University of Alabama in Huntsville
Final Report

# NASA eXploration Habitat (X-Hab)
# 2013 Academic Innovation Challenge

## Microgravity Random Access Stowage & Rack System

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# 1.0 Introduction

The University of Alabama in Huntsville (UAH) Mechanical and Aerospace Engineering (MAE) Department partnered with the National Aeronautics and Space Administration (NASA), Watring Technologies in Huntsville, AL, and the Huntsville Center for Technology (HCT) in order to design, manufacture, and implement a microgravity stowage and rack system installed in NASA's Deep Space Habitat (DSH) module at Marshall Space Flight Center (MSFC). The project was in response to the NASA eXploration Habitat (X-Hab) 2013 Academic Innovation Challenge completed during the 2012-2013 academic year. The goal was to design a system for a DSH during the fall 2012 academic semester, fabricate during the spring 2013 semester, and deliver the final system to MSFC in May 2013. The project allowed for collaborative interaction with NASA experts at MSFC, Johnson Space Center (JSC) in Houston, TX, and the Jet Propulsion Laboratory (JPL) in Pasadena, CA.

The design and fabrication of the final system was accomplished by the combined efforts of the UAH student design team members, the UAH capstone design course instructor, technical advisors, UAH faculty and sponsors, NASA points of contact, and the team's product manufacturer, Watring Technologies. The NASA Systems Engineering Handbook [1] was utilized throughout the entirety of the project in order to complete a high-quality end product. Figure 1 depicts the NASA Systems Engineering Engine by which the product was designed, realized, and implemented. The design began by outlining and defining all technical requirements and expectations for the project as specified by the stakeholder-NASA-in the original solicitation and requirements documents. Initially, extensive research was conducted in order to ensure the requirements were understood and attainable. A technical solution to the project was then established by defining a logical decomposition of the design and introducing a solution definition for the project. The design was completed by managing the technical and non-technical aspects of the project, including, but limited to, scheduling, cost analyses, designing components and interfaces, completing risk mitigation assessments, and completing detailed technical analyses of the design solution. From January until May 2013, the designed solution was modified, fabricated, tested, installed, and demonstrated. Several modifications were necessary in order to develop a functional gravitational (or One-G) demonstration product from the Zero Gravity (or Zero-G) product designed for microgravity environments.

The present report derives from the Preliminary Report created during the design phase of the project in the fall of 2012 with the final version providing detailed information regarding the fabrication and product delivery phases. This report will provide details of the design, fabrication, testing, installation, and demonstration of the final product. The details include a complete Project Requirements Document (PRD), a complete Product Design Specification (PDS), design drawings, technical analyses, hazard risk and safety assessments, manufacturing requirements and results, and testing results for the product. In addition, this report includes details of the major design reviews completed during the fall 2012 and spring 2013 academic semesters, a thorough product Operations Manual, a Requirements Verification Matrix, a detailed cost analysis, the UAH student design team poster, and an Educational Outreach Activities report.

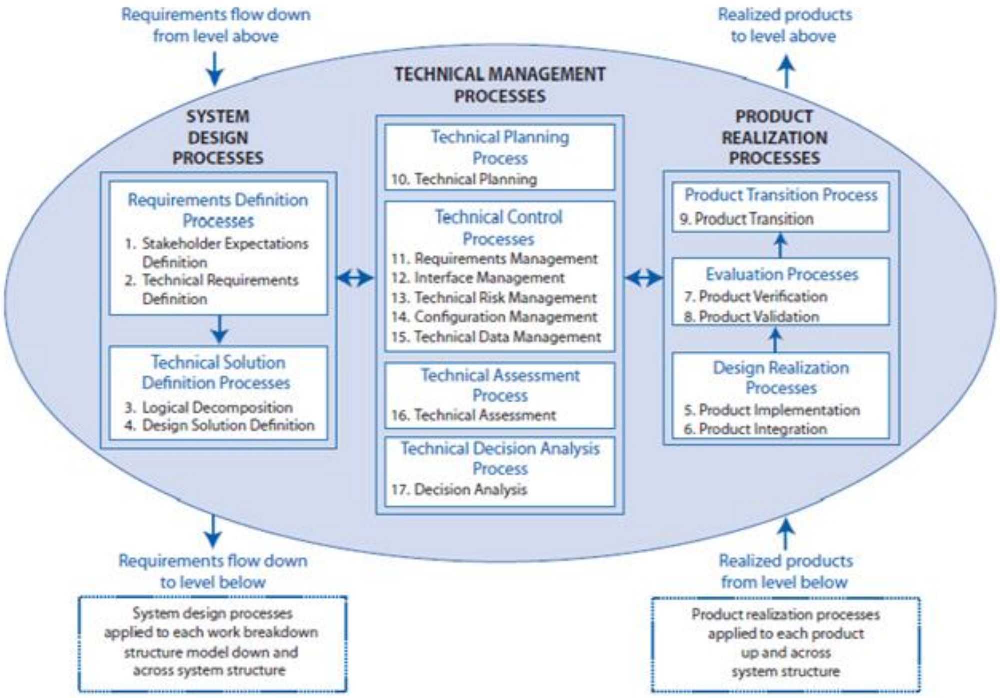



**Fig. 1:** NASA Systems Engineering Engine [1]

## 2.0 Purpose

The purpose of the X-Hab project is to provide relevant, real world engineering experience to the student design team members. The project also provides team members the opportunity to collaborate with NASA engineers and other experts in the aerospace industry. NASA engineers from MSFC, JSC, and JPL maintained an immediate role as stakeholders – or customers – of the final product. In addition, the team's design may be implemented as a part of a future expedition in a DSH environment. Specifically, the UAH team designed and manufactured, along with Watring Technologies, a microgravity random access stowage and rack system, which is intended to house food, medical, hygiene, maintenance, and other supplies for astronauts on a future space mission. An integral part of the project was to engage high school and middle school students at HCT, Whitesburg Middle School, Williams Middle School, and Challenger Middle School-all in Huntsville, AL- and to provide Science, Technology, Engineering, and Mathematics (STEM) outreach during the engineering design process to inspire future generations to pursue a space career.

The ***project vision*** is to develop innovative storage related technologies that will result in ideas and solutions for deep space exploration habitats. The ***objective*** of this project is to design a microgravity random access storage unit for a NASA MSFC DSH. The ***goal*** of this design is to efficiently and effectively house the supplies and tools needed for long term space missions involving the DSH. The storage system was required to be scalable in order to store the equivalent volume of over 100 single-sized Cargo Transfer Bags (CTBs). The dimensions will be provided in the Project Requirements section. The system will also be integrated with existing structures of the DSH. The final design product is a linear stowage system that maintains both functionality and versatility with respect to the ability to house various sizes of CTBs on future deep space missions. The system is translational, providing equal ease-of-access to all storage items.

Figure 2 provides the Product Breakdown Structure (PBS) for the design, detailing the system's architecture including all systems and subsystems of the design. Each major component necessary for the completion of the design is specified within the PBS. The diagram progresses from left to right from larger structural parts to smaller hardware components and fasteners.

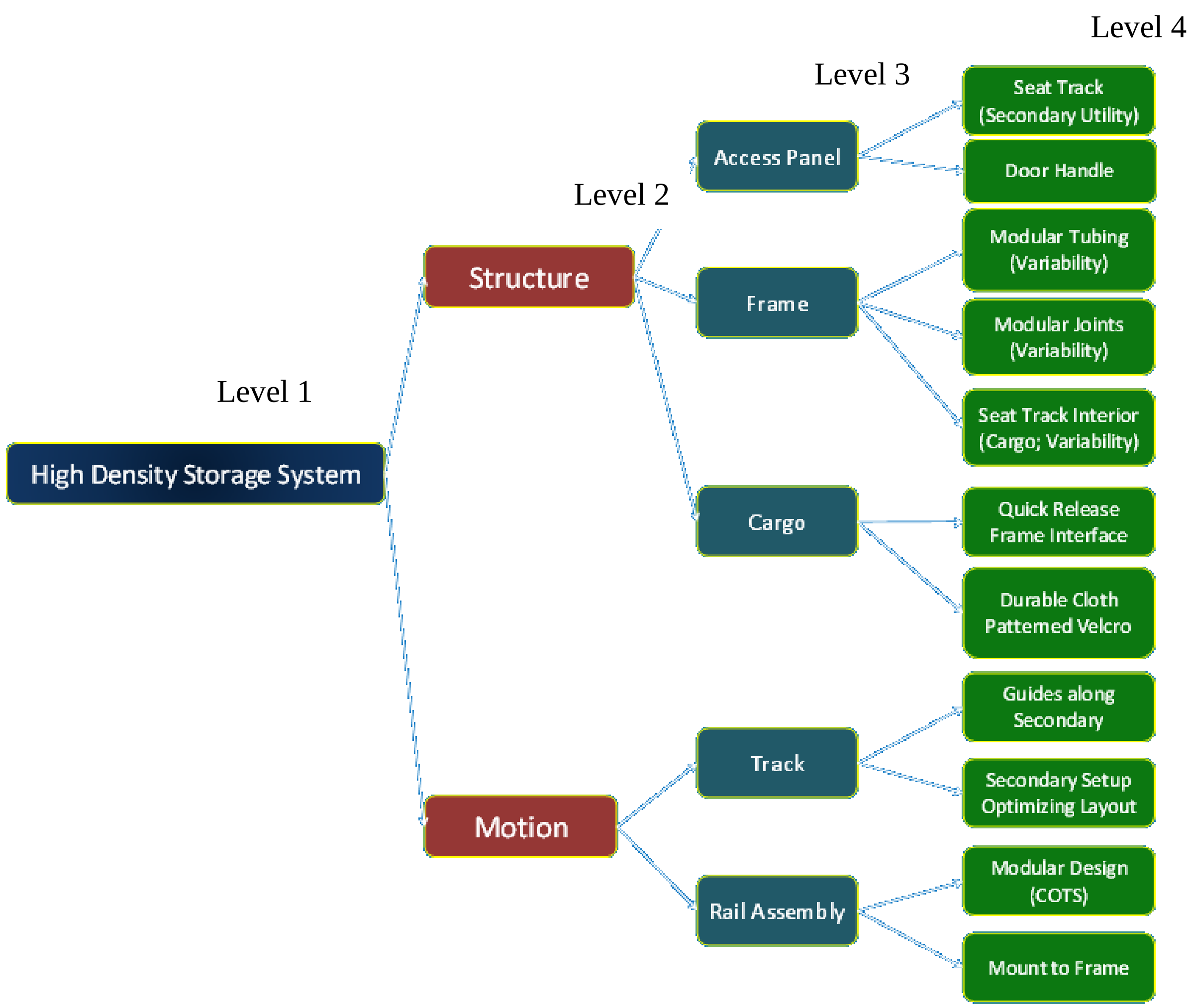



**Fig. 2:** Product Breakdown Structure (PBS)

The Concept of Operations is shown in Figure 3 and provides a general description of the operation of the random access stowage system. The items used during the mission are placed in the CTBs. The system provides an organizational structure for the CTBs with Velcro® fasteners. The units in the system can translate to allow for equal access of all CTBs during flight. The concept of operations guided the conceptual, preliminary, and detail design phases of the project and was used in the functional analysis of the system to ensure that the product met the functional requirements provided by the customers.

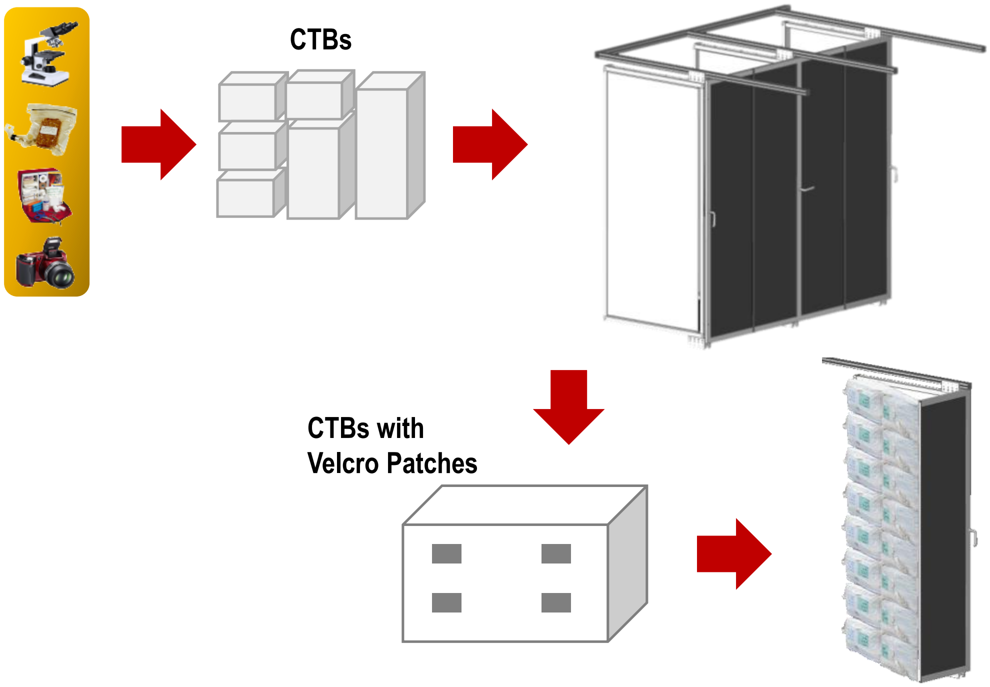



**Fig. 3:** Concept of Operations

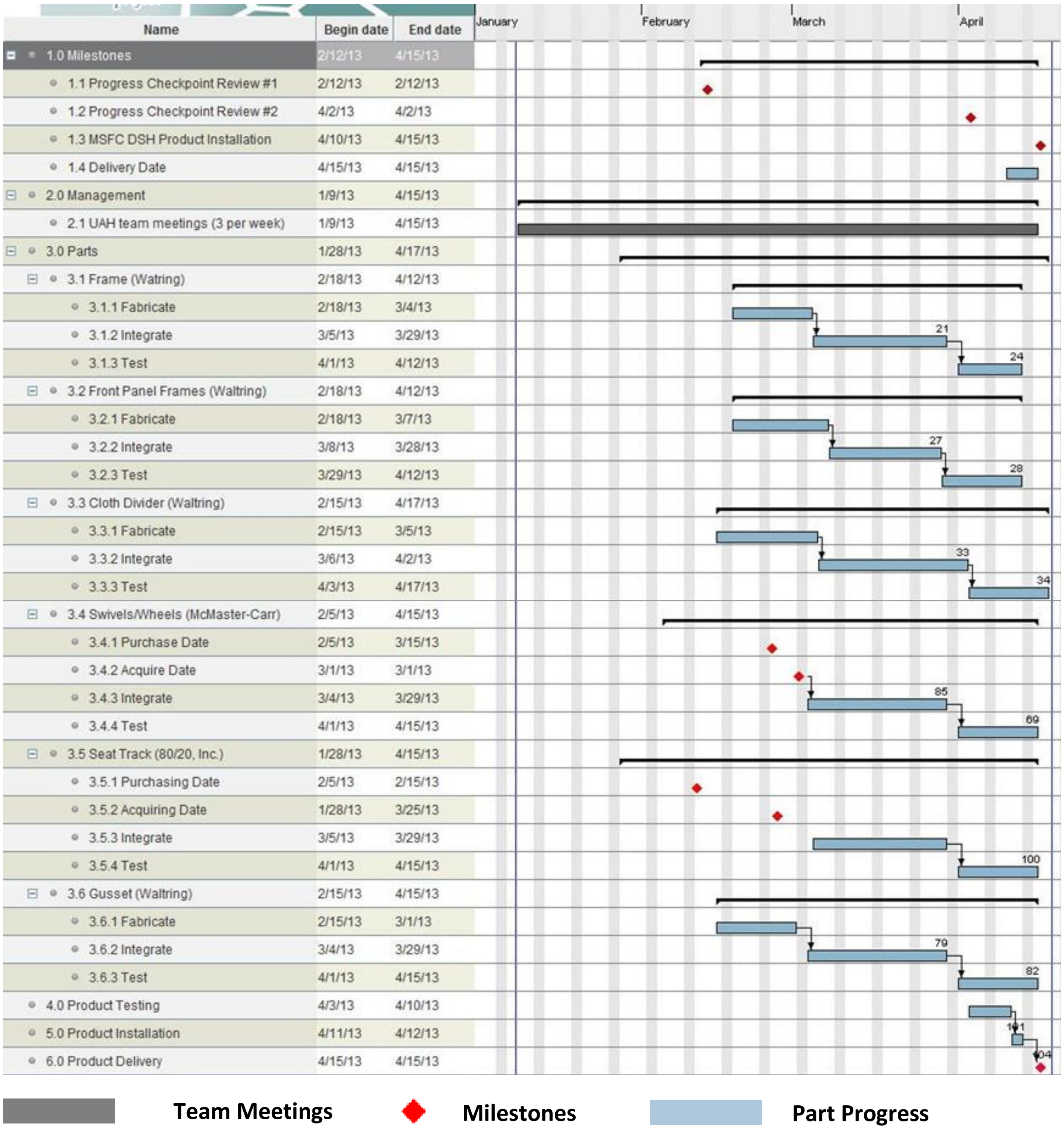
The final fabricated product, for use in a One-G environment, has fixed-translation casters in place of the translational tracks intended for use on the bottom of the stowage system designed for use in microgravity environments. This modification was made in order to accommodate demonstrational motion in the One-G environment of the DSH. The manufactured demonstration product also has a base plate on the floor of the system above the casters in order to allow for One-G loading demonstration. Theoretically, the system is designed to be loaded with CTBs only in the microgravity environment of space. A photograph of the final product installed in the DSH module at MSFC is provided in Figure 4.

**Fig. 4:** Final DSH Stowage System Designed by UAH Students

## 3.0 Work Breakdown Structure and Team Schedule

The Work Breakdown Structure (WBS) and the Team Schedule were produced during the beginning stages of the project and were updated throughout the project in order to provide structure and organization to the design and fabrication processes. The WBS, shown below in Figure 5, is a hierarchical breakdown of the work necessary to complete the fabrication and integration of the hardware during spring 2013. The WBS details the fabrication phase of the project including delivery to MSFC at the end of April 2013. The project checkpoints are represented in this chart, as well as the design team meetings. A similar WBS was created for fall 2013.

Figure 6 displays the Team Schedule that outlines all tasks and work completed by the design team during the course of the entire project. The dates on this schedule were followed closely in order to remain on course with time constraints and due dates. The Team Schedule displays that the 2012 fall semester consisted mainly of designing the subassemblies pertaining to the overall system and the 2013 spring semester consisted of fabricating, testing and installing the components of the system.



| Name | Begin date | End date |
|---|---|---|
| 1.0 Milestones | 2/12/13 | 4/15/13 |
| 1.1 Progress Checkpoint Review #1 | 2/12/13 | 2/12/13 |
| 1.2 Progress Checkpoint Review #2 | 4/2/13 | 4/2/13 |
| 1.3 MSFC DSH Product Installation | 4/10/13 | 4/15/13 |
| 1.4 Delivery Date | 4/15/13 | 4/15/13 |
| 2.0 Management | 1/9/13 | 4/15/13 |
| 2.1 UAH team meetings (3 per week) | 1/9/13 | 4/15/13 |
| 3.0 Parts | 1/28/13 | 4/17/13 |
| 3.1 Frame (Watring) | 2/18/13 | 4/12/13 |
| 3.1.1 Fabricate | 2/18/13 | 3/4/13 |
| 3.1.2 Integrate | 3/5/13 | 3/29/13 |
| 3.1.3 Test | 4/1/13 | 4/12/13 |
| 3.2 Front Panel Frames (Waltring) | 2/18/13 | 4/12/13 |
| 3.2.1 Fabricate | 2/18/13 | 3/7/13 |
| 3.2.2 Integrate | 3/8/13 | 3/28/13 |
| 3.2.3 Test | 3/29/13 | 4/12/13 |
| 3.3 Cloth Divider (Waltring) | 2/15/13 | 4/17/13 |
| 3.3.1 Fabricate | 2/15/13 | 3/5/13 |
| 3.3.2 Integrate | 3/6/13 | 4/2/13 |
| 3.3.3 Test | 4/3/13 | 4/17/13 |
| 3.4 Swivels/Wheels (McMaster-Carr) | 2/5/13 | 4/15/13 |
| 3.4.1 Purchase Date | 2/5/13 | 3/15/13 |
| 3.4.2 Acquire Date | 3/1/13 | 3/1/13 |
| 3.4.3 Integrate | 3/4/13 | 3/29/13 |
| 3.4.4 Test | 4/1/13 | 4/15/13 |
| 3.5 Seat Track (80/20, Inc.) | 1/28/13 | 4/15/13 |
| 3.5.1 Purchasing Date | 2/5/13 | 2/15/13 |
| 3.5.2 Acquiring Date | 1/28/13 | 3/25/13 |
| 3.5.3 Integrate | 3/5/13 | 3/29/13 |
| 3.5.4 Test | 4/1/13 | 4/15/13 |
| 3.6 Gusset (Waltring) | 2/15/13 | 4/15/13 |
| 3.6.1 Fabricate | 2/15/13 | 3/1/13 |
| 3.6.2 Integrate | 3/4/13 | 3/29/13 |
| 3.6.3 Test | 4/1/13 | 4/15/13 |
| 4.0 Product Testing | 4/3/13 | 4/10/13 |
| 5.0 Product Installation | 4/11/13 | 4/12/13 |
| 6.0 Product Delivery | 4/15/13 | 4/15/13 |



**Fig. 5:** Work Breakdown Structure-Spring 2013

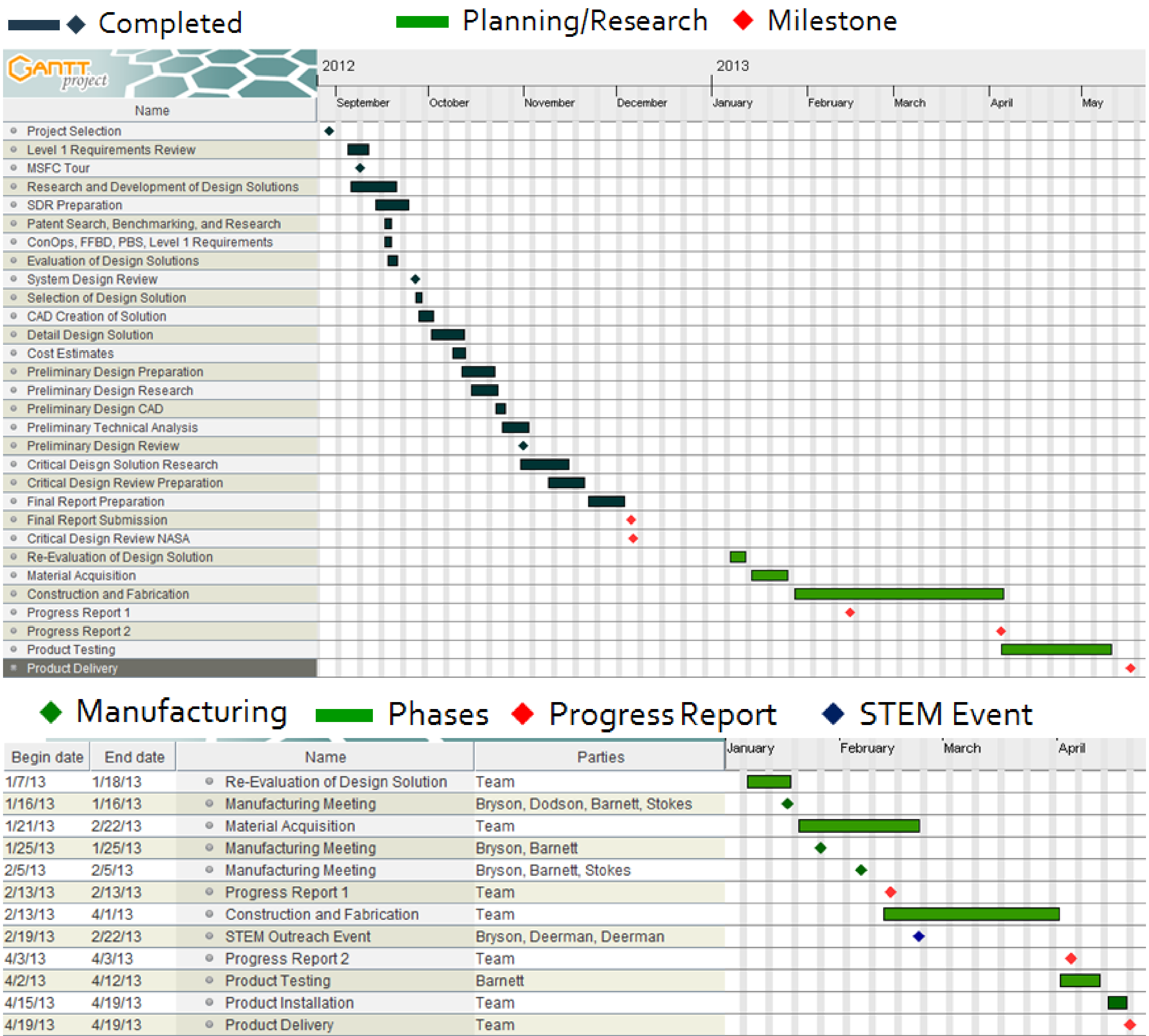



**Fig. 6:** Design Team Schedule

The following information lists the UAH student design team members with their educational majors and roles for the project specified. In addition, Table 1 provides UAH team member demographics. Refer to Appendix A for a photograph and biography for each of the UAH student design team members.

Adam Marlar – Aerospace Engineering, Technical Specialist, Concept Developer
Cameron Bradley – Mechanical Engineering, Technical Specialist, Concept Developer
Caroline Bryson – Mechanical Engineering, Team Lead & NASA Liaison

Christopher Barnett –Aerospace Engineering, Watring Technologies Liaison, Manufacturing & Concept Development, Technical Analysis
Clint Deerman – Mechanical Engineering, HCT Liaison & STEM Outreach Representative
David Brooks – Aerospace Engineering, Technical Researcher & Decision Analysis Coordinator
Drew Deerman - Mechanical Engineering, HCT Liaison & STEM Outreach Representative
Elizabeth Olivares – Aerospace Engineering, Assembly and Parts Management/Cost Analyst
Sarah Rogers – Mechanical Engineering, Human Factors, Finite Element Analysis Specialist
Taylor Stokes – Mechanical Engineering, Concept Developer, CAD, FEA
Thomas Dodson – Mechanical Engineering, Watring Technologies Liaison & Manufacturing Specialist

**Table 1: Design Team Member Demographics**

| Name | Age | Gender | Ethnicity |
|---|---|---|---|
| Adam Marlar | | | |
| Cameron Bradley | | | |
| Caroline Bryson | | | |
| Christopher Barnett | | | |
| Clint Deerman | | | |
| David Brooks | | | |
| Drew Deerman | | | |
| Elizabeth Olivares | | | |
| Sarah Rogers | | | |
| Taylor Stokes | | | |
| Thomas Dodson | | | |

## 4.0 Major Design Reviews

The following design reviews were conducted with MSFC, JSC, and JPL customers in attendance (JSC and JPL via teleconference) in order to detail the design and construction progress of the system for the NASA X-Hab Challenge.

- System Definition Review
  - First design review-fall 2013
  - Main objective: introduction of team and review of system requirements
  - Additional items:
    - Definition of mission statement
    - Description of vision and goals for the project
    - Discussion of research and system solution concept development

        - Review of proposed manufacturing and verification of system solution
- Preliminary Design Review
    - Second design review-fall 2013
    - Main objective: presentation of research results and preliminary system solution
    - Additional items:
        - Update of system requirements
        - Discussion of additional research including market surveys
        - Evaluation of several system solution concepts
        - Review Computer Aided Design (CAD) models and technical analysis for the selected preliminary solution
        - Risk assessment and mitigation
        - Description of STEM outreach efforts and student learning results
- Critical Design Review
    - Third design review-fall 2013
    - Main objective: detailed description of system solution and specifications
    - Additional items:
        - Update final system requirements and STEM outreach efforts
        - Review and update technical analysis
        - Demonstration of scaled system model
        - Verification and validation specifications
        - Finalization of manufacturing and DSH integration plans
- Design Certification Review
    - First design review-spring 2013
    - Main objective: evaluation of results and status of additional analysis, parts procurement, manufacturing, testing, verification, costs, and certification that the design solution meets the requirements
    - Additional items:
        - Detailed, updated CAD renderings of One-G demonstration product
        - Update technical analyses
        - Review of completed STEM outreach efforts

Additionally, two Manufacturing Progress Checkpoints were conducted during spring 2013 in order to update the customers on the fabrication status.

## 5.0 Conceptual Design

The conceptual design phase encompasses the development of design solutions after the requirements are understood and validated. An integral part of the conceptual design phase is to conduct thorough research – including patent searches and benchmarking. These activities are especially important as similar, existing designs can provide critical information as to what is beneficial and what is not. Trade studies are also conducted and evaluation matrices are created in order to evaluate project options such as manufacturing location, materials selection, and a design solution.

## 5.1 Project Requirements

As a part of the NASA Systems Engineering design process, before any design can begin, it is critical to understand and define all requirements of the project in question. This includes defining both the stakeholder's expectations and all technical requirements for the system. To fulfill this component of the project and to provide a crucial structure to the project's development, a Project Requirements Document was created. This document establishes the top level requirements as well as the flow down requirements for the microgravity random access stowage and rack system. Refer to Appendix B for the full document which includes a Customer Questionnaire. The following is a complete list of the Level I requirements provided to the design team by NASA at the onset of the project.

- Requirement 1- The stowage system concept shall be designed for a specified volume of the DSH.

- Requirement 2- The delivered demonstration product shall occupy only a percentage of the volume of the DSH.

- Requirement 3- Determination of the percentage developed shall depend on the design team's ability to show proof of concept.

- Requirement 4- The project product shall fit into the DSH space and volume (dimensions: 21.65 x 13.78 x 13.78 $ft^3$, approximate volume: 4,111 $ft^3$).

- Requirement 5- The project product shall be able to enter the DSH via the end cone (hatch) (dimensions: 50 in. w, 50 in. h, and diagonal 61 in.).

- Requirement 6- The project product shall be able to be configured and installed within the DSH volume specified in Requirement 5.

- Requirement 7- Once installed, the product shall not continuously impede the emergency translation path of the DSH (dimensions: 32 in. x 45 in.)

- Requirement 8- The stowage system shall be of minimum weight per NASA's recommendation. Note: no weight requirement (minimum or maximum) has been stated and the design team shall determine an acceptable weight for the system.

- Requirement 9- Any fasteners used within the system shall be of a common type and size to minimize the number of tools required to insert the fasteners, reduce the crew workload, and the minimize potential of using the wrong tool. Hand actuated fasteners shall also be of a common type and size to standardize the operation and adjustment a variety of latches and fasteners. If multi-turn fasteners are required by the system, the fastener shall fasten or unfasten in less than 10 revolutions. The number of fasteners used in an application shall be minimized. Note: no further details about fasteners, types, or sizes were specified by NASA.

- Requirement 10- The completed demonstration product shall be delivered to NASA MSFC (Building 4649) in May of 2013.

- Requirement 11- The mission scenario is long duration with infrequent re-supply; thus, the DSH stowage unit shall provide storage for items with varying functions (medical, food, hygiene, maintenance, entertainment, and food supplies, and science experiments).

- Requirement 12- Due to the frequent access needed for the aforementioned supplies, an easily reconfigurable design shall be implemented.

- Requirement 13- The stowage system shall have the following characteristics: flexibility, interchangeability, adjustability, and reusability.

- Requirement 14- The Zero-G system shall have self-stabilization capabilities, particularly during launch and landing. This does not pertain to the delivered One-G demonstration product.

- Requirement 15- The product shall be designed to be scalable to accommodate stowage of 100+ single sized Cargo Transfer Bags (CTBs) measuring 19.75” x 16.75” x 9.75”.

- Requirement 16- Non-standard stowage purposes shall be considered by the design team (e.g. items to be returned to Earth and cargo inventory fluctuations due to the addition of modules and spacecraft).

- Requirement 17- For high torque applications, the tool-actuated fastener head type shall be internal (Allen) or external hex-head styles.

- Requirement 18- The product shall be installed in the DSH in MSFC building 4649. The design team shall be responsible for providing all tools and equipment necessary to install the stowage system.

- Requirement 19- The system shall provide for temporary and non-standard storage purposes throughout the spacecraft.

- Requirement 20- The storage system shall be designed to allow for easy accessibility for mission critical and frequently used items.

- Requirement 21- Per *JSC 27301: Materials and Processes Selection, Control, and Implementation Plan for JSC Flight Hardware* [2], the spacing of the hook and loop fasteners shall have a maximum size of 4 $in^2$, maximum length of 4 in, and a minimum separation of 2 in.

- Requirement 22- Exposed fasteners shall be selected so that they will not snag clothing or cause injury to the crewmembers. Fasteners and latches shall not spring open and cause injury to the crewmembers. The use of cotter keys and safety wire shall be avoided.

- Requirement 23- The system shall utilize standardized user interfaces (visual, auditory, and tactile) and standard methods of operation across the system for consistency and ease of learning. Ease of operation shall be a primary goal. All fastener components intended for crew interaction shall be captive (i.e. one that is automatically retained in a work-piece when it is not performing its load-bearing job, and therefore does not require the crew to restrain and store it during maintenance.)

## 5.2 Patent Search

Patent searches were conducted during the fall of 2012 [3] and demonstrated that numerous products exist which serve as solutions to various storage methods. A patent search is an important endeavor in the design process as it exposes the team to products that already exist and can provide guidance as to advantageous and non-advantageous design aspects. A patent search also informs the team as to whether their design concepts have already been developed and how they have been implemented. A patent search is important to conduct so as to not infringe upon any currently existing patents.

During the patent search, a total of 37 patents were reviewed. Those with information relevant to the final UAH design are listed below Table 2 and shown in Figures 7 and 8.

**Table 2: Patent Search Results**

| Name | Patent # | Advantages | Disadvantages |
|---|---|---|---|
| Linear storage system [4] | 6027190 | Multiple points of access | Temporary blockage of translation path |
| Rail system for mobile storage [5] | 7165497 | Maintain path of translation | Potential for blockage and continuously impeding translation path |

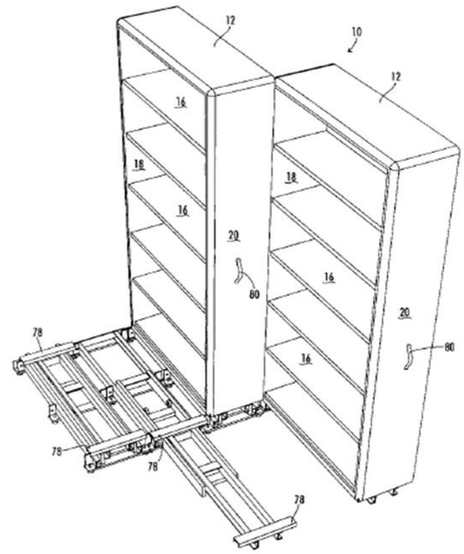



**Fig. 7:** Linear Storage System [4]

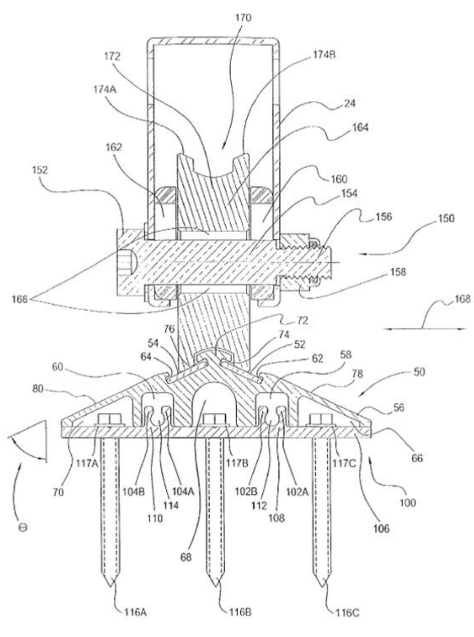



**Fig. 8:** Rail System [5]

## 5.3 Benchmarking

Many products were researched during the fall of 2012 and various methods of translational storage were evaluated [3]. Significant research on different concepts was conducted in order to provide the team with knowledge during the design process. This included research on commercially available products that are similar to the design concepts or any of the sub-systems. Several products were researched including a Static Drawer System, a Rolling

Shelf System with forward/aft motion, a Library Style Shelf with forward/aft motion, and a Rolling Shelf System with starboard/port motion. The Static Drawer System was strong and would keep supplies safe and secure during launch and operation. It was also safe and fairly easy to manufacture and had a fairly low total cost. However, it did not provide ease of access to supplies. The Rolling Shelf System with forward/aft motion provided ease of access to supplies, and was fairly strong and capable of keeping supplies safe and secure. However, it was deemed unsafe and would have a high difficultly level to manufacture and a high cost. The Library Style Shelves with forward/aft motion were strong and provided a fairly easy access to supplies. They also were easy to manufacture with a fairly low total cost. However this design was not very safe and did not provide safety to the supplies during launch and operation. The Rolling Shelf with starboard/port motion design provided the highest ease of accessibility to the supplies as well as a high degree of safety for the supplies during launch and operation. This design was also safe, easy to manufacture, and had a low total cost.

## 5.4 Interview Results

Several phone and in-person interviews were conducted during the fall of 2012 which aided the team's efforts to design an effective microgravity stowage system [3]. The interviews conducted by the team included six phone interviews with several professionals in the aerospace industry who had multiple years of experience in stowage inventory management on NASA Space Transportation Systems - or Space Shuttles. These interviews were conducted in order to gain a better understanding of what the design team should focus upon during the design process in the opinion of professionals. The information provided by the professionals was extremely valuable and helped the team in making informed design decisions. The names of the individuals interviewed are provided below along with their places of employment and position titles [6-11].

Connie Musler – JSC - ISS Stowage/Inventory Management
Kirk Teitge – Teledyne Brown Engineering – Engineer
Lynn Farris – MSFC - Former Shuttle Operations Coordinator
Margaret Gibb – JSC - ISS Stowage Management Support Lead
Tony Cox – Teledyne Brown – Engineer (7 years of experience with shuttle program)
Ursula Stockdale – JSC - Stowage Planner

The Interview Questionnaire is located in Appendix C. Responses to the interview questions (without identification of the respondents' names) are provided below.

<u>Question 1:</u> What is one aspect of current stowage systems that could be most improved upon?

<u>Answer(s):</u> *Stowage allocation, organization, and labeling, reconfigurable and accessible volumes, and modularization.*

<u>Question 2:</u> How important is it to be able to access all items with equal accessibility (regardless of location)? Rank 1-5 (1 being not important and 5 being very important)

<u>Average Response:</u> *3.5*

Question 3: What is the most important issue for a stowage system to address in space missions?

Answer(s): *Best use of space, account for trash, standardized CTB organization method (location coding), restraint of CTBs.*

Question 4: In two rack bays of current systems, how many CTBs are stored?

Answer(s): Average of 16-20 per rack bay, 32-40 total for two rack bays.

Question 5: In your opinion, how effective would the use of Velcro be for a fastener in stowage systems? Rank 1-5.

Average response: *3.5*

Answer(s): *Excellent for microgravity use, great way to simplify, minimizes need for multiple fasteners, usable in open volumes.*

In these interviews the team discovered that it is important to focus on efficient use of space, account for trash stowage, focus on a standardized stowage system for the CTBs, and focus on proper restraining of the CTBs. The interview results showed that it is very important to have equal access to all stowed items in the system. The interviews also showed that experts believe the use of Velcro as a fastener would be effective in restraining the CTBs. All of the experts interviewed agreed that in current space missions the ease of access of cargo greatly affects the science experiments taking place onboard the spacecraft. Therefore the team placed high priority on allowing easy access to the CTBs and their cargo. Through the research gathered through the Phone Interviews and the Benchmarking Research, the team was able to gain a better understanding of what to focus on in the design process and how to implement these into the design.

## 5.5 Research/Information Gathering

Thorough research gathering was conducted during the fall of 2012 and proved invaluable to the product design development and manufacturing processes [3]. Extensive research was conducted for all aspects of the design including materials, manufacturing, design complexity, collecting expert advice, technical analysis, cost analysis, and STEM outreach - to name a few. Materials research was conducted after a general design was chosen and a design evaluation matrix was created to aid in determination of the primary material to be utilized for the framing material. The research focused upon material strengths based on the yield strength and Young's modulus of different materials, including aluminum, steel, and composite materials [12]. Aluminum was selected as the optimal material for the framing structure of the design. This decision, as well as other material choices, was influenced primarily by the materials strength to weight ratio.

After the framing material was chosen, various aluminum sheet and tubing sizes were considered based upon performance parameters. Several materials were considered for the fabric backing of the structure such as awning fabric, Multi-Layer Insulation (MLI), and beta cloth. Research was also conducted to determine the best type of Velcro® that possesses the most resistance to electrostatic discharge in order to reduce the risk of combustion [13]. Additionally, the layout of the Velcro® patches conforms to specification 5.1.1.2 from JSC 27301 [14].

Manufacturing research was also conducted to determine the primary source of manufacturing. Several different entities pledged their support during manufacturing process. Watring Technologies was chosen as the primary location of manufacturing with other various small tasks assigned to the HCT machine shop. Inquiries were made with several Huntsville, AL awning companies for the fabrication of the durable cloth specified in the design. Based upon the aforementioned research and discussions, the manufacturing process was projected to have a maximum duration of three months.

After extensive research into the general design of the system including patent searches and benchmarking, several design solutions were formulated and eventually the best aspects of each concept were combined to develop a design solution. Several iterations of the design solution were evaluated based on the original requirements of the system. The cloth shelving with Velcro® patches was chosen – as opposed to an entire panel of Velcro® - primarily based on the criteria of operator safety. Volume calculations and research into CTB measurements yielded the optimum configuration and maximum storage capacity for the CTBs [15]. The selected stowage system design will be able to accommodate 56 single-sized CTBs based on volume calculations performed by the team. The CTBs will be attached to a fabric wall with hook and loop fasteners. The existing secondary structure to which the design will be attached is made of 80/20® extruded aluminum. The stowage system slides in the starboard/port axis of movement when pulled, and the CTBs will be accessible in the forward/aft directional axis.

Materials' costs research was conducted throughout the design process. The initial project budget of approximately $ was allocated as shown in Figure 9. Due to a change in the Level I system delivery and installation location requirement [15] (see Appendix B for the final PRD), the portion of the budget associated with travel costs was reallocated to the materials, supply, manufacturing & testing portion of the budget. All other costs were calculated using a best estimate of materials cost.

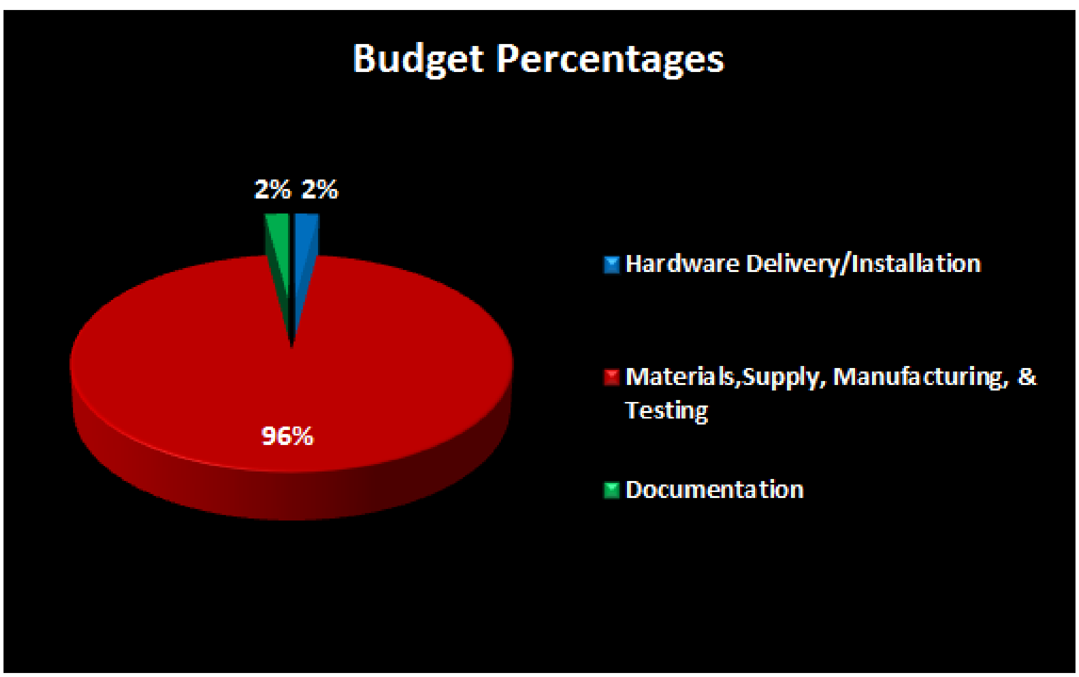



**Fig. 9:** Project Budget

## 5.6 Conceptualization and Trade Studies

As briefly mentioned in Section 5.5 several design concepts were developed before a design solution was selected. The patent search and benchmarking processes enabled the UAH team to compare and contrast different existing systems and consider how to adapt them to a microgravity environment. The preliminary design incorporated elements from different systems found during the patent search and benchmarking phases of the project.

The preliminary design is shown in Figure 10. This system incorporated a T-slot sliding system that extended the entire length of the frame and framework that completely enclosed the CTBs on one side. This design was reconsidered after the Preliminary Design Review and critical aspects of the design were changed to better meet the requirements of the project. These requirements included minimal mass for the entire system, incorporating 80/20® components into the sliding mechanism to make better use of the existing secondary structure, and making use of the curvature of the DSH in the project design. Figure 11 displays samples of the 80/20® extruded material.

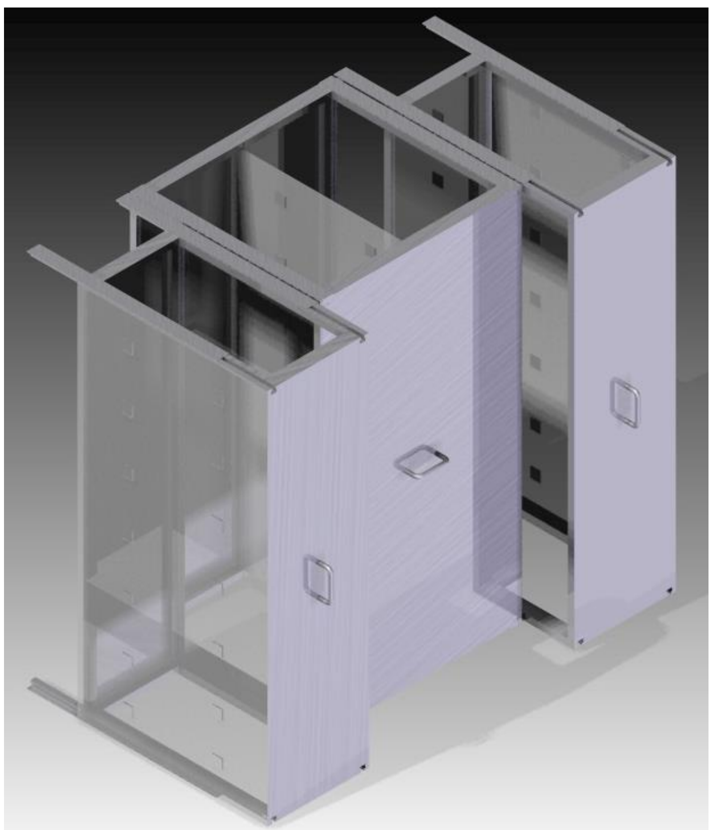


**Fig. 10:** Preliminary Design – Microgravity Stowage System

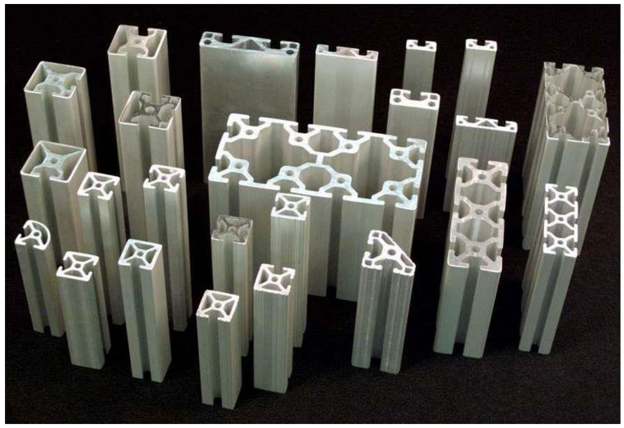


**Fig. 11:** 80/20® Samples

The UAH team considered the design requirements of the project during every phase of the design process. The top-level requirements were ease of access, system reliability, weight of system, operator safety, ease of manufacturing, and total cost. The various design concepts were researched, evaluated, and compared so that the team could make a well-informed and educated decision in order to deliver the best possible product. The team made sure to utilize several decision matrices to compare the design concepts. The matrices are shown in Tables 3-5. Figures 12-15 depict the design concepts/options evaluated in Table 3. The design concepts/options were the static drawer system, the rolling shelves (forward/aft), the library style shelves (forward/aft), and the rolling shelves (starboard/port).

