locked into place and the flip down platform at the bottom of the ramp would be deployed completing deployment. The pictures of Figure 9 display from left to right the porch stowed, partially deployed, and fully deployed respectively.

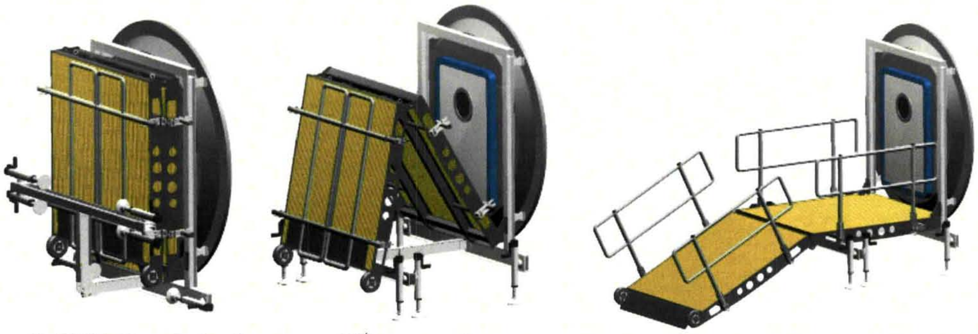

Figure 9. EVA Porch deployment (1st concept)

After presenting the first concept to the team during the Preliminary Integration review, valuable feedback was received, and some questions arose regarding the design. The first area of interest was flip down support structure. The T-shaped frame, including four jacks, would weigh a significant amount. Human factors issues arose regarding whether the weight would pose issues when two people are manually lowering the frame down into position. If for some reason the frame slipped during the fold down operation, the weight of the frame impacting or falling against someone could cause bodily harm. The next area of interest was the deck and ramp deployment. Figure 9 also shows minimal to no support for deployment other than what the hoist would provide. In addition, the angle at which the wheels on the ramp would contact the surface brought up some concerns that they may dig instead of roll on the dirt.

The design team took all the review comments into consideration and made the several changes to resolve the concerns. To minimize weight of the entire structure, the design team chose aluminum for the structure and a fiberglass grating for the deck and ramp. However, even though made of aluminum, the porch still weighed over a thousand pounds. To ensure that any person/s lowering or raising the T-shaped support frame could do so in a safe manor, the team added pneumatic struts to the design that would handle the majority of the load. So, an operation that may have originally required two very strong people to raise and lower the frame now only required a single person applying minimal force. The location of the new struts can be seen in Figure 10 below.

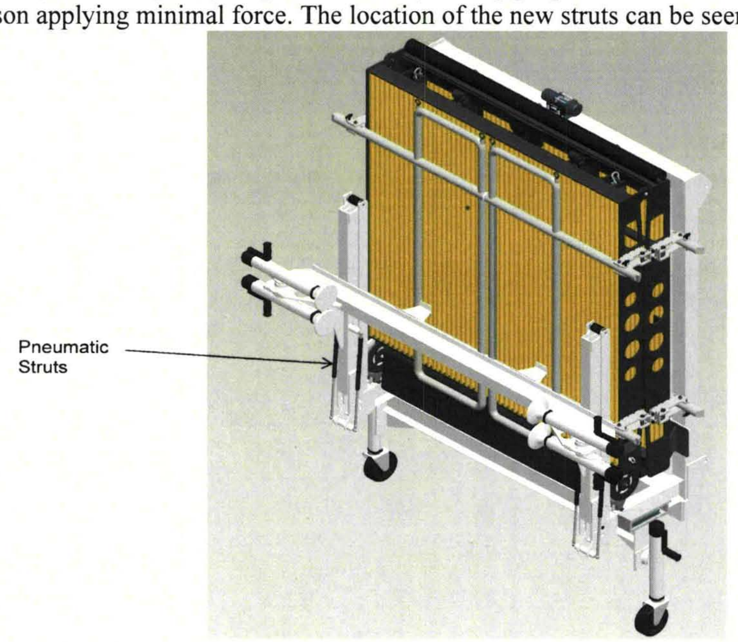

Figure 10. Pneumatic strut location

In addition to adding the struts, the design team modified the flip down T-shaped support structure and also added flip down rails. By doing so, the wheels of located on the ramp of the structure would be in contact with the structure during deployment and stowage, thus decreasing the stresses on the frame that attaches to the airlock. In addition, by adding flip down ramps, the angle at which the wheels will contact the dirt surface is shallower and decreases the chances that the wheels would dig into the dirt. Figure 11 below displays the T-frame changes and new flip down rails.