The design decision matrix compares each design concept/option and evaluates them based on the requirements (or criteria) to be considered in the design. These criteria were ease of access to cargo, system reliability, weight of system, operator safety, ease of manufacturing, and total cost. Each of the criteria was assigned a numerical weight based on its importance. System reliability and operator safety were assigned the greatest weight as they were two top-level requirements. Ease of cargo access and weight of the system were also important aspects, but not at the level of the previous two. Total cost and ease of manufacturing were assigned the lowest weight due to a healthy budget and excellent manufacturing resources.

**Table 3:** Overall Design Concept Decision Matrix

| X-HAB Design Project Decision Matrix | | | Option 1 | Option 2 | Option 3 | Option 4 |
|---|---|---|---|---|---|---|
| Overall Design Concept | | | Static Drawer System | Rolling Shelves (Forward/Aft Motion) | Library Style Shelves (Forward/Aft Motion) | Rolling Shelves (Starboard/Port Motion) |
| Criteria | Weight | Scale | | | | |
| Ease of Access | 20 | 5 = Most Supportive<br>1 = Least Supportive | 2 | 4 | 3 | 5 |
| System Reliability | 25 | 5 = Most Supportive<br>1 = Least Supportive | 5 | 3 | 4 | 3 |
| Weight of System | 15 | 5 = Most Supportive<br>1 = Least Supportive | 1 | 3 | 3 | 5 |
| Operator Safety | 25 | 5 = Most Supportive<br>1 = Least Supportive | 4 | 1 | 2 | 4 |
| Ease of Manufacturing | 10 | 5 = Most Supportive<br>1 = Least Supportive | 3 | 2 | 4 | 4 |
| Total Cost | 5 | 5 = Most Supportive<br>1 = Least Supportive | 3 | 2 | 4 | 4 |
| Weighted Totals in % | 100 | | 65 | 51 | 63 | 82 |

**Table 4:** Manufacturing Location Decision Matrix

| X-HAB Design Project Decision Matrix 2 | | | Option 1 | Option 2 | Option 3 | Option 4 |
|---|---|---|---|---|---|---|
| Manufacturing Location | | | Watring Technologies | UAHuntsville Machine Shop | HCT Machine Shop | Outside Contractor |
| Criteria | Weight | Scale | | | | |
| Cost | 15 | 5 = Most Supportive<br>1 = Least Supportive | 3 | 5 | 5 | 1 |
| Manufacturing Prowess | 30 | 5 = Most Supportive<br>1 = Least Supportive | 5 | 3 | 2 | 4 |
| Machining Capabilities | 20 | 5 = Most Supportive<br>1 = Least Supportive | 4 | 3 | 3 | 5 |
| Material Resources | 15 | 5 = Most Supportive<br>1 = Least Supportive | 4 | 2 | 1 | 5 |
| Product Cycle Time | 20 | 5 = Most Supportive<br>1 = Least Supportive | 5 | 3 | 2 | 5 |
| Weighted Totals in % | 100 | | 87 | 63 | 50 | 82 |

**Table 5:** Framing Material Decision Matrix

| X-HAB Design Project Decision Matrix 3 | | | Option 1 | Option 2 | Option 3 |
|---|---|---|---|---|---|
| Framing Material (80/20) | | | Aluminum | Composite | Steel |
| Criteria | Weight | Scale | | | |
| Cost | 15 | 5 = Most Supportive<br>1 = Least Supportive | 3 | 2 | 4 |
| Strength | 30 | 5 = Most Supportive<br>1 = Least Supportive | 5 | 3 | 5 |
| Ease of Fabrication | 20 | 5 = Most Supportive<br>1 = Least Supportive | 4 | 1 | 3 |
| Access to Materials | 15 | 5 = Most Supportive<br>1 = Least Supportive | 3 | 2 | 5 |
| Material Mass | 20 | 5 = Most Supportive<br>1 = Least Supportive | 4 | 5 | 2 |
| Weighted Totals in % | 100 | | 80 | 54 | 77 |

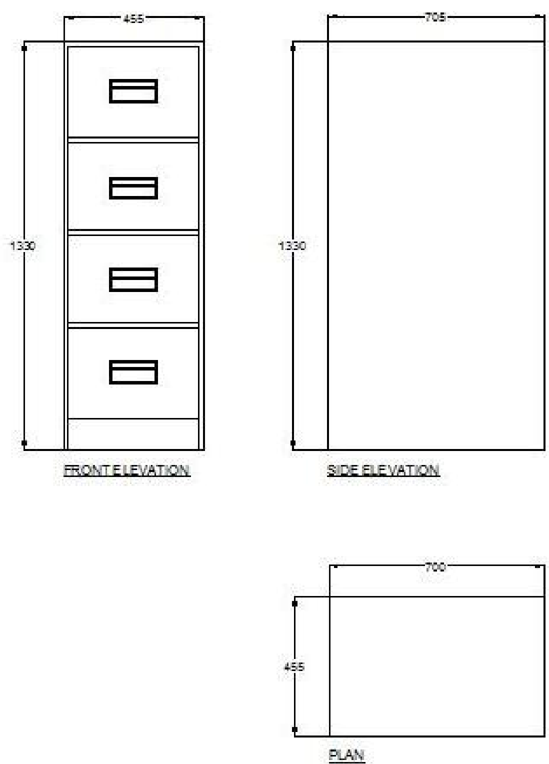



**Fig. 12:** Static Drawer System

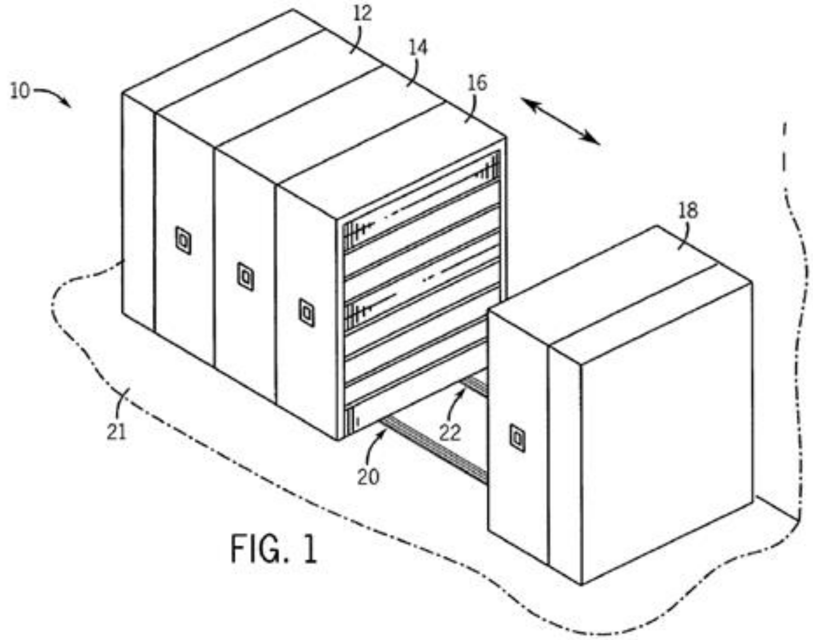



**Fig. 13:** Rolling Shelves (Forward/Aft)

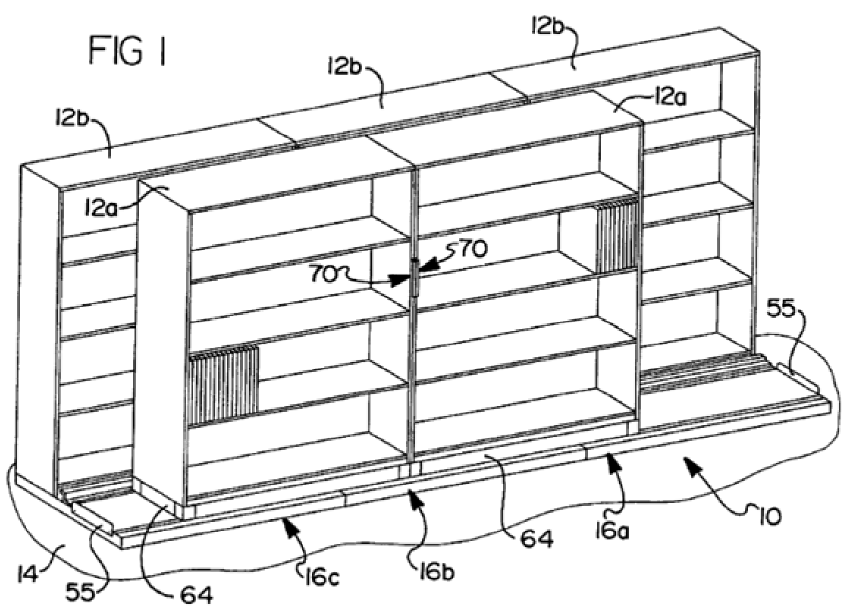



**Fig. 14:** Library Style Shelves (Forward/Aft)

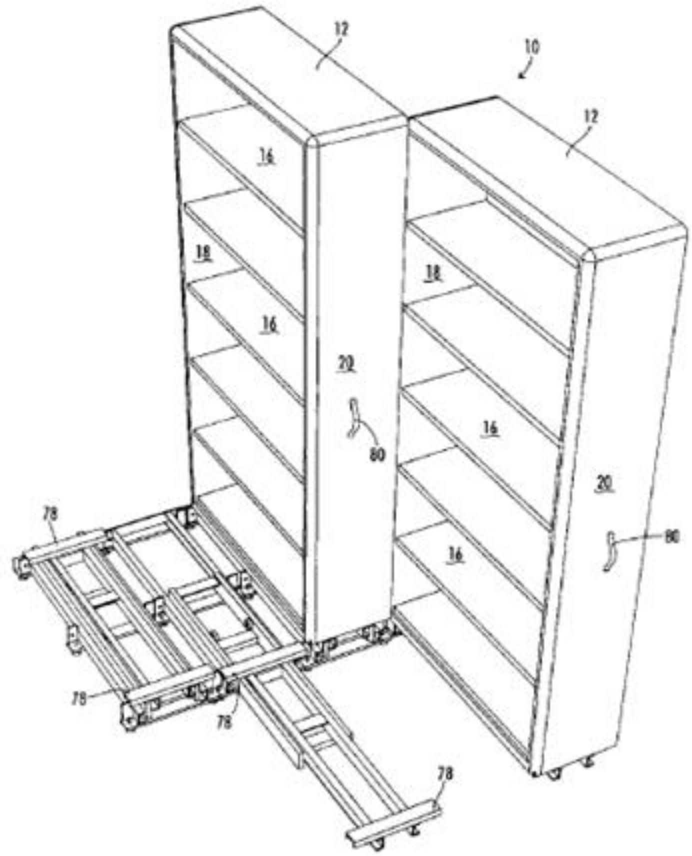


**Fig. 15:** Rolling Shelves (Starboard/Port)

The selected design solution is an adaptation of the rolling shelves in the starboard/port motion. It was determined to be the most effective design and the best deliverable product. A CAD rendering of the design is shown in Figure 16. The design eliminated most of the structural framework from the preliminary design. This change decreased the weight of the system to a minimal mass that adheres to the Level I requirements for the project. Another change was the use of a sliding mechanism. The design incorporates 80/20® components to ensure a better fit with the existing secondary structure in the DSH at MSFC. The change significantly decreases the complexity of manufacturing processes. The final change was to incorporate the utilization of the back curvature of the DSH. This was accomplished by creating a custom utility bag that will fit the curvature of the module. This modified design solution increases the storage of the system by using all available space for the mission items. Figure 17 shows how the bag will be incorporated into the system. Multiple considerations for the area of the design space closest to the outer hull have been made. The space can be utilized for a single custom utility bag for the storage of water, three custom utility bags for storage of contingency harnesses, trash storage, storage of used CTBs, and storage of cloth walls when the system is disassembled.

A CAD drawing of the structural frame of the One-G demonstration product is shown in Figure 18. The One-G demonstration design has multiple differences compared to the Zero-G theoretical design for a microgravity environment. The One-G demonstration product possesses a base plate to support the 1G loading of CTBs, gussets for added door support, an additional Unibearing™ on the track, and fixed-rotation casters attached to the bottom support structure. The casters will enable ease of use in 1G translation scenarios where, otherwise, friction would impede the motion of the translational tracks along the floor of the DSH. The system has a Vertical Displacement Compensation System on the top of the stowage system structure to adjust for leveling issues encountered in the DSH – primarily due to uneven floors.

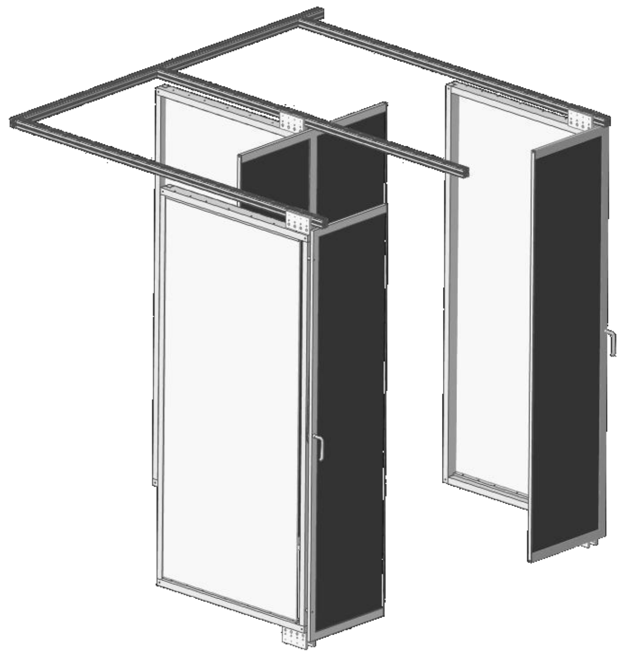


**Fig. 16:** Isometric View of the UAH Stowage Design Solution

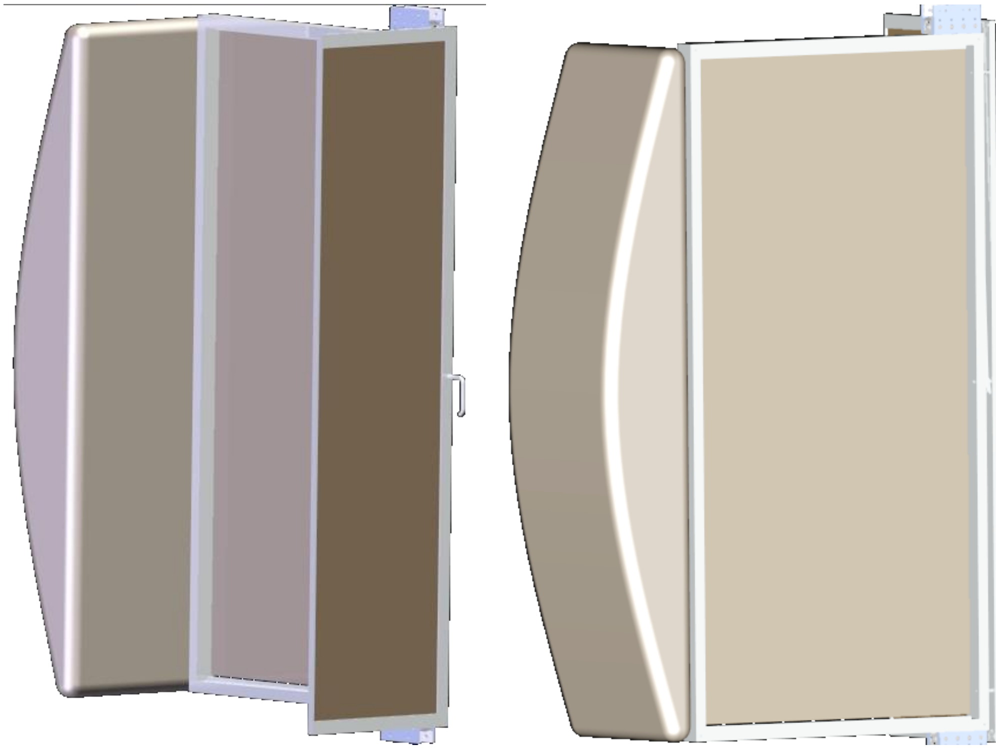


**Fig. 17:** Modified Design with a Custom Utility Bag

**Fig. 18:** Final 1G Demonstration Product without the Fabric Walls

# 6.0 Preliminary Design

The preliminary design phase of the project focused upon the development of the selected design concept. It incorporated activities from the conceptual design and system definition phases in order to establish an initial project baseline. The phase included the development of formal flow down requirements from the Level I requirements. These include external and internal interfaces, as well as more detailed design drawings. Various technical analyses were performed, and cost estimates and a team schedule were refined. In addition the system operation details were developed in order to proceed to the critical design phase.

## 6.1 Design Concept

The UAH design solution is a linear stowage system which moves perpendicular to the translational path of the DSH module. The system is an open concept design with unimpeded access to the outer curvature of the DSH. All items stowed in CTBs are equally easily accessible in the proposed stowage system. CTBs will be attached to a sheet of electro-static discharge resistant cloth using Velcro® patches to interface with the existing Velcro® patches on the CTBs. The described system motion will be accomplished using a track system developed from 80/20® aluminum, similar to the material currently implemented within the DSH. The track system will use a Unibearing™ and pieces of secondary structure to slide along its motion path. The Unibearing™ will be attached to the secondary that is already implemented in the DSH. The bearing will allow the 80/20® that is connected to the system to translate easily. When not in use, the unit will be held in place by a locking mechanism in the door. This will prevent any unwanted translation. The cloth structures will attach to the framework of the unit via seat tracks and push release attachment points that are used in seat tracks. These attachment points will allow the cloth to be removed easily if the unit is not being utilized in order to create extra usable space.

Several drawings of the system are provided in Figures 19-21. Figure 19 shows an overall view of the system with 3 units. The 3 units are sufficient to demonstrate the functionality of the system and its potential for duplication. Figure 20 provides a system drawing that shows each individual part labeled. The system consists of 7 main components including the door frame, door insert, system frame, cloth structure or sheet, seat track, and the Unibearing™ that is connected to the secondary structure of the DSH. Figure 21 shows the overall dimensions of the system measured in inches.

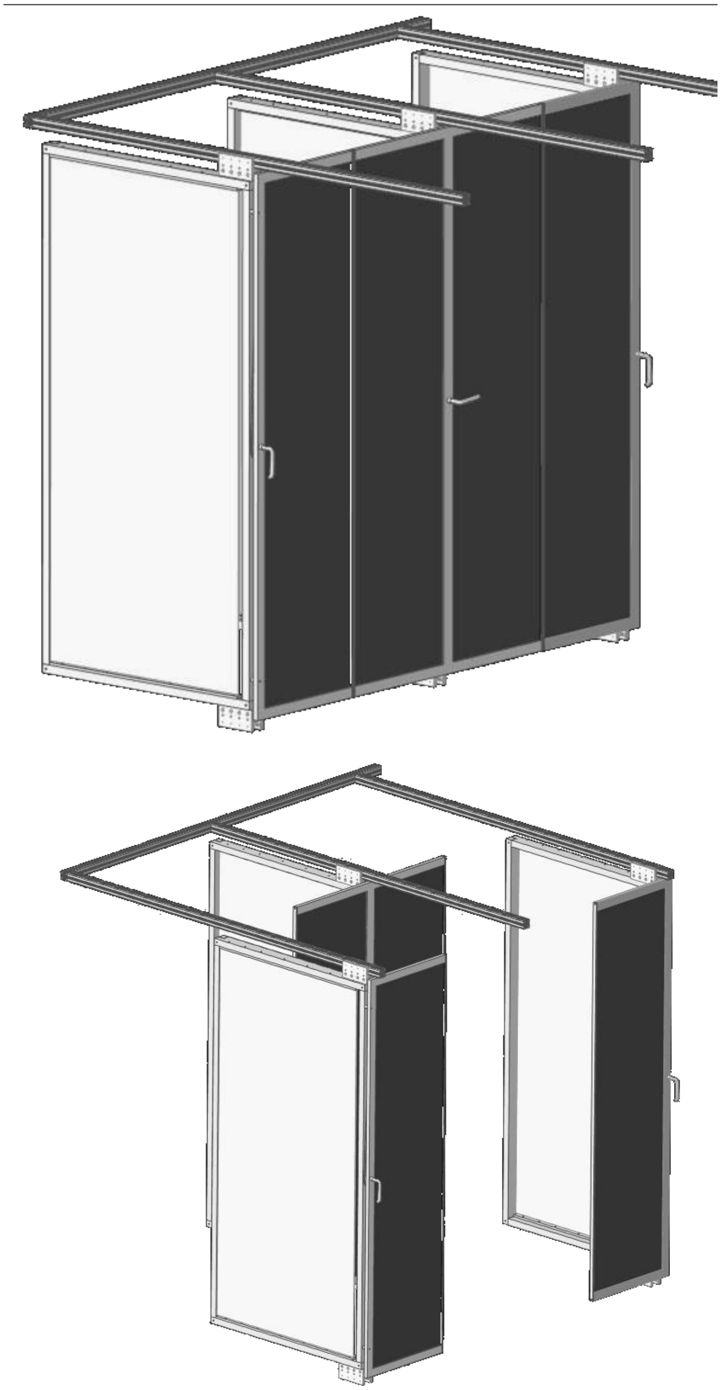


**Fig. 19:** Overall System Drawing (Stowed State and Accessible State)

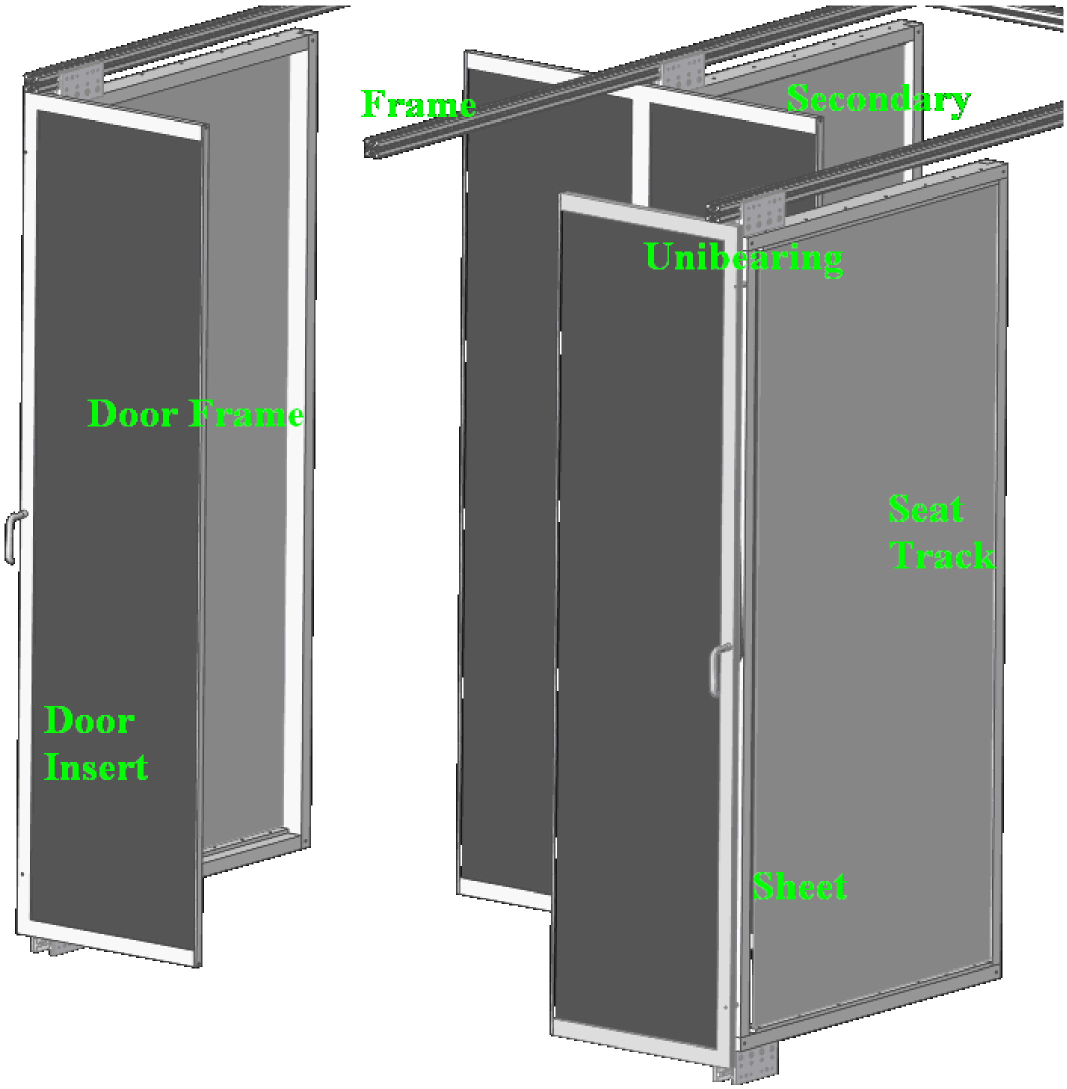



**Fig. 20:** Labeled System Drawing

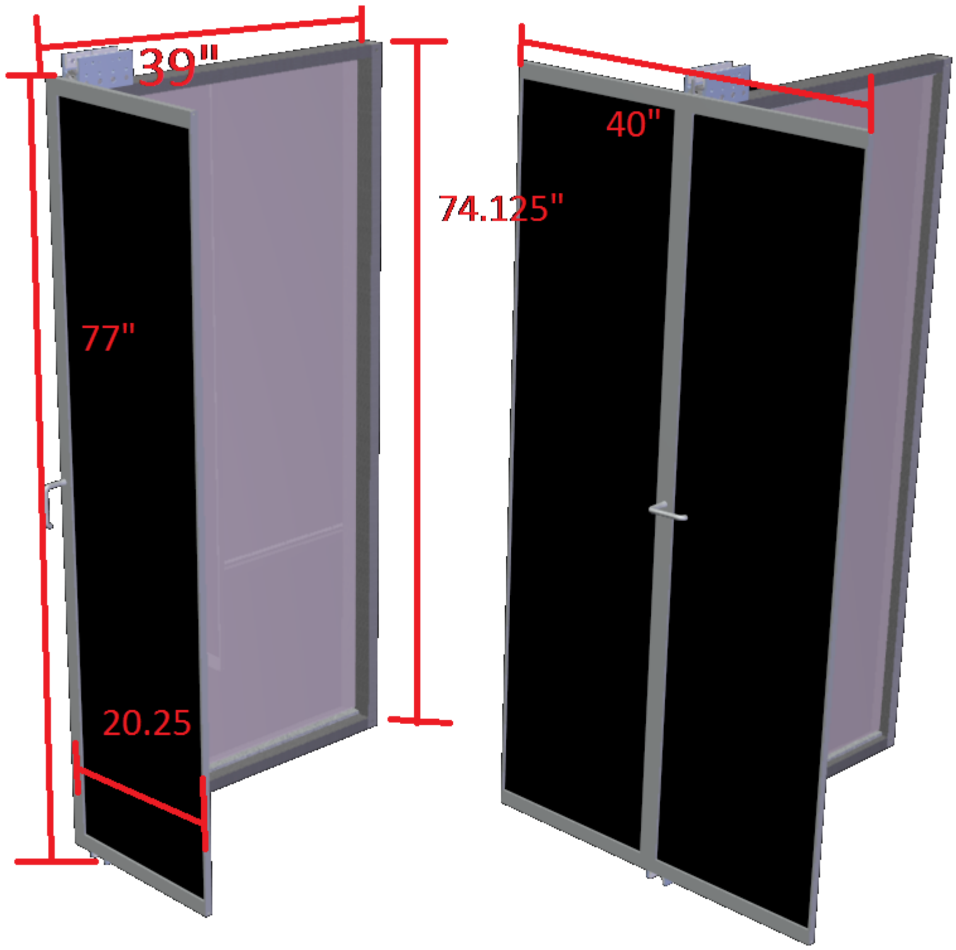



**Fig. 21:** System Drawing with Dimensions

## 6.2 Functional Flow Block Diagram

Figure 25 shows the functional flow block diagram for the system. This represents how the system functions after installation. The blocks flow from left to right. The steps for operation of the system begin with opening the door to the unit by pulling the handle. After the unit has been removed from the frame, a CTB can either be removed from the cloth structure or placed back onto the structure. The unit is then slid back into place.

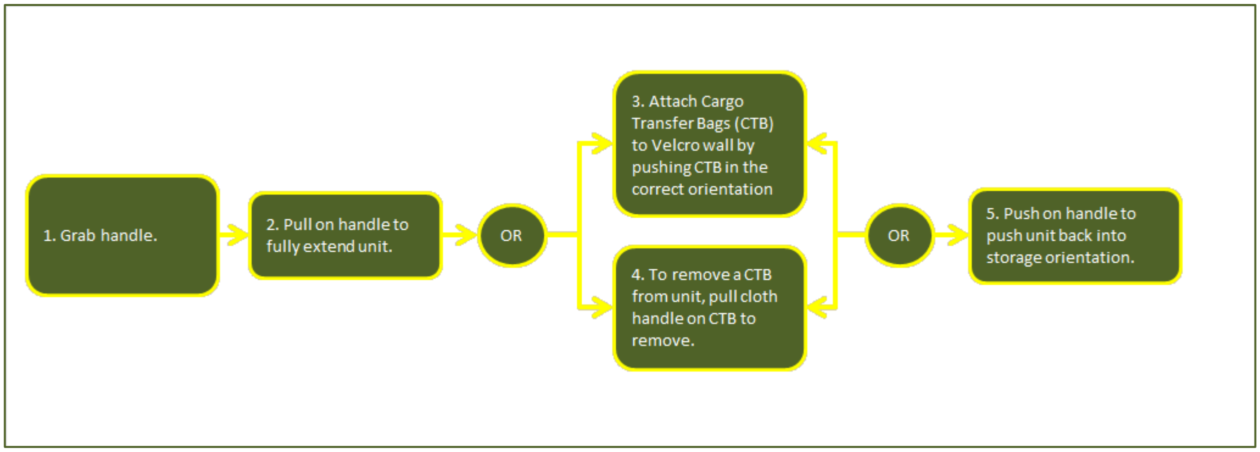



**Fig. 22:** Functional Flow Block Diagram

## 6.3 Interface Requirements

The internal and external interfaces used in the design are shown in Figure 23. The chart indicates the composition of the system and the specific connection types. The components are labeled and the types of connections are described by the legend. The bolts will consist of socket head cap screws that can be installed and removed with standard hex keys. This provides structural integrity while offering quick release for contingency situations. The connections from the cloth structure to the system are push release attachment points that are used in seat tracks and are common to the space industry. The bearing pads are made of an extremely durable composite, Ultra High Molecular Weight Polyethylene (UHMW-PE) [16]. Additional manufacturing information of the bearings utilized in the final design is provided in Appendix D.

An $N^2$ diagram, shown in Figure 24, displays the flow of the interactions through the system when it is engaged. The diagram begins at the top left and flows diagonally down to the bottom right side. The diagram displays the feedback loops in the connections made in the other segments. The first input is the user who inputs to the handle by engaging the release. The handle rotates and opens the locking mechanism in the frame. The frame slides along the track which moves the cloth structure containing the CTBs. The user removes the CTB from the unit and retrieves the required cargo.

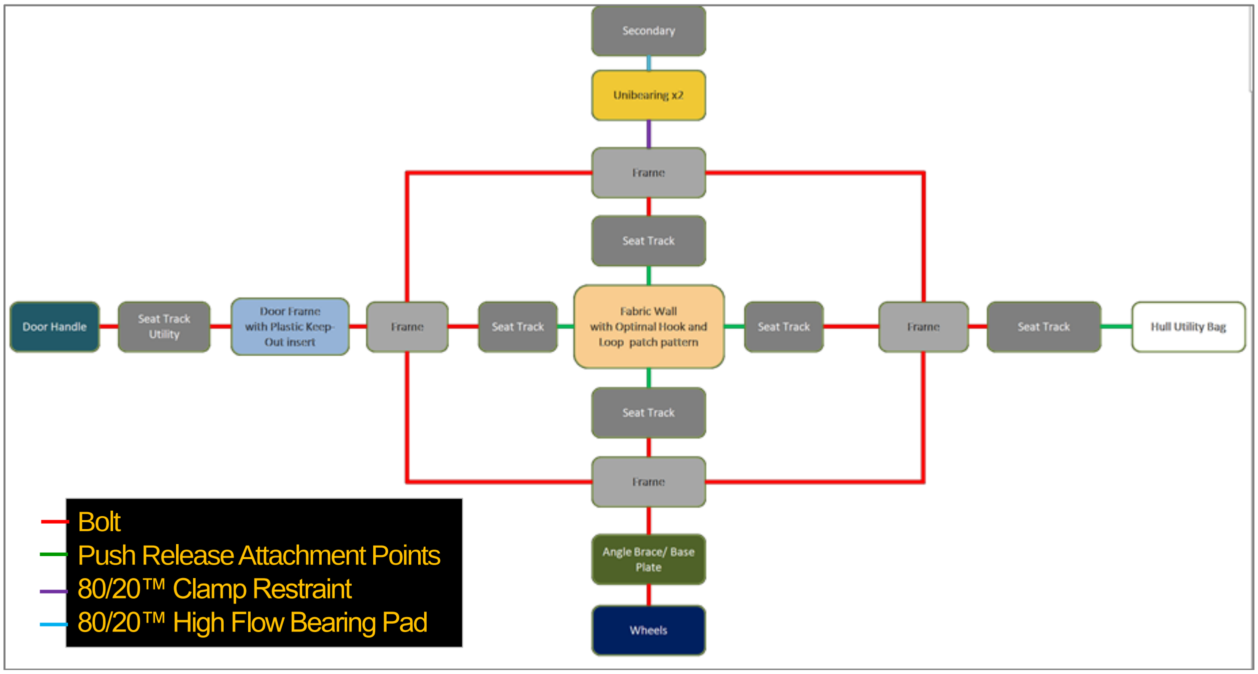



**Fig. 23:** Systems Compatibility Chart

| | | | | | |
|---|---|---|---|---|---|
| **User** | *Engage Release | *Pull Open | | | *Remove CTB |
| *Rotate | **Handle** | *Pull Open | *Release Lock | | |
| | | **Frame** | *Slide Open | *Pull out | |
| | | | **Track** | | |
| | | | | **Beta Cloth** | *Release CTB from Velcro |
| *Cargo received | | | | | **Cargo** |

**Fig. 24:** $N^2$ Diagram

## 6.4 Material Analysis

The rails for the frames will be made of 80/20® structural members. These members are made from 6105-T5 aluminum alloy, which has a yield strength of 35,000 psi and a density of 0.0975 lbs/in$^3$. By comparison, A36 steel, which is a common alloy for steel structural members, has a yield strength of 36,000 psi and a density of 0.284 lbs/in$^3$. Therefore, the chosen material exhibits 97% of the yield strength of steel at about 35% of the weight. Mass reduction was a Level I requirement of the design.

The frames will be fabricated using aluminum 6063 rectangular tubing. The alloy, 6063, was chosen because it has a yield strength of 31,000 psi and an ultimate tensile strength of 35,000 psi. The 6063 alloy has superior extrusion forming characteristics; however, the material in the heat affected zone of the weld becomes 6061 in T0 condition. The T0 condition has approximately a 20% reduction in strength compared to the T6 condition. Therefore, the material may need to be heat treated in order to restore the original T6 mechanical properties. As a result, 6061-T6 aluminum was chosen to make the frames for the doors, the bottom plates, the corner connectors, and the strengthening gibbs.

The linear bearings sold by the 80/20® Company are made from UHMW-PE [16]. This material has a low coefficient of friction versus aluminum; 0.12 static and 0.016 dynamic. This material has a Rockwell "R" hardness value of 67 and self-lubricating properties. Thus, it possesses very desirable wear resistance. This material has been in use in the medical field for joint replacement for the last forty plus years; therefore, no off gasing or health hazards to humans is expected.

The team has selected Class 2 hook and loop fasteners for their flame retardation characteristics. Two inch wide class 2 hook and two inch wide class 2 loop have a breaking strength of 230 pounds according to commercial item specification A-A-55126B [13]. This product has been extensively tested for various military applications.

Material Safety Data Sheets (MSDS) are shown in Appendix E for relevant materials used in the fabrication of the stowage system. The MSDS's delineate the proper procedures for safely handling and interacting with the materials. The datasheets also include physical properties and storage instructions for the materials. In addition, Table 6 provides the mechanical, thermal, and chemical properties for all materials used in the stowage system.

**Table 6:** Material Properties

| | Property | Aluminum 6061[22] | Aluminum 6063[23,24] | Plexiglass[20,21] |
|---|---|---|---|---|
| Mechanical Properties | Modulus of Elasticity | 10 x 10^6 psi | 10 x 10^6 psi | 0.33 x 10^6 psi |
| | Density | 2700 kg/m^3 | 2700 kg/m^3 | 1.2 g/cm^3 |
| | Fatigue Strength | 14 x 10^3 psi | 10 x 10^3 psi | 8.9 x 10^3 psi |
| | Poisson's Ratio | 0.33 | 0.33 | 0.38 |
| | Shear Modulus | 4.9 x 10^6 psi | 4.9 x 10^6 psi | 0.11 x 10^6 psi |
| | Shear Strength | 23.9 x 10^3 psi | 16.9 x 10^3 psi | 10 x 10^3 psi |
| | Ultimate Tensile Strength | 45000 psi | 27000 psi | 9.4 x 10^3 psi |
| | Yield Strength | 40000 psi | 21000 psi | 18000 psi |
| | Brindell Hardness | 95 | 60 | 10 |
| | | | | |
| Thermal Properties | Thermal Conductivity | 154 W/mK | 209 W/mK | 0.2 W/mK |
| | Melting Point | 1070 °F | 1130 °F | 424 °F |
| | Specific Heat | 895 J/kg-K | 900 J/kg-K | 1200 J/kg-K |
| | | | | |
| Chemical Make-up | Aluminum | 95.8 - 98.6% | 97.5% max | - |
| | Chromium | 0.04 - 0.35% | 0.1% max | - |
| | Copper | 0.15 - 0.40% | 0.1% max | - |
| | Iron | 0.007 | 0.35% max | - |
| | Magnesium | 0.8 - 1.2% | 0.45 - 0.90% | - |
| | Manganese | 0.15% max | 0.1% max | - |
| | Silicon | 0.4 - 0.8% | 0.2 - 0.6% | - |
| | Zinc | 0.0025 | 0 | - |

## 6.5 Technical Analysis

Several technical analyses were conducted to verify the system integrity. Three analyses were conducted using Femap® and Nastran® including a moment calculations, kick force deflections, principal and von Mises stress calculations. The team also conducted a volume analysis in order to verify the maximum volume that can be utilized, as well as a shear force analysis.

## 6.5.1 Kick Force von Mises

The von Mises stress analysis was performed on various sections of the system framework and was conducted using Finite Element Analysis (FEA) software. The equation used for the von Mises analysis is shown in Equation (1) below [12].

$$\sqrt{\frac{\quad}{\quad}} \qquad (1)$$

The stress analysis was conducted in order to evaluate the average local stress at specific locations. The first section analyzed was the handle on the front of the system with an applied 125 lb kick force/loading. The handle was constrained on both bolted connection points; in the translational x, y, and z directions as well as the rotational x and z directions. A 125 lb kick loading was applied to the center of the handle. During operational usage, the handle will experience a maximum 50 lb hand load and a 125 lb kick load, so the greater of the two was chosen for the present analysis. The load was applied to the bolt holes holding the handle in place since this would be where the load would be applied if the handle encountered a 125 lb force. The calculated maximum stress resulting to the handle was 4810 psi as shown in Figure 25. This load was considered acceptable as it is less than 50% of the overall yield stress of the material.

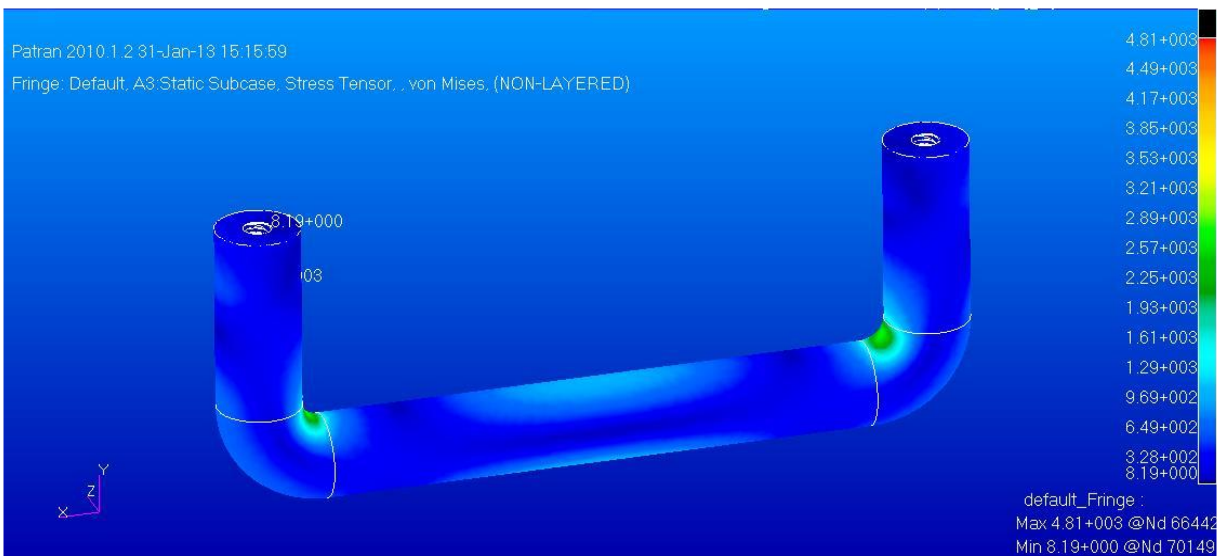



**Fig. 25: Stress Analysis of the Handle**

The next von Mises stress analysis was conducted on the front frame via a 125 lb kick force applied to the center of the beam. The unit's front frame was constrained (in the translational x, y, and z directions and rotational x and y directions) on the center front at four locations- two near the top of the unit and two near the bottom. These constraints were chosen as this is where the frame will be attached to the other parts of the frame and the door unit. A 125 lb kick loading was applied to the center of the frame at the handle interface. This front closeout panel will experience a maximum 50 lb hand load and a 125 lb kick load, so the greater of the two was chosen. The maximum average local stress was calculated to be 4210 psi as shown in Figure 26. This load was considered acceptable because it is less than 50% of the overall yield stress of the aluminum 6063 material.

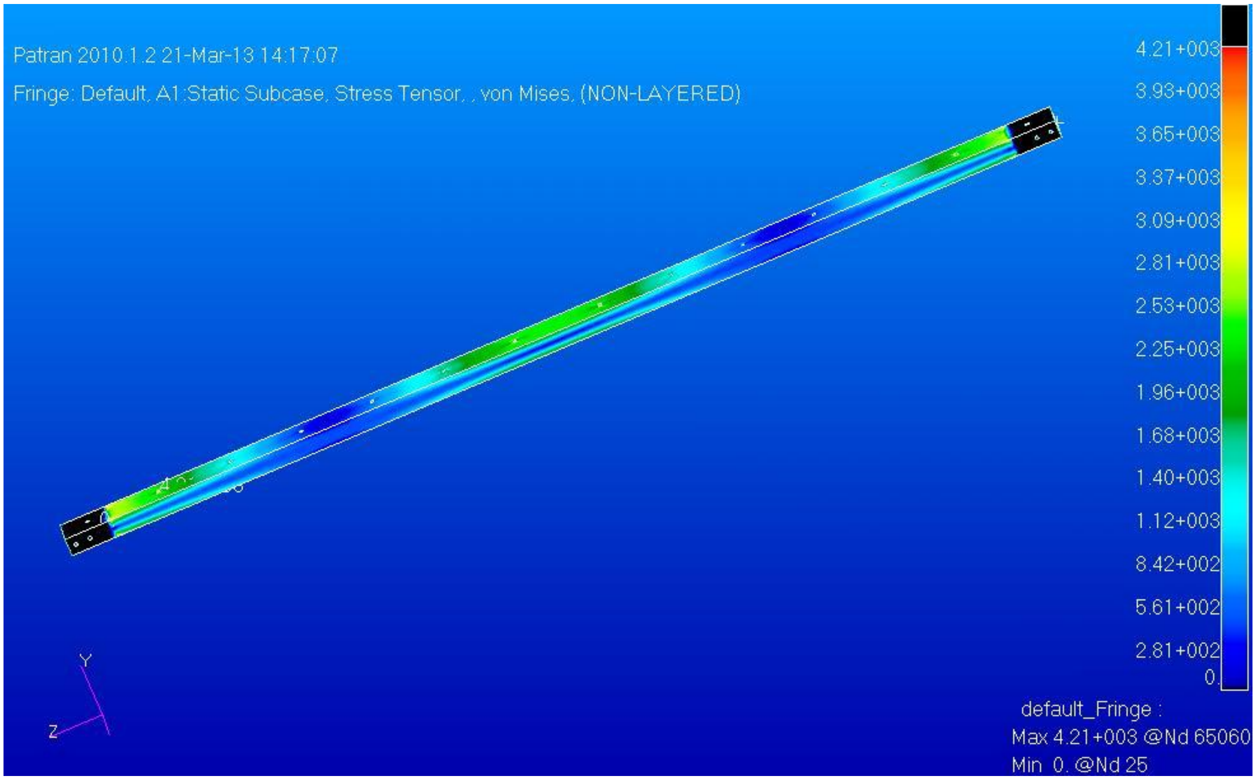


**Fig. 26:** von Mises Stress Analysis of the Unit Frame - Long Piece

The final von Mises stress analysis was conducted on the top of the frame using a 125 lb kick force located at the center of the beam. The unit's top frame was constrained (in the translational x, y, and z directions and rotational x, y and z directions) in the center from left to right in four locations - three near the top of the unit and one near the bottom. These constraints were chosen as this is where the frame will be attached to the other parts of the frame and the track system. A 125 lb kick loading was applied to the center of the frame at the handle interface. The maximum average local stress was calculated to be 3510 psi as shown in Figure 27. This load was considered acceptable because it was less than 50% of the overall yield stress of the aluminum 6063material.

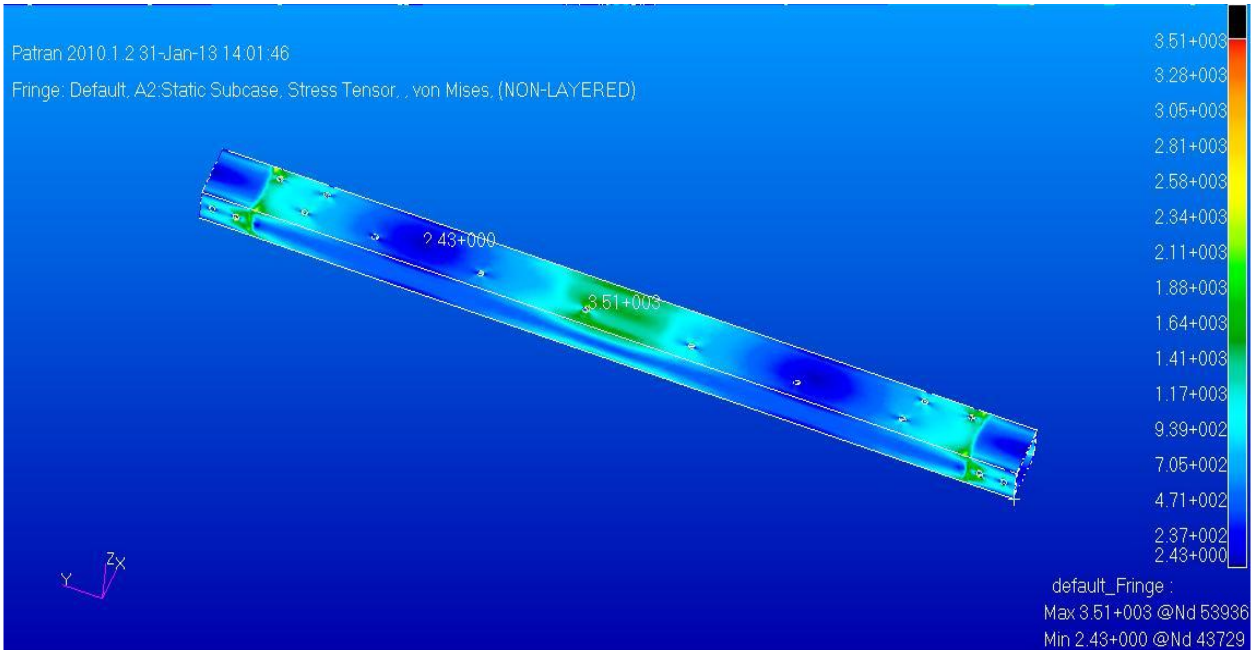



**Fig. 27:** von Mises Stress Analysis of the Frame Top

## 6.5.2 Deflection Analysis

A deflection analysis was performed to verify the maximum deflection of each member of the frame experiencing a 125 lb kick force. This was analysis was conducted in order to verify that the system would not undergo critical deformation, lock the track, or cause system failure. The equation used for the deformation analysis is as follows [12]

$$ - \qquad (2) $$

with load and boundary conditions the same as the von Mises and maximum principal stress calculations.

The first section analyzed was the handle of each unit with an applied 125 lb kick force. The load was applied to the exposed section of the handle, directed inward. The handle was constrained (in the translational x, y, and z directions and rotational x and z directions) at each connection point. These constraints were chosen as these are where the handle will be fastened to the frame behind it. A 125 lb kick loading was applied to the center of the frame at the handle interface. This front closeout panel will experience a maximum 50 lb hand load and a 125 lb kick load, so, again, the greater of the two was selected. The maximum deflection was determined to be 0.000798 in - as shown in Figure 28. This result was considered acceptable as it is within the margin of deflection set by the team of 0.1 in.

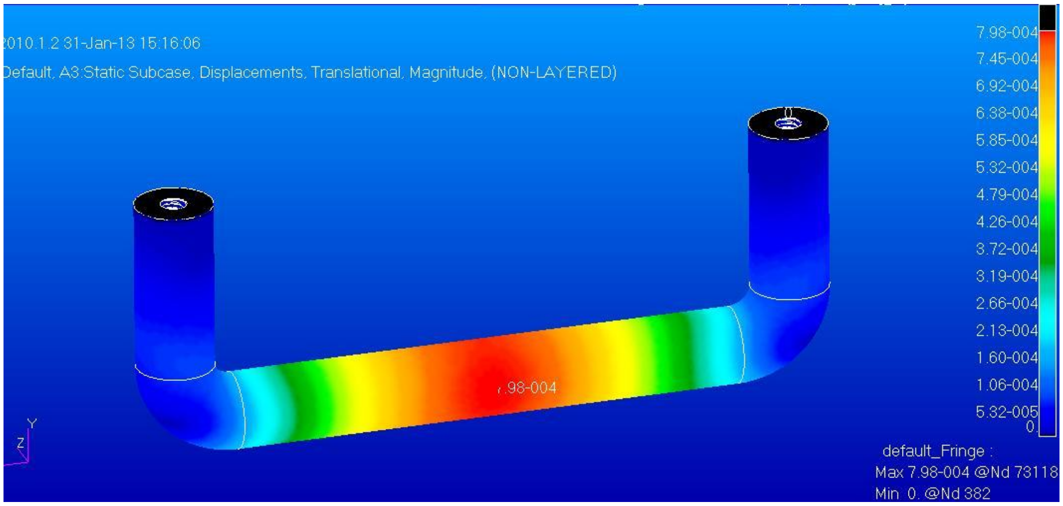



**Fig. 28:** Deflection Analysis for Handle Interface

The next deflection analysis was conducted on the front frame by simulating a 125 lb kick force located at the center of the beam. The unit's front frame was constrained (in the translational x, y, and z directions and rotational x and y directions) in four locations - two near the top of the unit and two near the bottom. These constraints were chosen because this is where the frame will be attached to the other parts of the frame and the door unit. A 125 lb kick load was applied to the center of the frame at the handle interface. This front closeout panel will experience a maximum 50 lb hand load and a 125 lb kick load, so the greater value was chosen. The maximum deflection was determined to be .0754 in as shown in Figure 29. This result was within the margin of deflection set by the team and is considered acceptable.

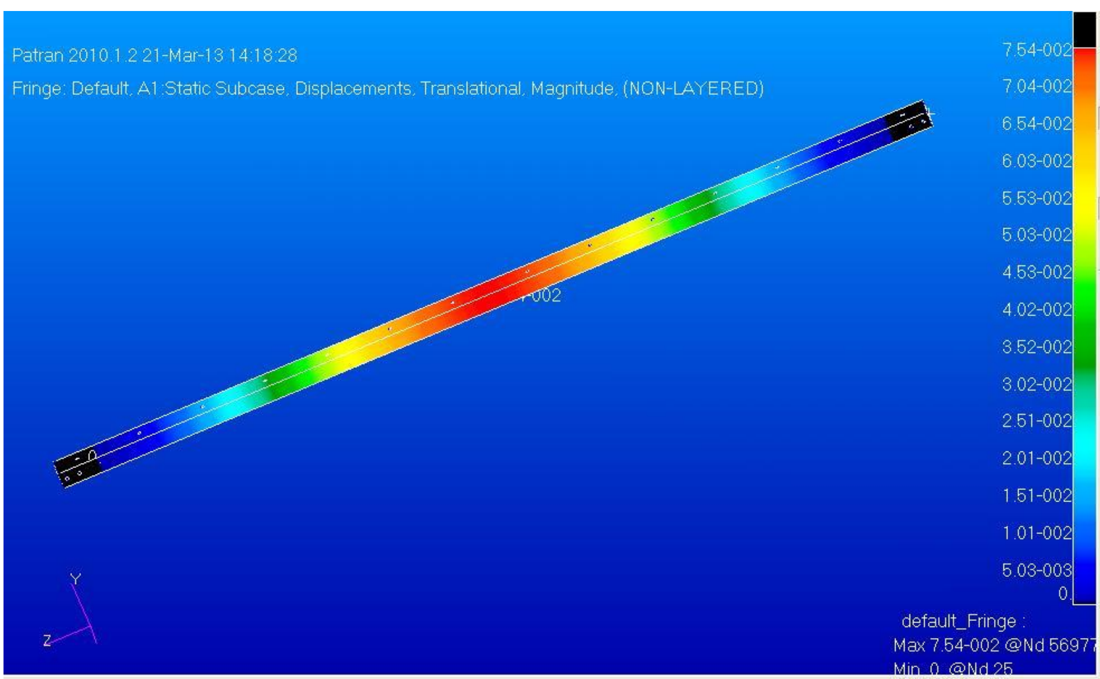



**Fig. 29:** Deformation Analysis of Front of Frame

The final deflection analysis was conducted on the top of the frame using a 125 lb kick force located at the center of the beam. The unit's top frame was constrained (in the translational x, y, and z directions and rotational x, y, and z directions) in the center in four places - three near the top of the unit and one near the bottom. These constraints were chosen because this is where the frame will be attached to the other parts of the frame and the track system. A 125 lb kick loading was applied to the center of the frame at the handle interface. The maximum deflection was calculated to be .0122 in as shown in Figure 30. This result was within the margin of deflection set by the team and is considered acceptable.

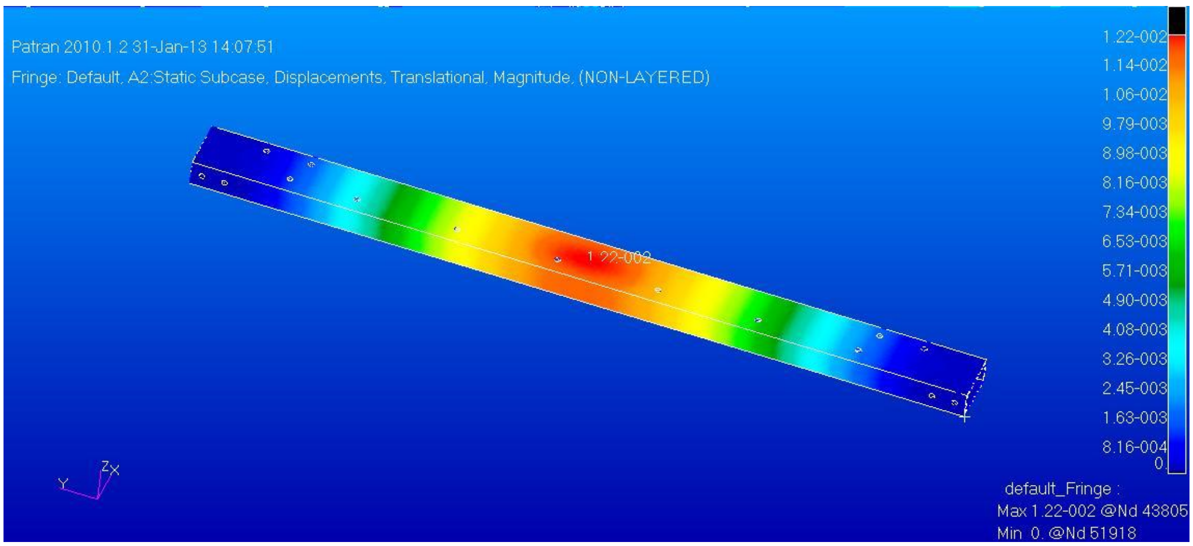



**Fig. 30:** Deformation Analysis of Frame Top

## 6.5.3 Shear Calculations

The shear analysis was conducted using the singularity function to determine the shear at the location of the fasteners. This provided data that was used in determining the materials and design of the framework supporting the cloth wall. The analysis was conducted assuming a 200 lb load distributed evenly across the top track. In equilibrium, the shear analysis was conducted to determine the shear in the frame at the fastener locations. The derived equations and values are shown below for shear analysis at fastener locations along top track (4 fasteners 12.5 inches apart starting at end) with 5.33 lb/in distributed load along the frame:

The error due to the approximation of the distributed load is shown in the stress value of .125 psi. This value should approach zero. The shear analysis concludes that a shear of approximately 50 psi will occur at the edges of the frame and will be the maximum shear of the frame. The material selected will be able to handle these shear stresses with a maximized factor of safety. Figure 31 and Figure 32 display the shear diagrams for the track system connected to the frame, and the frame itself.

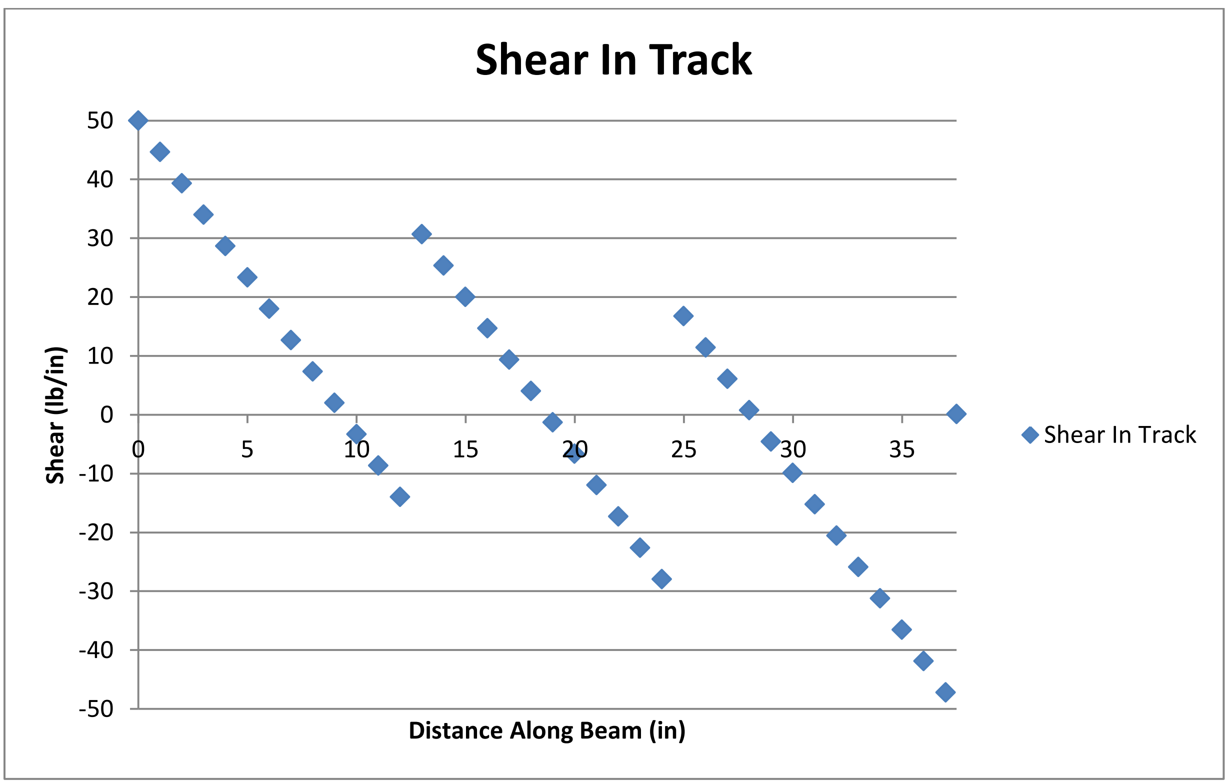



**Fig. 31:** Shear Diagram of Track

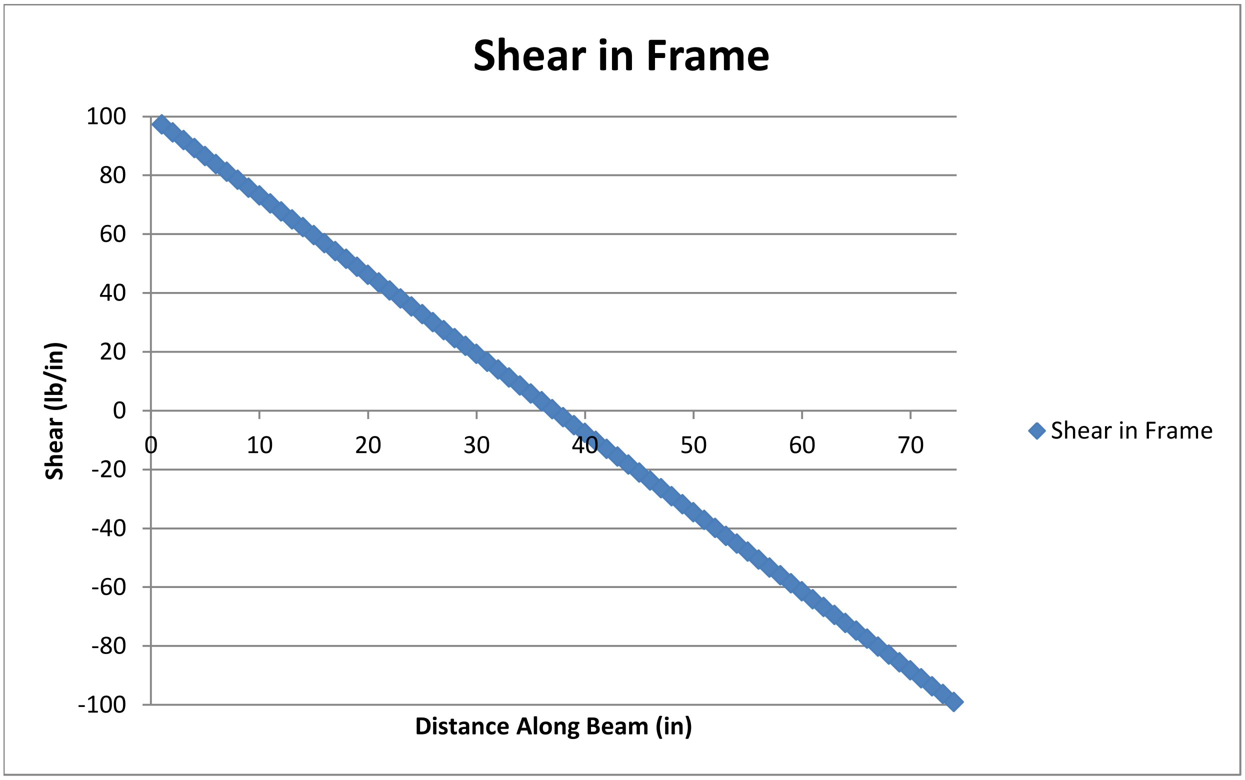



**Fig. 32:** Shear Diagram for Frame

## 6.5.4 Volume Analysis

Given the dimensions of the allocated DSH cubical area of 81.25"x37.5"x81.1" the volume of the cubical area is 247,101.56 $in^3$. This does not include the curvature of the DSH. The total volume including the curvature is 308,382.75 $in^3$. The volume of the CTBs the system is designed for (56 bags) is 180,623.63 $in^3$. This means that the CTBs utilize 73% of the DSH volume without the curvature. The curvature adds approximately 61,281.19 $in^3$ of DSH volume for empty CTB and cloth wall storage. This means to CTB storage volume is 241,904.82 $in^3$ - or 78% - including the customized bag for the curvature, and 66,477.93 $in^3$, or 21.5% of the total volume, for framework. These results are summarized in Table 7 below.

**Table 7:** Volume Analysis Results

| Item | Volume | Percentage of Total Volume |
|---|---|---|
| Framework | 66,477.93 $in^3$ | 21.5% |
| CTB Storage | 241904.82 $in^3$ | 78.5% |

## 6.6 Human Factors

The design of the system is completely mechanical in nature. No electrical components were used in the design of the system. The completely mechanical design promotes ease of use and will require no training or expertise to operate. The user will pull a handle to release the system in order to slide a unit for use. The user then removes or replaces a CTB onto the cloth structure depending on the situation. The user will slide the unit back into place. This will close the system. There are stops installed on the track to stop the unit from sliding too far out or too far in.

The system can still utilize the operational nomenclature (Opsnom) combo labels currently used on orbit. A proposed filing system for the bags is to number each unit numerically (1, 2, 3…) as shown in Figure 33. The horizontal levels of each unit are given an "A" or "B" designation. Each row is given a numerical designation from the bottom up (1-7). A sample label (3A3) is shown in Figure 34. Ergonomically, the bags that need to be used most often need to be placed between 36-72 inches above the floor. This meets the reach requirements specified in NASA/SP-2010-3407 [17]. The UAH designed system will accommodate the 50 lb kick load defined in the NASA/SP-2010-3407 [17]. The final stowage system product has ergonomically designed handles. The placement of the handles conforms to requirements for standard table top height (36-72 inches from the DSH module floor). The cloth shelving and Velcro® patches are white to conform to the requirements of flight hardware. The spacing between CTBs is 0.3" in the vertical direction and 0.4" in the horizontal direction to allow adequate space to remove and replace CTBs. Labels are stamped on all system components for ease of assembly/disassembly.

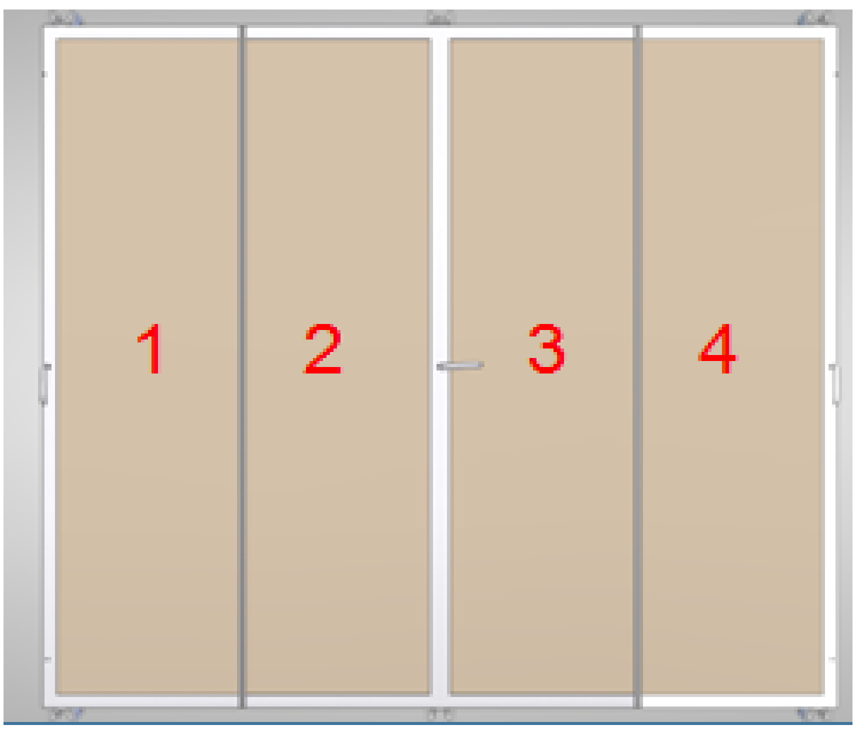



**Fig. 33:** Full System - Front View

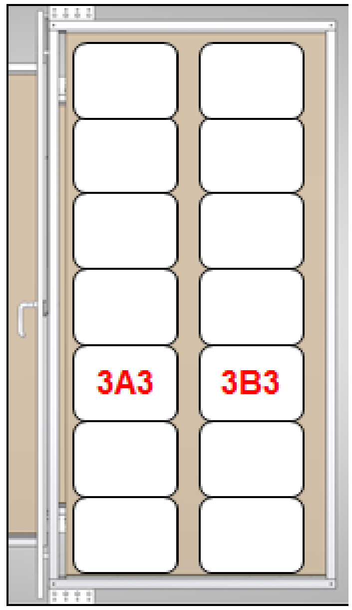



**Fig. 34:** Fully Loaded Unit - Side View

In order to warn users of potential hazards, labels are placed on the final demonstration product. As shown in Figure 35, a label was placed on each door panel to warn users that the units are moving objects.


**Fig. 35:** Moving Object Warning Label

A pinch point warning label, shown in Figure 36, was placed near the gap between units to warn users that the gap is smaller than 1”. Figure 37 shows where the warning labels are actually placed on the final stowage system.


**Fig. 36:** Pinch Point Warning Label

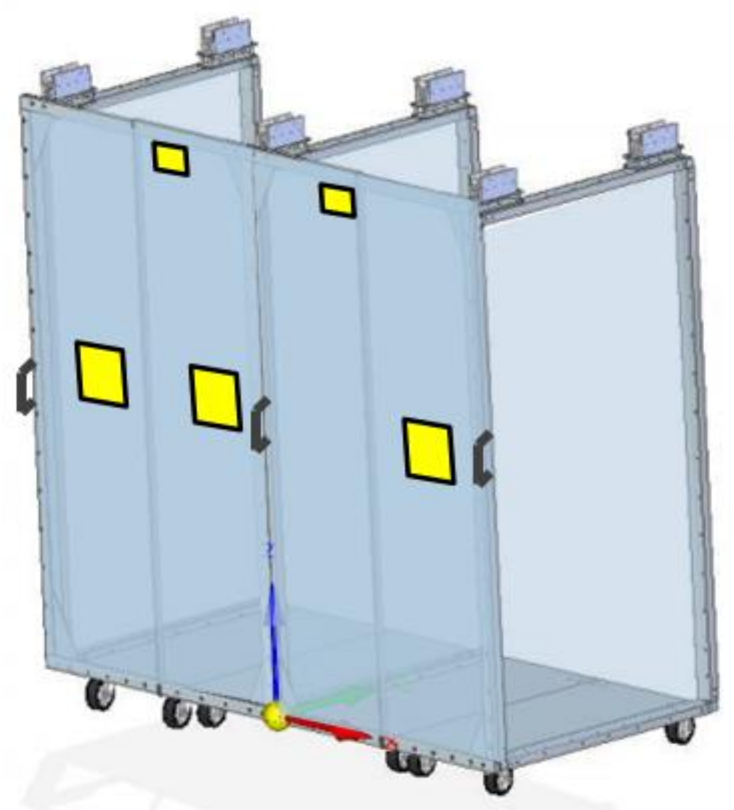


**Fig. 37:** Label Placement

## 7.0 Detail Design and Fabrication

This section provides a detailed description of the final design solution for the Zero-G system and the actual One-G demonstration product. Content includes detailed drawings, part specifications, manufacturing methods and results, assembly and installation methods, operational and maintenance instructions, and verification tests.

## 7.1 Product Design Specifications

A Product Design Specifications (PDS) document was created in order to detail all design solution specifications. The PDS establishes the purpose, functional requirements, corporate constraints and social, political and legal requirements for the NASA X-Hab Microgravity Random Access Stowage & Rack System Project. The complete PDS is included in Appendix F.

## 7.2 Detailed Drawings

The system designed by the UAH team addresses multiple challenges prescribed by the 2013 academic challenge. The designed system will exist in a microgravity environment and was designed for such. However, as the fabricated design would be utilized in a One-G DSH environment, certain differences exist between the Zero-G design and the One-G design. Both designs are composed primarily of aluminum; chosen for its strength to weight advantage and the team's desire to reduce the launch costs as much as possible. The system has an aluminum tubing frame and is modular in design with the focus on openness and simplicity. It guides along the secondary structure - 15/15 aluminum track - and utilizes a Commercial Off-The-Shelf (COTS) design solution via the use of 80/20® and a Unibearing™ Assembly. The system mounts to the frame via the common anchor interface used with 80/20®. This allows the shelf to fully extend for ease of access. The shelf is restrained by the locking mechanism that extends into the secondary frame work, controlled by the handle in the center of the unit. The shelf slides out, which reveals the interior design solution: a cloth structure that utilizes hook and loop fasteners that will serve as the CTB attachment points. The door itself has a frame of aluminum, with the interior made of a composite material, to provide a solid close out panel to prevent unintended interactions. For detailed design drawings refer to Appendix G. Figure 38 provides a general rendering of the system as it would appear in the capsule.

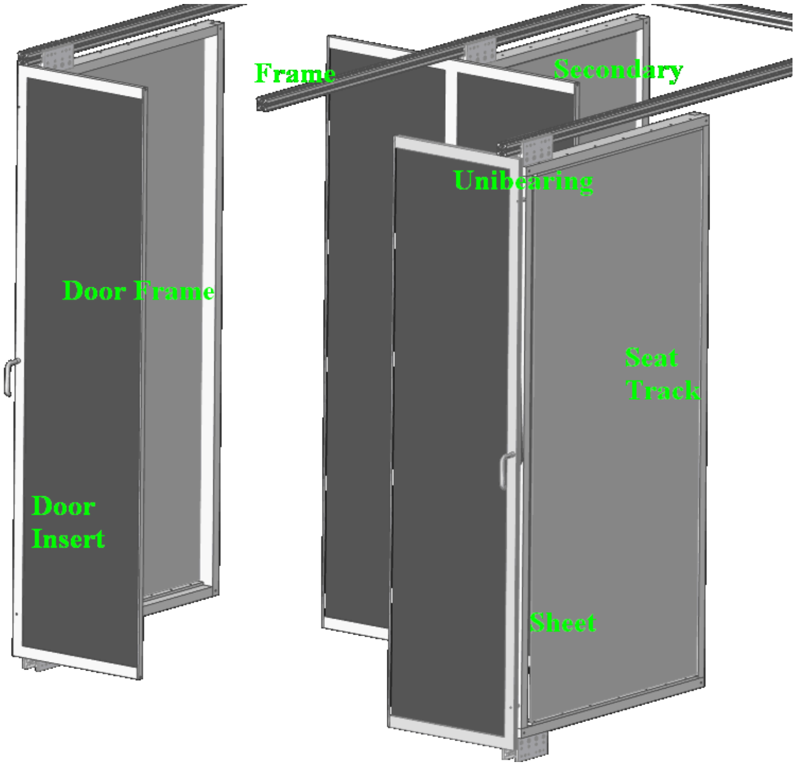



**Fig. 38:** Complete Zero-G System

As stated, some design differences exist between the microgravity, Zero-G design and the fabricated, One-G MSFC DSH demonstration product. The demonstration stowage system has base plates along the system floor in order to support demonstrational CTB loading in One-G operating environments. Fixed-rotation casters attached to the One-G stowage system support structure on the bottom of the system replace the track in the Zero-G design and make demonstrational translation in the DSH module possible. Reinforcements, in the form of gussets, were also added to the doors to offer needed support in One-G environments. Drawings of the aforementioned parts of the final One-G demonstration product are shown in Appendix H. Figure 39 display a rendering of the One-G stowage system with parts labeled.

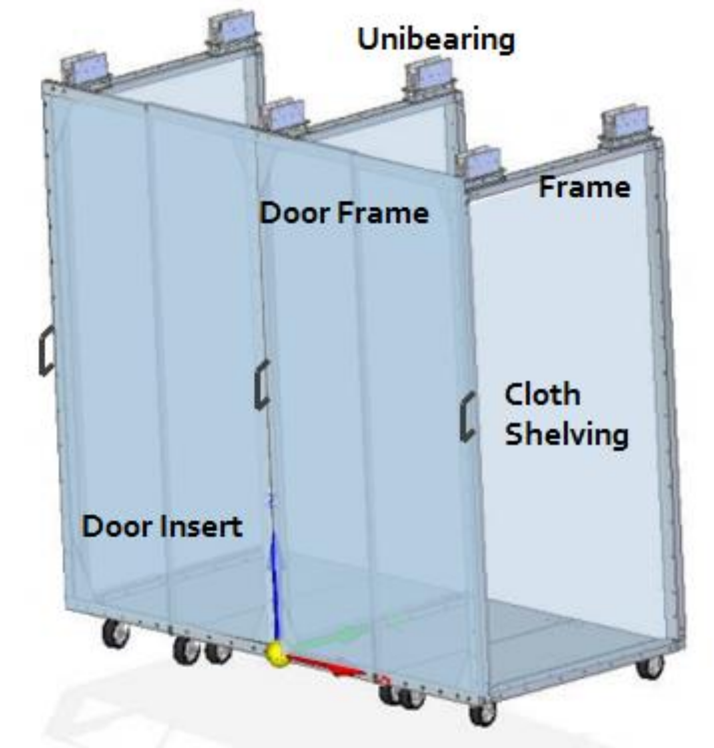



**Fig. 39:** One-G System

## 7.3 Parts List

The present section details the fabricated One-G system parts organized by subsystems as delineated in Tables 8, 9 and 10. The information provided details quantity, purpose, dimensions, and component source. Refer to Appendix H for parts drawings corresponding to each part listed Table 8.

**Table 8:** Center Unit

| Part Name | Quantity | Purpose | Material | Part Origination | Manufacturing/ Machining |
|---|---|---|---|---|---|
| Vertical Frame Component | 2 | Load Bearing Framework | Aluminum | Watring | COTS |
| Horizontal Frame Component | 2 | Load Bearing Framework | Aluminum | Watring | COTS |
| Frame Joint | 4 | Connecting Frame Components | Aluminum | Watring | COTS |
| Long Vertical Seat Track | 4 | To attach canvas wall | Aluminum | Watring | COTS |
| Horizontal Seat Track | 2 | To attach canvas wall | Aluminum | Watring | COTS |

| **Table 8:** Center Unit (cont.) | | | | | |
|---|---|---|---|---|---|
| Long Angle Aluminum | 2 | To attach the base plate | Aluminum | Watring | COTS |
| Short Angle Aluminum | 2 | To attach the base plate | Aluminum | Watring | COTS |
| Base Plate | 2 | To hold up the system | Aluminum | Watring | COTS |
| Gusset | 2 | Hold the Door Panel in place | Aluminum | Watring | COTS |
| Vertical Door Flange | 1 | Hold the Door Panel in place | Aluminum | Watring | COTS |
| Horizontal Door Flange | 2 | Hold the Door Panel in place | Aluminum | Watring | COTS |
| Thin VDCS Plate | 2 | Adjust for uneven floors | Aluminum | Watring | COTS |
| Thick VDCS Plate | 2 | Adjust for uneven floors | Aluminum | Watring | COTS |
| Door Panel | 2 | Keep items in unit | Plastic | Watring | COTS |
| Handle | 1 | Pull/Push unit in/out | Aluminum | Watring | COTS |
| Unibearing™ | 2 | keep unit going straight | Aluminum | Watring | COTS |
| Caster | 6 | allow the unit to roll in/out | | Watring | COTS |
| Door End Bar | 2 | keep door panel in place | Aluminum | Watring | COTS |
| Fasteners | as needed | to hold parts together | Varies | Watring | COTS |
| Canvas Wall | 1 | Hold the CTBs | Canvas | Watring | COTS |
| Steel Rings | as needed | Hold Canvas Wall | Steel | Watring | COTS |

**Table 9:** Left Unit

| Part Name | Quantity | Purpose | Material | Part Origination | Manufacturing/ Machining |
|---|---|---|---|---|---|
| Vertical Frame Component | 2 | Load Bearing Framework | Aluminum | Watring | COTS |
| Horizontal Frame Component | 2 | Load Bearing Framework | Aluminum | Watring | COTS |
| Frame Joint | 4 | Connecting Frame Components | Aluminum | Watring | COTS |
| Long Vertical Seat Track | 4 | To attach canvas wall | Aluminum | Watring | COTS |
| Horizontal Seat Track | 2 | To attach canvas wall | Aluminum | Watring | COTS |
| Long Angle Aluminum | 1 | To attach the base plate | Aluminum | Watring | COTS |
| Short Angle Aluminum | 1 | To attach the base plate | Aluminum | Watring | COTS |
| Base Plate | 1 | To hold up the system | Aluminum | Watring | COTS |
| Gusset | 2 | Hold the Door Panel in place | Aluminum | Watring | COTS |
| Vertical Door Flange | 1 | Hold the Door Panel in place | Aluminum | Watring | COTS |
| Horizontal Door Flange | 2 | Hold the Door Panel in place | Aluminum | Watring | COTS |
| Thin VDCS Plate | 2 | Adjust for uneven floors | Aluminum | Watring | COTS |
| Thick VDCS Plate | 2 | Adjust for uneven floors | Aluminum | Watring | COTS |
| Door Panel | 1 | Keep items in unit | Plastic | Watring | COTS |
| Handle | 1 | Pull/Push unit in/out | Aluminum | Watring | COTS |
| Unibearing™ | 2 | keep unit going straight | Aluminum | Watring | COTS |
| Caster | 4 | allow the unit to roll in/out | | Watring | COTS |
| Door End Bar | 1 | keep door panel in place | Aluminum | Watring | COTS |
| Fasteners | as needed | to hold parts together | Varies | Watring | COTS |
| Canvas Wall | 1 | Hold the CTBs | Canvas | Watring | COTS |
| Steel Rings | as needed | Hold Canvas Wall | Steel | Watring | COTS |

**Table 10:** Right Unit

| Part Name | Quantity | Purpose | Material | Part Origination | Manufacturing/ Machining |
|---|---|---|---|---|---|
| Vertical Frame Component | 2 | Load Bearing Framework | Aluminum | Watring | COTS |
| Horizontal Frame Component | 2 | Load Bearing Framework | Aluminum | Watring | COTS |
| Frame Joint | 4 | Connecting Frame Components | Aluminum | Watring | COTS |
| Long Vertical Seat Track | 4 | To attach canvas wall | Aluminum | Watring | COTS |
| Horizontal Seat Track | 2 | To attach canvas wall | Aluminum | Watring | COTS |
| Long Angle Aluminum | 1 | To attach the base plate | Aluminum | Watring | COTS |
| Short Angle Aluminum | 1 | To attach the base plate | Aluminum | Watring | COTS |
| Base Plate | 1 | To hold up the system | Aluminum | Watring | COTS |
| Gusset | 2 | Hold the Door Panel in place | Aluminum | Watring | COTS |
| Vertical Door Flange | 1 | Hold the Door Panel in place | Aluminum | Watring | COTS |
| Horizontal Door Flange | 2 | Hold the Door Panel in place | Aluminum | Watring | COTS |
| Thin VDCS Plate | 2 | Adjust for uneven floors | Aluminum | Watring | COTS |
| Thick VDCS Plate | 2 | Adjust for uneven floors | Aluminum | Watring | COTS |
| Door Panel | 1 | Keep items in unit | Plastic | Watring | COTS |
| Handle | 1 | Pull/Push unit in/out | Aluminum | Watring | COTS |
| Unibearing™ | 2 | keep unit going straight | Aluminum | Watring | COTS |
| Caster | 4 | allow the unit to roll in/out | | Watring | COTS |
| Door End Bar | 1 | keep door panel in place | Aluminum | Watring | COTS |
| Fasteners | as needed | to hold parts together | Varies | Watring | COTS |
| Canvas Wall | 1 | Hold the CTBs | Canvas | Watring | COTS |
| Steel Rings | as needed | Hold Canvas Wall | Steel | Watring | COTS |

## 7.4 Manufacturing Methods

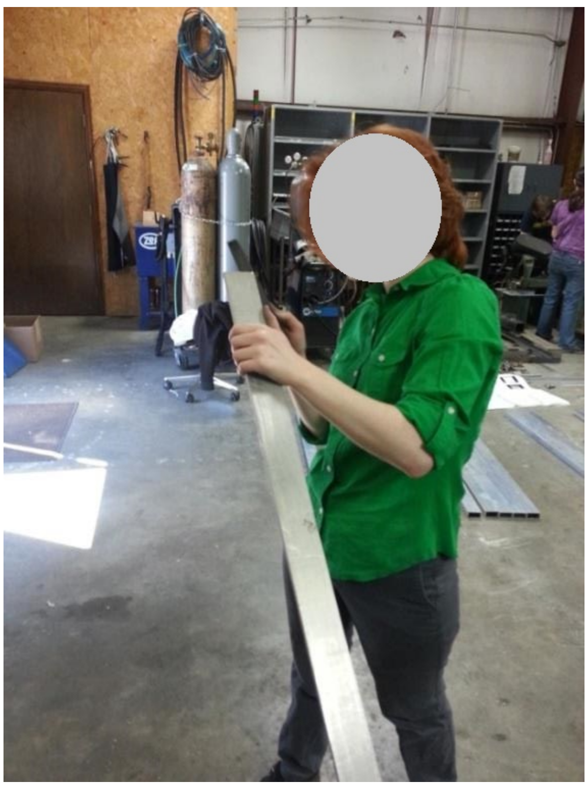
Manufacturing of the One-G stowage system components began by establishing contact early with the fabrication consultant, Watring Technologies, Inc. The UAH design team thoroughly discussed the fabrication requirements with the consultant. Watring Technologies, Inc. subsequently placed an order with L. Miller & Son, Inc. (Huntsville, AL) to have the basic pieces of material water jet cut from one-eighth inch, one-quarter inch, three-quarter inch, and three inch thick 6061 aluminum stock. The material was cut primarily to finished dimensions and delivered to Watring Technologies, Inc. by Larry Mayo. Watring Technologies appointed Larry Mayo to serve as the lead assembler to oversee the construction of the stowage unit. The remaining aluminum components, including aluminum box tubing, the 80/20® rail, and Unibearings™, were delivered to Watring Technologies. The fabric walls were the final remaining major component obtained during the fabrication phase. The walls were constructed by Mathis Upholstery (Huntsville, AL). After final delivery of the last metal components, work commenced to fabricate the frame for the stowage system units. Upon completion of the frame, measurements were verified for the fabric walls. The measurements were sent to Mathis Upholstery to complete the fabric wall via the provision of dimensioned drawings.

Some of the aluminum pieces that L. Miller & Son, Inc. delivered to Watring Technologies were not cut to the exact finished dimensions and required secondary operations. Machinists at Watring Technologies, Inc. completed the secondary operations. The three inch thick aluminum pieces were water jet cut into the shape of an "L". The pieces served as corner pieces and connectors for the box tubing. Approximately one-quarter of an inch had to be machined from the three inch thickness so that the pieces would slide inside of the rectangular aluminum tubing. The three-quarter inch thick material was sawed to length and then had a step machined along the sides to accept the window panes. The machining was completed by Gerald Lanz, Senior Engineer at Watring Technologies. After the box tubing was cut to length, the first four frames were dry fitted together and then matched drilled with a quarter inch drill bit so that the main frames could be held together with quarter inch hex head fasteners. All of the construction operations that were performed at Watring Technologies were completed during a four day period that spanned a Thursday through Saturday.

After the first weekend of construction, it was determined that the best course of action would be to relocate all of the metal items to Larry Mayo's workshop where the members of the UAH team could contribute to fabrication of the product without violating Watring Technologies company policies. Larry Mayo served as the communication link between Watring Technologies and the UAH project team. During the second weekend of fabrication operations, the final two frames were fitted, drilled, and bolted together. Addition of seat track to the inside of the frame followed for anchoring of the fabric wall. The three-quarter inch aluminum bars were fitted together to form window frames for the doors. The window frames were fitted to the main frames with the one-eighth inch plates in position, and all components were matched drilled to facilitate the major assembly portion. Much of the attachment was done by self-drilling screws long enough to penetrate all of the layers of components. Primary mount points of the window frame to the main frame were drilled to accept compression nuts to aid in the disassembly and reassembly of the units. Match drilling and light machining continued during the UAH spring break until the frames were completed and free standing units were finished.

The final assembly steps began with the attachment of the one-quarter inch floor plates to the frames. With this step completed, the layout, drilling, and installation of the casters followed. The plexi-glass for the front door panel windows was ordered after the door frames were completed to ensure proper dimensions were sent to the glass company so that the panes could be exactly cut to size. With the arrival of the fabric walls, which were only temporarily installed to check the accuracy of construction and size, construction was completed. Because the fabric arrived late, it was the last item to be installed in the stowage system units. Fabrication was completed on Saturday, April 13, 2013, with the disassembly of the stowage system that afternoon for transportation to MSFC the following Monday, April 15, 2013.

Refer to section 7.3 for the parts/components list for the stowage system. Refer to section 7.2, Appendix G, and Appendix H for detailed CAD drawings in deployed and stowed states and mechanical drawings including drawings of each part with dimensions and units specified. Pictures showing the fabrication, assembly, installation, and demonstration of the final stowage system project are shown in Figures 40-46.