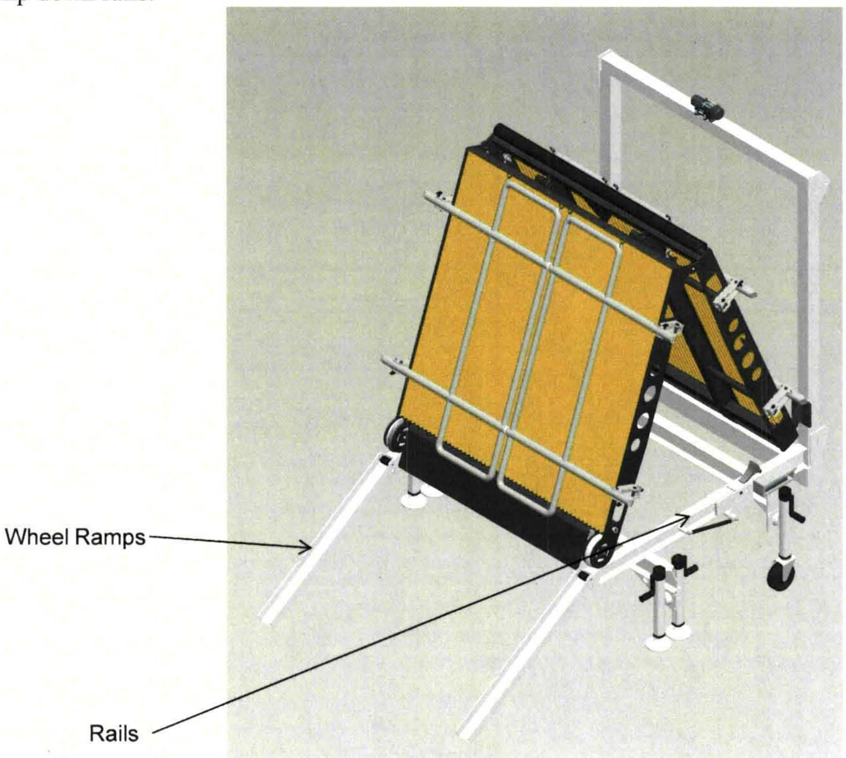

Figure 11. Rail and Wheel Ramp additions

At this point in the design process, the team's 3-D model was a very good representation of what the EVA Porch would look like and what it would provide. As with each rendition, the updated design must be reviewed. With the EVA Porch model now updated, the updates and models were presented to the team during the CAD Integration review. This review allows the team to review an overall CAD model of the HDU DSH and determine what and if any changes are necessary. Even though collaboration takes place every week during weekly tag up meetings, gaining a clear understanding of how all the subsystems come together can be difficult, and that's why the CAD integration review is so important. At this point, changes to the EVA Porch were minimal, but improved the overall design.

After analyzing the load on the T-shaped flip down structure, the design team determined that only one flat footed jack stand was necessary instead of two. This change still met design requirements and cut the overall weight. In addition, the design team moved the hoist to the bottom of the upper support beam to decrease the angle at which the hoist would have to pull the main deck to stow the porch. By doing so, the stress the beam would see during deployment and integration was decreased, and the team could now mount the already existing airlock light on top of the upper support beam, where it would otherwise be blocked after integration of the porch. Also, the previous CAD models showed the fiberglass grating going in parallel with the handrails. This configuration concerned the team because walking in the direction of the grating does not provide the best grip and could potentially increase the potential of slipping. To resolve the issue, the design team rotated the grating 90 degrees. Figure 12 below depicts the changes and shows how the EVA Porch was represented during the CAD Integration Review.