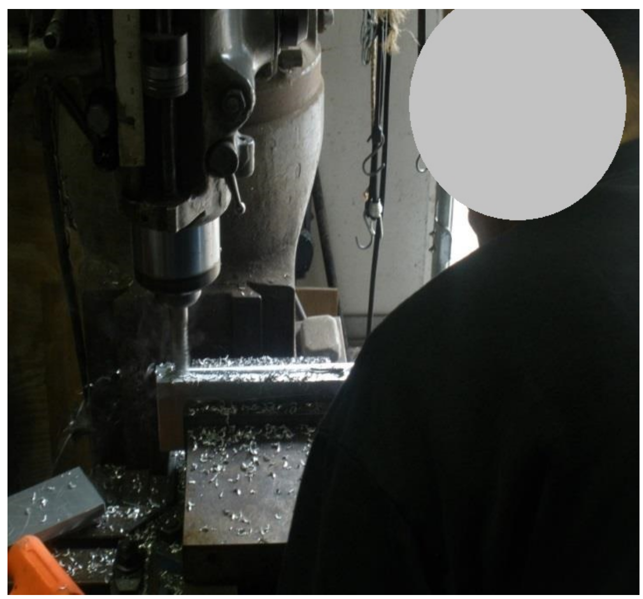


**Fig. 40:** UAH Team Members Fabricating Parts

**Fig. 41:** One-G Aluminum Structural Frame

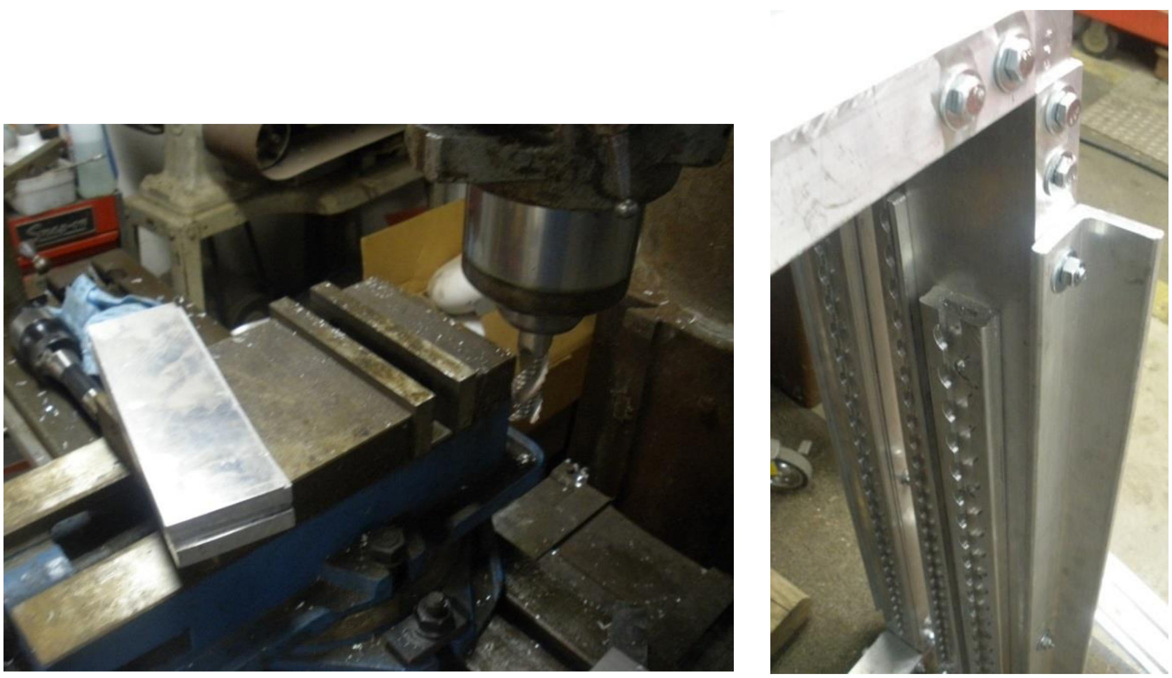


**Fig. 42:** Fabricated Structural Members

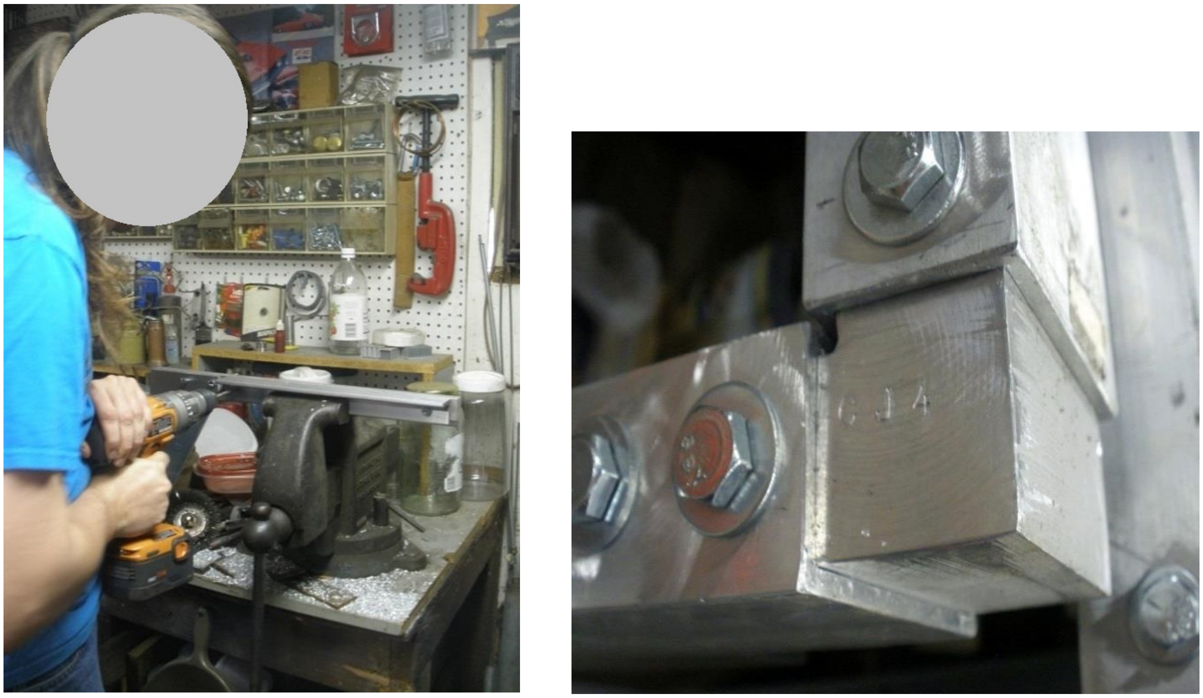


**Fig. 43:** Labeled Structural Members

**Fig. 44:** MSFC DSH One-G System Installation

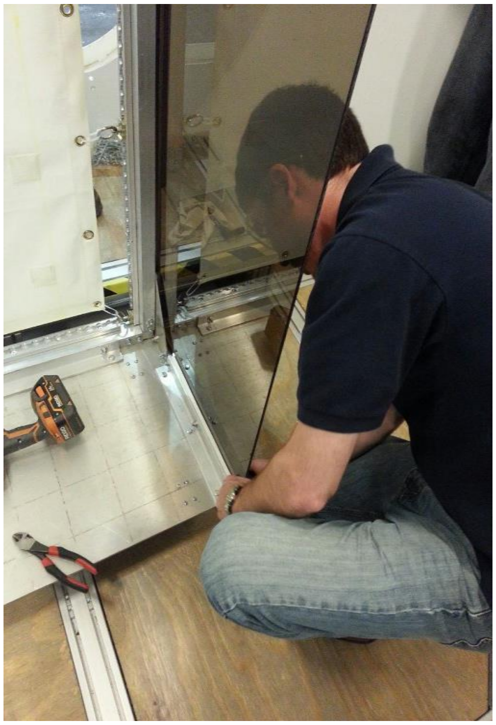



**Fig. 45:** One-G System Base Plate Installation


**Fig. 46:** Final One-G System Installed at MSFC

## 7.5 Operations Manual

A complete Operations Manual [18] was produced in order to document proper operations, assembly/disassembly, installation, maintenance, storage, and utilization of the stowage system product. The manual also contains the Concept of Operations, instructions for daily maintenance, repair procedures, deploy/stow procedures, and a parts list.

## 7.6 Verification Tests

Table 11 details the verification tests completed and the results. Specifically, a Velcro® life cycle test and dynamic vibration modal test were completed. The Velcro® life cycle test was performed by the design team required one day to complete. The test involved using a sample of Velcro® to be used on the canvas sheet as the fastening points for the Velcro® patches on the CTBs. The test sample included two pieces of Velcro®, a hook piece and loop piece, and involved adhering the two pieces together, pulling them apart, and documenting the number of cycles completed to failure. The results from this test concluded that the Velcro® had a life of 10,000 cycles. From calculation and data interpretation of the results, it was concluded that the Velcro® was adequate in the application of intended use within the stowage system and has an estimated usable life of three years.

**Table 11:** Verification Tests

| Test | Date | Purpose | Location | Duration | Cost | Assistance Required |
|---|---|---|---|---|---|---|
| Velcro® Life Cycle Test | December 2012 | Determine the average life cycle of the Velcro® patches | UAH | 1 day | | None |
| Vibration Test | April 11-12, 2013 | Determine natural frequencies of the system's frame | NASA MSFC Building 4619 | 2 days | | NASA MSFC personnel |

As detailed in Table 11, additional testing was completed in order to further verify and validate the designed and manufactured One-G system. A dynamic modal survey test was completed on the framing substructure of the stowage system. The test spanned the course of two days and was completed by MSFC personnel at NASA MSFC Building 4619. UAH design team members were responsible for producing and providing an initial test plan to NASA MSFC personnel as well as oversight and observation of the test for documentation purposes. The design team calculated the natural frequencies of the frame before the test in order to provide a frequency range that would capture all critical vibrations in the structure. Figure 47 includes the equation and results from this calculation. The actual dynamic modal test involved placing the aluminum framing structure on soft foam in order to simulate a free-free boundary condition.

**Case Number 2b. Uniform beam; both ends fixed**

Uniform Load (w) per unit length including beam weight

$$f_n = \frac{K_n}{2\pi}\sqrt{\frac{EIg}{wl^4}}$$

$f_n$ = natural frequency (cycles per second)
$K_n$ = constant where n refers to the mode of vibration
$g$ = gravitational acceleration (units consistent with length dimensions)
$E$ = modulus of elasticity
$I$ = area moment of inertia
$l$ = length of beam
$w$ = weight of beam + uniform loading

**Natural Frequency Calculation for Horizontal Tubing (Short Aluminum Tubing)**

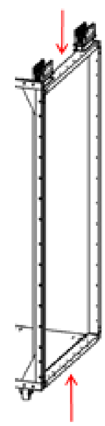
| Mode | Kn (constant w.r.t. mode of vibration) | Natural Frequency, f (cycles/sec) | Number of Sensors Needed for Mode Shape |
|---|---|---|---|
| 1 | 22.4 | 194.422 | 3 |
| 2 | 61.7 | 535.528 | 5 |
| 3 | 121 | 1050.226 | 7 |
| 4 | 200 | 1735.910 | 9 |
| 5 | 299 | 2595.186 | 11 |

6063 Aluminum Square Tubing

Dimensions: 2.5"x1.25x0.125"

l = 3.125 ft
E = 1.44e9 lb/ft^2
weight/ft = 1.393 lbs
w = weight of tube = 4.35 lbs
I = 2.66087963 × $10^{-5}$ ft^4
g = 32.2 ft/s^2

Frequency Range for Testing: 0-3000 Hz



**Natural Frequency Calculation for Vertical Tubing (Long Aluminum Tubing)**

| Mode | Kn (constant w.r.t. mode of vibration) | Natural Frequency, f (cycles/sec) | Number of Sensors Needed for Mode Shape |
|---|---|---|---|
| 1 | 22.4 | 28.234 | 3 |
| 2 | 61.7 | 77.769 | 5 |
| 3 | 121 | 152.514 | 7 |
| 4 | 200 | 252.089 | 9 |
| 5 | 299 | 376.872 | 11 |

6063 Aluminum Square Tubing

Dimensions: 2.5"x1.25x0.125"

l = 6.76 ft
E = 1.44e9 lb/ft^2
weight/ft = 1.393 lbs
w = weight of tube = 9.42 lbs
I = 2.66087963 × $10^{-5}$ ft^4
g = 32.2 ft/s^2

Frequency Range for Testing: 0-500 Hz

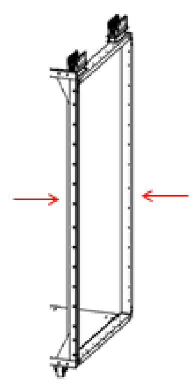


**Fig. 47:** Pre-test Calculations of Frame Structure's Natural Frequencies

The frequency range used for all testing was 0-400 Hz. A roving impact hammer and five triaxial accelerometers were used to excite structural modes and record vibrations within the frame to determine the natural frequencies of the structure. Frequency Response Functions (FRFs) were acquired by vibration diagnostic analysis software for each impact location. Three-dimensional modal images were produced to model the frame's behavior to the impacts. Important results from the test are highlighted below:

- The system's frames have no modes near known forcing functions
- The frame has a Mode 1 at 2.29 Hz and was identified as a rigid body mode (global mode) causing the system to rock in the x direction identified in Figure 48
- The frame has a Mode 2 at 2.493 Hz and was identified as a rigid body mode (global mode) causing the system to rock in the y direction identified in Figure 48
- The frame has a Mode 3 at 6.463 Hz and was identified as a torsional mode about the z axis identified in Figure 48
- The frame also has a Mode at 55 Hz causing the vertical aluminum supports to experience a $2^{nd}$ bending in the x and y directions identified in Figure 49

After reviewing the results of the aforementioned modal analysis, the design team concluded that since the frames of the system have no modes near known forcing functions and the frame's modes have been identified and documented, the system is expected to exceed the structural soundness required for its intended use. For complete details of the test setup and results, including photos, plots, and data tables, refer to Appendix A.9 for the MSFC Dynamic Modal Test Results.

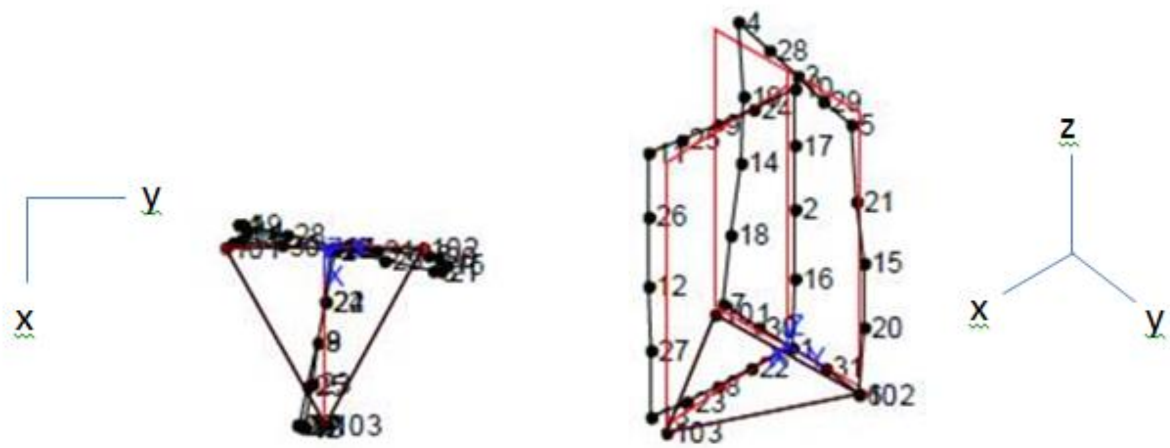



**Fig. 48:** Mode Shape Animations of System Frame after Impact

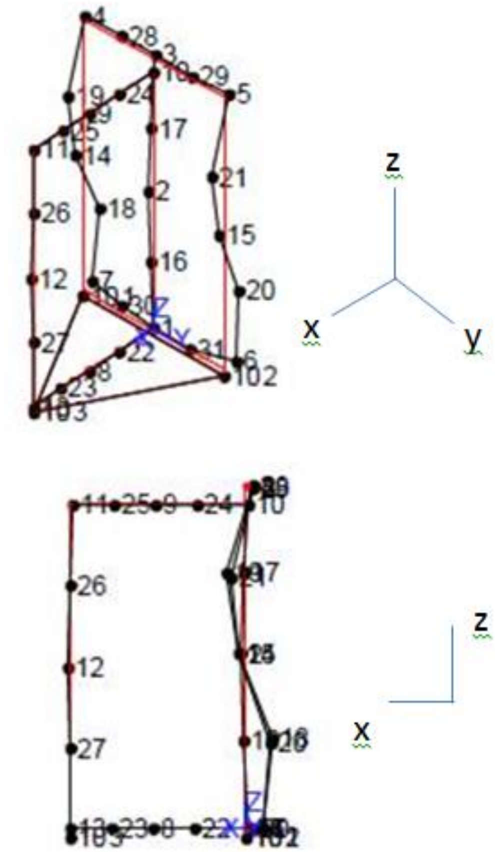


**Fig. 49:** Mode Shape Animations of System Frame after Impact

## 7.7 Requirements Verification Matrix

The Requirements Verification Matrix is shown in Table 12. The matrix was produced to verify that the final stowage system product met all the requirements outlined in the Level 1 Requirements document specified by NASA. The matrix defines how each requirement was verified and ensures that the proper documentation is available to delineate that all initial requirements have been addressed.

**Table 10:** Requirements Verification Matrix

| Req. No. | Document | Paragraph | Shall Statement | Verification Success Criteria | Facility or Lab | Performing Organization | Result |
|---|---|---|---|---|---|---|---|
| 1.1.1 | PRD | 1.1.1 Requirement 1 | The stowage system concept shall be designed for a specified volume of the DSH. | Calculations | X-Hab Team | X-Hab Team | Met |

**Table 10:** Requirements Verification Matrix (cont.)

| Req. No. | Document | Paragraph | Shall Statement | Verification Success Criteria | Facility or Lab | Performing Organization | Result |
|---|---|---|---|---|---|---|---|
| 1.1.2 | PRD | 1.1.2 Requirement 2 | The delivered demonstration product shall occupy only a percentage of the volume of the DSH. | Calculations | X-Hab Team | X-Hab Team | Met |
| 1.1.3 | PRD | 1.1.3 Requirement 3 | Determination of the percentage developed shall depend on the design team's ability to show proof of concept. | Calculations | X-Hab Team | X-Hab Team | Met |
| 1.1.4 | PRD | 1.1.4 Requirement 4 | The project product shall fit into the DSH space and volume (dimensions: 21.65 x 13.78 x 13.78 $ft^3$, approximate volume: 4,111 $ft^3$). | Calculations | X-Hab Team | X-Hab Team | Met |
| 1.1.5 | PRD | 1.1.5 Requirement 5 | The project product shall be able to enter the DSH via the end cone (hatch) (dimensions: 50 in. W, 50 in. H, and diagonal 61 in.). | Calculations | X-Hab Team | X-Hab Team | Met |
| 1.1.6 | PRD | 1.1.6 Requirement 6 | The project product shall be able to be configured and installed within the aforementioned DSH volume. | Calculations | X-Hab Team | X-Hab Team | Met |

| **Table 10:** Requirements Verification Matrix (cont.) | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Req. No.** | **Document** | **Paragraph** | **Shall Statement** | **Verification Success Criteria** | **Facility or Lab** | **Performing Organization** | **Result** |
| 1.1.7 | PRD | 1.1.7 Requirement 7 | Once installed, the product shall not continuously impede the emergency translation path of the DSH (dimensions: 32 in. x 45 in.) | Calculations | X-Hab Team | X-Hab Team | Met |
| 1.1.8 | PRD | 1.1.8 Requirement 8 | The stowage system shall be of minimum weight per NASA's suggestion (No weight requirement or maximum has been stated. The design team shall determine an acceptable weight for the system.). | Calculations | X-Hab Team | X-Hab Team | Met |
| 1.1.10 | PRD | 1.1.10 Requirement 10 | The completed demonstration product shall be delivered to NASA MSFC Building 4649 in May of 2013 and be installed in the DSH module on site. The design team shall be responsible for all tools and equipment necessary for delivery and installation. | xxx | X-Hab Team | X-Hab Team | Met |

| **Table 10:** Requirements Verification Matrix (cont.) | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Req. No.** | **Document** | **Paragraph** | **Shall Statement** | **Verification Success Criteria** | **Facility or Lab** | **Performing Organization** | **Result** |
| 1.2.1 | PRD | 1.2.1 Requirement 1 | The DSH stowage unit shall provide storage for items with varying functions (medical, food, hygiene, maintenance, entertainment, and food supplies, and science experiments). | Design | X-Hab Team | X-Hab Team | Met |
| 1.2.2 | PRD | 1.2.2 Requirement 2 | Due to the frequent access needed for the aforementioned supplies, an easily reconfigurable design shall be implemented. | Design | X-Hab Team | X-Hab Team | Met |
| 1.2.3 | PRD | 1.2.3 Requirement 3 | The stowage system shall have the following characteristics: flexibility, interchangeability, adjustability, and reusability. | Design | X-Hab Team | X-Hab Team | Met |
| 1.2.4 | PRD | 1.2.4 Requirement 4 | The designed product shall have self-stabilization capabilities, particularly during launch and landing. | Design | X-Hab Team | X-Hab Team | Met |
| 1.2.5 | PRD | 1.2.5 Requirement 5 | The product shall be designed to be scalable to accommodate stowage of 100+ single sized Cargo Transfer Bags (CTBs) measuring 19.75” by 16.75” by 9.75”. | Design | X-Hab Team | X-Hab Team | Met |

| **Table 10:** Requirements Verification Matrix (cont.) | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Req. No.** | **Document** | **Paragraph** | **Shall Statement** | **Verification Success Criteria** | **Facility or Lab** | **Performing Organization** | **Result** |
| 1.2.6 | PRD | 1.2.6 Requirement 6 | Non-standard stowage purposes shall be considered by the design team | Design | X-Hab Team | X-Hab Team | Met |
| 1.2.7 | PRD | 1.2.7 Requirement 7 | For high torque applications, the tool-actuated fastener head type shall be internal (Allen) or external hex-head styles. | Design | X-Hab Team | X-Hab Team | Met |
| 1.3.1 | PRD | 1.3.1 Installation/Removal | The product shall be installed in the DSH in MSFC building 4649. The design team shall be responsible for providing all tools and equipment necessary to install the stowage system. | xxx | X-Hab Team | X-Hab Team | Met |
| 1.3.2 | PRD | 1.3.2 Reliability | The system shall provide for stowage installation of temporary and non-standard storage purposes throughout the spacecraft. | Design | X-Hab Team | X-Hab Team | Met |
| 1.3.3 | PRD | 1.3.3 Mission Reliability | The storage system shall be designed to allow for easy accessibility for mission critical and frequently used items. | Design | X-Hab Team | X-Hab Team | Met |

| Table 10: Requirements Verification Matrix (cont.) | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Req. No.** | **Document** | **Paragraph** | **Shall Statement** | **Verification Success Criteria** | **Facility or Lab** | **Performing Organization** | **Result** |
| 1.3.4 | PRD | 1.3.4 Mechanical Safety | Exposed fasteners shall be selected so that they will not snag clothing or cause injury to the crewmembers. Fasteners and latches shall not spring open and cause injury to the crewmembers. | Design | X-Hab Team | X-Hab Team | Met |
| 1.3.5 | PRD | 1.3.5 Human Performance/Human Engineering | The system shall utilize standardized user interfaces (visual, auditory, and tactile) and standard methods of operation across the system for consistency and ease of learning. Ease of operation shall be a main concern for the design team. All fastener components intended for crew interaction shall be captive. | Design | X-Hab Team | X-Hab Team | Met |
| 2.1.1.1 | PRD | 2.1.1 Physical Requirements | The product shall fit within the space allowed by the secondary structure of the Deep Space Habitat. This space includes two, full rack bays (81.1”x81.125”x37.5”), and one overhead area (43.25”x37.5”). | Calculations | X-Hab Team | X-Hab Team | Met |

| **Table 10:** Requirements Verification Matrix (cont.) | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Req. No.** | **Document** | **Paragraph** | **Shall Statement** | **Verification Success Criteria** | **Facility or Lab** | **Performing Organization** | **Result** |
| 2.1.1 .2 | PRD | 2.1.1 Physical Requirements | The design team shall produce a product that has enough components to successfully demonstrate the design | Design | X-Hab Team | X-Hab Team | Met |
| 2.1.2 .1 | PRD | 2.1.2 Functional Requirements | The design shall have variability of shelf height to accommodate various CTB sizes | Design | X-Hab Team | X-Hab Team | Met |
| 2.1.2 .2 | PRD | 2.1.2 Functional Requirements | The design shall have a quick-release mechanism installed in order to allow access to the primary structure of the DSH. | Design | X-Hab Team | X-Hab Team | Met |
| 2.1.2 .3 | PRD | 2.1.2 Functional Requirements | Per JSC 27301: Materials and Processes Selection, Control, and Implementation Plan for JSC Flight Hardware, the spacing of the hook and loop fasteners shall have a maximum size of four in2, maximum length of four in, and a minimum separation of two in. | Design | X-Hab Team | X-Hab Team | Met |
| 2.1.3 .1 | PRD | 2.1.3 Operational Requirements | The design shall be completely manual in operation and mechanical in design. | Design | X-Hab Team | X-Hab Team | Met |

**Table 10:** Requirements Verification Matrix (cont.)

| Req. No. | Document | Paragraph | Shall Statement | Verification Success Criteria | Facility or Lab | Performing Organization | Result |
|---|---|---|---|---|---|---|---|
| 2.1.3.2 | PRD | 2.1.3 Operational Requirements | Instructions shall be provided to NASA detailing how to remove and re-install the product. After the initial installation by the team, NASA will be responsible for the product. | xxx | X-Hab Team | X-Hab Team | Met |
| 2.1.3.3 | PRD | 2.1.3 Operational Requirements | The team shall be responsible for eliminating all safety concerns with the design concepts produced (e.g. entrapment, pinch points, etc.). | Design | X-Hab Team | X-Hab Team | Met |
| 2.1.3.4 | PRD | 2.1.3 Operational Requirements | Should the system have mechanical parts, the design team shall be responsible for mitigating any safety hazards due to these parts. | xxx | X-Hab Team | X-Hab Team | Met |
| 2.1.3.5 | PRD | 2.1.3 Operational Requirements | The system shall be designed to accommodate space for user control on all interfaces per NASA standards (HIDH). | Design | X-Hab Team | X-Hab Team | Met |

## 7.8 Hazard Analysis

An established standard for assessing safety hazards and risks, specifically US Military Standard 882-B [19], was utilized in order to predict and evaluate all safety hazards posed by the stowage system design, manufacturing, testing, and specifications. The military standard assessment process is based upon the three tables shown in Figure 50. The first table is used to determine the frequency of the hazard occurrence. The second is used to assess the consequence of the hazard, and the third table is used to compare the two aforementioned characteristics in order to establish a hazard risk index number. The numbers are based upon a scale; whereby 1-5

**Table 8.6** The hazard frequency of occurrence

| Description | Level | Individual item | Inventory |
|---|---|---|---|
| Frequent | A | Likely to occur frequently (probability of occurrence > 10%) | Continuously experienced. |
| Probable | B | Will occur several times in life of an item (probability of occurrence = 1–10%) | Will occur frequently. |
| Occasional | C | Likely to occur sometime in life of an item (probability of occurrence = 0.1–1%) | Will occur several times. |
| Remote | D | Unlikely, but possible to occur in life of an item (probability of occurrence = 0.001–0.1%) | Unlikely, but can reasonably be expected to occur. |
| Improbable | E | So unlikely that it can be assumed that occurrence may not be experienced (probability of occurrence < 0.0001%) | Unlikely to occur, but possible. |

**Table 8.7** The hazard consequence of occurrence

| Description | Category | Mishap definition |
|---|---|---|
| Catastrophic | I | Death, system loss, or severe environmental damage |
| Critical | II | Severe injury, occupational illness, major system damage, or reversible environmental damage |
| Marginal | III | Minor injury, minor occupational illness, minor system damage, or environmental damage |
| Negligible | IV | Less than minor injury, occupational illness, system damage, or environmental damage |

**Table 8.8** The hazard-assessment matrix

| | Hazard category | | | |
|---|---|---|---|---|
| Frequency of occurrence | I Catastrophic | II Critical | III Marginal | IV Negligible |
| A. Frequent | 1 | 3 | 7 | 13 |
| B. Probable | 2 | 5 | 9 | 16 |
| C. Occasional | 4 | 6 | 11 | 18 |
| D. Remote | 8 | 10 | 14 | 19 |
| E. Improbable | 12 | 15 | 17 | 20 |

| Hazard-risk index | Criterion |
|---|---|
| 1–5 | Unacceptable |
| 6–9 | Undesirable |
| 10–17 | Acceptable with review |
| 18–20 | Acceptable without review |

Source for Tables 8.6–8.7: MIL-STD 882B.

**Fig. 50:** Military Standard 882-B

is unacceptable, 6-9 is undesirable, 10-17 is acceptable with review, and 18-20 is acceptable without review. After an initial risk index number assessment is completed, mitigation approaches are developed in order to design such that safety hazards can be minimized. Finally, all of the hazards are reevaluated using the same Military Standard 882-B in order to assess the post-mitigation hazard risk index number. The goal is to be able to increase the hazard risk index numbers so that they within the 10-20 range. A color-coded legend describing the various ranges of hazard-risk index numbers is provided Table 11.

**Table 11:** Risk Assessment Legend

| Legend | |
|---|---|
| **Hazard Risk Index** | **Criterion** |
| **1-5** | **Unacceptable** |
| **6-9** | **Undesirable** |
| **10-17** | **Acceptable with review** |
| **18-20** | **Acceptable without review** |

The hazards, pre and post risk index numbers, and mitigation methods associated with the UAH designed stowage system are provided in Table 12. Hazards assessed ranged from the possibility of operator injury caused by the translational tracks on the floor and ceiling of the system to the possibility of CTB interference impeding the motion of the storage system. The project level hazards were also assessed and are shown in Table 13. These include difficulty in parts procurement, communication with Watring Technologies, and locating effective team meeting locations.

**Table 12: System-Level Risk Assessment & Mitigation**

| Hazard Type | Pre-Mitigation Hazard-Risk Index Number | Mitigation | Post-Mitigation Hazard-Risk Index Number |
|---|---|---|---|
| Operator(s) injuring extremities in translational tracks on top and bottom of system | **5** | Warning Labels informing users of dangers of moving system | **10** |
| Operator(s) pinching appendages in door panel when sliding system closed | **6** | Warning Labels | **11** |
| System components temporarily blocking keep-out zones | **8** | System will be designed to move easily and quickly to free access to zones. | **12** |

| Table 12: System-Level Risk Assessment & Mitigation (cont.) | | | |
|---|---|---|---|
| **Hazard Type** | **Pre-Mitigation Hazard-Risk Index Number** | **Mitigation** | **Post-Mitigation Hazard-Risk Index Number** |
| Rigid system components falling/collapsing from fatigue and injuring user(s) | **8** | System will be made primarily of fabric making hazard occurrence virtually obsolete | **15** |
| Operator wedged between system and stationary object (wall, another rack, etc.) | **8** | System will have no solid walls. Only one point for entrapment exists between the back of the system and the outer curvature of DSH. | **12** |
| System blocks access to external (primary) structure permanently | **8** | System will be not encroach upon allocated space in outer hull; can be easily moved providing complete access to outer hull for emergency | **12** |
| CTBs causing interference-impeding motion while translating system | **8** | Allow for spacing between CTBs to decrease likelihood of interference. Amount of space dictated by the Velcro™ patch pattern of 2 inches apart comforming with NASA ESD standard | **17** |
| Operator(s) injuring appendages between moving external system structure | **9** | Rigid external structures vastly reduced to mitigate from hazard | **14** |
| CTBs falling from 1G stacked orientation injuring user(s) pre-launch | **10** | Restraints and fasteners will be used to eliminate likelihood of CTBs falling pre-launch | **11** |

| Table 12: System-Level Risk Assessment & Mitigation (cont.) | | | |
|---|---|---|---|
| **Hazard Type** | **Pre-Mitigation Hazard-Risk Index Number** | **Mitigation** | **Post-Mitigation Hazard-Risk Index Number** |
| Sharp edges/corners causing bodily harm to operator(s) | **11** | System is primarily fabric which will greatly reduce number of sharp edges. Labels will be provided to warn users of hazard posed by sharp edges. | **14** |
| If sliding, system could slide over and injure feet, toes, etc. | **11** | Warning labels will be implemented | **17** |
| System components temporarily blocking aisle ways | **13** | Easily sliding system on tracks to quickly free pathways. Open system without rigid walls making it easy to step through. | **15** |
| Fatigue causing falling components (parts) to injure user(s) | **14** | High Fidelity Parts will be used and minimized to reduce the hazard | **17** |
| Cutting fingers on Velcro | **16** | Warning Labels will be used to notify users of potential hazard. | **16** |
| Operator(s) pinching appendages in clamps and carabiners used with grommets | **18** | Number of clamps will be minimized and frequent use will not be needed | **19** |

| Table 13: Project-Level Risk Assessment and Mitigation (cont.) | | | |
|---|---|---|---|
| **Hazard Type** | **Pre-Mitigation Hazard-Risk Index Number** | **Mitigation** | **Post-Mitigation Hazard-Risk Index Number** |
| Difficulty locating 6061 aluminum suppliers | **6** | Adjusted design specifications to utilize 6063 aluminum which has more suppliers | **18** |
| Difficulty obtaining effective team meeting locations | **9** | Reached out to other departments at UAHuntsville for meeting space | **18** |
| Potential difficulty meeting manufacturing deadlines due to parts procurement and fabrication anomalies | **6** | Adjusted schedule to begin manufacturing process before Spring 2013 academic semester to remain on track | **11** |

## 7.9 Reliability

Two distinctive types of Fault Tree Analysis (FTA) were developed to thoroughly evaluate two potential failure modes of the UAH stowage system design. Figure 51 depicts the details and contributing factors to the potential failure of the translational track system of the design. The track failure would ultimately cause the loss of the translational ability of the stowage system. The aforementioned failure is the top level block in the figure. Level two and three blocks are shown delineating specific occurrences contributing to the overall track failure. For example, excessive forces due to launch loads could cause deformation to the 80/20® aluminum track component(s) which would result in loss of the translational ability of the stowage system. Logic gates are shown connecting the level blocks together. The "AND" block suggests that all items must occur simultaneously to cause the preceding failure mode. The "OR" logic gate denotes that any combination or single occurrence will cause the preceding failure mode. The circular blocks denote singular occurrences that would cause the preceding level failure modes. Figure 52 displays the FTA of another potential failure mode of the stowage system; the loss of effective storage ability due to failure of stitching that fastens the Velcro® to the cloth wall.

The FTA diagrams ultimately aided the UAH design team in implementing appropriate preventative measures to prevent and minimize occurrence of the failure modes. Implementations include safety protocols, technical analysis, appropriate testing, and design changes.

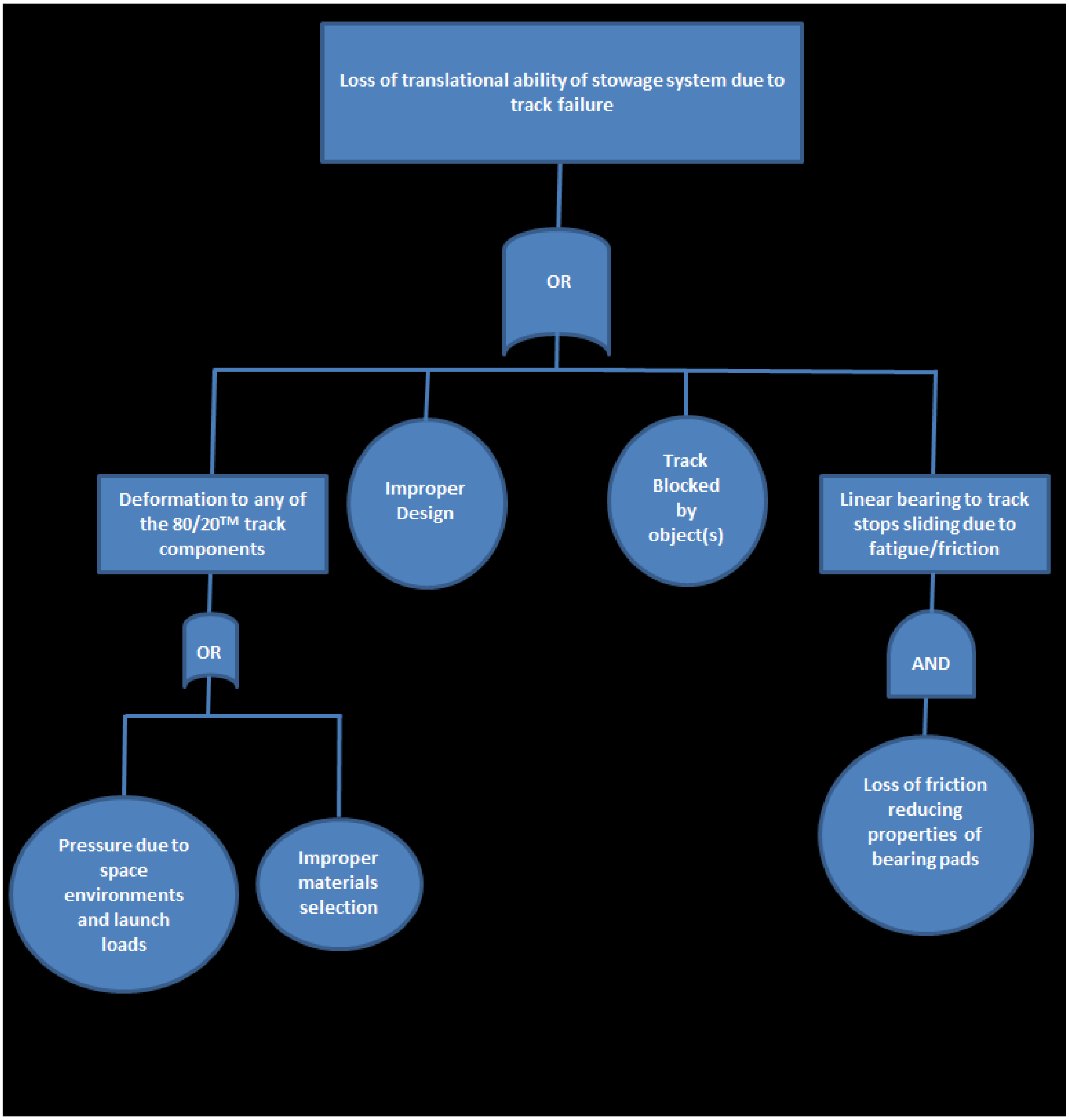



**Fig. 51:** Fault Tree Analysis – Translational Track Failure

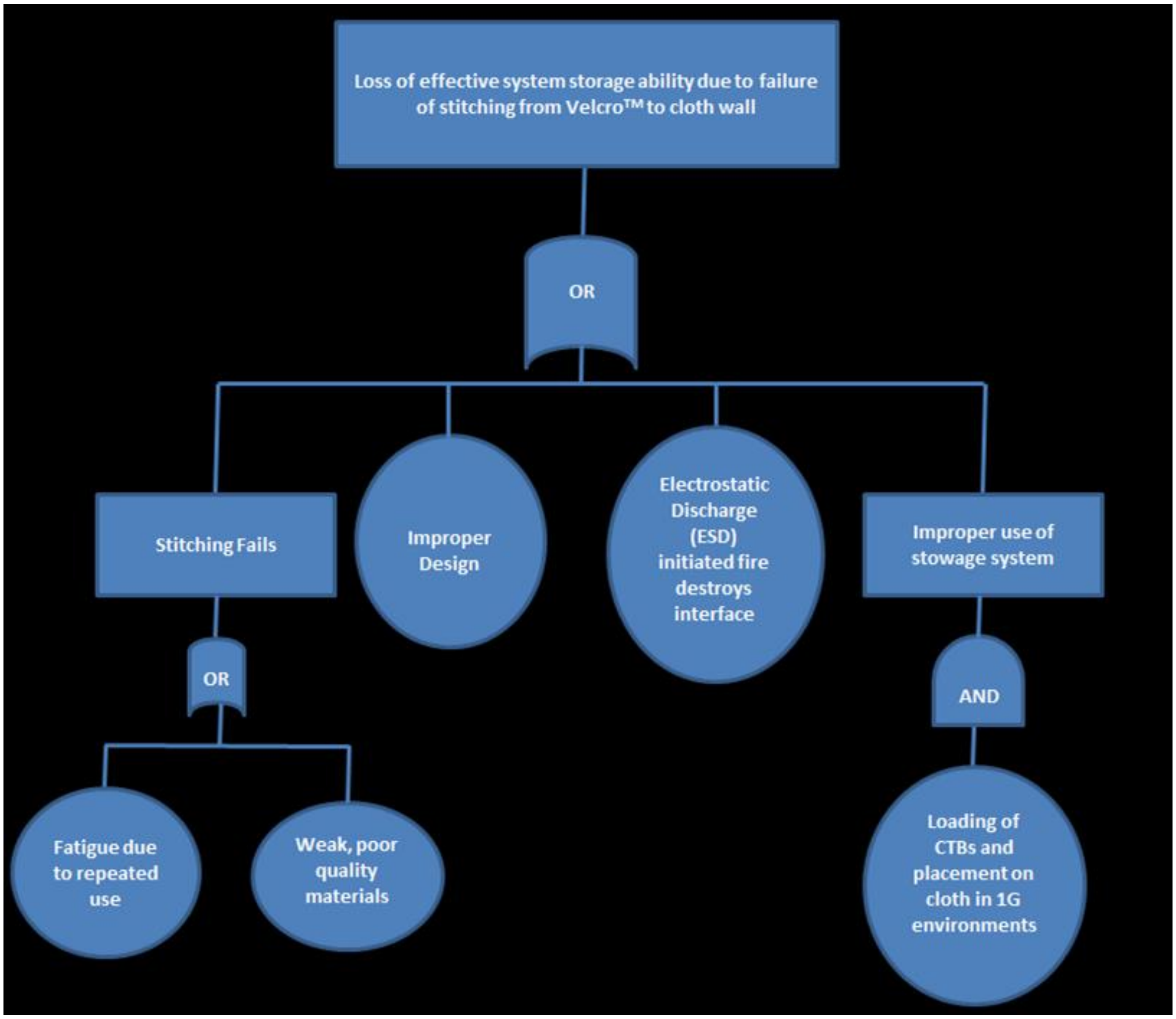



**Fig. 52:** Fault Tree Analysis – Velcro® Stitching Failure

## 7.10 Budget and Final Costs

The total operating budget allocated to the stowage system design project was $. The entities providing financial support to the UAH team are detailed in Table 14.

**Table 14:** UAH Stowage System Design Supporting Entities

| Entity | Budget |
|---|---|
| NASA/NSGC | |
| Alabama Space Grant Consortium (ASGC) | |
| UAH Dean of Engineering | |
| UAH Office of Vice-President of Research | |
| **TOTAL TEAM OPERATING BUDGET:** | |

Within the UAH X-Hab proposal, UAH Faculty Team Advisor C. Carmen submitted a $ operating budget. This budget included costs required to transport and deliver the final product from Huntsville, AL to JSC in Houston, TX. However, the product delivery location was changed by NASA to MSFC. Since MSFC is in extremely close proximity to UAH, a generous portion of the budget became available. In February 2013, C. Carmen sought approval from NASA to utilize the extra funds to allow two UAH team members the opportunity to present two separate papers at the 2013 International Astronautical Congress (IAC) in Beijing, China in October, 2013. The request was approved and team members Chris Barnett and Taylor Stokes will present papers regarding the UAH stowage system design at the 2013 IAC.

## 7.10.1 Parts Cost

A detailed listing of the cost of each part required to fabricate the UAH designed X-Hab stowage system is provided in Table 15.

**Table 15:** Parts Cost

| Item | Team Cost |
|---|---|
| Plexiglas Sheet (48"x96"x0.05") | |
| Flame Retardant Canvas Sheet Walls (with Velcro®) | |
| Aluminum Tubing | |
| Tie Down Rings | |
| High Fidelity Aluminum Handles | |
| Fasteners | |
| Angle Aluminum | |
| Unibearing™ | |
| Casters | |
| Seat Track | |
| 1515 Track | |
| Aluminum Plates, base plates, joints, and gussets | |
| 1515 Brackets | |
| Additional materials, parts and components – including adjustments to the estimated line items above | |
| **TOTAL PARTS COST** | |

## 7.10.2 Manufacturing Cost

Table 16 provides a detailed listing of the cost of each manufacturing procedure that was required to complete the final product. The main manufacturing entity, Watring Technologies, has extensive spaceflight hardware design and manufacturing experience and provided the specified services at greatly reduced rates.

| **Table 16: Manufacturing Cost** | |
|---|---|
| **Task** | **Team Cost** |
| Drilling Labor | |
| Milling Labor | |
| Welding Labor | |
| Deburring and Burnishing Labor | |
| Water-jetting Labor | |
| **TOTAL MANUFACTURING COST:** | |

## 7.10.3 Testing Cost

Table 17 provides a detailed listing of the cost of each test performed. Many of the tests or analyses were completed by the team with no costs incurred. The dynamics test was provided by NASA MSFC at no cost to the team. NOTE: the cost of the material for a test sample was combined with the cost of the material as specified in Table 15.

| **Table 17:** Testing Cost | | |
|---|---|---|
| **Task/Item** | **Retail Cost** | **Team Cost** |
| Volume Analysis | | |
| Weight Analysis | | |
| Functional Analysis | | |
| Human Factors Analysis | | |
| Velcro Life Cycle Test | | |
| Dynamic Test | | |
| Fatigue Testing | | |
| Test Fixtures | | |
| Test Samples (Additional Parts) | | |
| **TOTAL TESTING COST ESTIMATE** | | |

## 7.10.4 Engineering Effort Cost

Refer to section 7.10.5 for costs associated with the engineering labor incurred by the UAH students for the X-Hab design project. The estimated costs are for product delivery and transportation, installation, meeting expenses, documentation, and team labor.

## 7.10.5 Total Cost

The total estimated cost associated with the design project is provided below in Table 18. Retail costs and team costs are provided. The UAH student design team calculated an estimate for the total project hours expended by each team member and multiplied this number by a standard hourly engineering rate of $ to determine the design team labor costs. Team labor and testing costs were the primary differences between retail cost and team cost. Note that the total estimated cost is still an "estimate" as the two team members presenting at the 2013 IAC will do so in September 2013 and final costs cannot be finalized until October 2013.

**Table 18:** Cost Analysis

| **Item/Task** | **Retail Cost** | **Team Cost** |
|---|---|---|
| Parts Cost | | |
| Manufacturing Cost | | |
| Testing Cost | | |
| Design Team Labor | | |
| Product Delivery/Transportation to MSFC | | |
| Installation (Supplies, Potential Labor, etc.) within MSFC DSH | | |
| Team Meeting Expenses | | |
| Documentation (Printing costs, etc.) | | |
| Product Placard | | |
| STEM Outreach Events | | |
| Team Research Assistant (Jeremy Traum) | | |
| IAC Airfare for 2 Students | | |
| IAC Hotel Accommodations for 2 Students | | |
| IAC Expenses for 2 Students (Food, Conferences Fees, Transportations, etc.) | | |
| **TOTAL COST ESTIMATE** | | |

## 7.11 Invention Disclosure Form

An invention disclosure form was not completed for this design project due to the fact that the project is governed by the UAH/NSGF X-Hab Sub-Contract. This contract was not distributed to the student design team for legal reasons. A copy of the official sub-contract can be obtained by authorized individuals through the UAH Office of Sponsored Programs (OSP). However, a team member met with Mr. Kannan Grant, Director of the UAH Office of Technology Commercialization (OTC) to discuss patent legalities. General conclusions as a result of the meeting were the following: NASA owns the rights to the hardware that is installed in the DSH at MSFC and it is understood that the design team has no intellectual property rights to the design. The design team has the period of one year after the final product and technical report submission to NASA to seek a release of intellectual property rights from NASA and UAH in order to apply for a patent on the design. More information regarding rights and the contract can be obtained by contacting Mr. Grant.

## 7.12 Team Poster

A team poster (shown in Figure 53) was created as part of the design class requirements as well as to display during functions such as STEM outreach activities and university open house events.


**Fig. 53:** Design Team Poster

## 7.13 Educational Outreach Activities

A crucial part of the UAH design project was to conduct STEM outreach activities with local schools in the North Alabama region. An Educational Outreach Activities Report [20] that details all STEM events conducted during fall 2012 and spring 2013 was written by two of the UAH design team members – Clint and Drew Deerman. STEM efforts were conducted with the project's main contact, Huntsville Center for Technology, as well as Whitesburg Middle School, Williams Middle School, and Challenger Middle School. The Educational Outreach Activities Report contains details regarding all events, outreach efforts, and results.

## 8.0 Issues and Solutions

Throughout the design process, multiple issues occurred that, if not dealt with properly, would have hindered the progress of the project. In the conceptual design phase, the most difficult issue was effectively communicating design ideas to fellow team members. The issue was resolved by using whiteboards and physical examples to aid in accurate visualization of design concepts. In addition, difficulty finding available space for team meetings and work sessions was experienced. As a result, the team contacted other UAH departments requesting meeting space. These issues continued throughout the design project, and solution approaches were applied continuously in order to work effectively as a team.

During the preliminary design phase, the initial design concept was determined to increase system mass allocations. Because of the necessity to promote minimal mass in order to facilitate launch loads, steps were taken to resolve the issue. System mass was decreased by using alternative materials in the design concept as well as creating an open concept design with minimal rigid exterior walls. Lack of communication in the form of email feedback and responses from local manufacturing entities caused issues with the project. The problems were resolved through continued attempts to communicate and by reaching out to other consulting parties. Through these efforts, communication was re-established, and the manufacturing contacts were brought up to date on the project progress.

During the detail design phase, track system design challenges with Zero-G and One-G environments presented the team with several obstacles. The issues were resolved by thoroughly researching different design solutions and reexamining different solutions for track system implementation. Also, the team's lack of experience with NASA's Review Item Discrepancy (RID) and Request for Action (RFA) process and documentation caused issues with the project. To resolve the issue, a meeting was held to address questions about the appropriate process with the MSFC point of contact, Ms. Anne Carter, and she provided a document used by NASA to respond to RFAs, as well as informed the team on details of the process. See Appendix J for all the RID forms submitted by NASA and completed by the team upon entrance to the Critical Design Review (CDR).

## 8.1 Parts Procurement

The parts procurement phase of the project created some difficulties for the team. This phase of the project was greatly influenced by the purchasing process that the team followed. All of the parts were purchased through Watring Technologies with the approval of Dr. Christina

Carmen. The process was new and challenging for all team members because of their inexperience with industry-style purchase orders. The requirements for approving purchase orders for the project required very careful planning and execution to keep construction and fabrication on schedule. This necessitated that the team begin meeting with Watring Technologies more frequently and requiring more updates on parts procurement than originally planned.

One specific issue that was encountered by the team was the failure of a subcontracting company to deliver the aluminum tubing needed for the skeleton of the system. The material was ordered with ample time for delivery and several updates were requested by the team of an estimated delivery date but the company could not provide any information regarding the order. The team decided to withdraw their order for the aluminum and purchase the material from a different company. This was done with the requirement that the company provide the team with a tracking number for the order so that the team could monitor the status of the order.

## 8.2 Technical Analysis

The technical analysis completed for the system solution provided the team with a comparison of different FEA and CAD packages. The original FEA package that was used for the system became unavailable to the team in the second phase of the project. This was due to a change in permissions from one of the team members who was completing the analysis. This forced the team to create new FEA models and to repeat the process with the new FEA package. This issue also created a solution for the team because the team changed the requirements for the system solution and increased the loading that the material would have to withstand. The analysis was completed with the new software and loading requirements to the satisfaction of the team.

## 8.3 Manufacturing

The manufacturing of the system took place at Watring Technologies and an additional subcontractor shop. The main issues with the manufacturing process were the need for space for parts and fabrication, the inexperience of some of the team members with manufacturing processes, and the complex schedules of the team members and the manufacturing specialists. The issue of space needed for parts and fabrication was resolved by moving the main fabrication and assembly processes to the subcontractor shop. This provided the team with more space to work and a dedicated storage facility for their components. The inexperience of the team members with manufacturing was mitigated by training team members to complete certain processes and assigning more experienced team members to more complex processes. The complex schedule of the team members and manufacturing specialists created the need for careful planning and notification of when the shop would be available to the students and when the students would be available. This planning was carried out, and each student was able to gain experience in manufacturing processes as well as hands on experience with different hand tools and milling machines.

## 8.4 Assembly

Each unit in the system solution contains almost identical components and fasteners. After the decision was made to match drill the components to enable ease of manufacturing, the team realized that this would create an issue in the assembly stage and, in particular, the reassembly phase when the system was installed in the habitat at MSFC. Therefore, a naming convention was devised that incorporated the three unit design, the name of the component, and the location of the component relative to the overall configuration. This convention was put into place by stamping all of the components when they were completed and match drilled so that the team would be able to reassemble the units with no confusion.

## 8.5 Verification Tests

The verification tests for the system were completed with the Level 1 requirements and the completed system solution. The only issue encountered by the team was that the overall width of the system was larger than originally anticipated. This increase was due to the type of fasteners used and the additional material that was needed to increase the stability of the system when constructed. This increase did not violate the Level 1 requirements. The system was still in compliance with the allotted space provided for the team. However, the configuration of the habitat had to be changed to accommodate for the increase in width. The MSFC habitat personnel approved this change, and the habitat was reconfigured for the system solution.

## 8.6 Lessons Learned

Some of the most unexpected lessons gained through this assignment have ironically had very little to do with the technical aspects of engineering. While the team gained a great deal of experience and new knowledge in a variety of technical aspects, those were areas of anticipated gain. The knowledge gained related to planning, scheduling, budgeting, and teamwork were constant surprises.

It's worth noting that as a group, the members did not feel that there could have been a more supportive, productive, engaged, and balanced work team. Everyone thoroughly enjoyed the assignment, working together, and was satisfied with the accomplishments of the team. The project was formidable. The team began by trying to track the time and take minutes of the meetings, but that alone became a task that had to be relegated to posted assignments in Dropbox®, email lists, and sample set decision-making.

While the size of the team allowed for delegation to each individual's strength and assigning the workload in manageable portions, the number of members in the group also made it virtually impossible for the team to consistently meet together. However, while the team never developed true subcommittees, having a somewhat larger team meant that members could pair-off for some tasks, thus preventing too many occasions where students had to work late alone or in isolation. Thus, it would be the team’s recommendation to allow for larger groups for more formidable assignments, particularly where the customer is oriented to such detail and frequent meetings- as is NASA.

In retrospect, the team also realized that they did not have enough time to devote to this project if they had adhered to the academic expectations for out-of-class work. This assignment was in essence a full-time job. The students on the UAH team who had traditional employment would have truly been seriously handicapped had they not been paired with team members who did not work full-time. All members tackled that issue effectively early on and distributed the workload so that tasks that could be completed after hours could be assigned to those needing that luxury the most. Likewise, the team did not anticipate the compelling need for simple communication tools necessary to support project progress. Students that did not have unlimited texting or smart phone access to email could have easily been disadvantaged had communication issues not proactively been dealt with in the early stages of the team development. In many cases, decision-making and communication was dependent upon sharing screen shots from phones, accessing the Internet during off-site meetings, texting questions that needed quick responses, and messaging photos of parts, materials, drawings, etc. The team had to rely on a combination of high-tech communication tools as well as more traditional means of communication. This became increasingly challenging as the team neared the end of the semester and scheduling became an unexpected barrier. For example, when the team leader proposed meeting date options, at times some team members did not see or respond to the messages in time for alternate dates to be offered. This resulted in partial group meetings at best and wasted time at the worst. The team responded to this dilemma by triaging the situation and developing a somewhat unofficial telephone tree system--where the team learned each other's schedules, classrooms, and pathways in order to reach each other on short notice. It is the members recommendation that future teams be prepared to expect that communication and meeting scheduling to be as formidable as the technical tasks associate with these assignments. Members would also recommend that students be encouraged to start on their projects sooner. We began meeting and planning right away, but should have started making more concrete progress sooner.

It is also noteworthy to report that coordinating meeting times represented only a small portion of the scheduling challenges work teams face. While the team made an admirable effort to plan the project through to completion, many of the variables were beyond the control of the team and thus strictly adhering to the team's timeline became impossible.

If meetings were postponed by the customer, work could not be pursued until certain decisions or agreements were achieved. Thus, meeting dates often got pushed into the scheduled work dates. This created obstacles for team members who had agreed to reschedule work or family obligations in order to fulfill planned team work/meeting times. Thus, when the work/meeting times changed, flexibility was challenged. Team members had to step up and take over for those who could not flex their schedule and then tasks were shifted around to balance the work load. This led to a many off-line, unplanned communication and coverage. While the team had the personalities, talent, and willingness to compensate for these unexpected problems, it was understood that other teams might be pressed to maintain productivity when faced with barriers beyond their control.

Budgeting was an area that the team felt should be given special consideration for students. The members realized very quickly why companies have entire divisions devoted to purchasing. In many cases it is very difficult to obtain basic pricing information. Vendors want online inquiries made before they provide product costs. Further, students cannot legitimately explore meaningful budgeting because without the benefit of quantity purchasing, pricing is basically hypothetical. However, the team did learn the rationale for research and development representing such high overhead for corporations because there is so much trial and error associated with the development of a new concept.

Overall, this assignment provided a vital learning experience. Its scope and sequence was necessary to achieve what the team recognizes as the desired learning outcomes. Likewise, members agree that having a bona fide corporate customer interested in legitimate deliverables supports the development of a compelling learning environment. However, the team suggests that learning and applying leadership, teamwork, communication, scheduling, budgeting, research, development, production, and testing skills in such a limited amount of time on such substantive projects is taxing to participating students' success in other courses, ability to meet employer's expectations for quality, and even the health and safety of the student. The team literally put in countless hours, many of them very late at night in empty buildings. Members were all exhausted and consistently felt compromised in some way. However, members also found the experience exhilarating and rewarding. The team believes that among the most valuable lessons learned in this project was how critical the make-up of the team is to success. Optimism, tenacity, compassion, vision, encouragement, communication, enthusiasm, leadership, and follower-ship are just as important as technical skills.

# 9.0 Conclusion

## 9.1 Summary

The UAH X-Hab Random Access Microgravity Stowage and Rack System design project was successful. A design concept was chosen, and a detailed design solution was developed. The designed microgravity stowage system is a linear system which operates with a perpendicular motion to the DSH translational path. The designed system is an open concept with minimal rigid walls for easy access to stowed items. The system uses a cloth wall attached to the external structure with Velcro® patches corresponding to the existing Velcro® patches on the CTBs. These serve as attachment points for the bags containing the stowed items. The system motion is initiated by handles on the front of the system and is executed via a translational track developed from 80/20® aluminum on the top and bottom of the structure. The product was designed in response to the Level I requirements from NASA, as well as the Flow-Down requirements stipulated by the team. Therefore, the design solution fulfills all of the Level I requirements established by NASA. The product has been designed to fit within the allocated space in the DSH. The product has taken into consideration minimal mass requirements in order to facilitate launch loads. The stowage system is designed to accommodate the maximum number of CTBs within the allotted volume. The system will not continuously impede the emergency translation path of the DSH specified by NASA. The stowage system is designed to be scalable to accommodate 100+ CTBs. The established Military Standard 882-B was used in order to mitigate safety hazards associated with the stowage system design and specifications. The details of the concerns are delineated in the Safety and Reliability sections of the present report.

Design adjustments were made in order to establish a One-G demonstration product from the designed microgravity configuration of the stowage system. Modifications included a base plate on the bottom of the system to accommodate One-G CTB loading for demonstration purposes. In addition to this, fixed-position casters replaced the translational tracks on the bottom of the system in order to more easily facilitate movement for One-G demonstration. An additional Unibearing™ attachment point was added to the system as well as gussets for door support and a vertical displacement compensation system to account for any leveling issues of the DSH module floor. The demonstration product was fabricated during the spring 2013 semester. The details developed in the detail design phase were used in order to complete manufacturing and installation of the final demonstration product into the DSH at MSFC 4649 during the week of April 15-19, 2013. Facilities at Watring Technologies in Huntsville as well as manufacturing contact, Larry Mayo's, residence were utilized to complete fabrication and assembly of the system. The final stowage system product performs as specified and effectively serves to demonstrate the loading and maintainable organization of CTBs in a linear, translational stowage system. The product fulfills all of the Level 1 Requirements and the product design specifications specified by NASA and the design team. Both the design and fabrication phases of the NASA X-Hab Microgravity Random Access Stowage and Rack System project were successful and were completed before the established deadline.

## 9.2 Design Uncertainties

The present section identifies design uncertainties encountered during the course of the project, namely the design phase. Most of the uncertainties were resolved during the fabrication phase. The information is based on the research completed by the team for the design project as well as knowledge gained throughout the experience. All items mentioned in this section have potential unknowns that the team could not account for nor gather additional supporting information.

Many uncertainties with the project were encountered during the design phase. The first uncertainty pertained to the cloth structure. The manufacturer was unable to provide the team with material properties for the cloth being considered for the cloth structure. These properties were needed to better understand the material product life and how it will behave under repeated loadings during system use. Due to this and time constraints during the fabrication phase, no additional testing or research could be conducted concerning the cloth structure, including durability, reliability, or product life cycle. Also due to time constraints and available resources, extensive research and testing could not be performed on the grommets used as attachment points from the cloth structure to the frame.

Another uncertainty during the design phase was the potential for an unbalanced environment in the DSH model at MSFC. The installation location poses a possible problem if the alignment of the secondary structure is not level, due to relocation and movement of the DSH. This would create problems during the installation because initial measurements could fluctuate depending on how the product was reassembled after it was moved. Fortunately, during the fabrication phase of the project, this concern was alleviated through a discussion with NASA officials. A vertical displacement compensation system was used in order to account for leveling issues inside the DSH. The compensation system was attached to the Unibearing™™ slides allowing the stowage system to be leveled easily.

The microgravity design for this project assumes a zero gravity environment. The physical One-G design, intended for demonstrational use and proof of concept, incorporates parts and components that can adapt the system to on Earth operation. These components include wheels and mountings from the wheels to the frame. During the design phase of the project, these components had not been included and were still being researched. During the fabrication phase, after consulting with the lead manufacturer, a final decision was made concerning wheels. Fixed casters were used to allow the stowage system to translate easily on the floor of the DSH and demonstrate its intended movement and direction. Due to limited research and testing performed, the casters installed on the delivered, demonstrational product are not recommended for overloading in a gravity environment. Uncertainties exist for the casters concerning failure, fatigue, and durability.

During the design phase, the location of the vibration testing was uncertain because of the need for more details regarding the design and resource allocation for the team. The locations being researched included Wyle Laboratories and MSFC. During the final phase of the project, a decision was made to utilize MSFC facilities for the aforementioned test. A dynamic test was performed in order to document the stowage system frame’s natural frequencies.

## 9.3 Recommendations

Should this product be researched, considered, and produced again in the future, the design team has provided important recommendations for consideration. First, further research and analysis should be conducted on possible materials for the cloth shelving structure, especially material properties. This component of the stowage system is critical to the success of its function and performance. The design produced utilizes a woven polypropylene material (commonly associated with tarpaulins) due to its sole use being demonstration purposes. For a space configuration, a higher strength and more versatile fabric, such as beta cloth, should be chosen. Due to the component’s complexity and unique nature, it is strongly recommended that detailed drawings of the cloth sheet be produced and provided to the manufacturer. It is critical that the Velcro® and grommet patterns be exact in order to accommodate the maximum number of CTBs possible per cloth sheet.

With time and money allowing, additional testing should be performed to enhance the soundness of the design. Tensile strength testing on all aluminum tubing used for the stowage system’s frame as well as tensile testing on the cloth structure is recommended. Detailed fatigue testing of the cloth structure should also be completed due to repeated use and loading. Additional finite element analysis should include a variety of load cases and model all reasonable possibilities for product operating environment and conditions. The design team recommends that additional research also be completed concerning beneficial testing for the stowage system other than the aforementioned. Also, emphasis should be placed on providing the test facility with test plans in a timely manner and also allowing ample time to arrange the facilities for testing and produce the test plans.

The alignment of the existing secondary structure of the Deep Space Habitat may not be completely level or square. This could cause potential issues involving the installation of the stowage system. Additional investigation and testing should be performed in order to ensure quick and easy installation of the final product.

It is recommended that parts procurement of all unique and common parts and materials be completed as early as possible in the fabrication phase. Failure to order parts in a timely manner can result in manufacturer inability to complete a satisfactory final product by deadline. Concerning future projects of this caliber, a great deal of experience is recommended in the area of computer aided design drawings and drafting. It is imperative that a complete and fluid drawing package be produced by the end of the critical design phase and provided to the lead manufacturer at the earliest possible time.

When an outside manufacturer is utilized to solely complete the fabrication and assembly of the final product, communication is critical. It is recommended that weekly meetings be established during the entire design phase. Also, meetings twice a week should be initiated immediately starting in the fabrication phase of the project. This will allow for lead engineers on the project to ensure all requirements and needs of the manufacturer are met in the timeliest manner. Also, a backup plan for product fabrication and completion is recommended to be in place should any issues arise with the manufacturing. As with all design projects, a successful and functional product that meets all customer requirements is the most crucial part of the process. Any other precautions that future project teams see fit in order to achieve this goal should be implemented.

If a design team, similar to the size and structure of the one working on this project, is used in future endeavors, a detailed analysis of all individual members' interests, skills, and expertise is recommended. This will provide for the most seamless design and fabrication process and ultimately lead to the production of a satisfactory final product.

## 10.0 Acknowledgements

The following entities and their respective members were crucial to the success of the project. Their suggestions, assistance, and advice was greatly appreciated.

- Supporting Entities:
  - Watring Technologies
  - Huntsville Center for Technology
  - Alabama Space Grant Consortium
  - UAHuntsville Office of Vice President of Research
  - UAHuntsville Office of the Dean of the College of Engineering
  - UAHuntsville Mechanical & Aerospace Engineering Department
  - Marshall Space Flight Center
  - Johnson Space Center
  - Jet Propulsion Laboratory
  - National Space Grant Foundation
  - Williams Middle School
  - Challenger Middle School
  - Whitesburg Middle School
- Supporting Members:
  - Ms. Sarah Shull
  - Dr. A. Scott Howe
  - Ms. Anne Carter
  - Mr. David Reynolds
  - Dr. Paul Bookout
  - Mr. James Wrape
  - Dr. Christina Carmen
  - Dr. Dale Watring

- Mr. Gerald Lanz
- Mr. Larry Mayo
- Mr. Michael Evans
- Mr. Mark Pillotte
- Mr. Tim White
- Mr. Bob Druckman
- Jeremy Traum: UAH X-Hab Student Research Assistant
- Dr. John Gregory
- Ms. Michaela Kenon
- Ms. Anna Robinson
- Ms. Lisa Davis
- Ms. Nancy Gregson
- Ms. Teri Mitchell

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[18] Operations Manual Microgravity Random Access Stowage & Rack System, eXploration Habitat (X-Hab) 2013 Academic Innovation Challenge, University of Alabama in Huntsville, Mechanical & Aerospace Engineering Department

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## Signature Page – Individual Tasks

The undersigned agree that the individual project tasks and responsibilities designated below were completed by the associated team member.

__________________________/________
Adam Marlar (Patent searches, benchmarking, research)

__________________________/________
Cameron Bradley (Work breakdown structure)

__________________________/________
Caroline Bryson (Team lead, NASA liaison, team schedule, concept of operations, RIDs, PDS)

__________________________/________
Christopher Barnett (Manufacturing liaison, technical analysis)

__________________________/________
Clint Deerman (HCT liaison, STEM outreach, presentation outlines, risk assessment, FTA, RIDs, PDS)

__________________________/________
David Brooks (Evaluation matrices, patent searches, bench marking, research)

__________________________/________
Drew Deerman (PRD, PDS, HCT liaison, STEM outreach, RIDs)

__________________________/________
Elizabeth Olivares (Cost Analysis, Assembly/Parts Management, Manufacturing)

__________________________/________
Sarah Rogers (Finite element analysis, human factors, SOP)

__________________________/________
Taylor Stokes (All CAD models, PBS, system compatibility diagram, $N^2$ diagram)

__________________________/________
Thomas Dodson (Manufacturing liaison, cost analysis)

# Appendix A: Team Biographies

# Appendix B: Project Requirements Document

**Project Requirements Document (PRD)**
**NASA X-Hab Microgravity Random Access Stowage & Rack System**

Prepared by
MAE 490-02 Team 1 Project Office: Technology Hall N225
The University of Alabama in Huntsville
Huntsville, AL

Customer Representative(s):
Anne Carter
George C. Marshall Space Flight Center
Human Exploration and Operations Office
Redstone Arsenal, MSFC/4201/310
Marshall Space Flight Center, Alabama 35812

Instructor:
Christina L. Carmen, PhD
Faculty Sponsor, MAE 490-02 Instructor
5000 Technology Drive
Huntsville, Alabama 35899

**Project Requirements Document Approval**

The undersigned agree that the attached PRD as marked will be the basis for or MAE 490 Class Project. From this time forward, any questions or clarifications concerning the PRD shall be submitted in writing through the MAE 490 Instructor to the Customer Representative and the answer distributed to all MAE 490 participants in writing.

To change the PRD after signatures are completed shall require that the change be stated in writing and that a person authorized by every one of the signers below endorse the change with their signature. The revision will be labeled uniquely and distributed to all participants simultaneously.

The original of this document will be kept on file with the UAH Instructor. All signers will receive a copy of the original document.

___________________________/_______________

Anne Carter, Customer Representative

___________________________/_______________

Adam Marlar, Student

___________________________/_______________

Cameron Bradley, Student

________________________/_______________

Caroline Bryson, Student

___________________________/_______________

Christopher Barnett, Student

___________________________/_______________

Clint Deerman, Student

___________________________/_______________

David Brooks Student

___________________________/_______________

Drew Deerman, Student

___________________________/_______________

Sarah Rogers, Student

___________________________/_______________

Taylor Stokes, Student

___________________________/_______________

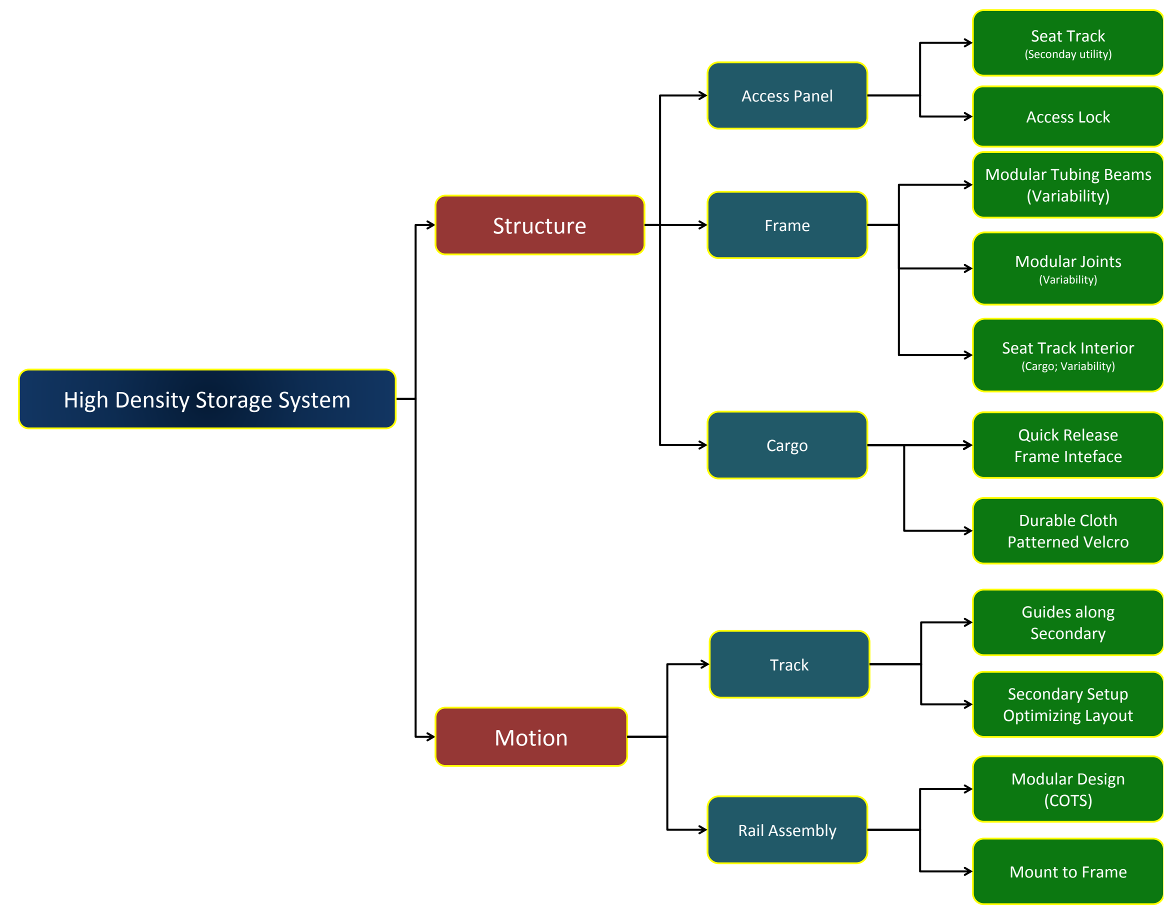
Thomas Dodson, Student

___________________________/_______________

Christina Carmen, MAE 490/491/492 Instructor

**PROJECT SCOPE:** This document establishes the requirements for the NASA X-Hab - Microgravity Random Access Stowage & Rack System Project. The University of Alabama in Huntsville (UAH) Mechanical and Aerospace Engineering (MAE) Department is partnering with the National Aeronautics and Space Administration (NASA), Watring Technologies, and the Huntsville Center for Technology (HCT) in order to design, manufacture, and implement a microgravity stowage system to be installed in NASA's Deep Space Habitat Module at Marshall Space Flight Center (MSFC).

**SYSTEM ARCHITECTURE:**




Product Break Down Structure

**Figure 1 – Team 1 PBS**

## 1. LEVEL 1 REQUIREMENTS (Top-Level System Requirements)

### 1.1 Physical Requirements

1.1.1. Requirement 1. The stowage system concept shall be designed for a specified volume of the DSH.

1.1.2. Requirement 2. The delivered demonstration product shall occupy only a percentage of the volume of the DSH.

1.1.3. Requirement 3. Determination of the percentage developed shall depend on the design team's ability to show proof of concept.

1.1.4. Requirement 4. The project product shall fit into the DSH space and volume (dimensions: 21.65 x 13.78 x 13.78 $ft^3$, approximate volume: 4,111 $ft^3$).

1.1.5. Requirement 5. The project product shall be able to enter the DSH via the end cone (hatch) (dimensions: 50 in. w, 50 in. h, and diagonal 61 in.).

1.1.6. Requirement 6. The project product shall be able to be configured and installed within the aforementioned DSH volume.

1.1.7. Requirement 7. Once installed, the product shall not continuously impede the emergency translation path of the DSH (dimensions: 32 in. x 45 in.)

1.1.8. Requirement 8. The stowage system shall be of minimum weight per NASA's suggestion (No weight requirement or maximum has been stated. The design team shall determine an acceptable weight for the system.).

1.1.9. Requirement 9. If applicable, fasteners on the system shall be of a common type and size to minimize the number of tools required to operate the fasteners, the crew workload required to collect the appropriate tools, and the potential for trying to use the wrong tool. Hand actuated fasteners shall also be of a common type and size to minimize frustration of having to remember how to operate a variety of latches and fasteners. If multi-turn fasteners are required by the system, the fastener shall fasten or unfasten in less than 10 turns. The number of fasteners used in an application shall be minimized. No further details about fasteners, types, or sizes were specified by NASA.

1.1.10. Requirement 10. The completed demonstration product shall be delivered to NASA MSFC Building 4649 in May of 2013 and be installed in the DSH module on site. The design team shall be responsible for all tools and equipment necessary for delivery and installation.

### 1.2 Functional Requirements

1.2.1. Requirement 1. The mission scenario is long duration with infrequent re-supply; thus, the DSH stowage unit shall provide storage for items with varying functions (medical, food, hygiene, maintenance, entertainment, and food supplies, and science experiments).

1.2.2. Requirement 2. Due to the frequent access needed for the aforementioned supplies, an easily reconfigurable design shall be implemented.

1.2.3. Requirement 3. The stowage system shall have the following characteristics: flexibility, interchangeability, adjustability, and reusability.

1.2.4 Requirement 4. The designed product shall have self-stabilization capabilities, particularly during launch and landing (This does not pertain to the delivered demonstration product).

1.2.5. Requirement 5. The product shall be designed to be scalable to accommodate stowage of 100+ single sized Cargo Transfer Bags (CTBs) measuring 19.75" by 16.75" by 9.75".

1.2.6. Requirement 6. Non-standard stowage purposes shall be considered by the design team (e.g. items waiting to be returned to the ground and cargo inventory fluctuations due to the addition of modules and spacecraft).

1.2.7. Requirement 7. For high torque applications, the tool-actuated fastener head type shall be internal (Allen) or external hex-head styles.

## 1.3 Operational Requirements

1.4.1 Installation/Removal. The product shall be installed in the DSH in MSFC building 4649. The design team shall be responsible for providing all tools and equipment necessary to install the stowage system.

1.4.2 Reliability The system shall provide for stowage installation of temporary and non-standard storage purposes throughout the spacecraft.

1.4.3 Mission Reliability. The storage system shall be designed to allow for easy accessibility for mission critical and frequently used items.

1.4.4 Mechanical Safety. Exposed fasteners shall be selected so that they will not snag clothing or cause injury to the crewmembers. Fasteners and latches shall not spring open and cause injury to the crewmembers. The use of cotter keys and safety wire shall be avoided.

1.4.5 Human Performance/Human Engineering. The system shall utilize standardized user interfaces (visual, auditory, and tactile) and standard methods of operation across the system for consistency and ease of learning. Ease of operation shall be a main concern for the design team. All fastener components intended for crew interaction shall be captive. A captive fastener is one that is automatically retained in a work-piece when it is not performing its load-bearing job, and therefore does not require the crew to restrain and store them during maintenance.

## 2. LEVEL 2 REQUIREMENTS

### 2.1 UAH Design Team's Rack & Stowage System Requirements

#### 2.1.1 Physical Requirements

2.1.1.1 Requirement 1. The product shall fit within the space allowed by the secondary structure of the Deep Space Habitat. This space includes two, full rack bays (81.1"x81.125"x37.5"), and one overhead area (43.25"x37.5").

2.1.1.2 Requirement 2. The product shall fit between structural ribs of the primary structure of the DSH (distance center to center of ribs: 47.25 in.).

2.2.1.3 Requirement 3. The design team shall produce a product that has enough components to successfully demonstrate the design (i.e. If the design has sliding racks, 3 full racks must be produced in order to demonstrate the product).

#### 2.1.2 Functional Requirements

2.1.2.1. Requirement 1. The design shall have variability of shelf height to accommodate various CTB sizes.

2.1.2.2. Requirement 2. The design shall have a quick-release mechanism installed in order to allow access to the primary structure of the DSH.

2.1.2.3. Requirement 3. Per JSC 27301: Materials and Processes Selection, Control, and Implementation Plan for JSC Flight Hardware, the spacing of the hook and loop fasteners shall have a maximum size of four in2, maximum length of four in, and a minimum separation of two in.

#### 2.1.4 Operational Requirements

2.1.4.1 Facilities, transportation, and storage. The design shall be completely manual in operation and mechanical in design.

2.1.4.2 Installation/Removal. Instructions shall be provided to NASA detailing how to remove and re-install the product. After the initial installation by the team, NASA will be responsible for the product.

2.1.4.3 Safety The team shall be responsible for eliminating all safety concerns with the design concepts produced (e.g. entrapment, pinch points, etc.).

2.1.4.4 Mechanical Safety. Should the system have mechanical parts, the design team shall be responsible for mitigating any safety hazards due to these parts.

2.1.4.5 Human Performance/Human Engineering. The system shall be designed to accommodate space for user control on all interfaces per NASA standards (HIDH).

## X.1 CLARIFICATIONS AND GUIDELINES

The sections documents specific questions and answers that were asked of the customer and not embodied in the specification before the document was signed. These comments are not officially part of the specification but serve as guidance in interpreting the document that is made available to all parties through the PRD. Be sure to document all questions, individual providing the response and date.

1. Pressure level requirements for the stowage system.
2. Launch loads the system must withstand.

## X.2 REVISIONS

Document specific changes made upon each revision of the CDD; state the reasons for the revision and the date.

## X.3 GLOSSARY

This glossary defines every acronym in the document.

CTB – Cargo Transfer Bag
DSH – Deep Space Habitat
HIHD – Human Integration Design Handbook
MSFC – Marshall Space Flight Center
MPLM – Multi-Purpose Logistics Module
NASA – National Aeronautics and Space Administration
X-Hab – eXploration Habitat Academic Innovation Challenge 2013
UAH –University of Alabama in Huntsville

## X.4 REFERENCES

Document references appear below that are specifically cited in this document. They must be referenced by number to the text in this document that cites them and be descriptive enough that any signing party can gain access to the document.


Reference 1
Title: EO40 X-Hab 2013 NSFG Project Number: 2013-ESMD-XHAB-05 Requirements for UAH Proposal: Design and Development of a Microgravity Random Access Stowage and Rack System
Produced By: George C. Marshall Space Flight Center MSFC, Alabama 35812
Effective Date: August 20, 2012
To Gain Access, Contact: Anne Carter

Reference 2
Title: Human Integration Design Handbook (HIHD), NASA/SP-2010-3407
Applicable Sections: Sections 4, 7.7, 8.2-8.4 and 9
Produced By: NASA
Date: January 27, 2010
To Gain Access, Visit the Following Website:

Reference 3:

Title: eXploration Habitat (X-Hab) 2013 Academic Innovation Challenge Solicitation

Produced By: National Space Grant Foundation
101 Constitution Avenue NW, Suite 650 East
Washington DC 20001-2133

Date: March 08, 2012

**Customer Questionnaire**

**Team 1** NASA X-Hab Project **Fall 2012**

Microgravity Random Access Stowage & Rack System

**<u>HCT/STEM</u>**

1. What type of STEM tool is required of the team (Presentation, activities, props, survey)?
2. What age group/grade levels will the STEM tool be used for?
3. What are the expectations from HCT concerning specific involvement with the project?
4. Who are the individuals from HCT (Faculty, Staff, Students) who will be involved with the NASA X-Hab project?

**<u>NASA/MSFC</u>**

1. The solicitation document mentioned the possible need for workstations in the stowage unit. How many of these workstations need to be implemented into the design, and what requirements will each station have?
2. Is it to the discretion of Team 1 to choose whether to design/manufacture either the vertical or horizontal orientation (depending on configuration of habitat) of the micro-gravity rack and stowage system?
3. How do we test the simulated mission duration usage of the stowage systems?
4. What are the end cone dimensions?
5. What is the maximum allowable weight for our design?
6. How are we going to stabilize (can we use permanent mounting)?
7. What does the current stowage design that is in place look like/how does it function?
8. "DSH MPLM will be powered and vented…" So, how much of the "120 Volts Direct Current" will be provided/can be promised for our Rack & Stowage System? Is it recommended that our design use power or not?
9. If design has acoustic concerns, what are our limits?
10. Clarification: Our design can extend into the aisle of the module; however, cannot take up the space permanently. Is this true?
11. Level 1 Requirements Document – Page 2, 'Scope/Purpose', Paragraph 2 – Clarification: Should design occupy entire volume of MPLM or not? How do we determine a percentage that is acceptable?
12. Level 1 Requirements Document – Page 2, 'Applicable Documents', Paragraph 1 – Clarification: What are the pressurized vehicle requirements that were supposed to be in Appendix A? Contact: NASA POC (Sarah Shull, sarah.a.shull@nasa.gov).
13. Since the designed product can fill the entirety of available space, but the demonstration product must only occupy a small area of the available space, will we design an actual product and a product solely for demonstration?
14. What specific tools will we need to be able to install the stowage system in the MPLM? How to attach it, etc.?
15. What are middeck lockers specifically? Details aren't provided in Appendix A along with the description of CTBs.
16. How will our design be mounted or attached to the capsule, will there be pre-set bolting points or do we have a free hand for the mounting system?
17. What type of upkeep/maintenance is available? (Parts/components will eventually break)
18. Spare parts?
19. Will seat tracks be required on the face of the racks? Are we required to design handles?

20. Are there keep-out zones? If so, where are they?
21. Are the mockups required to be oil free?
22. Do we need to design or include interface panels on the racks?
23. Will the racks need to be rotated?
24. Will the racks need side access?
25. Is there a standoff? If so, do we need to design for avionics to access the standoff?
26. Do we need a closeout panel on the front of our racks or can it be open?
27. Do we need to include labels on our mockups (mate with, opsnom)?
28. What is the mass allocation for our system?
29. Will there be a separate launch configuration and orbit configuration for stowed items?
30. Will we be using the old ISS habitat module?
31. Can we get the ICD for the bags that will be stowed?
32. Can we get a sample of the bags (CTBs)?

**<u>Watring Technologies</u>**

1. What will be the duties of the team in relation to working with Watring Technologies to manufacture the designed product?
2. What material limitations does the manufacturer have, if any?

**<u>Instructor – Dr. Carmen</u>**

1. How much manufacturing will the team be personally responsible for?

**<u>Technical Advisors/Other Professionals:</u>**

1. What are the launch loads our system must withstand?
2. What temperatures are to be expected? (Will the capsule be assembled under pressurized conditions or will it be treated like it would on earth, shipped in parts and therefore temp extremes happen)
3. What are the heights of each individual crew member?
4. How do you test a prototype during microgravity?
5. Should the measurements showcase be given in English or SI units?

## Appendix C: Interview Questionnaire

# NASA X-Hab Interview Questionnaire

## Microgravity Stowage and Rack System

**Name:** ____________________________
**Company:** _________________________
**Position:**___________________________
**Date:**______________________________

Question 1: What is one aspect of current stowage systems that could be most improved upon?

Question 2: How important is it to be able to access all items with equal accessibility (regardless of location)? Rank 1-5 (1 being not important and 5 being very important)

Question 3: What is the most important issue for a stowage system to address in space missions?

Question 4: In two rack bays of current systems, how many CTBs are stored?

Question 5: In your opinion, how effective would the use of Velcro be for a fastener in stowage systems? Rank 1-5.

# Appendix D: Bearing Material Specifications

Fractional

# 80/20® Inc.

*The **Industrial** Erector Set®*

## Engineering Specifications On UHMW-PE Bearing Pads

| Property | Test Method | Unit | Typical Value |
|---|---|---|---|
| Specific Gravity | ASTM D-792 | g/cm3 | |
| Yield Strength @ 73°F | ASTM D-638 | p.s.i. | |
| Ultimate Tensile Strength @ 73°F | ASTM D-638 | p.s.i. | |
| Break Elongation @ 73°F | ASTM D-638 | % | |
| Yield Strength @ 250°F | Stress Strain Diagram | p.s.i. | |
| Ultimate Tensile Strength @ 250°F | Stress Strain Diagram | p.s.i. | |
| Break Elongation @ 250°F | Stress Strain Diagram | % | |
| Hardness - Rockwell "R" Scale | ASTM D-785 | - | |
| - Shore "D" Scale | ASTM D-2240 | - | |
| Flexural Modulus of Elasticity | Bend Creep/1 min. value | p.s.i. | |
| Shear Strength | ASTM D-732 | p.s.i. | |
| Izod Impact @ + 23°C | ASTM D-256A | ft-lbs/in. notch | |
| @ - 140° C | ASTM D-256A | ft-lbs/in. notch | |
| Environmental Stress Cracking @ F50 | ASTM D-1693 Mod | hrs. | |
| Water Absorption | ASTM D-570 | - | |

## Abrasive Resistance - Sand Slurry Test

- Each material listed below was rotated 24 hours @ 1750 r.p.m.
- Carbon Steel = abrasive rating of 100.
- The weight loss for each material is relative to 100.
- The lower the figure, the better the abrasive resistance.
- 50-50 sand/water slurry.

WEARS LIKE A PIGS NOSE

| | | | | | |
|---|---|---|---|---|---|
| UHMW-PE | 15 | Nylon | 31 | High MW polyethylene | 44 |
| TFE | 72 | Stainless Steel | 84 | Polypropylene | 87 |
| Polycarbonate | 96 | Polyacetal | 110 | TFE/glass fiber | 113 |
| Normal MW polyethylene | 125 | Phosphor bronze | 193 | Yellow brass | 409 |
| Phenolic laminate | 571 | Hickory wood | 967 | Hi Carbon Steel | 100 |

## Coefficient Of Friction

UHMW-PE Polymer has a lower coefficient of friction than glass. Together with its self-lubricating characteristics it is an ideal material for bearings, bushings, valves, wear strips, or any application where sliding contact is encountered.

| Materials | Static | Kinetic | Test Method |
|---|---|---|---|
| Aluminum* vs. UHMW-PE | 0.12 | 0.016 | ASTM D-1894 |
| Mild Steel vs. Mild Steel | 0.30 - 0.40 | 0.25 - 0.35 | |
| Mild Steel vs. UHMW-PE | 0.15 - 0.20 | 0.12 - 0.20 | |
| UHMW-PE vs UHMW-PE | 0.20 - 0.30 | 0.20 - 0.30 | |

*Anodized 204 R1 Spec on extruded aluminum

9

## Comparison of Dynamic Coefficient of Friction on Polished Steel

| Property | UHMW-PE |
|---|---|
| Dry | 0.10 - 0.22 |
| Water | 0.05 - 0.10 |
| Oil | 0.05 - 0.08 |

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# Appendix E: Material Safety Data Sheets (MSDS)

## P61 Polycarbonate Material Safety Data Sheet

### 1 PRODUCT AND COMPANY IDENTIFICATION

**A&C Plastics, Inc.**
615 Northdale
Houston, TX 77087

EMERGENCY PHONE NUMBERS:
Chemtrec: (800) 424-9300 (24hrs) or (703) 527-3887
Medical: Rocky Mountain Poison Control Center
(866) 767-5089 (24Hrs)

| Phone Number | Available Hrs |
|---|---|
| (800) 231-4155 | 8:00 am - 5:30pm CST |

| | |
|---|---|
| Product Name | TUFFAK (R) XL Polycarbonate Sheet |
| Product Synonym(s) | |
| Chemical Family | Polycarbonate |
| Chemical Formula | N/A |
| Chemical Name | See Ingredients |
| EPA Reg Num | |
| Product Use | |

### 2 COMPOSITION / INFORMATION ON INGREDIENTS

| Ingredient Name | CAS RegistryNumber | Typical % | OSHA |
|---|---|---|---|
| Methylene chloride | 75-09-2 | < 3 ppm | Y |
| Carbonic dichloride, polymer with 4,4'-(1-methylethylidene)bis[phenol], 4-(1,1-dimethylethyl)phenyl ester | 103598-77-2 | 0-99 | N |
| Carbonic dichloride, polymer with 4,4'-(1-methylethylidene)bis[phenol], 4-(1-methyl-1-phenylethyl)phenyl ester | 111211-39-3 | 0-99 | N |
| Carbonic dichloride, polymer with 4,4'-(1-methylethylidene)bis[phenol] | 25971-63-5 | 0-99 | N |

The substance(s) marked with a "Y" in the OSHA column, are identified as hazardous chemicals according to the criteria of the OSHA Hazard Communication Standard (29 CFR 1910.1200)

While this material is not classified as hazardous under Federal OSHA regulations, this MSDS contains valuable information critical to the safe handling and proper use of this product. This MSDS should be retained and available for employees and other users of this product.

The components of this product are all on the TSCA Inventory list.

### 3 HAZARDS IDENTIFICATION

**Emergency Overview**
Polycarbonate sheet material
HANDLE IN ACCORDANCE WITH GOOD INDUSTRIAL HYGIENE AND SAFETY PRACTICES.

**Potential Health Effects**

Inhalation and skin contact are expected to be the primary routes of occupational exposure to this material. As a finished product, it is a synthetic, high molecular weight polymer. Due to its chemical and physical properties, this material does not require special handling other than the good industrial hygiene and safety practices employed with any industrial material of this type. Under normal processing conditions, this material will release fume or vapor.

# P61 Polycarbonate Material Safety Data Sheet

Components of these releases may vary with processing time and temperatures. These process releases may produce eye, skin and/or respiratory tract irritation and, with repeated or prolonged exposures, nausea, drowsiness, headache and weakness.

## 4 FIRST AID MEASURES

IF IN EYES, immediately flush with plenty of water.

IN CASE OF CONTACT, flush the area with plenty of water. Remove contaminated clothing and shoes. Wash clothing before reuse. Get medical attention if irritation develops and persists.

IF INHALED, remove to fresh air.

## 5 FIRE FIGHTING MEASURES

**Fire and Explosive Properties**

| | | | |
|---|---|---|---|
| Auto-Ignition Temperature | >510/950 F | | |
| Flash Point | NA | Flash Point Method | |
| Flammable Limits- Upper | NA | | |
| Lower | NA | | |

**Extinguishing Media**

Use water spray, carbon dioxide, foam or dry chemical.

**Fire Fighting Instructions**

Fire fighters and others who may be exposed to products of combustion should wear full fire fighting turn out gear (full Bunker Gear) and self-contained breathing apparatus (pressure demand NIOSH approved or equivalent). Fire fighting equipment should be thoroughly decontaminated after use.

**Fire and Explosion Hazards**

Heated material can form flammable vapors with air.

## 6 ACCIDENTAL RELEASE MEASURES

**In Case of Spill or Leak**

Contain spill. Sweep or scoop up and remove to suitable container. Consult a regulatory specialist to determine appropriate state or local reporting requirements, for assistance in waste characterization and/or hazardous waste disposal and other requirements listed in pertinent environmental permits.

## 7 HANDLING AND STORAGE

**Handling**

Avoid temperature extremes during storage; ambient temperature preferred.

**Storage**

Use only with adequate ventilation.

## 8 EXPOSURE CONTROLS / PERSONAL PROTECTION

**Engineering Controls**

Investigate engineering techniques to reduce exposures below airborne exposure limits. Provide ventilation if necessary to control exposure levels below airborne exposure limits (see below). If practical, use local

# P61 Polycarbonate Material Safety Data Sheet

## 8 EXPOSURE CONTROLS / PERSONAL PROTECTION

mechanical exhaust ventilation at sources of air contamination such as open process equipment.

**Eye / Face Protection**

Use good industrial practice to avoid eye contact.

**Skin Protection**

Minimize skin contamination by following good industrial hygiene practice. Wearing protective gloves is recommended. Wash hands and contaminated skin thoroughly after handling.

**Respiratory Protection**

Avoid breathing dust. When airborne exposure limits are exceeded (see below), use NIOSH approved respiratory protection equipment appropriate to the material and/or its components. Consult respirator manufacturer to determine appropriate type equipment for given application. Observe respirator use limitations specified by NIOSH or the manufacturer. For emergency and other conditions where exposure limit may be significantly exceeded, use an approved full face positive-pressure, self-contained breathing apparatus or positive-pressure airline with auxiliary self-contained air supply. Respiratory protection programs must comply with 29 CFR § 1910.134.

**Airborne Exposure Guidelines for Ingredients**

| Exposure Limit | | Value |
|---|---|---|
| **Methylene chloride** | | |
| ACGIH TWA | - | 50 ppm 174 mg/m3 |
| OSHA Skin designator | - | Y |
| OSHA STEL PEL | - | 125 ppm |
| OSHA TWA PEL | - | 25 ppm |

-Only those components with exposure limits are printed in this section.
-Skin contact limits designated with a "Y" above have skin contact effect. Air sampling alone is insufficient to accurately quantitate exposure. Measures to prevent significant cutaneous absorption may be required.
-ACGIH Sensitizer designator with a value of "Y" above means that exposure to this material may cause allergic reactions.
-WEEL-AIHA Sensitizer designator with a value of "Y" above means that exposure to this material may cause allergic skin reactions.

## 9 PHYSICAL AND CHEMICAL PROPERTIES

| | |
|---|---|
| Appearance/Odor | Polycarbonate sheet material |
| pH | NA |
| Specific Gravity | 1.15 to 1.19 |
| Vapor Pressure | NA |
| Vapor Density | NA |
| Melting Point | 218 C/424 F |
| Freezing Point | NA |
| Boiling Point | NA |
| Solubility In Water | Insoluble |
| Percent Volatile | 0 |

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# P61 Polycarbonate Material Safety Data Sheet

## 10 STABILITY AND REACTIVITY

**Stability**

This material is chemically stable under normal and anticipated storage and handling conditions.

**Hazardous Polymerization**

Does not occur.

**Incompatibility**

None known.

**Hazardous Decomposition Products**

Thermal decomposition may yield toxic hydrocarbons which includes methane, phenolics, bisphenol A, diphenyl carbonate.

## 11 TOXICOLOGICAL INFORMATION

**Toxicological Information**

Bisphenol A- carbonic dichloride copolymer 4-(1-methyl-1-phenylethyl)phenyl ester
Single exposure (acute) studies indicate that a similar material is practically non-toxic if swallowed (rat LD50 >5,000 mg/kg), no more than slightly toxic if absorbed through skin (rabbit LD50 >2,000 mg/kg), non-irritating to rabbit skin and slightly irritating to rabbit eyes.

## 12 ECOLOGICAL INFORMATION

**Ecotoxicological Information**

No data are available.

**Chemical Fate Information**

No data are available.

## 13 DISPOSAL CONSIDERATIONS

**Waste Disposal**

Incineration is the recommended method for disposal observing all local, state and federal regulations.

## 14 TRANSPORT INFORMATION

| | |
|---|---|
| DOT Name | NOT REGULATED |
| DOT Technical Name | |
| DOT Hazard Class | |
| UN Number | |
| DOT Packing Group | PG |
| RQ | |

## 15 REGULATORY INFORMATION

# P61 Polycarbonate Material Safety Data Sheet

**Hazard Categories Under Criteria of SARA Title III Rules (40 CFR Part 370)**

| | | | |
|---|---|---|---|
| Immediate (Acute) Health | N | Fire | N |
| Delayed (Chronic) Health | N | Reactive | N |
| | | Sudden Release of Pressure | N |

The components of this product are all on the TSCA Inventory list.