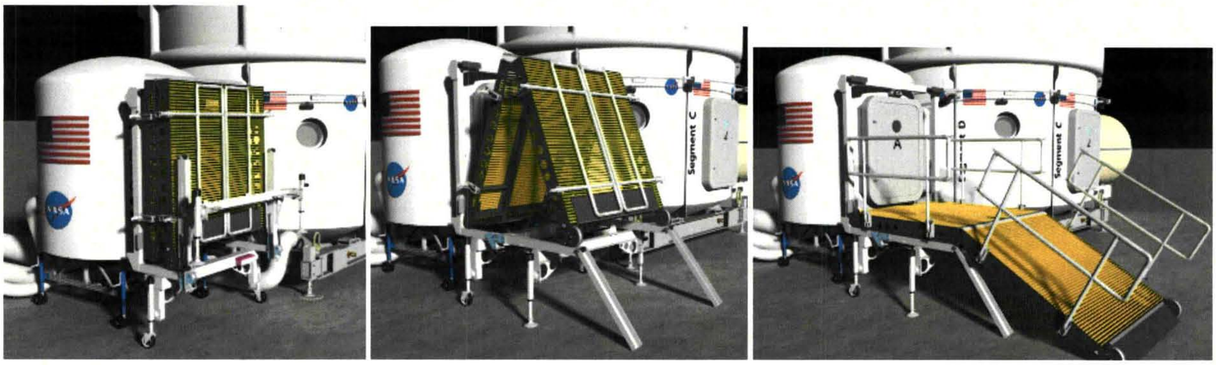

Figure 12. EVA Porch CAD Review Deployment Sequence

After the CAD Integration Review, the team had finally reached a stage when supplies and materials could begin to be ordered. Shortly before the Final Integration Review, the team made a few final changes. Most notably of the changes were to the flip down ramps and the flip down platform at the bottom of the ramp. First, after analyzing the angle at which the wheels would enter the surface, even with the use of the added flip down ramps, the team decided to add secondary ramps that would begin to deploy the wheels and ramp away from the main structure, thus allowing the wheels to contact the surface at a very shallow angle, almost decreasing the chances of the wheels digging to zero. For purposes similar to the flip down ramps, the team increased the width of the flip down platform to decrease the angle at which a person would enter the surface. A few other notable changes were designing groves into the handrails that would hold LED lights to illuminate the ramp during nighttime activities, and designing an angled aluminum piece that would permanently be installed to fill the gap between the main deck and ramp of the porch. Once the Final Integration Review was complete and the design team was given the go ahead, fabrication began. Within a couple of months, the team delivered and integrated the EVA Porch. Figure 13 shows the finished EVA Porch integrated with the Airlock.

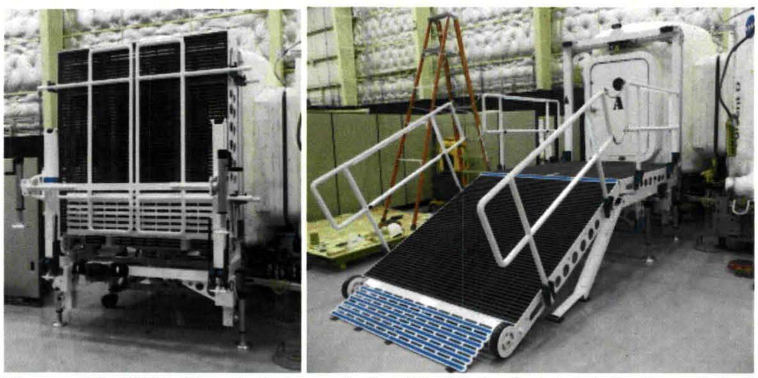

Figure 13. EVA Porch Integrated with Airlock (right deployed, left stowed)

D. Test Operations

Because of the complexity of deploying an operational prototype for the first time, a series of tailored test operations for the HDU-DSH were designed to prepare the team, the hardware and software, and procedures for the eventual Desert RaTS activities. With the large number of systems being integrated and tested for the HDU-DSH it was important to have a common document that had descriptions, testing procedures, and operational procedures for each system. In an attempt to minimize documentation development, an HDU-DSH Operations Manual was created. The Operations Manual consisted of procedures required for each subsystem, technology demonstration, and operational work stations for both the setups required by the HDU project and for the operations to be conducted during the formal analog mission test by astronaut crew members. This Operations Manual was also used for the training and certification of HDU DSH operators.

The first phase of the testing involved the Habitat Test-bed (HaT) where key subsystems and simulation tools of the HDU DSH were laid out on a bench top test bed. This HaT capability allowed the team to perform tests on each DSH system prior to integration in the HDU shell. That allowed the HDU team to test and debug systems prior to integration in the HDU DSH to minimize troubleshooting on post installation test operations. These tests were done throughout the integration phase from March 2011 through July 2011 as hardware was delivered to be integrated into the HDU DSH. The next phase included the individual system tests that verified each independent system was performing as expected following integration activities, again between March and July 2011. The Integrated System Test, mentioned earlier, was a test to evaluate and measure performance of systems operating together for the first time. This test occurred in late July 2011. The next phase in August 2011 was a dry run test performed at the Johnson Space Center Rock Yard where Lunar and Martian surface simulations exist.

Unlike the 2010 campaign, during the 2011 campaign the HDU project did not transport the HDU DSH system to the Rock Yard at JSC for the dry run tests. In 2010, the team felt it was imperative to get a dry run on the effort for transportation to Arizona, and packing everything for shipment and transporting it to another area on JSC provided this insight. After the transportation effort in 2010 the team felt there was enough insight into the transportation process to facilitate the cost savings of not transporting to the Rock Yard for dry runs. Instead, the HDU DSH system stayed in Building 220 and supported the SEV Rovers at the Rock Yard remotely in an analogous way that the DSH would support, at a distance, MMSEV crews deployed close to a NEA. These tests also engaged the Space Exploration Vehicle rovers, and all procedures run at the Desert RATS 2010 campaign were first executed at the Rock Yard.