**Ingredient Related Regulatory Information:**

| **SARA Reportable Quantities** | CERCLA RQ | SARA TPQ |
|---|---|---|
| Methylene chloride | 1000 LBS | |
| Carbonic dichloride, polymer with 4,4'-(1-methylethylidene)bis[phenol], 4-(1,1-dimethylethyl)phenyl ester | NE | |
| Carbonic dichloride, polymer with 4,4'-(1-methylethylidene)bis[phenol] | NE | |
| Carbonic dichloride, polymer with 4,4'-(1-methylethylidene)bis[phenol], 4-(1-methyl-1-phenylethyl)phenyl ester | NE | NE |

**SARA Title III, Section 313**

This product does contain chemical(s) which are defined as toxic chemicals under and subject to the reporting requirements of, Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 and 40 CFR Part 372. See Section 2

Methylene chloride

**California Prop 65 - Carcinogen**

This product does contain the following chemical(s), as indicated below, currently on the California list of Known Carcinogens.

Methylene chloride

**Massachusetts Right to Know**

This product does contain the following chemicals(s), as indicated below, currently on the Massachusetts Right to Know Substance List.

Methylene chloride

**New Jersey Right to Know**

This product does contain the following chemical(s), as indicated below, currently on the New Jersey Right-to-Know Substances List.

Methylene chloride

**Pennsylvania Environmental Hazard**

This product does contain the following chemical(s), as indicated below, currently on the Pennsylvania Environmental Hazard List.

Methylene chloride

**Pennsylvania Right to Know**

This product does contain the following chemical(s), as indicated below, currently on the Pennsylvania Hazardous Substance List.

Methylene chloride

**Pennsylvania Special Hazard**

This product does contain the following chemical(s), as indicated below, currently on the Pennsylvania Special Hazard List.

Methylene chloride

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# P61 Polycarbonate Material Safety Data Sheet

## 16 OTHER INFORMATION

**Revision Information**

| | | |
|---|---|---|
| Revision Date | 03 MAY 2005 | Revision Number 10 |
| Supercedes Revision Dated | 03-MAY-2005 | |

**Key**
NE= Not Established NA= Not Applicable (R) = Registered Trademark

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ThyssenKrupp Materials NA, Inc.

# MATERIALS SAFETY DATA SHEET

## Aluminum Alloys

### SECTION I. MATERIAL IDENTIFICATION

| COMPANY | RE-ISSUE DATE | IDENTIFICATION NUMBER |
|---|---|---|
| ThyssenKrupp Materials NA, Inc.<br>22355 West Eleven Mile Road<br>Southfield, Michigan 48033 | 5-Dec-08 | N/A |
| **TRADE NAME** | **EMERGENCY PHONE NUMBER** | **PREPARED BY:** |
| Aluminum Alloys | (248) 233-5681 | J. VanValkenburg |
| **CHEMICAL NAME** | **FORMULA DOT** | **IDENTIFICATION NO.** |
| Aluminum (Does not include Lithium or Nickel Alloys) | AL | N/A |

### SECTION II HAZARDOUS INGREDIENTS

| MATERIAL OR COMPONENT BASE METAL | CAS NUMBER | % COMPOSITION BY WEIGHT | PHYSICAL Description | OSHA-mg/m3 8-HR. - TWA | ACGIH mg/m3 8-HR. - TWA | WISHA PEL mg/m3 |
|---|---|---|---|---|---|---|
| ALUMINUM | 7429-90-5 | 80.0-99. 7 | AS ALUMINUM DUST | 15 | 10 | 10 |

NOT ALL OF THE ELEMENTS LISTED BELOW ARE PRESENT IN ALL ALLOYS OF ALUMINUM

| ALLOYING ELEMENTS | CAS NUMBER | % COMPOSITION BY WEIGHT (1) | PHYSICAL Description | OSHA-mg/m3 8-HR. - TWA | ACGIH mg/m3 8-HR. - TWA | WISHA PEL mg/m3 |
|---|---|---|---|---|---|---|
| BERYLLIUM | 7440-41-7 | 0.002 | AS DUST/FUME | 0.002 | 0.002 | 0.005* |
| CHROMIUM | 7440-47-3 | 0.1-1.0 | AS METAL | 0.5 | 0.5 | 0.5 |
| COBALT | 7440-48-4 | 0.1-10.0 | AS DUST/FUME | 0.1 | 0.05 | 0.05 |
| COPPER | 7440-50-8 | 1.0-20.0 | AS COPPER DUST | 1.0 | 1.0 | 1.0 |
| | | | AS COPPER FUME | 0.1 | 0.2 | 0 .1 |
| IRON | 7439-89-6 | 1.0-10.0 | AS IRON OXIDE FUME | 10.0 | 5.0 | 5.0 |
| LEAD | 7439-92-1 | 1.0-10.0 | AS DUST/FUME | 0.05 | 0.15 | 0.05 |
| MAGNESIUM | 7439-95-4 | 1.0-20.0 | AS DUST/OXIDE FUME | 10.0 | 10.0 | 10.0 |
| MANGANESE | 7439-96-5 | 1.0-10.0 | AS MANGANESE | 1.0 | 1.0 | 5.0 |
| NICKEL | 7440-02-0 | 0.0-2.40 | AS DUST/FUME | 1.0 | 1.5 | |
| SILICON | 7440-21-3 | 10.0-20.0 | AS SILICON DUST/FUME | 5.0 | 10.0 | 10.0 |
| | | | AS RESPIRABLE FRACTION | 5.0 | | 5.0 |
| SILVER | 7440-22-4 | 0.1-1.0 | AS METAL DUST/FUME | 0.01 | 0.1 | 0.01 |
| TIN | 7440-31-5 | 1 0-10.0 | AS OXIDE | 2.0 | 2.0 | 2.0 |
| ZINC | 1314-13-2 | 1 0-10.0 | AS OXIDE FUME | 5.0 | 5.0 | 5.0 |
| | | | AS ZINC OXIDE TOTAL DUST | 10.0 | 10.0 | 10.0 |

Aluminum alloys may be comprised of all or variations of the alloys shown here.

PEL=Permissible Exposure Limit (1) % of Alloying Material Varies with Grade of Material. Other trace elements of <1% May be in Present.

### SECTION III. PHYSICAL DATA

| MATERIAL (At Normal Conditions) | APPEARANCE AND ODOR |
|---|---|
| SOLID | Metallic appearance; No Odor |
| **MELTING POINT** | **SPECIFIC GRAVITY** |
| 440-1215 Deg. F | 2.6-2.9 |

### SECTION IV. FIRE AND EXPLOSIVE

**SPECIAL FIRE FIGHTING PROCEDURES:** Damp aluminum dust with hydrogen may form explosive air mixtures. Small chips, fine turnings and dust may ignite readily. Explosion potential may exist when dust and fines are dispensed in the air. Avoid contact with metal oxides, molten aluminum and moisture. Aluminum Products in their solid state present no fire or explosive hazard.

### SECTION V. REACTIVITY DATA

| STABILITY | CONDITIONS TO AVOID Contact with Halogen Acids, Sodium Hydroxide, |
|---|---|
| Stable | Anhydrous Bromine, Iodates, and Ammonium Nitrates |

**HAZARDOUS DECOMPOSITION PRODUCTS**

Metallic Dust Or Fumes May Be Produced During Welding, Burning, Grinding And Possibly Machining. Refer To ANSI Z49.1

### SECTION VI. Environmental

| | |
|---|---|
| SPILL OR LEAK PROCEDURES | N/A |
| WASTE DISPOSAL METHODS | Disposal must comply with applicable Federal, State and Local disposal and discharge laws. |

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ThyssenKrupp Materials NA, Inc.

# MATERIALS SAFETY DATA SHEET

## Aluminum Alloys

### SECTION VII. HEALTH HAZARD DATA

**NOTE:** ALUMINUM PRODUCTS IN THEIR NATURAL STATE DO NOT PRESENT AN INHALATION OR CONTACT HAZARD. HOWEVER OPERATIONS SUCH AS BURNING, WELDING, SAWING, BRAZING AND GRINDING MAY RELEASE FUMES AND/OR DUST WHICH MAY PRESENT HEALTH HAZARDS.

**EFFECTS OF OVEREXPOSURE:**

**Acute -** Dust or fume may cause irritation to the eyes, nose, or throat and may leave a metallic taste in the mouth. Inhalation of oxides of Manganese, Magnesium, Zinc and Copper may be manifested as flu-like symptoms commonly known as "metal fume fever". Phosphorous dust is considered a nuisance dust.

**Chronic -**

**Aluminum:** Inhalation of Aluminum Oxide fume or an accumulation of Silicon in the lungs may result in benign pneumoconiosis.

**Beryllium:** Inhalation of beryllium dust or fume may cause chronic beryllium disease (CBD) and a cancer hazard. It may also cause eye, skin, and respiratory system irritation.

**Cobalt:** May cause lung inflammation and damage, and diffuse pulmonary fibrosis from inhalation. Classified as a carcinogen by IARC.

**Chromium:** May enter and affect the body through inhalation, ingestion, or skin contact with kidney & liver damage. The National Toxicology Program (NTP) and the Internal Agency for Research on Cancer (IARC) report they possess sufficient evidence to establish a causal relationship for human cancer from Hexavalent Chromium.

**Copper:** Inhalation may cause nose and throat irritation and metal fume fever and prolonged contact may cause dermatitis, discoloration of skin, hair and teeth.

**Iron:** Inhalation of Iron Oxide fume or dust may result in a lung condition known as siderosis.

**Lead:** Lead compounds can be toxic & may cause cancer when ingested or inhaled. Lead is a cumulative poison and excessive exposure can have an adverse effect on human reproduction. Acute exposure to lead can be manifested as abdominal pain, nausea, constipation, anorexia, or vomiting, and in severe cases death.

**Manganese:** Inhalation may result in symptoms such as headache, restlessness, neurological dysfunction, damage to the central nervous system or muscular weakness, scarring of the lungs and reproductive harm in males.

**Magnesium:** Inhalation may result in inflammation of the respiratory tract and fever. Dust and fume may cause irritation to the eyes, nose and throat.

**Nickel:** Inhalation of nickel dust or fume may inflame the respiratopry tract, cause nasal or lung cancer.

**Silicon:** An accumulation of Silicon in the lungs may result in benign pneumoconiosis, chronic bronchitis.

**Silver:** May cause eyes, nasal, septum, throat and skin irritation and intestinal disturbance.

**Tin:** May cause eye, skin, and respiratory system irritation and siderosis.

**Zinc:** Dust or fume may cause irritation to the eyes, nose, or throat and may leave a metallic taste in the mouth. Inhalation of oxides may cause "metal fume fever".

**Welding Fume:** Is listed as a possible carcinogen to humans.

**Coatings:** If coated with oil, contact may cause skin irritation/dermatitis.

### SECTION VIII. EMERGENCY AND FIRST AID PROCEDURES

**Inhalation:** In the event of excessive exposure to dust or fume, remove the employee to fresh air. If breathing is difficult administer artificial respiration or oxygen. Obtain immediate medical assistance.

**Skin:** Abrasions and cuts should be washed and closed by a clean compress and be immediately medically treated. Should skin irritation occur, wash affected area with mild soap and rinse with clean warm water. Obtain medical assistance.

**Eyes:** Depending on the type and nature of exposure, relief may be obtained by fresh air or rinsing the eyes with clean water. Obtain medical assistance.

**Medical Conditions Aggravated by Exposure:**

Persons with a predisposition to respiratory disorders may be adversely affected by particulates or respiratory irritants generated during the mfg. process.

### SECTION IX. SPECIAL PROTECTION INFORMATION & CONTROL MEASURES

**Note:** Consult your regional codes or Code of Federal Regulations, Title 29, Part 1910. Subpart G-Occupational Health and Environmental Control, Subpart I Personal Protective Equipment. Subpart P-Welding, Cutting, and Brazing, and Subpart Z-Toxic and Hazardous Substances. Certain welding type activities may produce hazardous substances such as carbon monoxide, ozone, phosgene in the presence of certain chemicals, or produce inert suffocating atmospheres in addition to the production of ultraviolet radiation and/or noise.

**Ventilation:** Additional air make up systems may be required if, local exhaust or ventilation systems are not sufficient to maintain exposure levels to contaminates below prescribed limits. When inhalation controls are not sufficient to reduce the exposure below the applicable exposure limit then use OSHA/NIOSH approved respiratory protection within the use limitations of the respirator.

**Personal Protection:** To avoid contact use appropriate protective gloves or clothing to protect against cutting edges. Appropriate heat shielding garments should be used for activities using or generating heat. Eyes should be protected by using safety glasses, goggles, helmet, face shield as appropriate to the operation being performed.

**Precautions to be taken in handling and storage:**

Be alert to sharp edges and unsecured Lifts.

### SECTION X. OTHER INFORMATION

**SARA Section 313 Toxic Chemical List, de minimis Concentrations**

> 1.0%: Copper, Aluminum, Zinc, and Manganese

> 0.1%: Chromium. Cobalt, Lead, and Nickel

TSCA Status All components are listed on the TSCA inventory

CERCLA Hazardous Substances Chromium, Lead, Copper & Zinc

**California Proposition 65**

The state of California lists chromium (Hexavalent compounds), nickel, lead, and cobalt as chemicals known to cause cancer and reproductive toxicity.

Cadmium, cadmium compounds, and lead may be present as impurities of the manufacturing process.

Chromium (Hexavalent compounds) may be generated during certain manufacturing processes.

The information in this MSDS was obtained from sources which we believe are reliable. However, the information is provided without any representation or warranty, expressed or implied, regarding the accuracy or correctness. The conditions or methods of handling, storage, use, and disposal of the product are beyond our control and may be beyond our knowledge. For this and other reasons, we do not assume responsibility and expressly disclaim liability for loss, damage or expense arising out of or in any way connected with handling, storage, use or disposal of the product. Data sheets of individual manufacturers are available upon request.

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# Aluminum Alloy (Nominal) Composite Sheet

ThyssenKrupp Materials NA, Inc.
22355 West Eleven Mile road
Southfield, Michigan 48034
(248) 233-5681

Issued December 5, 2008

| Alloy CAS No. | Name | Aluminum % | Magnesium % | Lead % | Nickel % | Arsenic % | Chromium % | Zinc % | Silicon % | Silver % | Beryllium % | Iron % | Manganese % | Copper % | Cobalt % | Misc. % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 357 | | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 1100 | Fabricated Parts & Products | >82.0 | <5.0 | - | - | - | <0.35 | - | <1.0 | - | - | <1.0 | <1.5 | - | - | - |
| 1350 | Fabricated Parts & Products | >82.0 | <5.0 | - | - | - | <0.35 | - | <1.0 | - | - | <1.0 | <1.5 | - | - | - |
| 2011 | Screw Machine Stock | >83.0 | <1.4 | <0.8 | - | - | <0.16 | - | <12.6 | - | - | <1.1 | - | <6.1 | - | - |
| 2014 | Wrought Products | >86.0 | <6.6 | - | <0.1 | - | <0.36 | <10.6 | <1.5 | - | <0.002 | <1.5 | <1.5 | <5.1 | - | - |
| 2017 | Fabricated Parts & Products | 85-97 | <2.0 | - | <2.4 | - | <0.3 | - | <1.4 | <0.71 | | <1.4 | <1.9 | <6.9 | - | - |
| 2024 | Wrought Products | >86.0 | <6.6 | - | <0.1 | - | <0.36 | <10.6 | <1.5 | - | <0.002 | <1.5 | <1.5 | <5.1 | - | - |
| 2219 | Fabricated Parts & Products | 85-97 | <2.0 | - | <2.4 | - | <0.3 | - | <1.4 | <0.71 | | <1.4 | <1.9 | <6.9 | - | - |
| 2224 | Wrought Products | >86.0 | <6.6 | - | <0.1 | - | <0.36 | <10.6 | <1.5 | - | <0.002 | <1.5 | <1.5 | <5.1 | - | - |
| 2324 | Wrought Products | >86.0 | <6.6 | - | <0.1 | - | <0.36 | <10.6 | <1.5 | - | <0.002 | <1.5 | <1.5 | <5.1 | - | - |
| 3002 | Fabricated Parts & Products | >92.0 | <2.8 | - | 0-0.05 | - | <0.6 | <1.8 | <1.9 | - | | | <2.0 | - | - | - |
| 3003 | Fabricated Parts & Products | >82.0 | <5.0 | - | - | - | <0.35 | - | <1.0 | - | - | <1.0 | <1.5 | - | - | - |
| 3004 | Fabricated Parts & Products | >82.0 | <5.0 | - | - | - | <0.35 | - | <1.0 | - | - | <1.0 | <1.5 | - | - | - |
| 3105 | Fabricated Parts & Products | >82.0 | <5.0 | - | - | - | <0.35 | - | <1.0 | - | - | <1.0 | <1.5 | - | - | - |
| 4032 | Fabricated Parts & Products | <85.0 | <2.1 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 5005 | Fabricated Parts & Products | >82.0 | <5.0 | - | - | - | <0.35 | - | <1.0 | - | - | <1.0 | <1.5 | - | - | - |
| 5052 | Fabricated Parts & Products | >84.9 | <6.6 | - | 0-0.09 | - | <0.6 | <4.0 | <1.1 | - | | | <1.5 | - | - | - |
| 5083 | Fabricated Parts & Products | >82.0 | <5.0 | - | - | - | <0.35 | - | <1.0 | - | - | <1.0 | <1.5 | - | - | - |
| 5086 | Fabricated Parts & Products | >82.0 | <5.0 | - | - | - | <0.35 | - | <1.0 | - | - | <1.0 | <1.5 | - | - | - |
| 5182 | Fabricated Parts & Products | >82.0 | <5.0 | - | - | - | <0.35 | - | <1.0 | - | - | <1.0 | <1.5 | - | - | - |
| 5205 | Fabricated Parts & Products | >84.9 | <6.6 | - | 0-0.09 | - | <0.6 | <4.0 | <1.1 | - | | | <1.5 | - | - | - |
| 5454 | Fabricated Parts & Products | >82.0 | <5.0 | - | - | - | <0.35 | - | <1.0 | - | - | <1.0 | <1.5 | - | - | - |
| 5657 | Fabricated Parts & Products | >84.9 | <6.6 | - | 0-0.09 | - | <0.6 | <4.0 | <1.1 | - | | | <1.5 | - | - | - |
| 6005 | Fabricated Parts & Products | >89.9 | <2.1 | - | 0-0.30 | - | <0.5 | <2.5 | <1.8 | - | | <1.1 | <1.5 | <1.3 | - | - |
| 6013 | Fabricated Parts & Products | >89.9 | <2.1 | - | 0-0.30 | - | <0.5 | <2.5 | <1.8 | - | | <1.1 | <1.5 | <1.3 | - | - |
| 6020 | Fabricated Parts & Products | >89.9 | <2.1 | - | 0-0.30 | - | <0.5 | <2.5 | <1.8 | - | | <1.1 | <1.5 | <1.3 | - | - |
| 6040 | Fabricated Parts & Products | >89.9 | <2.1 | - | 0-0.30 | - | <0.5 | <2.5 | <1.8 | - | | <1.1 | <1.5 | <1.3 | - | - |
| 6061 | Fabricated Parts & Products | >82.0 | <5.0 | - | - | - | <0.35 | - | <1.0 | - | - | <1.0 | <1.5 | - | - | - |
| 6063 | Fabricated Parts & Products | >82.0 | <5.0 | - | - | - | <0.35 | - | <1.0 | - | - | <1.0 | <1.5 | - | - | - |
| 6082 | Fabricated Parts & Products | >89.9 | <2.1 | - | 0-0.30 | - | <0.5 | <2.5 | <1.8 | - | | <1.1 | <1.5 | <1.3 | - | - |
| 6101 | Fabricated Parts & Products | >82.0 | <5.0 | - | - | - | <0.35 | - | <1.0 | - | - | <1.0 | <1.5 | - | - | - |
| 6105 | Fabricated Parts & Products | >82.0 | <5.0 | - | - | - | <0.35 | - | <1.0 | - | - | <1.0 | <1.5 | - | - | - |
| 6262 | Screw Machine Stock | >83.0 | <1.4 | <0.8 | - | - | <0.16 | - | <12.6 | - | - | <1.1 | - | <6.1 | - | - |
| 7022 | Fabricated Parts & Products | >84.0 | <3.8 | - | <0.3 | - | <0.4 | <10.6 | <1.1 | - | | <1.2 | <1.1 | <3.4 | - | - |
| 7040 | Fabricated Parts & Products | >84.0 | <3.8 | - | <0.3 | - | <0.4 | <10.6 | <1.1 | - | | <1.2 | <1.1 | <3.4 | - | - |
| 7049 | Fabricated Parts & Products | >84.0 | <3.8 | - | <0.3 | - | <0.4 | <10.6 | <1.1 | - | | <1.2 | <1.1 | <3.4 | - | - |
| 7050 | Wrought Products | >86.0 | <6.6 | - | <0.1 | - | <0.36 | <10.6 | <1.5 | - | <0.002 | <1.5 | <1.5 | <5.1 | - | - |

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# Aluminum Alloy (Nominal) Composite Sheet

ThyssenKrupp Materials NA, Inc.
22355 West Eleven Mile road
Southfield, Michigan 48034
(248) 233-5681

Issued December 5, 2008

| Alloy CAS No. | Name | Aluminum % | Magnesium % | Lead % | Nickel % | Arsenic % | Chromium % | Zinc % | Silicon % | Silver % | Beryllium % | Iron % | Manganese % | Copper % | Cobalt % | Misc. % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7068 | Fabricated Parts & Products | >84.0 | <3.8 | - | <0.3 | - | <0.4 | <10.6 | <1.1 | - | | <1.2 | <1.1 | <3.4 | - | - |
| 7075 | Wrought Products | >86.0 | <6.6 | - | <0.1 | - | <0.36 | <10.6 | <1.5 | - | <0.002 | <1.5 | <1.5 | <5.1 | - | - |
| 7129 | Fabricated Parts & Products | >84.0 | <3.8 | - | <0.3 | - | <0.4 | <10.6 | <1.1 | - | | <1.2 | <1.1 | <3.4 | - | - |
| 7150 | Wrought Products | >86.0 | <6.6 | - | <0.1 | - | <0.36 | <10.6 | <1.5 | - | <0.002 | <1.5 | <1.5 | <5.1 | - | - |
| 7175 | Wrought Products | >86.0 | <6.6 | - | <0.1 | - | <0.36 | <10.6 | <1.5 | - | <0.002 | <1.5 | <1.5 | <5.1 | - | - |
| 7475 | Wrought Products | >86.0 | <6.6 | - | <0.1 | - | <0.36 | <10.6 | <1.5 | - | <0.002 | <1.5 | <1.5 | <5.1 | - | - |
| ALUMEC | Wrought Products | >86.0 | <6.6 | - | <0.1 | - | <0.36 | <10.6 | <1.5 | - | <0.002 | <1.5 | <1.5 | <5.1 | - | - |
| QC-7 | Wrought Products | >88.0 | <6.6 | - | <0.1 | - | <0.36 | <10.6 | <1.5 | - | <0.002 | <1.5 | <1.5 | <5.1 | - | - |
| | | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

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SIERRA ALUMINUM COMPANY
ALUMINUM EXTRUSIONS · PAINTING · ANODIZING · FABRICATION

**Issue Date:** March 1, 2008

# MATERIAL SAFETY DATA SHEET

| TRADE NAME (Common Name or Synonym) Aluminum Alloy | CHEMICAL NAME Aluminum billet 6063 |
|---|---|

## I. INGREDIENTS

| Material or Component | CAS Number | % Weight | EXPOSURE LIMITS OSHA PEL (mg/m³) | ACGIH TLV (mg/m³) |
|---|---|---|---|---|
| Base Metal | | | | |
| Aluminum (Al) | 7429-90-5 | Remainder | Not Established | 10.0 Metal Dust & Oxide<br>5.0 Welded Fume |
| Alloying Elements | | | | |
| Chromium (Cr) | 7440-47-3 | 0.01-0.1 | 1.0 Chrome Metal | 0.5 Chrome Metal |
| Copper (Cu) | 7440-50-8 | 0.01-0.10 | 0.1 Fume, 1.0 Dust | 0.2 Fume, 1.0 Dust |
| Iron (Fe) | 1309-37-1 | 0.17-0.35 | 10 Oxide Fume | 5 Oxide Fume |
| Magnesium (Mg) | 1309-48-4 | 0.45-0.9 | 15 Oxide Fume | 10 Oxide Fume |
| Manganese (Mn) | 7439-96-5 | 0.01-0.10 | 5c Dust, 5c Fume | 5c Dust, 1 Fume |
| Silicon (Si) | 7440-21-3 | 0.20-0.60 | Not Established | 10 Total Dust |
| Titanium (Ti) | 7440-32-6 | 0.01-0.10 | 15 Ti Dioxide | 10 Ti Dioxide |
| Zinc (Zn) | 1314-13-2 | 0.0-0.10 | 5 Oxide Fume | 10 Dust, 5 Fume |

NOTE: Aluminum alloys will be comprised of various cominations of the elements shown above. In addition, other alloying elements may be present in minute quantities. No permissable exposure limits (PEL) or threshold limit values (TLV) exist for aluminum alloys. Values shown are applicable to component elements.

## II. PHYSICAL DATA

| MATERIAL IS (At Normal Conditions) | | APPEARANCE AND ODOR | % VOLATILE BY VOLUME: | VAPOR DENSITY |
|---|---|---|---|---|
| _ LIQUID _ SOLID _ GAS | _ OTHER | Silvery-Grey, Odorless | N/A | N/A |

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| ACIDITY/ALKALINITY pH = N/A | Melting Point<br>Boiling Point | 900-1200<br>N/A | °F °F | Specific Gravity (H20 = 1) Approx. 2.5-2.9<br>Solubility in water (% by weight) Negligible | VAPOR PRESSURE (mm Hg at 20°C) N/A |
|---|---|---|---|---|---|

## III. PERSONAL PROTECTIVE EQUIPMENT

| | | | |
|---|---|---|---|
| RESPIRATORY PROTECTION Appropriate respirator depending upon potential airborne contaminants and their concentrations. If exposure limits are reached or exceeded, use NIOSH approved equipment. | | HANDS, ARMS AND BODY Appropriate gloves to prevent abrasions. | |
| EYES AND FACE | Safety glasses or shield for selected operations | OTHER CLOTHING AND EQUIPMENToperations and safety codes. | As required depending on |

## IV. EMERGENCY MEDICAL PROCEDURES

INHALATION:
EYE CONTACT:
SKIN CONTACT:
INGESTION:

Remove to fresh air; if condition continues, consult a physician. Flush thoroughly with running water to remove particulate; obtain medical attention. Remove particles by washing thoroughly with soap and water. Seek medical attention if condition persists. If significant amounts of metal are ingested, consult physician.

## V. HEALTH/SAFETY INFORMATION

**Health**

For standard operations (e.g. melting, cutting, grinding), aluminum alloys present a low health risk by inhalation and are usually considered a nuisance dust. Toxicity by ingestion -- none expected. Skin and eyes -- not an irritant. Welding and plasma cutting of alloys high in copper (2000 and 7000 series) may present the potential for overexposure to copper fumes which can result in upper respiratory tract irritation, nausea, and metal fume fever. Nickel and chromium are other alloying elements considered hazardous as fume; however, they do not present a carcinogenic or other health concerns due to their low concentrations of the chemical form in which they are present. Overexposure to lead fumes over an extended period of time can result in such toxic effects as central nervous system disturbances, renal changes, peripheral neuropathy, gastrointestinal disturbances, anemia, and chromosomal changes. The welding of aluminum alloys may generate carbon monoxide, carbon dioxide, ozone nitrogen oxides, infrared radiation and ultraviolet radiation. OCCUPATIONAL EXPOSURE LIMITES: See Product Ingredients Section I.

**Fire and Explosion**

| | | | |
|---|---|---|---|
| **FLASH POINT N/A °F** | **AUTO IGNITION TEMPERATURE N/A °F** | **FLAMMABLE LIMITS IN AIR Lower N/A % Upper N/A %** | **EXTINGUISHING MEDIA For molten aluminum use dry power or sand.** |

| | |
|---|---|
| **FIRE AND EXPLOSION HAZARDS Aluminum tubular products do not present fire or explosion hazards under normal conditions.** | **EXTINGUISHING MEDIA NOT TO BE USED Do not use water or halogen agents on molten aluminum.** |

**Reactivity**

| | |
|---|---|
| **STABILITY _ Stable _ Unstable** | **INCOMPATIBILITY (MATERIALS TO AVOID) Reacts with strong acids to form hydrogen gas.** |

**CONDITIONS TO AVOID Aluminum products under normal conditions are stable during use, storage and transportation. Halogen acids and sodium hydroxide in contact with aluminum may generate explosive mixtures of hydrogen. Finely divided aluminum, such as small chips and fines, will form explosive mixtures in air. It also will form explosive mixtures in air in the presence of bromates, iodates, or ammonium nitrate. Strong oxidizers cause violent reactions with considerable heat generation.**

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## VI. ENVIRONMENTAL

SPILL OR LEAK PROCEDURES Fine turnings and small chips should be swept or vacuumed. Scrap metal can be reclaimed for reuse.

WASTE DISPOSAL METHOD* Used or unused product should be disposed of in accordance with Federal, State or Local Laws and Regulations. *Disposer must comply with Federal, State and Local disposal or dischage laws.

## VII. ADDITIONAL INFORMATION

Do not touch cast aluminum metal or heated aluminum product without knowing metal temperature. Aluminum experiences no color change during heating. Burns could result. Series 2000 and 7000 alloys should be stress relieved prior to sawing or cutting to avoid cracking. Aluminum power must be packaged and shipped as a flammable solid. Minimize and control operations producing dust and fume.

**DISCLAIMER The information in this MSDS was obtained from sources which we believe are reliable, however, the information is provided without any representation or warranty, express or implied, regarding the accuracy or correctness. The Conditions or methods of handling, storage, use and disposal of the product are beyond our control and may be beyond our knowledge. For this and other reasons, we do not assume responsibility and expressly disclaim liability for loss, damage or expense arising out of or in any way connected with the handling, storage, use or disposal of the product.**

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**Issue Date:** March 1, 2008

# MATERIAL SAFETY DATA SHEET

| TRADE NAME (Common Name or Synonym) Aluminum Alloy | CHEMICAL NAME Aluminum billet 6061 |
|---|---|

## I. INGREDIENTS

| Material or Component | CAS Number | % Weight | EXPOSURE LIMITS OSHA PEL (mg/m³) | ACGIH TLV (mg/m³) |
|---|---|---|---|---|
| Base Metal | | | | |
| Aluminum (Al) | 7429-90-5 | Remainder | Not Established | 10.0 Metal Dust & Oxide<br>5.0 Welded Fume |
| Alloying Elements | | | | |
| Chromium (Cr) | 7440-47-3 | 0.04-0.35 | 1.0 Chrome Metal | 0.5 Chrome Metal |
| Copper (Cu) | 7440-50-8 | 0.15-0.40 | 0.1 Fume, 1.0 Dust | 0.2 Fume, 1.0 Dust |
| Iron (Fe) | 1309-37-1 | 0.2-0.70 | 10 Oxide Fume | 5 Oxide Fume |
| Magnesium (Mg) | 1309-48-4 | 0.8-1.20 | 15 Oxide Fume | 10 Oxide Fume |
| Manganese (Mn) | 7439-96-5 | 0.05-0.15 | 5c Dust, 5c Fume | 5c Dust, 1 Fume |
| Silicon (Si) | 7440-21-3 | 0.40-0.8 | Not Established | 10 Total Dust |
| Titanium (Ti) | 7440-32-6 | 0.05-0.15 | 15 Ti Dioxide | 10 Ti Dioxide |
| Zinc (Zn) | 1314-13-2 | 0.05-0.25 | 5 Oxide Fume | 10 Dust, 5 Fume |

NOTE: Aluminum alloys will be comprised of various cominations of the elements shown above. In addition, other alloying elements may be present in minute quantities. No permissable exposure limits (PEL) or threshold limit values (TLV) exist for aluminum alloys. Values shown are applicable to component elements.

## II. PHYSICAL DATA

| MATERIAL IS (At Normal Conditions) | | APPEARANCE AND ODOR | % VOLATILE BY VOLUME: | VAPOR DENSITY |
|---|---|---|---|---|
| _ LIQUID _ SOLID _ GAS | _ OTHER | Silvery-Grey, Odorless | N/A | N/A |

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| | | | |
|---|---|---|---|
| ACIDITY/ALKALINITY pH = N/A | Melting Point 900-1200 °F °F<br>Boiling Point N/A | Specific Gravity (H20 = 1) Approx. 2.5-2.9<br>Solubility in water (% by weight) Negligible | VAPOR PRESSURE (mm Hg at 20°C) N/A |

## III. PERSONAL PROTECTIVE EQUIPMENT

| | | | |
|---|---|---|---|
| RESPIRATORY PROTECTION Appropriate respirator depending upon potential arborne contaminants and their concentrations. If exposure limits are reached or exceeded, use NIOSH approved equipment | | HANDS, ARMS AND BODY Appropriate gloves to prevent abrasions. | |
| EYES AND FACE | Safety glasses or shield for selected operations | OTHER CLOTHING AND EQUIPMENT operations and safety codes | As required depending on |

## IV. EMERGENCY MEDICAL PROCEDURES

INHALATION:
EYE CONTACT:
SKIN CONTACT:
INGESTION:

Remove to fresh air; if condition continues, consult a physician. Flush thoroughly with running water to remove particulate; obtain medical attention. Remove particles by washing thoroughly with soap and water. Seek medical attention if condition persists. If significant amounts of metal are ingested, consult physician.

## V. HEALTH/SAFETY INFORMATION

**Health**

For standard operations (e.g. melting, cutting, grinding), aluminum alloys present a low health risk by inhalation and are usually considered a nuisance dust. Toxicity by ingestion -- none expected. Skin and eyes -- not an irritant. Welding and plasma cutting of alloys high in copper (2000 and 7000 series) may present the potential for overexposure to copper fumes which can result in upper respiratory tract irritation, nausea, and metal fume fever. Nickel and chromium are other alloying elements considered hazardous as fume; however, they do not present a carcinogenic or other health concerns due to their low concentrations of the chemical form in which they are present. Overexposure to lead fumes over an extended period of time can result in such toxic effects as central nervous system disturbances, renal changes, peripheral neuropathy, gastrointestinal disturbances, anemia, and chromosomal changes. The welding of aluminum alloys may generate carbon monoxide, carbon dioxide, ozone nitrogen oxides, infrared radiation and ultraviolet radiation. OCCUPATIONAL EXPOSURE LIMITES: See Product Ingredients Section I.

**Fire and Explosion**

| | | | |
|---|---|---|---|
| **FLASH POINT N/A °F** | **AUTO IGNITION TEMPERATURE N/A °F** | **FLAMMABLE LIMITS IN AIR Lower N/A % Upper N/A %** | **EXTINGUISHING MEDIA For molten aluminum use dry power or sand.** |

| | |
|---|---|
| **FIRE AND EXPLOSION HAZARDS Aluminum tubular products do not present fire or explosion hazards under normal conditions.** | **EXTINGUISHING MEDIA NOT TO BE USED Do not use water or halogen agents on molten aluminum.** |

**Reactivity**

| | |
|---|---|
| **STABILITY _ Stable _ Unstable** | **INCOMPATIBILITY (MATERIALS TO AVOID) Reacts with strong acids to form hydrogen gas.** |

**CONDITIONS TO AVOID Aluminum products under normal conditions are stable during use, storage and transportation. Halogen acids and sodium hydroxide in contact with aluminum may generate explosive mixtures of hydrogen. Finely divided aluminum, such as small chips and fines, will form explosive mixtures in air. It also will form explosive mixtures in air in the presence of bromates, iodates, or ammonium nitrate. Strong oxidizers cause violent reactions with considerable heat generation.**

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## VI. ENVIRONMENTAL

SPILL OR LEAK PROCEDURES Fine turnings and small chips should be swept or vacuumed. Scrap metal can be reclaimed for reuse.

WASTE DISPOSAL METHOD* Used or unused product should be disposed of in accordance with Federal, State or Local Laws and Regulations. *Disposer must comply with Federal, State and Local disposal or discharge laws.

## VII. ADDITIONAL INFORMATION

Do not touch cast aluminum metal or heated aluminum product without knowing metal temperature. Aluminum experiences no color change during heating. Burns could result. Series 2000 and 7000 alloys should be stress relieved prior to sawing or cutting to avoid cracking. Aluminum power must be packaged and shipped as a flammable solid. Minimize and control operations producing dust and fume.

**DISCLAIMER The information in this MSDS was obtained from sources which we believe are reliable, however, the information is provided without any representation or warranty, express or implied, regarding the accuracy or correctness. The Conditions or methods of handling, storage, use and disposal of the product are beyond our control and may be beyond our knowledge. For this and other reasons, we do not assume responsibility and expressly disclaim liability for loss, damage or expense arising out of or in any way connected with the handling, storage, use or disposal of the product.**

# Appendix F: Product Design Specification

**Product Design Specification**

**NASA X-Hab Microgravity Random Access Stowage & Rack System**

Prepared by

MAE 490/1/2-02 Team 1 Project Office: Technology Hall N225

The University of Alabama in Huntsville

Huntsville, AL

Customer Representative:

Anne Carter

George C. Marshall Space Flight Center

Human Exploration and Operations Office

Redstone Arsenal, MSFC/4201/310

Marshall Space Flight Center, Alabama 35812

This Product Design Specification is developed for use in a class at the University of Alabama in Huntsville and does not contact a legal agreement or imply direction to perform work by a Government Agency.

**Product Design Specification Approval**

The undersigned agree that the attached Product Design Specification as marked describes the product/prototype specifications for the MAE 490/1/2 Class Project. From this time forward, any questions, clarifications or changes concerning the Product Design Specification shall be submitted in writing through the MAE 490/1/2 Instructor to the Customer Representative and the answer distributed to all MAE 490/1/2 participants in writing.

To change the Product Design Specification after signatures are completed shall require that the change be stated in writing and that a person authorized by every one of the signers below endorse the change with their signature. The revision will be labeled uniquely and distributed to all participants simultaneously.

The original of this document will be kept on file with the UAH Instructor. All signers will receive a copy of the original document.

___________________________/_______________

Anne Carter, Customer Representative

___________________________/_______________

Adam Marlar, Student

___________________________/_______________

Cameron Bradley, Student

___________________________/_______________

Caroline Bryson, Student

___________________________/_______________

Christopher Barnett, Student

___________________________/_______________

Clint Deerman, Student

___________________________/_______________

David Brooks Student

___________________________/_______________

Drew Deerman, Student

___________________________/_______________

Elizabeth Olivares, Student

___________________________/_______________

Sarah Rogers, Student

___________________________/_______________

Taylor Stokes, Student

___________________________/_______________

Thomas Dodson, Student

___________________________/_______________

Christina Carmen, MAE 491/2 Instructor

**1.** **<u>SCOPE</u>** This specification establishes the purpose, functional requirements, corporate constraints and social, political and legal requirements for the NASA X-Hab - Microgravity Random Access Stowage & Rack System Project. The mission of the NASA X-Hab - Microgravity Random Access Stowage & Rack System Project is to design, manufacture, and implement a microgravity stowage system to be installed in NASA's Deep Space Habitat Module at Marshall Space Flight Center (MSFC).

**2.** **<u>CUSTOMER REQUIREMENTS</u>** The NASA X-Hab - Microgravity Random Access Stowage & Rack System Project is described in terms of its initial requirements and constraints as dictated by the customer.

**2.1** **<u>Requirement 1</u>.** The stowage system concept shall be designed for a specified volume of the DSH. This requirement was met.

**2.2** **<u>Requirement 2</u>.** The delivered demonstration product shall occupy only a percentage of the volume of the DSH. This requirement was met.

**2.3** **<u>Requirement 3</u>.** Determination of the percentage developed shall depend on the design team's ability to show proof of concept. This requirement was met.

**2.4** **<u>Requirement 4</u>.** The project product shall fit into the DSH space and volume (dimensions: 21.65 x 13.78 x 13.78 $ft^3$, approximate volume: 4,111 $ft^3$). This requirement was met.

**2.5** **<u>Requirement 5</u>.** The project product shall be able to enter the DSH via the end cone (hatch) (dimensions: 50 in. w, 50 in. h, and diagonal 61 in.).This requirement was met.

**2.6** **<u>Requirement 6</u>.** The project product shall be able to be configured and installed within the aforementioned DSH volume. This requirement was met.

**2.7** **<u>Requirement 7</u>.** Once installed, the product shall not continuously impede the emergency translation path of the DSH (dimensions: 32 in. x 45 in.) This requirement was met with the design of the product.

**2.8** **<u>Requirement 8</u>.** The stowage system shall be of minimum weight per NASA's suggestion (No weight requirement or maximum has been stated. The design team shall determine an acceptable weight for the system.). This requirement was met with the design of the product.

**2.9** **<u>Requirement 9</u>.** If applicable, fasteners on the system shall be of a common type and size to minimize the number of tools required to operate the fasteners, the crew workload required to collect the appropriate tools, and the potential for trying to use the wrong tool. Hand actuated fasteners shall also be of a common type and size to minimize frustration of having to remember how to operate a variety of latches and fasteners. If multi-turn fasteners are required by the system, the fastener shall fasten or unfasten in less than 10 turns. The number of fasteners used in an application shall be minimized. No further details about fasteners, types, or sizes were specified by NASA. This requirement was met with the design of the product.

**2.10** **Requirement 10.** Due to the frequent access needed for the aforementioned supplies, an easily reconfigurable design shall be implemented. This requirement was met with the design of the product.

**2.11** **Requirement 11.** The stowage system shall have the following characteristics: flexibility, interchangeability, adjustability, and reusability. This requirement was met with the design of the product.

**2.12** **Requirement 12.** The designed product shall have self-stabilization capabilities, particularly during launch and landing (This does not pertain to the delivered demonstration product due to a difference in materials used for construction). This requirement was met with the design of the product.

**2.13** **Requirement 13.** The product shall be designed to be scalable to accommodate stowage of 100+ single sized Cargo Transfer Bags (CTBs) measuring 19.75" by 16.75" by 9.75". This requirement was met with the design of the product.

**2.14** **Requirement 14.** Concerning launch loads, the system shall be designed to accommodate the expected launch environments for the potential launch vehicles on which the end item may launch to missions beyond low earth orbit (no specific numerical launch loads were provided by NASA). This requirement was not met because it was considered beyond the scope of the project since the end product will be for demonstrational and proof of concept purposes on Earth. In addition; the information was not provided to the design team for their consideration in their design.

**2.15** **Requirement 15.** On orbit fire protection is provided via portable fire extinguishers that require a port for the interface to the system. Therefore, the design team shall not be responsible for providing fire safety tools. This requirement was not met because the listing stated that the information was "…for information only" in the UAH X-Hab Level 1 Rqmts. 20 Aug 2012 document.

**2.16** **Requirement 16.** If the design has acoustic concerns, the design team shall consider and conform to the acoustic limits set by NASA. This requirement was met.

## 3. MAJOR COMPONENT LIST

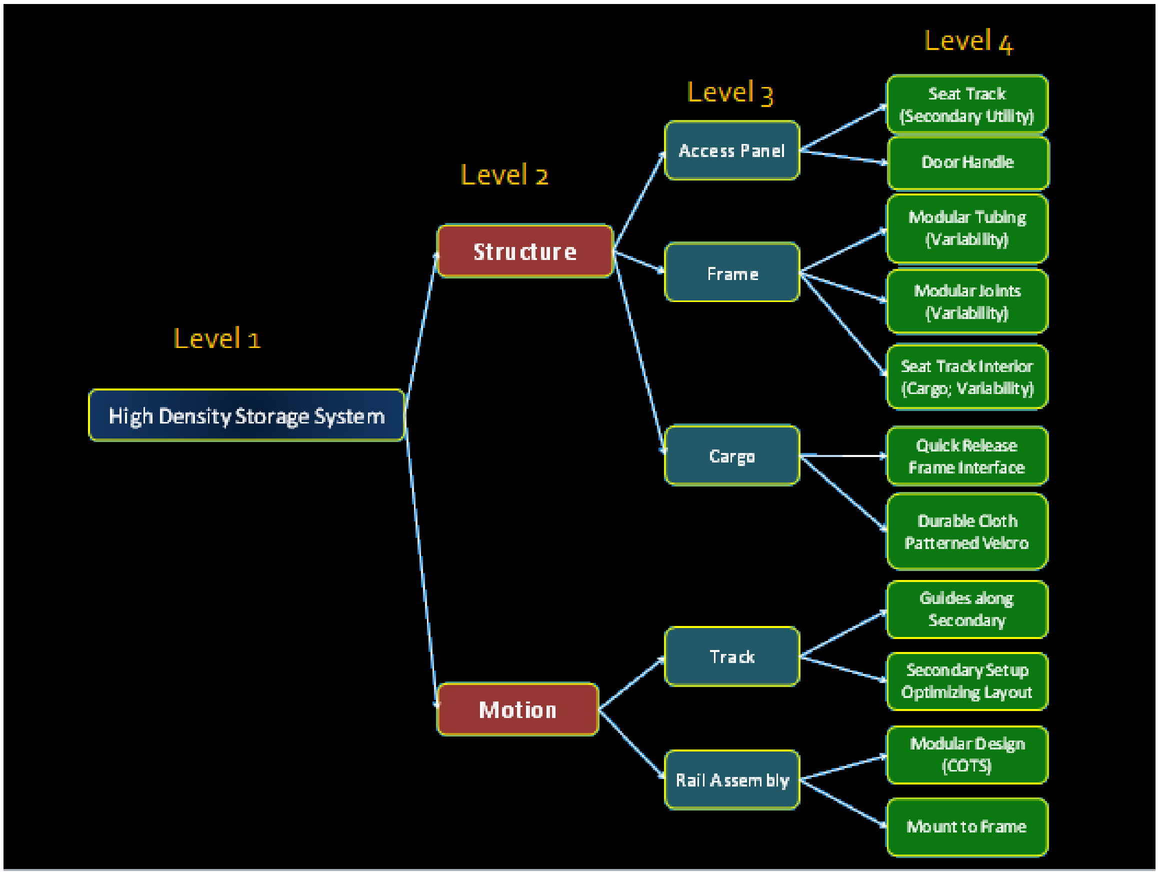



**Figure 1 –Major Component Diagram**

## 4. PURPOSE AND MARKET FOR PRODUCT

**4.1 Product Name:** Deep Space Habitat Stowage System

**4.2 Product Purpose and Function it is to Perform:** The stowage system for the mission scenario provides space and organization for long duration missions with infrequent re-supply; thus, the DSH stowage unit shall provide storage for items with varying functions (medical, food, hygiene, maintenance, entertainment, and food supplies, and science experiments). These items will be contained in Cargo Transfer Bags (CTBs). The delivered demonstration product will provide proof of concept and allow for on Earth (1G) demonstration of the stowage system’s uses and functionality.

**4.3 Predictable Unintended Uses of Product:** This design could potentially be used in a 1g configuration with the current configuration to store Cargo Transfer Bags. The system’s cloth shelving would be used with fully loaded CTBs instead of empty, demonstrational bags. The fully extended drawer could be used to reach above the system by climbing on the drawer.

**4.4 Product Special Features:** The design utilizes seat track to attach the cloth shelving. The storage system is able to translate for easy access of all storage items. There are multiple handles on the large drawers to increase the ease of use. None of the CTBs are blocked in the functional configuration of this design. The open design takes up minimal space in the Habitat. The product features non-rotating, locking casters for easy demonstration of the system's intended motion. These casters also add to the stability of the motion of the system as well as lock it in place when movement is unwanted. Base plates are added in each unit of the system in order for on Earth (1G) demonstration of the system's capability of stowing CTBs. The system will utilize vertical displacement spacers between the bearings at the top of each unit and the 80/20® track, which will provide an easy leveling mechanism should the end product need such a procedure.

**4.5 Intended Market, Need, Demand:** This product meets the needs of the NASA Deep Space Habitat astronauts for high density storage that is easy to use and easy to operate in a limited space environment. The demand for this type of equipment is high because of the importance of effective use of space in space missions.

**4.6 Company Selling Price/Estimated Retail Price:** The retail budget for this project is estimated to be approximately $. This will include the materials, manufacturing, labor, delivery, installation, and design costs.

**4.7 Product Competition:** Resupply Stowage Platform (RSPs), Resupply Stowage Racks (RSRs), and Zero-Gravity Stowage Rack (ZSRs) are the other storage systems that exist that could possibly compete with the product design.

## 5. FUNCTIONAL REQUIREMENTS

**5.1 Functional Performance:** In order to open unit, the operator will unlock the casters on the bottom of the unit using a foot or hand, grab handle with his or her hand, and pull out unit until fully extended. The operator will attach Cargo Transfer Bags (CTBs) to Velcro wall using order designed for optimal use of unit. In order to remove a CTB from unit, pull cloth handle on CTB to remove. In order to close unit, push unit back into place using system's handle or front panel closeout and lock the casters on the bottom of the unit using a foot or hand. The design stowage system will be able to accommodate 56 single sized Cargo Transfer Bags. The system will utilize Velcro fasteners attached to 3 canvas sheets (1 wide, 2 deep, 7 high on each sheet).

**5.2 Physical Requirements:** The total size of the storage system (3 storage units) will be 87" wide by 81.125" high by 38.5" deep. The overall shape of the system models a rectangular prism. The track interface will consist of 80/20® materials. The frame the track system will bolt to will be made of aluminum tubing. The doors to each unit will be plastic composite. The shelving will be made of a high strength canvas and will have Velcro attachment points. The storage system will weigh about 250 pounds mass, including the secondary 80/20® attachment points.

**5.3 Service Environment:** The stowage system will be constructed and installed in a 1g environment. The functional, final product from the UAH Design Team will be built on Watring and UAH facilities. This product will be delivered and installed at the Marshall Space Flight Center in the Deep Space Habitat Module. The designed, theoretical system will operate in a 0g environment with environmental controls that maintain a livable environment for the astronauts.

**5.4** **<u>Life-Cycle Issues</u>:** The main concern is the life of the bearing pads (Unibearing™®) for the track system. This issue will be addressed through testing.

**5.5** **<u>Human Factors</u>:** In a "space" (microgravity) configuration, the CTBs that are used most often will need to be located at the top of the system, between 36 inches from the bottom (standard table top height). The cloth shelving as well as all close out covers should be white, especially for flight configuration. The main operator-machine interface will be the system's handles. Labels will be placed on all system components to aid in the assembly and disassembly of the product.

**5.6** **<u>Facilities, Transportation and Storage</u>:** The design shall be completely manual in operation and mechanical in design.

## 6. <u>CORPORATE CONSTRAINTS</u>

**6.1** **<u>Time to Market</u>:** The time available to design, manufacture, test, and install the final product is 10 months (August 2012-May 2013)

**6.2** **<u>Manufacturing Requirements</u>:** The combined efforts of Watring Technologies, Inc. along with the UAH Project Team members will be utilized in order fabricate the final demonstration product. Projected required tools include: CNC Milling Center, CNC Turning Center, Press Brake, Drill Press, and Assorted Manual Equipment. Aluminum tubing used for systems frame will be match drilled do decrease machining time. Water jets will be utilized for the system's support gussets. Seat track will be added on any possible surface to increase the amount of attachment points.

**6.3** **<u>Suppliers</u>:** This following is a list of suppliers (manufacturers) of the end materials used to fabricate the final product.

- Watring Technologies
- 80/20®, Inc.
- McMaster-Carr®
- L. Miller & Son, Inc.(lmsmetalsales.com)
- Online Metal Store (OnlineMetals.com)
- Mathis Upholstery
- Huntsville Glass

**6.4** **<u>Trademark, Logo, Brand Name:</u>** None are stipulated as a product design specification.

**6.5** **<u>Financial Performance</u>:** Considering the high demand for a system that will provide a solution to offer effective, easily accessible, variable storage for long duration deep space missions, the design will be extremely profitable for many years to come.

**6.6** **<u>Corporate Ethics</u>:** The suggestion is to follow the fundamental canons outlined by the engineering code of ethics created by National Society of Professional Engineers (NSPE) when dealing with suppliers, citizens, society at large, owners of intellectual property, each other, etc. The paramount concern is the overall safety and welfare of the public.

**6.7** **<u>Budget</u>:** The initial allocated budget and estimated final development cost of the prototype is $.

## 7. <u>SOCIAL, POLITICAL AND LEGAL REQUIREMENTS</u>

**7.1** **<u>Safety and Environmental Regulations</u>:** The section is not applicable to the design.

**7.2** **<u>Standards</u>:** The Human Integration Design Handbook (HIDH) standards specified by NASA are followed to adhere to any set standards regarding implementation of the product. In addition, the NASA standards (Specification 5.1.1.2 from the JSC 27301 Materials & Processes Selection Control & Implementation Plan for Flight Hardware) regarding Velcro were followed in order to limit the likelihood of fires caused by electro-static discharge (ESD).

**7.3** **<u>Safety and Product Liability</u>:** Warning labels will be implemented on the system wherever a risk of operator injury is possible. Per level 1 requirements, the system will not impede the set dimensions of the emergency translational path in the DSH designated by NASA. As a result of the risk assessment and mitigation analysis performed by the design team, all safety hazards have been mitigated.

## 8. Glossary

This glossary defines every acronym in the document.

CTB – Cargo Transfer Bag

DSH – Deep Space Habitat

HIHD – Human Integration Design Handbook

MSFC – Marshall Space Flight Center

MPLM – Multi-Purpose Logistics Module

NASA – National Aeronautics and Space Administration

X-Hab – eXploration Habitat Academic Innovation Challenge 2013

PDS – Product Design Specification

CR – Customer Requirement

MSR – Market Survey Requirement

UAH –University of Alabama in Huntsville

## 9. References

Document references below that are specifically cited in this document. They must be referenced by number to the text in this document that cites them and be descriptive enough that any signing party can gain access to the document.

Reference 1
Title: EO40 X-Hab 2013 NSFG Project Number: 2013-ESMD-XHAB-05 Requirements for UAH Proposal: Design and Development of a Microgravity Random Access Stowage and Rack System
Produced By: George C. Marshall Space Flight Center MSFC, Alabama 35812
Effective Date: August 20, 2012

Reference 2
Title: Human Integration Design Handbook (HIHD), NASA/SP-2010-3407
Applicable Sections: Sections 4, 7.7, 8.2-8.4 and 9
Produced By: NASA
Date: January 27, 2010

Reference 3:
Title: eXploration Habitat (X-Hab) 2013 Academic Innovation Challenge Solicitation
Produced By: National Space Grant Foundation
101 Constitution Avenue NW, Suite 650 East
Washington DC 20001-2133

**Date: March 08, 2012**

# Appendix G: Design Drawings

The following are detailed design drawings with all dimensions specified in inches.

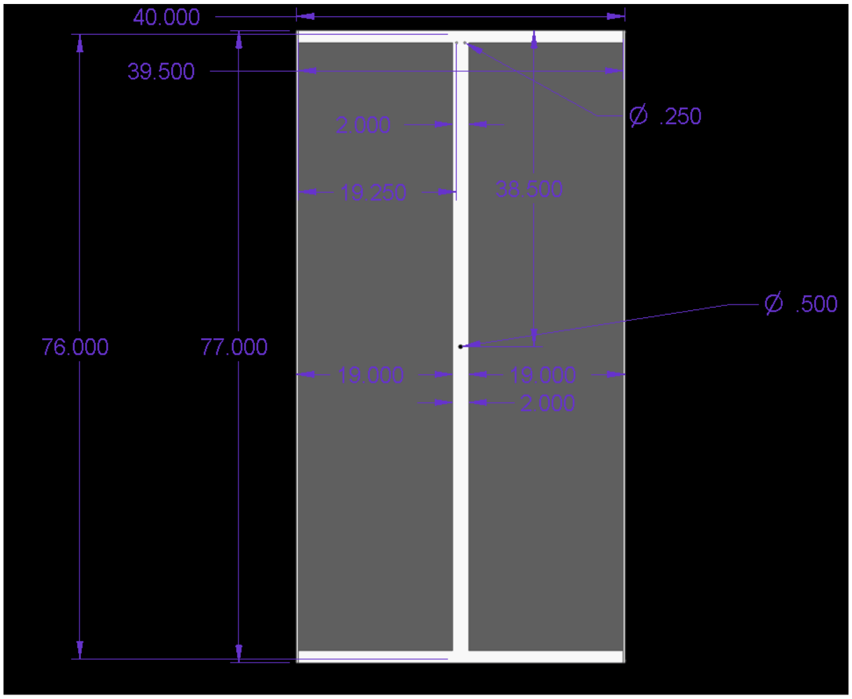



**Fig. G-1:** Center Door Front

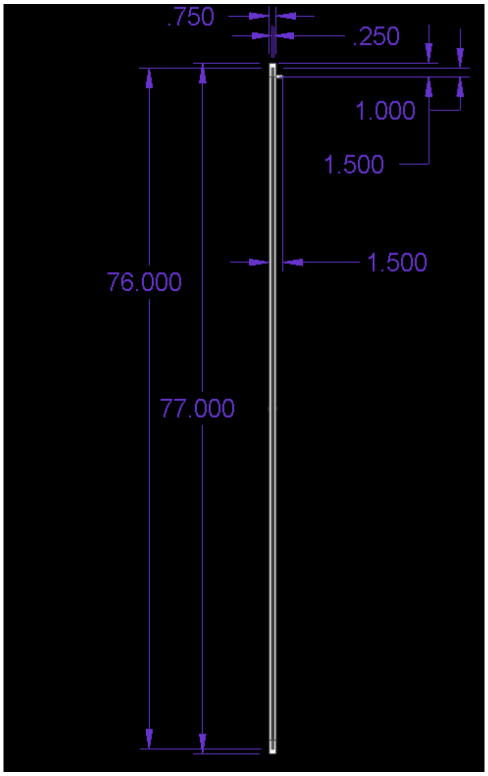



**Fig. G-2:** Center Side Door

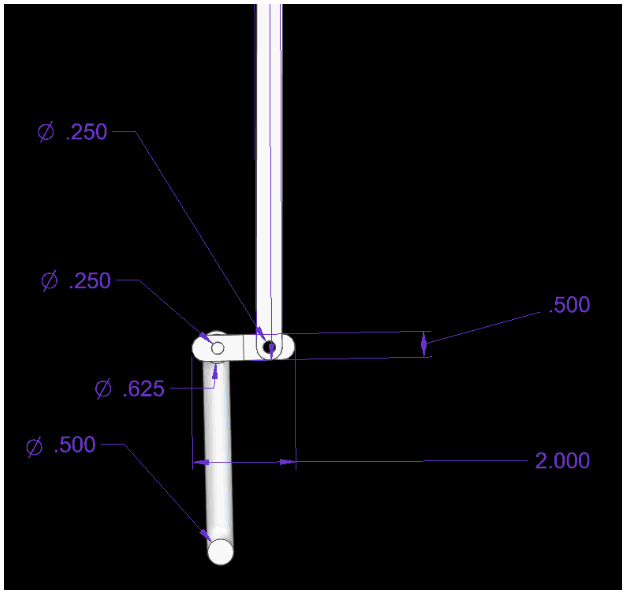



**Fig. G-3:** Handle Assembly Back

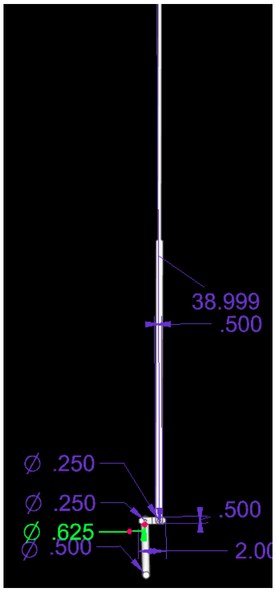


**Fig. G-4:** Handle Assembly Back

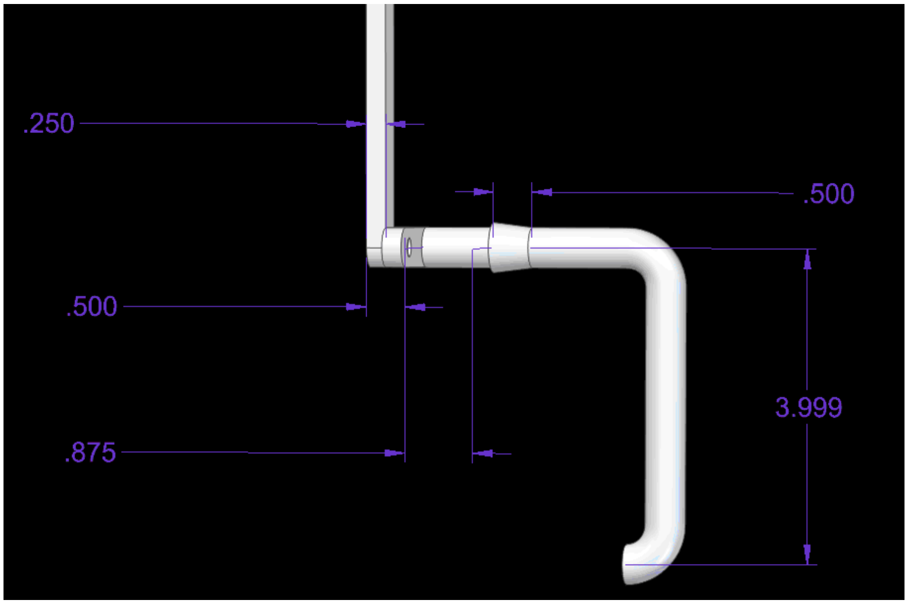


**Fig. G-5:** Handle Assembly Side

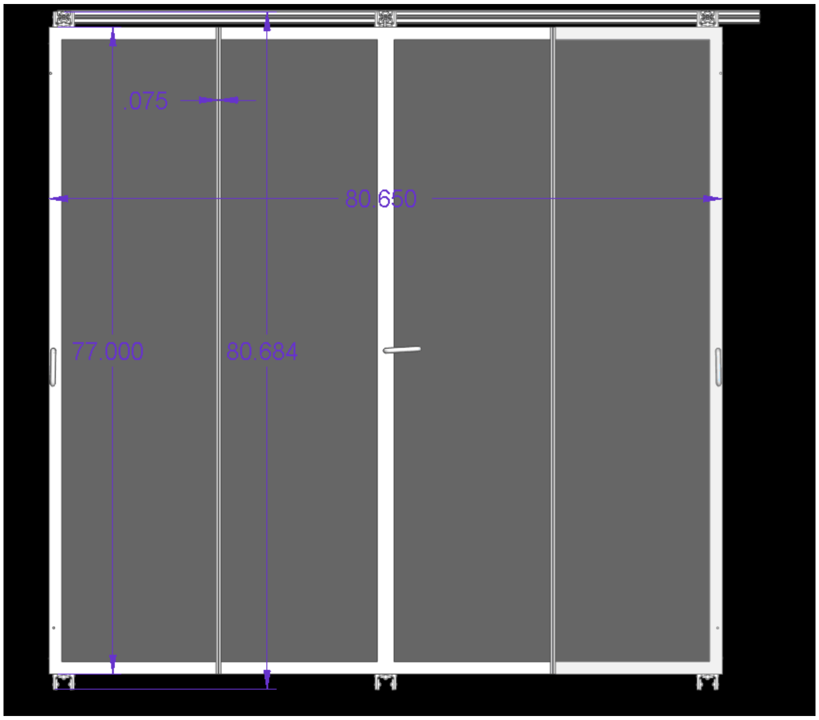



**Fig. G-6:** Overall Front

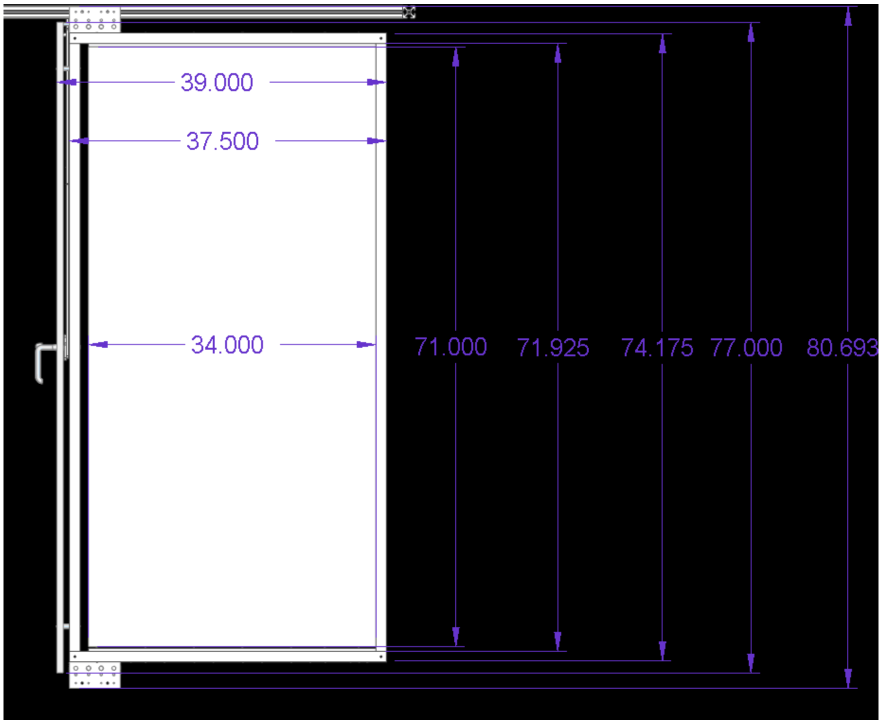



**Fig. G-7:** Overall Side

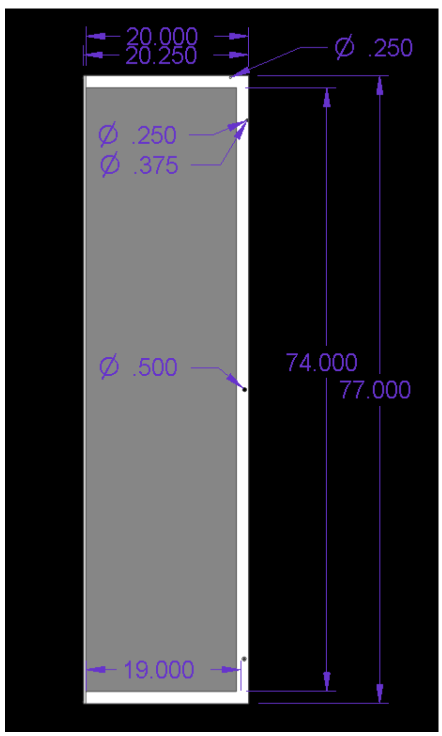



**Fig. G-8:** Single Door Back

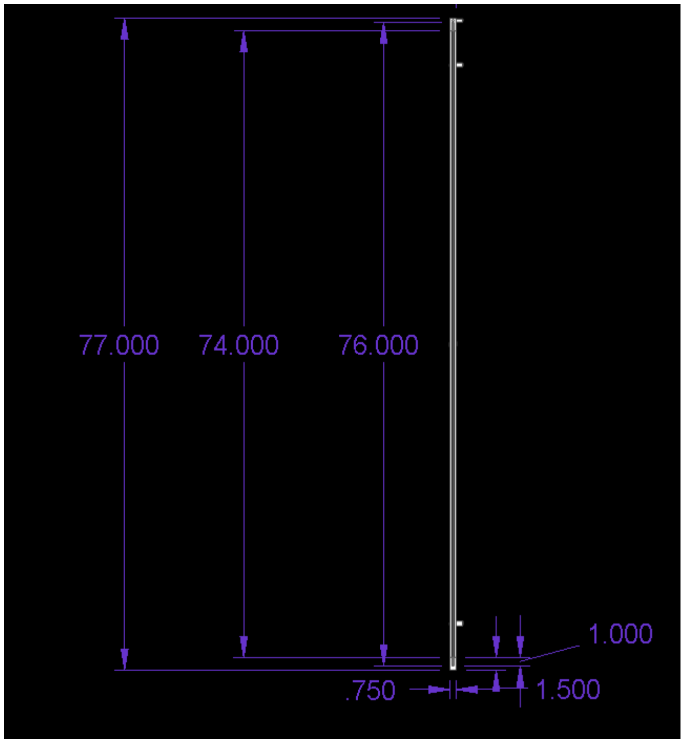



**Fig. G-9:** Single Door Right

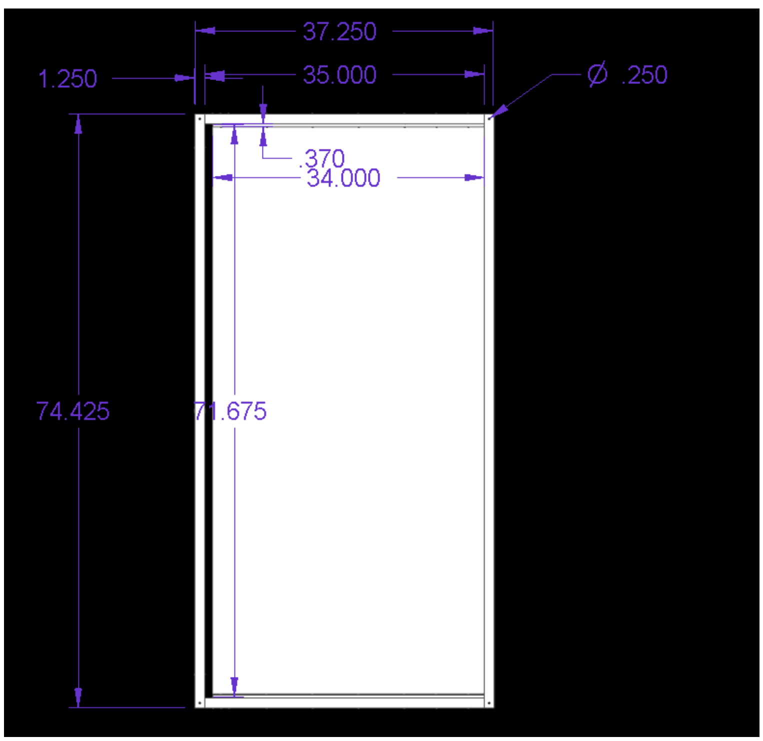



**Fig. G-10:** Frame Side

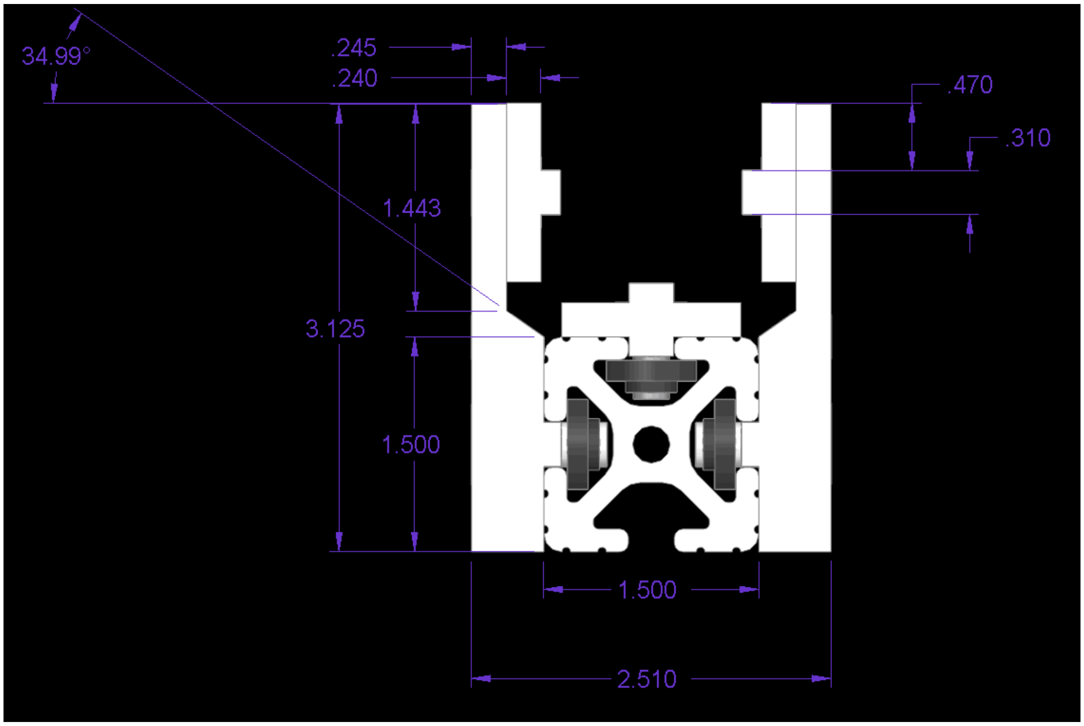


**Fig. G-11:** Unibearing™ Front

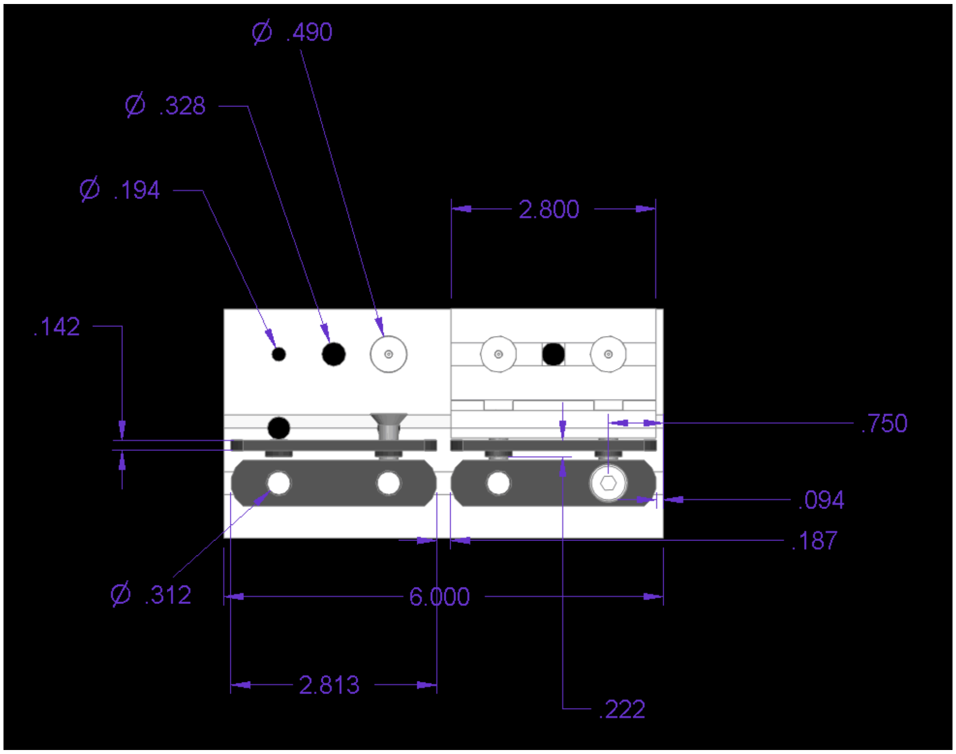



**Fig. G-12:** Unibearing™ Side Cross Section

# Appendix H: One-G System Parts

All dimensions are in inches.