Finally, the culmination of all the test and integration activities was the utilization of the HDU DSH in Arizona to support the Desert RaTS 2011 field test operations from late August through mid-September of 2011. At each of the phases of testing, the same Operations Manual was utilized and updated, again, to minimize required documentation development.

E. HDU-DSH Evolution

In 2012, the HDU Project will report to the Advanced Exploration Systems (AES) program of NASA's Human Exploration Operations Mission Directorate (HEOMD). The HDU DSH will continue to mature and test new technologies and improved subsystems to increase understanding of techniques and technologies required for long duration space habitation. However, with the additions of the Health and Hygiene Module and the X-Hab inflatable loft to the HDU DSH configuration, the HDU project does not anticipate the development of major new infrastructure projects in upcoming campaigns and will instead be able to focus on a variety of improvements and technology infusion. To facilitate that new focus, the HDU Project team will change the paradigm of a year-long integration process leading up to one annual analog mission test to one of smaller integration windows and two annual test opportunities.

Proposed schedule for review and integration process:

- 8/1/11 - Release Announcement of Opportunity (AO)
- 8/31/11 – AO responses due
- 10/11 – HDU-DSH System Definition Review - define the basic concepts for the systems that would constitute the HDU Deep Space Habitat. This included the systems, the workstations, and the technology demonstrations. Include items for consideration in this window and the next window.
- 11/11 – HDU-DSH System Implementation Review - Each subsystem identifies the hardware being designed or selected and defines a preliminary plan for integration into or on the HDU-DSH. Finalize decisions of elements to be implemented in this window and those to be deferred to next window.
- Early 1/12 – HDU-DSH Integration Review - Each subsystem finalizes their system design and delivers their contribution to the Master Equipment Lists (MEL), the integrated electrical schematic, and integrated CAD model. Each subsystem finalizes the plan for integration into or on the HDU-DSH.
- 1/12-2/12 – Integration activities
- 2/12 – HDU-DSH Test Readiness Review
- 3/12 – Integrated Systems Test opportunity

For reference, this is the proposed schedule for the next Announcement of Opportunity

- 2/1/12 - Release Announcement of Opportunity (AO)
- 2/28/12 – AO responses due

- 4/12 – HDU-DSH System Definition Review - define the basic concepts for the systems that would constitute the HDU Deep Space Habitat. This included the systems, the workstations, and the technology demonstrations. Include items for consideration in this window and the next window.
- 5/12 – HDU-DSH System Implementation Review - Each subsystem identifies the hardware being designed or selected and defines a preliminary plan for integration into or on the HDU-DSH. Finalize decisions of elements to be implemented in this window and those to be deferred to next window.
- Early 6/12 – HDU-DSH Integration Review - Each subsystem finalizes their system design and delivers their contribution to the Master Equipment Lists (MEL), the integrated electrical schematic, and integrated CAD model. Each subsystem finalizes the plan for integration into or on the HDU-DSH.
- 6/12-7/12 – Integration activities
- 8/12 – HDU-DSH Test Readiness Review
- 9/12 – Mission Operations Test opportunity

Figure 14 shows the notional top level schedule for one fiscal year of the HDU-DSH system integration cycle. As an example, note that the "Collaboration" lane shows a development cycle that meets up with the HDU Systems integration cycle in the second window of the year, but it could line up in the first window of the year or even in the first window of the following fiscal year. The HDU-DSH team would urge potential collaborators to respond as soon as possible to begin collaboration even if the integration timeframe may be two or three cycles in the future.

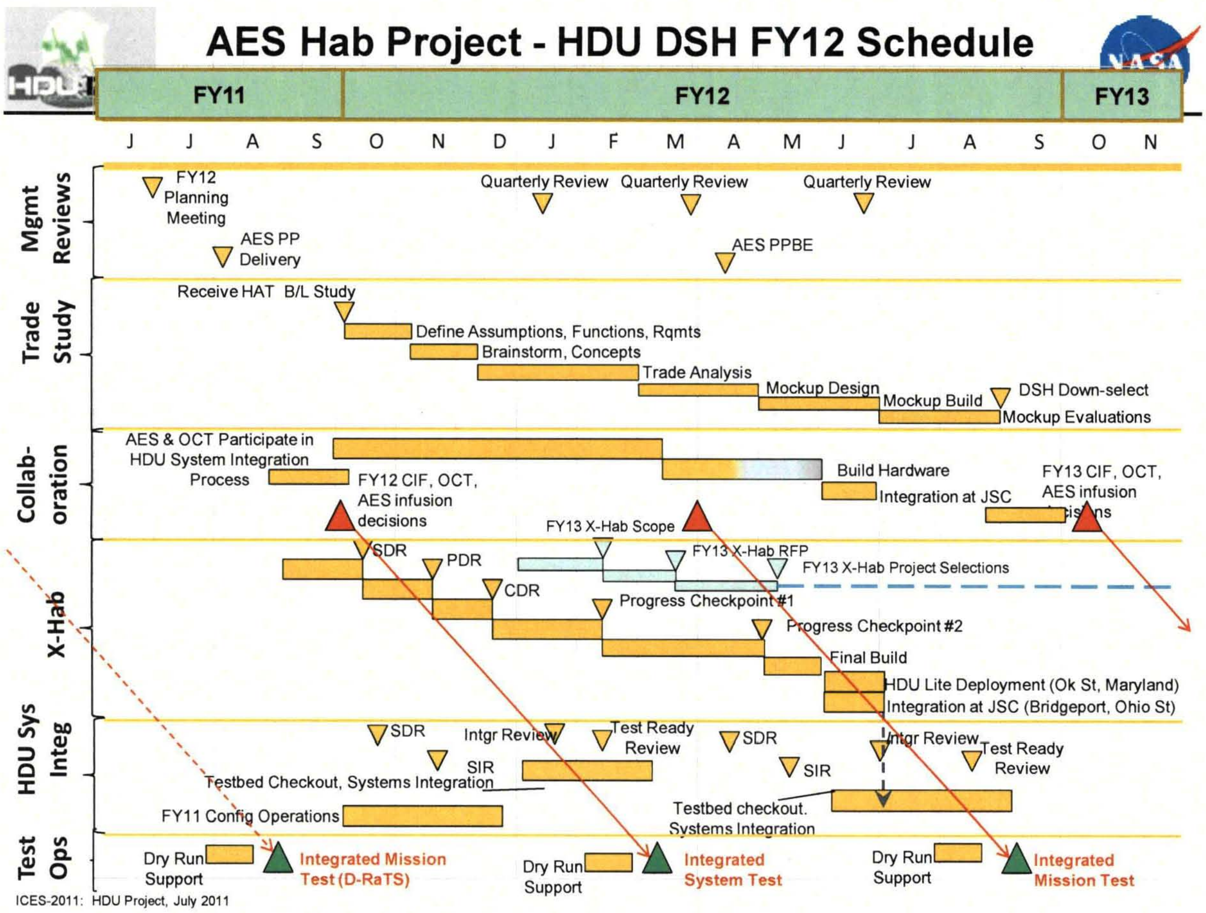

Figure 14. The planned schedule for FY12 reflecting the new paradigm of the twice-yearly test campaign approach

V. Conclusion

The HDU project has matured a rapid prototyping approach using tailored review and test programs in the past two years that enabled the successful deployment of the first generation of a Deep Space Habitat in 2011 as depicted in Figure 15. Adding three significant new elements to the HDU configuration and updating systems to convert from the PEM configuration of 2010 to the DSH configuration of 2011 was enabled by the HDU integration strategy. Utilizing the 3-D integrated CAD model as a collaboration and a planning tool as well as a design tool allows the model to be a valuable asset during the design process as was discussed for the EVA platform as well as for all the systems integrated around the upper hatch of the HDU-DSH. Looking forward, the HDU project will continue to evolve the DSH configuration for future analog mission tests, and the team plans to optimize the review and test processes from 2010 and 2011 to allow for an additional test opportunity per year.

Figure 15. The first generation of the Habitat Demonstration Unit – Deep Space Habitat utilized for the Desert RaTS 2011 campaign.

VI. References

1. Gill, T. R., Merbitz, J. C., Kennedy, K. J., Toups, L., Tri, T. O., Howe, A. S. "Habitat Demonstration Unit Pressurized Excursion Module Systems Integration Strategy." *Proceedings of the 41st International Conference on Environmental Systems (ICES 2011)*; Portland, Oregon, 18-21 July 2011.

2. Howe, A. S., Kennedy, K. J., Guirgis, P. L., and Boyle, R. M. "A Dual-Chamber Hybrid Inflatable Suitlock (DCIS) for Planetary Surfaces or Deep Space." *Proceedings of the 41st International Conference on Environmental Systems (ICES 2011)*; Portland, Oregon, 18-21 July 2011.