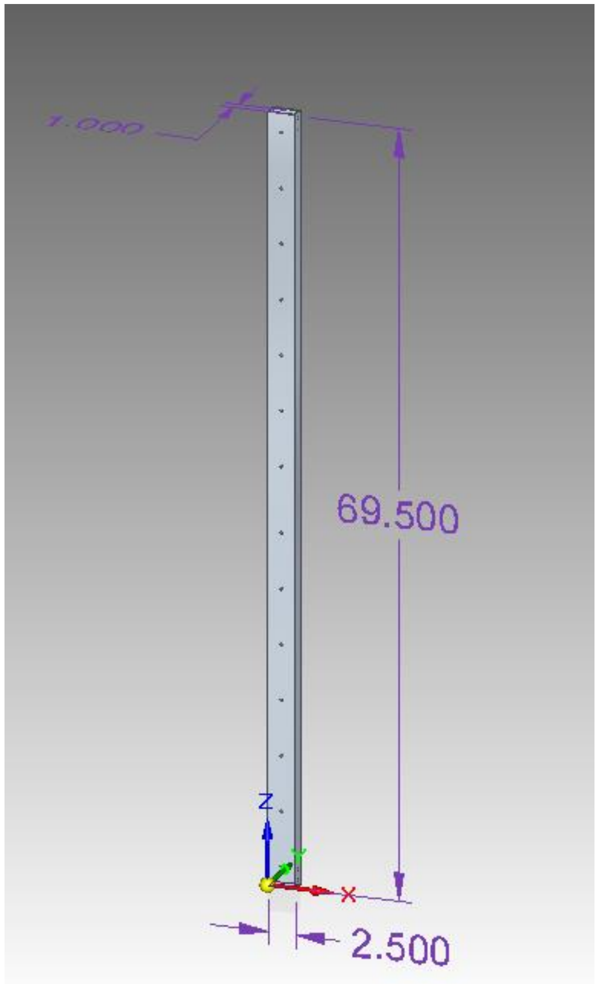



**Fig. H-1:** Frame Vertical

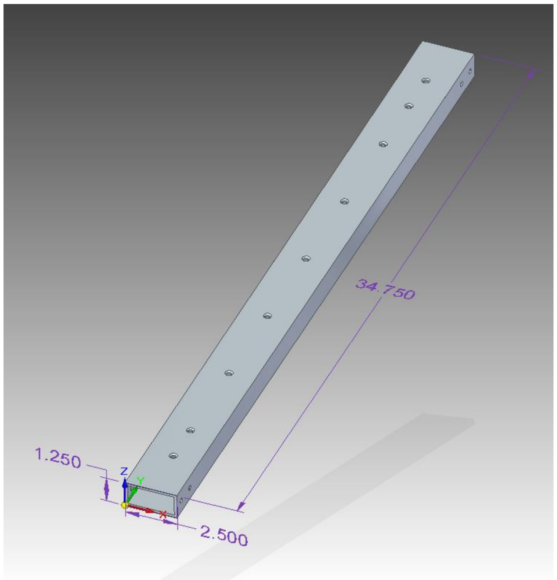



**Fig. H-2:** Frame Horizontal

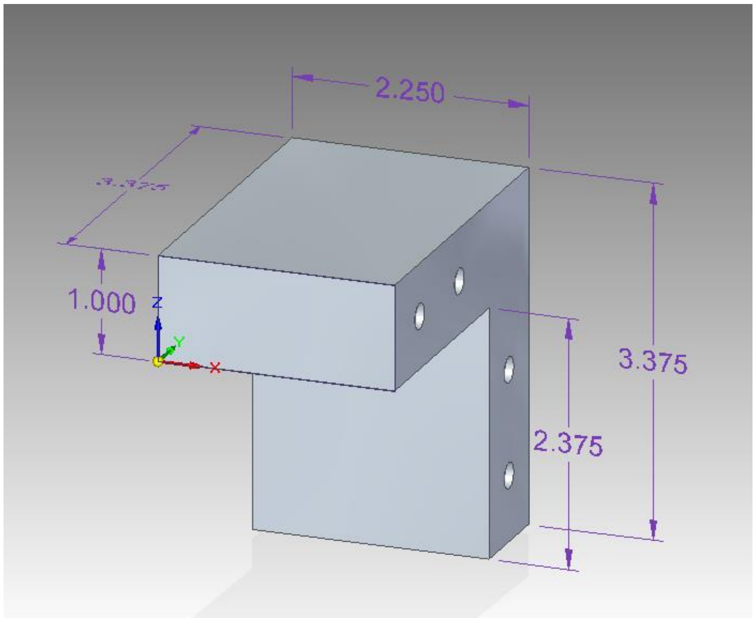



**Fig. H-3:** Frame Joint

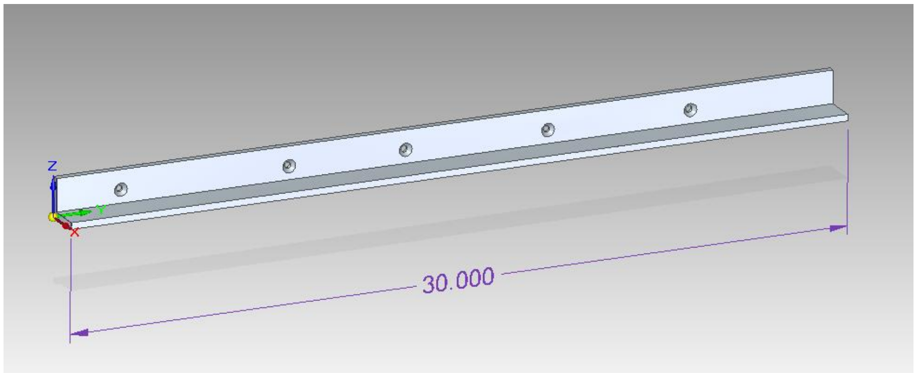



**Fig. H-4:** Long Angle Aluminum

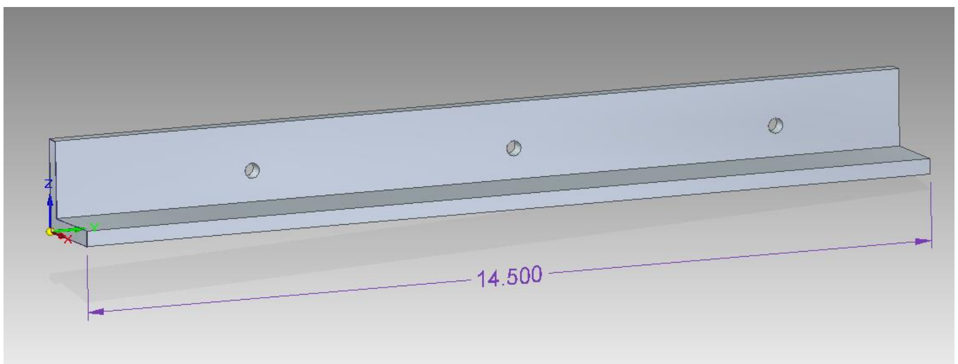



**Fig. H-5:** Short Angle Aluminum

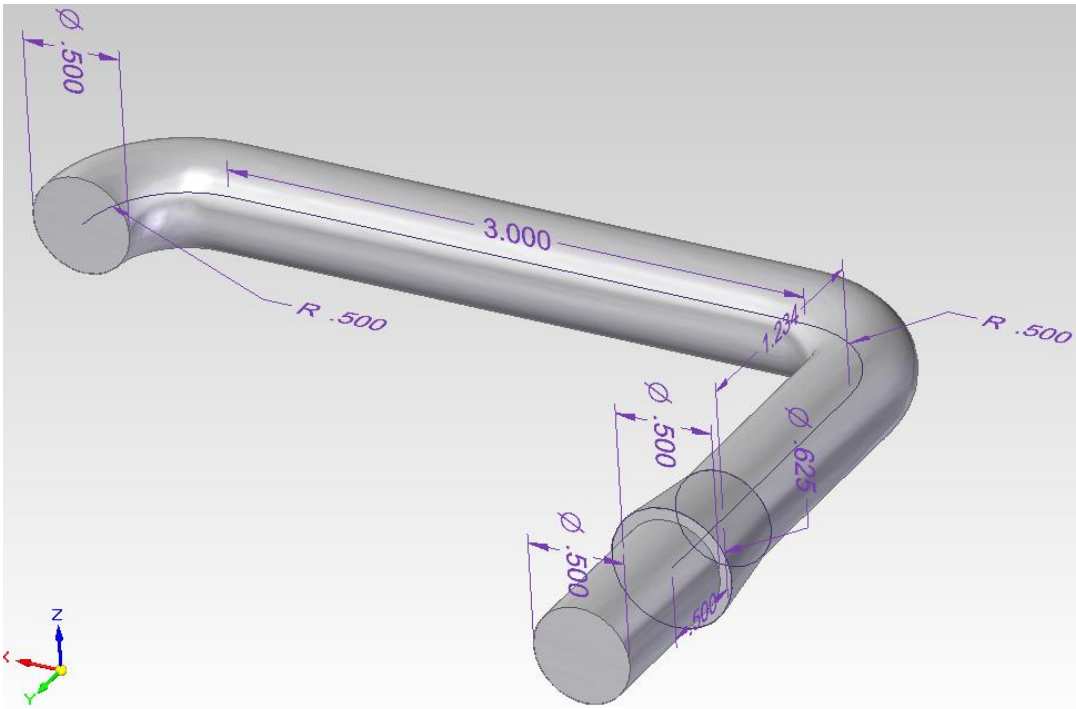



**Fig. H-6:** Door Handle

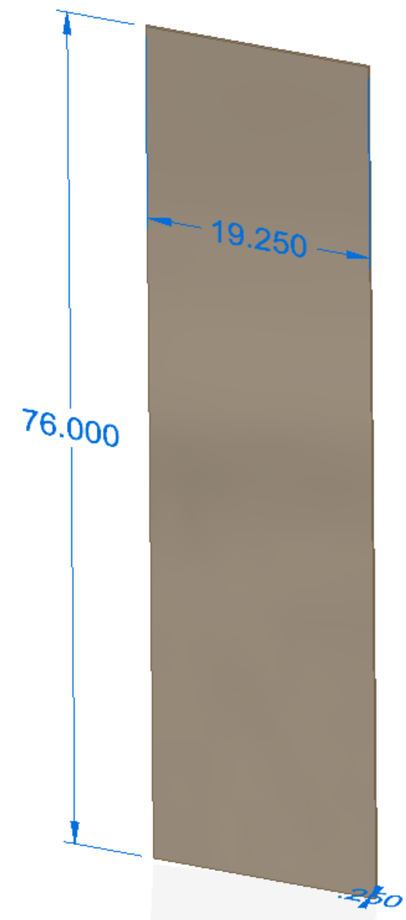



**Fig. H-7:** Door Panel

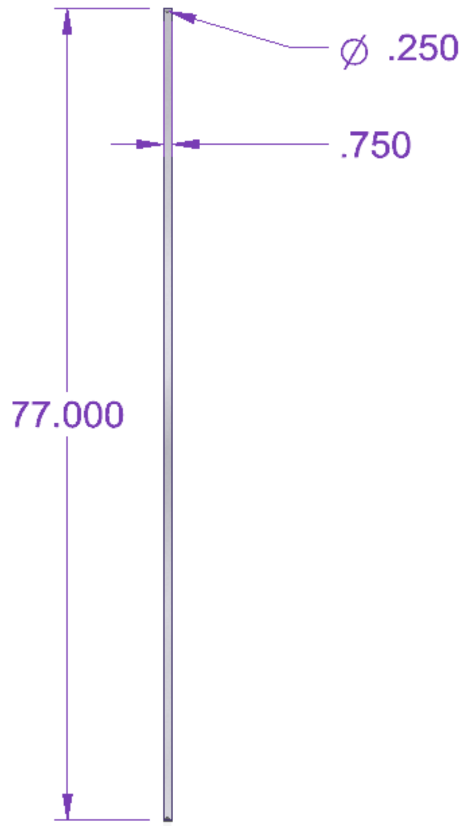



**Fig. H-8:** Door End

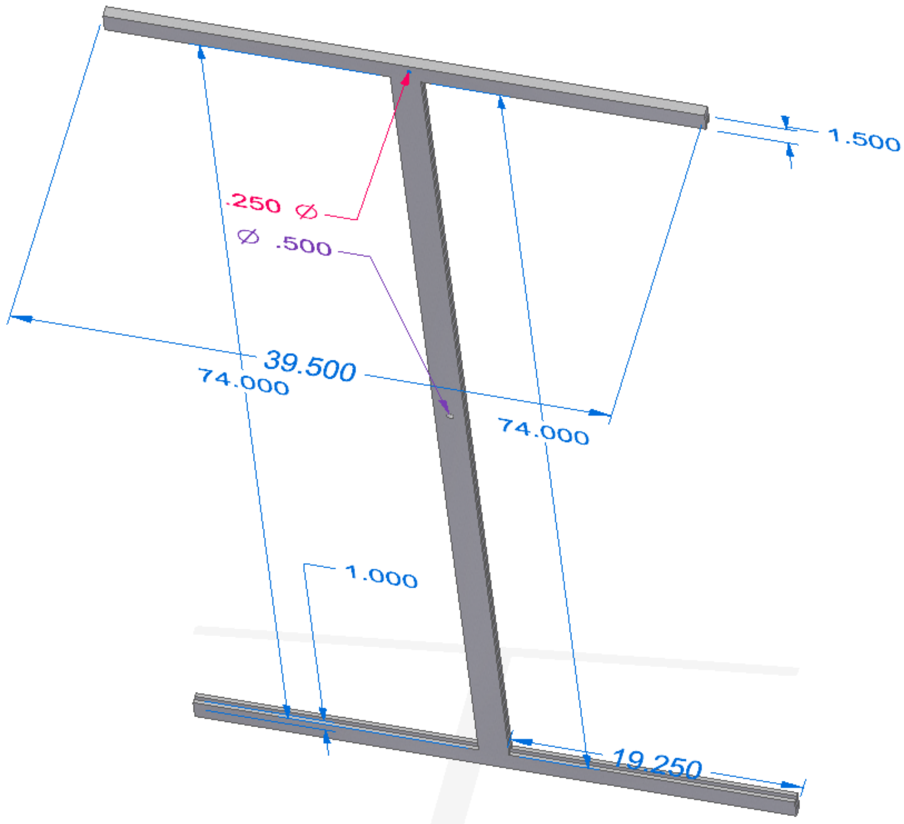


**Fig. H-9:** Center Door Frame

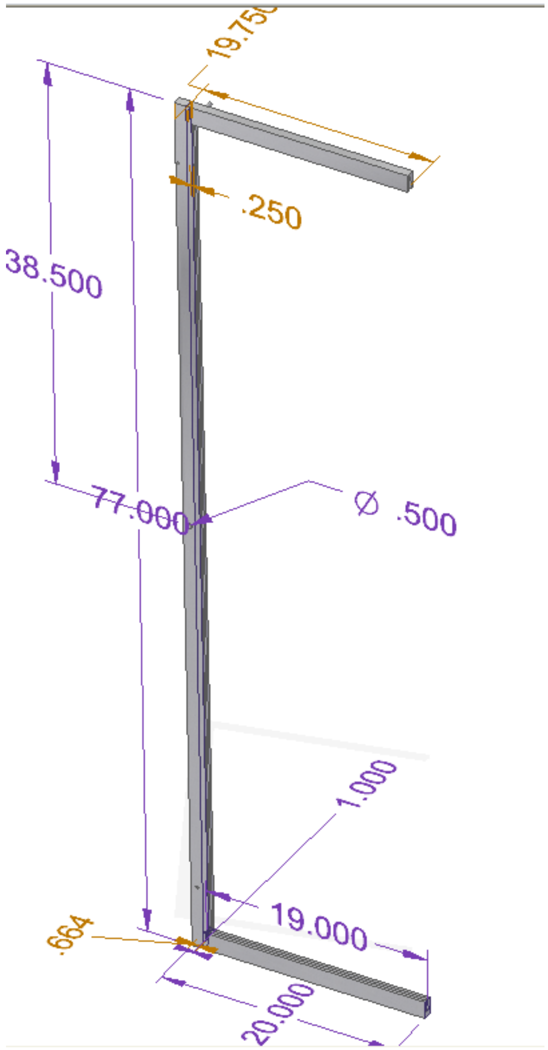



**Fig. H-10:** Single Door Frame

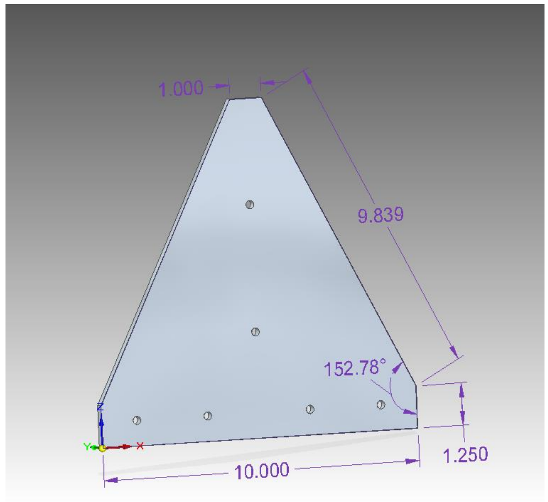



**Fig. H-11:** Center Unit Gusset

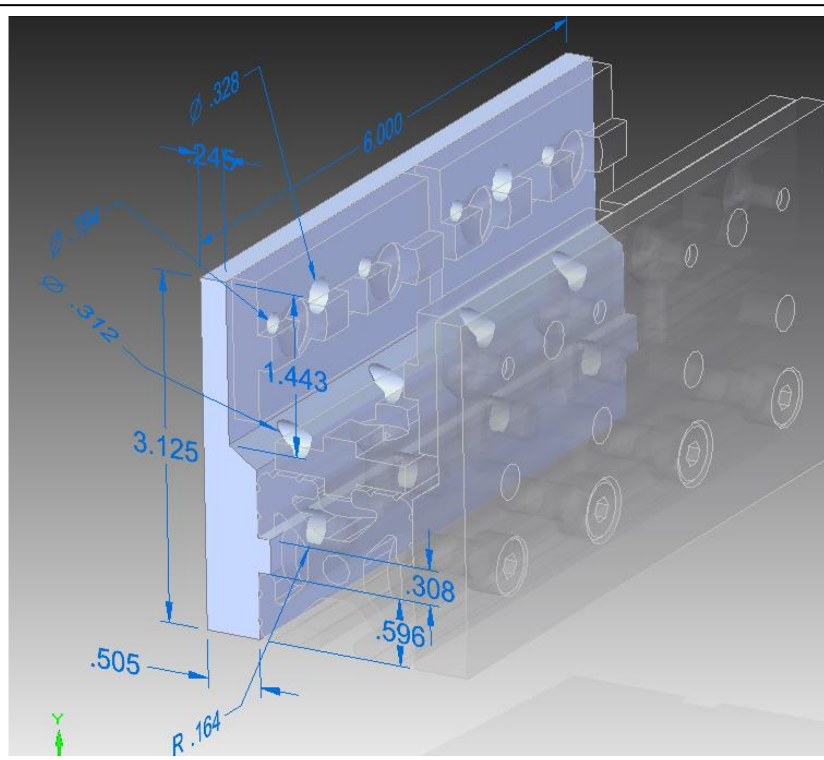



**Fig. H-12:** Unibearing™ Support Section

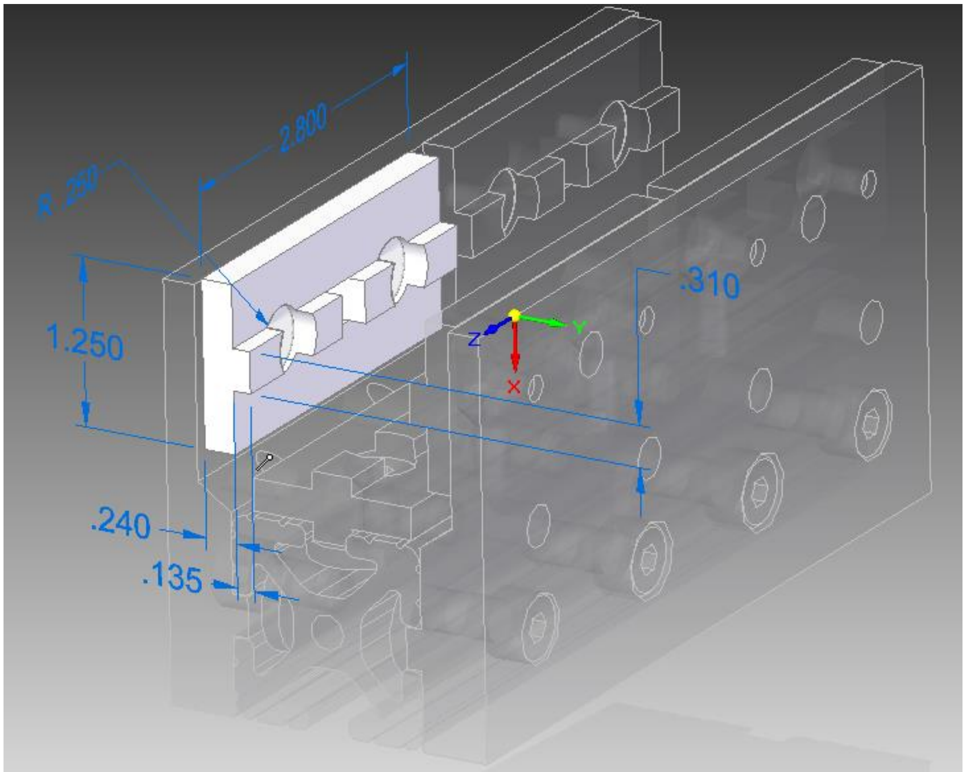



**Fig. H-13:** Unibearing™ Bearing Pad

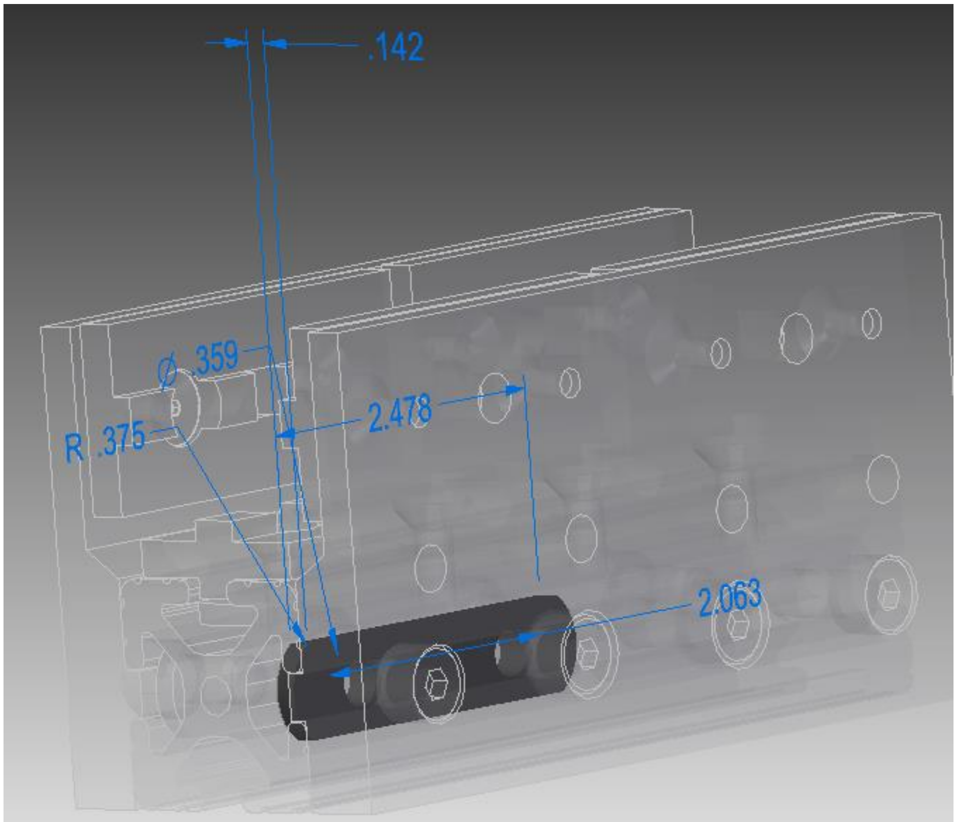



**Fig. H-14:** Unibearing™ Clamp Plate

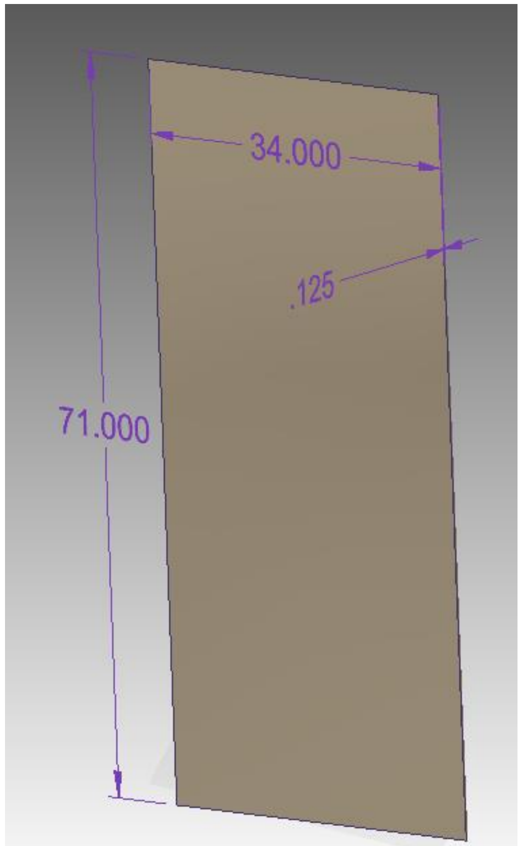



**Fig. H-15:** Cloth Structure

**Fig. H-16:** Push Release Attachment Point

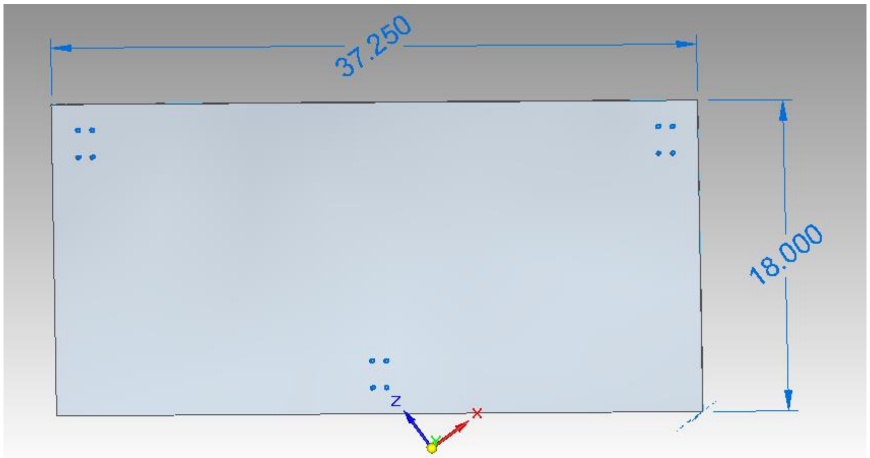



**Fig. H-17:** Base Plate

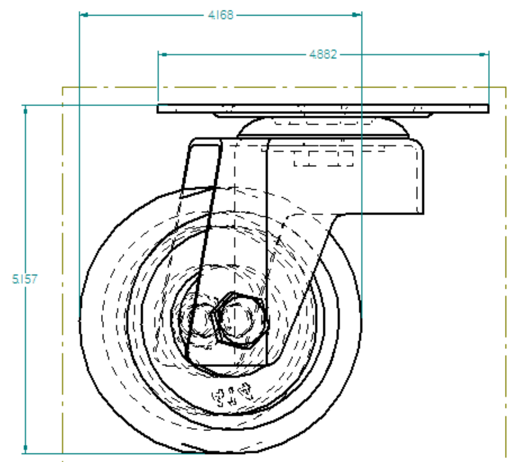



**Fig. H-18:** Caster

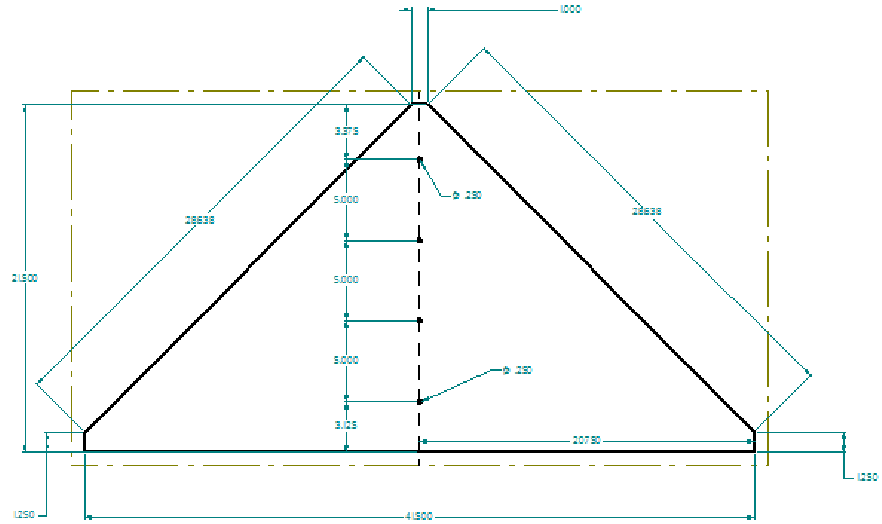



**Fig. H-19:** Gusset

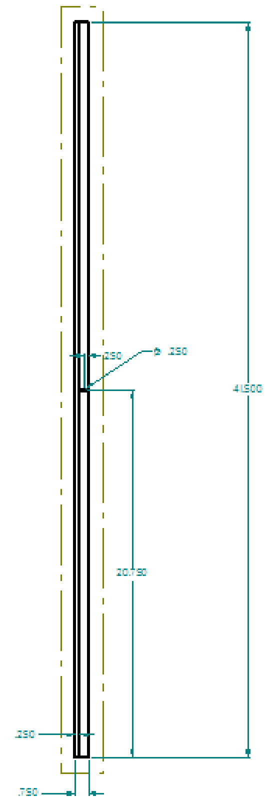



**Fig. H-20:** Flange

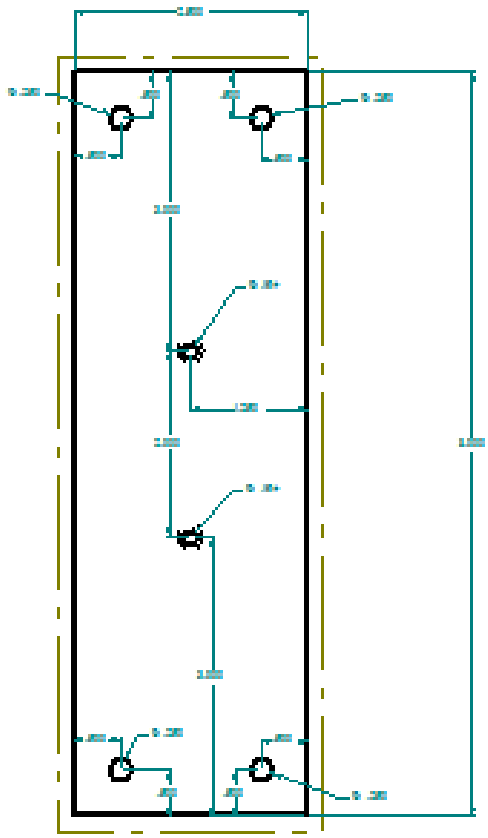


**Fig. H-21:** Vertical Displacement Compensation System

# Appendix I: MSFC Dynamic Vibration Modal Test Report

## Micro Stowage System Substructure Modal Survey Test Results

The modal survey of the Micro Stowage System substructure was performed at Marshall Space Flight Center building 4619 on April 11-12, 2013. The structure was placed on soft foam to approximate a free-free boundary condition, as shown in Figure I-1. Modal data was acquired using a Leuven Measurement Systems (LMS) Scadas 305 frontend connected to a laptop controller as shown in Figure I-2. Data was acquired in the frequency range from 0 to 400Hz with a resolution of approximately 0.1953Hz.


**Fig. I-1:** Test Structure

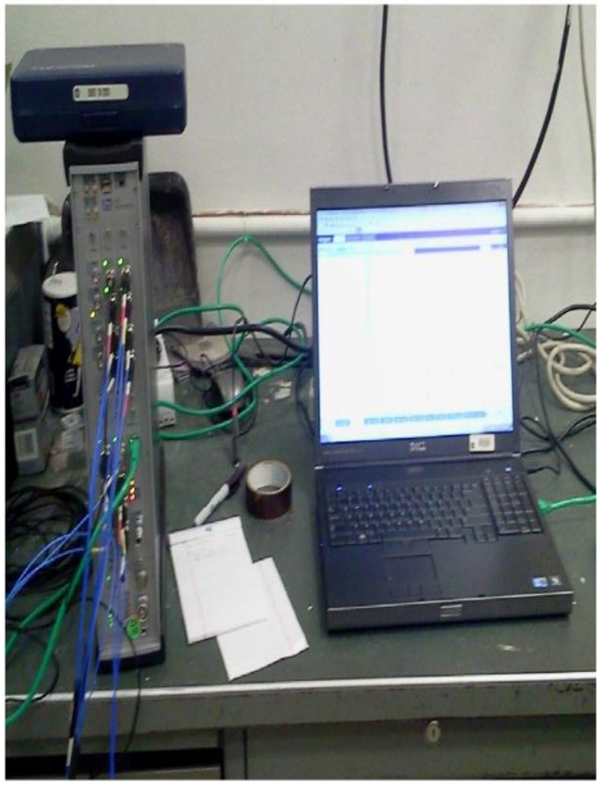


**Fig. I-2:** Data Acquisition System and Controller

A Multiple Reference Impact Test was selected as the test method to excite the structural modes and acquire the necessary data. Five PCB 356B21 triaxial accelerometers were placed on the structure using wax. A PCB 086C02 modally tuned impact hammer was used to excite the structure at 4 measurement nodes in varying directions. Table I-1 provides a summary of the impact nodes used, along with the impact directions at each node. Input locations and directions are shown in Table I-2. Frequency Response Functions (FRFs) were acquired for each impact location. After all six input locations were acquired, the accelerometers were moved to the next 5 response locations. This method of roving the accelerometers and acquiring FRFs was repeated until the data at all measurement nodes of interest were acquired.

**Table I-1:** Input Locations and Directions

| Node | X, in. | Y, in. | Z, in. | Reference Dir. | |
|---|---|---|---|---|---|
| 2 | 0 | 0 | 38 | +X | -Y |
| 5 | 0 | 21 | 74 | -Z | |
| 9 | 20 | 0 | 70 | -Y | -Z |
| 12 | 38 | 0 | 35 | -Y | |

**Table I-2:** Input Locations and Directions

| Node | X, in. | Y, in. | Z, in. | Response Dir. | | |
|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | -X | +Y | +Z |
| 2 | 0 | 0 | 38 | -X | +Y | +Z |
| 3 | 0 | 0 | 74 | -X | +Y | -Z |
| 4 | 0 | -21 | 74 | +X | -Y | -Z |
| 5 | 0 | 21 | 74 | +X | -Y | -Z |
| 6 | 0 | 21 | 0 | +X | +Y | -Z |
| 7 | 0 | -21 | 0 | +X | +Y | -Z |
| 8 | 20 | 0 | 0 | -X | +Y | +Z |
| 9 | 20 | 0 | 70 | +X | +Y | -Z |
| 10 | 0 | 0 | 70 | +X | -Y | +Z |
| 11 | 38 | 0 | 70 | -X | +Y | +Z |
| 12 | 38 | 0 | 35 | +X | +Y | -Z |
| 13 | 38 | 0 | 0 | +X | +Y | +Z |
| 14 | 0 | -21 | 38 | -X | -Y | +Z |
| 15 | 0 | 21 | 38 | +X | +Y | +Z |
| 16 | 0 | 0 | 19 | -X | +Y | +Z |
| 17 | 0 | 0 | 55 | -X | -Y | +Z |

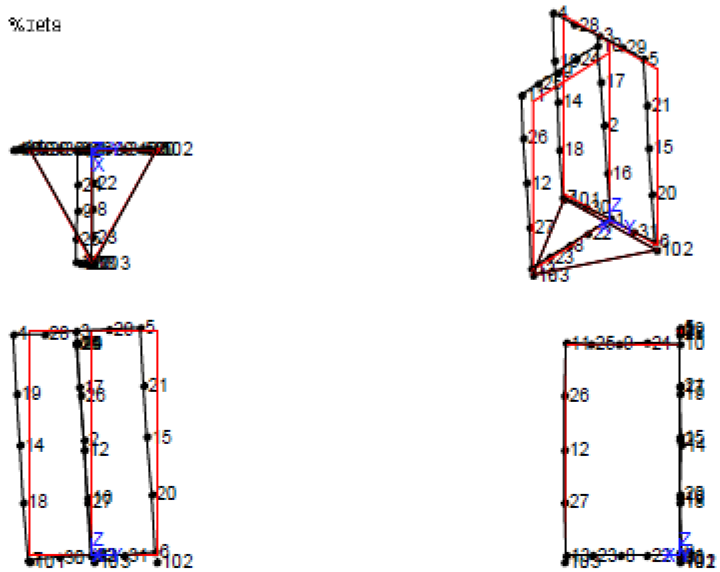
| Node | X, in. | Y, in. | Z, in. | Response Dir. | | |
|---|---|---|---|---|---|---|
| 18 | 0 | -21 | 19 | -X | -Y | +Z |
| 19 | 0 | -21 | 55 | -X | -Y | +Z |
| 20 | 0 | 21 | 19 | +X | +Y | +Z |
| 21 | 0 | 21 | 55 | +X | +Y | +Z |
| 22 | 11 | 0 | 0 | +X | +Y | +Z |
| 23 | 29 | 0 | 0 | +X | +Y | +Z |
| 24 | 11 | 0 | 70 | +X | +Y | +Z |
| 25 | 29 | 0 | 70 | +X | +Y | +Z |
| 26 | 38 | 0 | 52.5 | +X | -Y | +Z |
| 27 | 38 | 0 | 17.5 | +X | +Y | +Z |
| 28 | 0 | -10.5 | 74 | -X | -Y | +Z |
| 29 | 0 | 10.5 | 74 | -X | -Y | +Z |
| 30 | 0 | -10.5 | 0 | -X | -Y | +Z |
| 31 | 0 | 10.5 | 0 | -X | +Y | -Z |
| 101 | 0 | -21 | -2 | +X | +Y | +Z |
| 102 | 0 | 21 | -2 | +X | +Y | +Z |
| 103 | 38 | 0 | -2 | +X | +Y | +Z |

Table I-3 shows the estimated results from 0 to120 Hz with the remaining plots showing the resulting shapes.

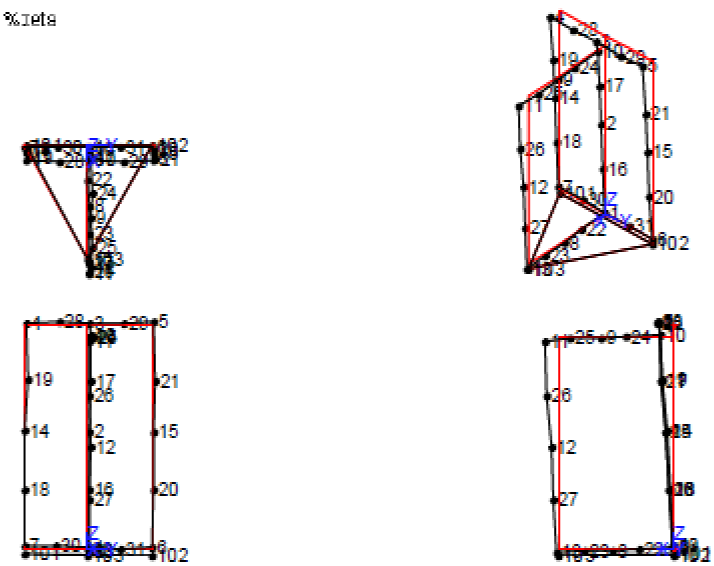
**Table I-3:** Modal Frequencies and Dominant Shape Directions

| Mode | Frequency Hz | %Critical Damping | magX | magY | magZ |
|---|---|---|---|---|---|
| 1 | 2.297 | 7.53 | 0.05 | 0.98 | 0.21 |
| 2 | 2.493 | 7.85 | 0.96 | 0.17 | 0.23 |
| 3 | 6.463 | 4.92 | 0.57 | 0.82 | 0.07 |
| 4 | 8.515 | 5.83 | 0.21 | 0.12 | 0.97 |
| 5 | 8.747 | 1.18 | 0.16 | 0.85 | 0.51 |
| 6 | 9.372 | 0.67 | 0.10 | 0.99 | 0.06 |
| 7 | 12.735 | 1.60 | 0.97 | 0.24 | 0.05 |
| 8 | 21.809 | 0.46 | 0.99 | 0.08 | 0.10 |
| 9 | 22.721 | 1.65 | 0.51 | 0.18 | 0.84 |
| 10 | 23.566 | 2.16 | 0.63 | 0.75 | 0.20 |
| 11 | 25.438 | 0.42 | 0.03 | 1.00 | 0.05 |
| 12 | 26.114 | 0.56 | 0.02 | 1.00 | 0.10 |
| 13 | 26.308 | 0.76 | 0.16 | 0.93 | 0.32 |
| 14 | 33.515 | 2.00 | 1.00 | 0.05 | 0.04 |
| 15 | 46.623 | 0.22 | 0.98 | 0.04 | 0.21 |
| 16 | 46.704 | 0.14 | 0.98 | 0.05 | 0.18 |
| 17 | 48.643 | 0.43 | 0.99 | 0.06 | 0.09 |
| 18 | 50.81 | 0.17 | 0.05 | 1.00 | 0.04 |
| 19 | 51.461 | 0.21 | 0.03 | 1.00 | 0.03 |
| 20 | 55.029 | 1.08 | 0.99 | 0.06 | 0.12 |
| 21 | 60.404 | 0.77 | 0.11 | 0.14 | 0.98 |
| 22 | 71.325 | 0.23 | 0.32 | 0.92 | 0.21 |
| 23 | 72.632 | 0.37 | 0.99 | 0.13 | 0.11 |
| 24 | 73.109 | 0.39 | 0.95 | 0.23 | 0.21 |
| 25 | 77.959 | 0.64 | 0.99 | 0.05 | 0.09 |
| 26 | 79.66 | 0.60 | 1.00 | 0.07 | 0.06 |
| 27 | 83.653 | 0.19 | 0.16 | 0.97 | 0.18 |
| 28 | 84.933 | 0.25 | 0.10 | 0.91 | 0.40 |
| 29 | 87.074 | 0.32 | 0.05 | 0.90 | 0.42 |
| 30 | 103.196 | 0.47 | 0.18 | 0.16 | 0.97 |
| 31 | 119.455 | 0.33 | 0.97 | 0.07 | 0.25 |
| 32 | 119.551 | 0.20 | 0.96 | 0.06 | 0.27 |
| 33 | 119.552 | 0.20 | 0.98 | 0.08 | 0.21 |

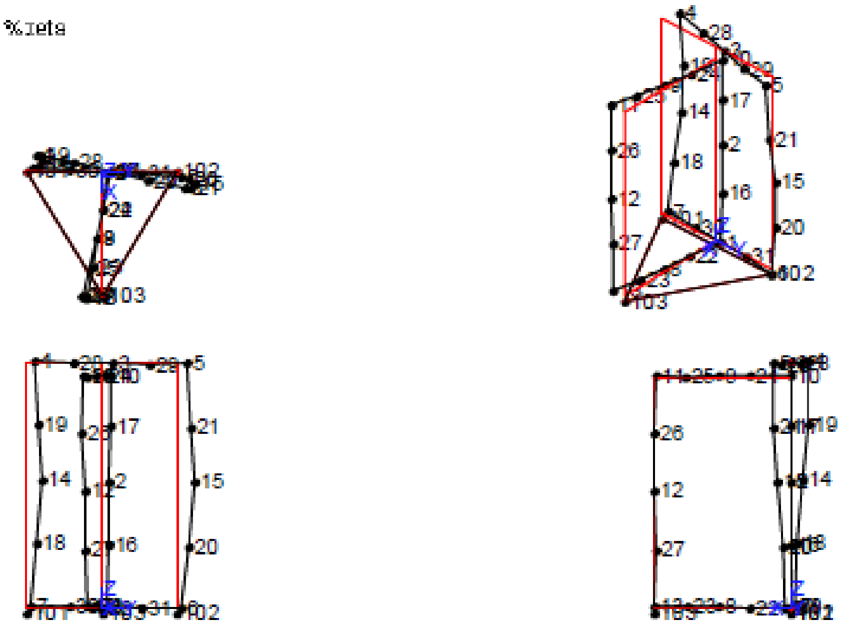
MSS_CMF&Geo.unv
Mode Nr : 1
2.297 Hz : 7.530 %zeta



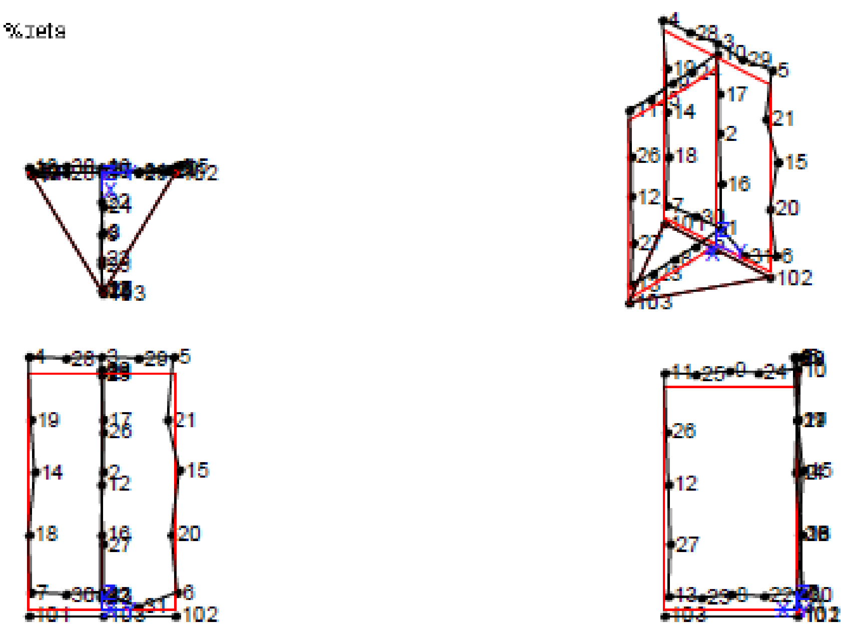
MSS_CMF&Geo.unv
Mode Nr : 2
2.493 Hz : 7.845 %zeta

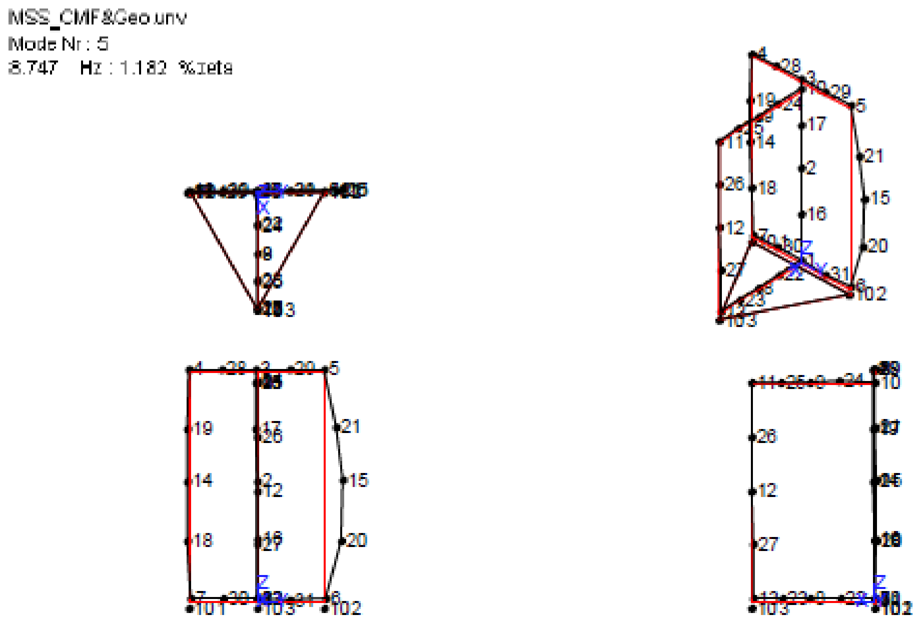


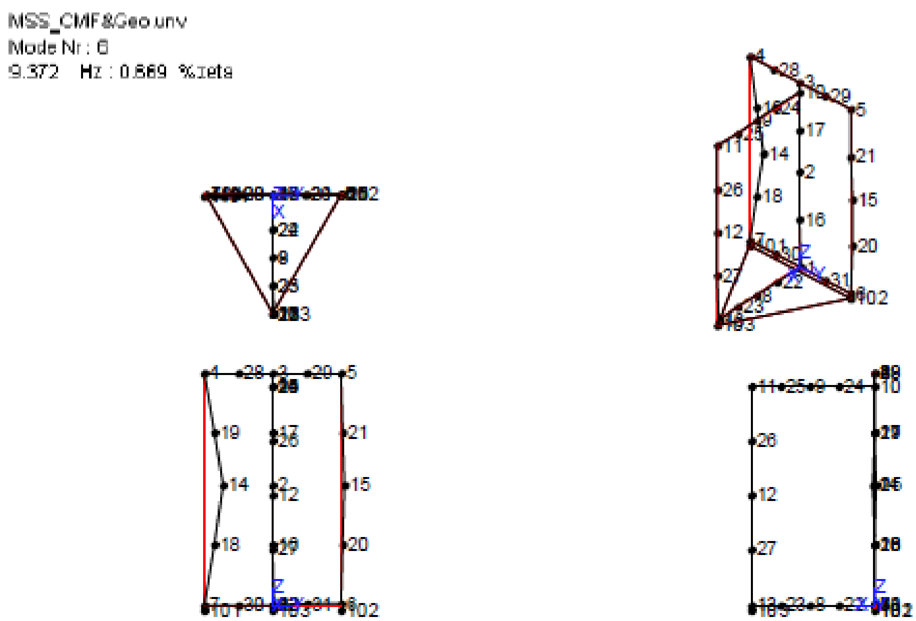
MSS_CMF&Geo.unv
Mode Nr : 3
6.463 Hz : 4.915 %zeta



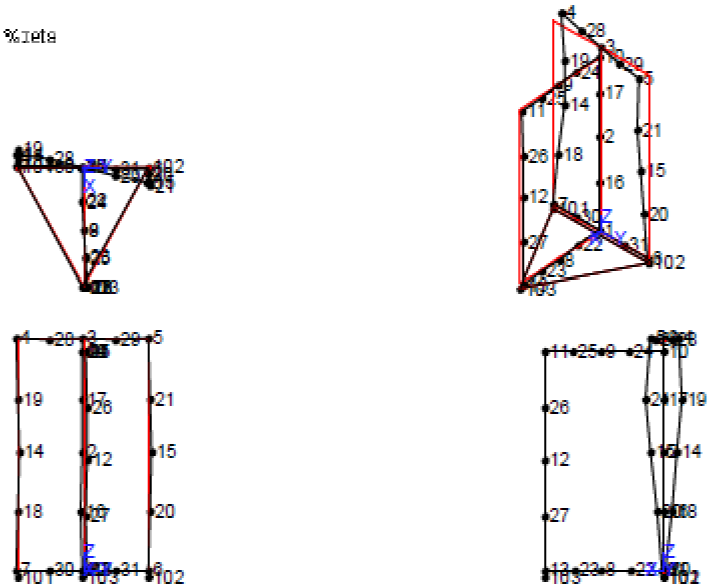
MSS_CMF&Geo.unv
Mode Nr : 4
8.515 Hz : 5.831 %zeta



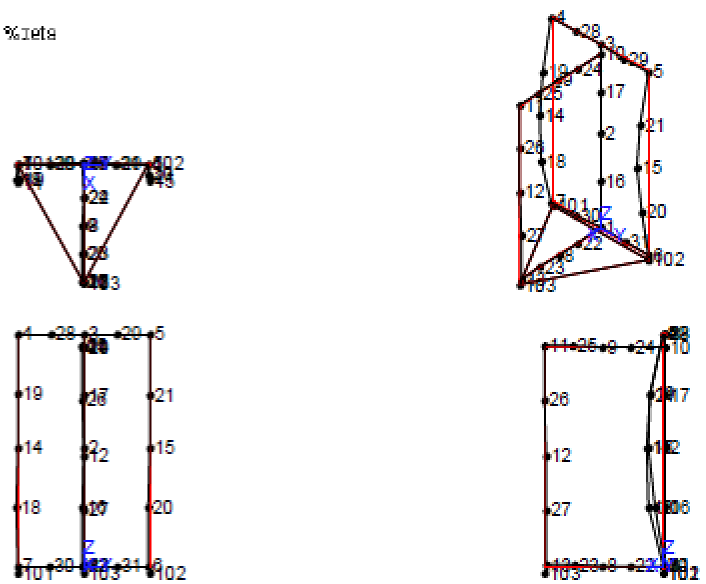

MSS_CMF&Geo.unv
Mode Nr : 5
8.747 Hz : 1.182 %zeta


MSS_CMF&Geo.unv
Mode Nr : 6
9.372 Hz : 0.669 %zeta

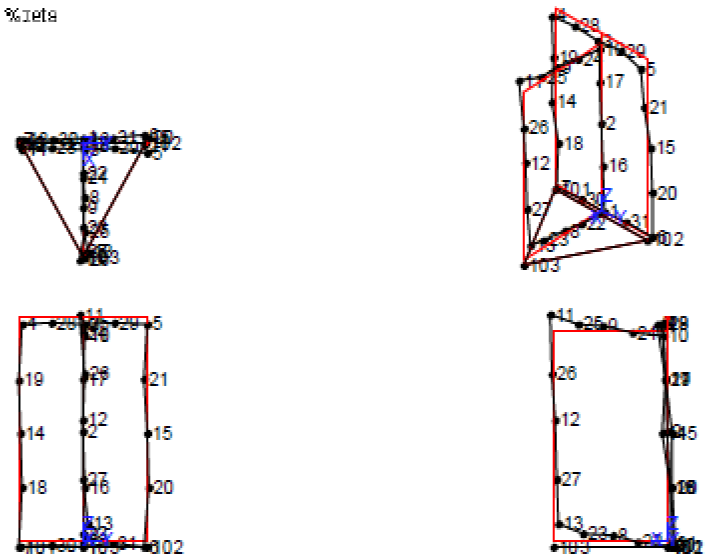
MSS_CMF&Geo.unv
Mode Nr : 7
12.735 Hz : 1.597 %zeta



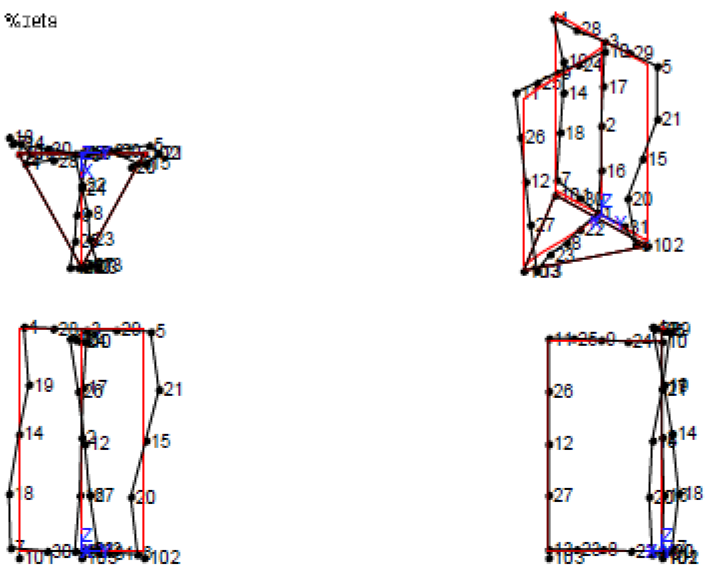
MSS_CMF&Geo.unv
Mode Nr : 8
21.809 Hz : 0.462 %zeta



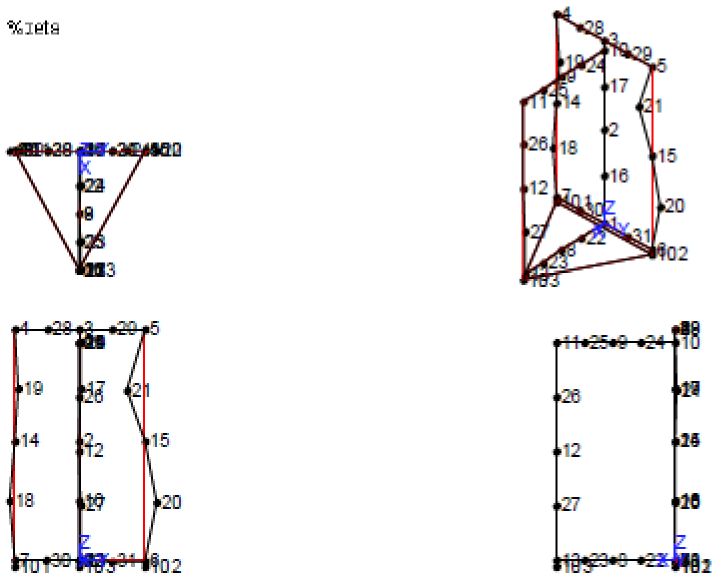
MSS_CMF8Geo.unv
Mode Nr : 9
22.721 Hz : 1.649 %rela



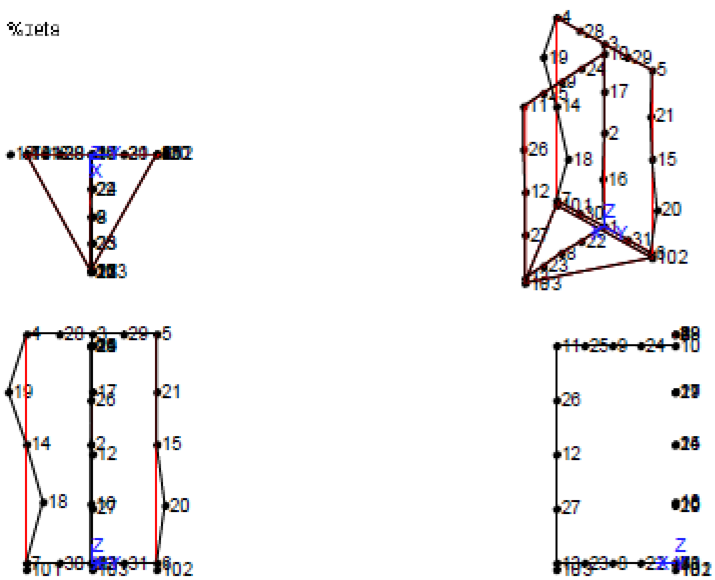
MSS_CMF8Geo.unv
Mode Nr : 10
23.586 Hz : 2.163 %rela



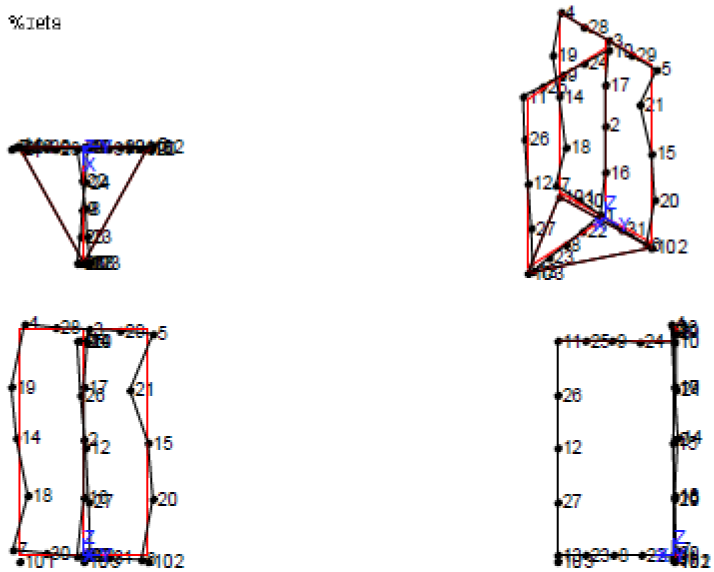
MSS_CMIF&Geo.unv
Mode Nr : 11
25.438 Hz : 0.417 %zeta



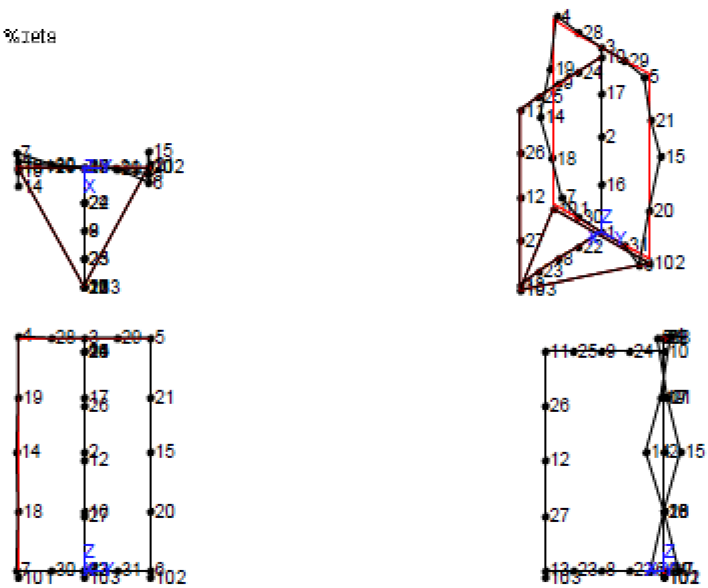
MSS_CMIF&Geo.unv
Mode Nr : 12
26.114 Hz : 0.559 %zeta



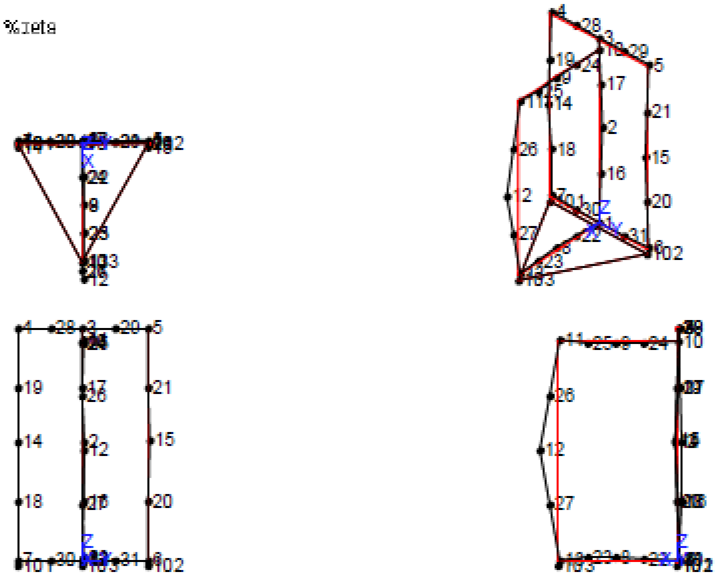
MSS_CMIF&Geo.unv
Mode Nr : 13
26.308 Hz : 0.757 %zeta



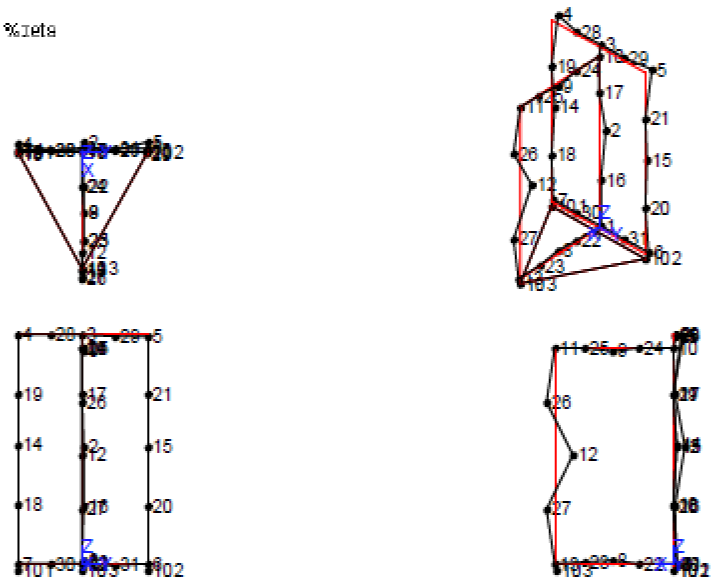
MSS_CMIF&Geo.unv
Mode Nr : 14
33.515 Hz : 1.999 %zeta



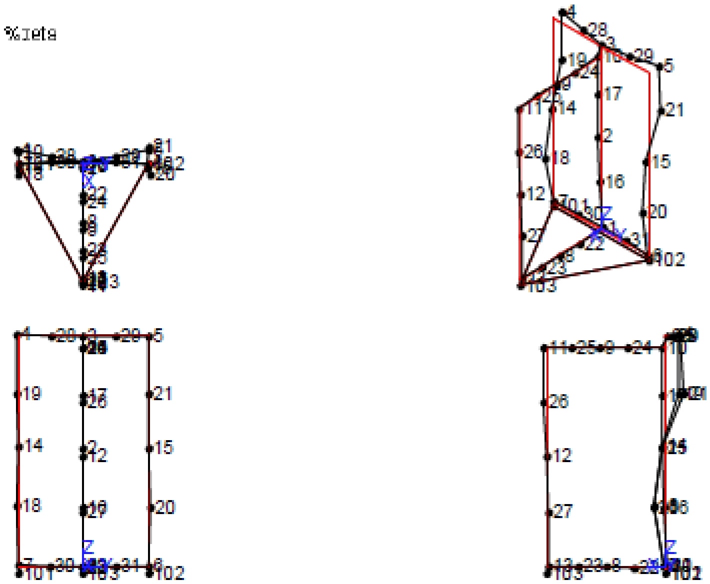
MSS_CMF&Geo.unv
Mode Nr : 15
46.823 Hz : 0.224 %zeta



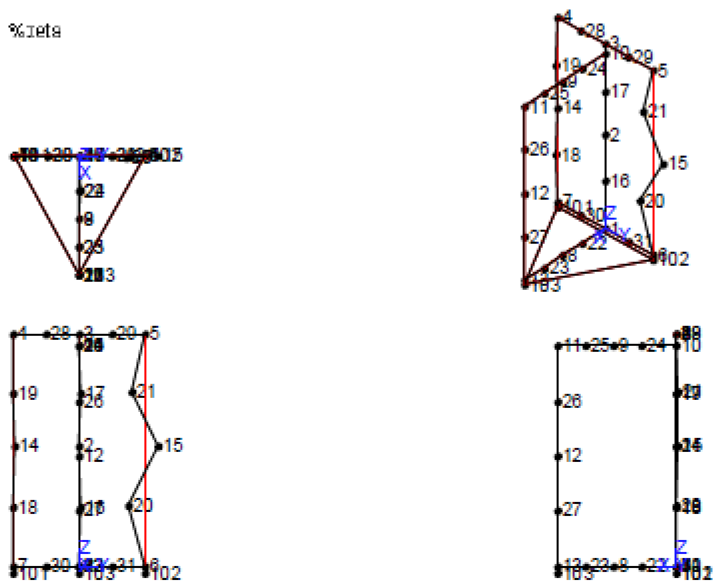
MSS_CMF&Geo.unv
Mode Nr : 16
46.704 Hz : 0.136 %zeta



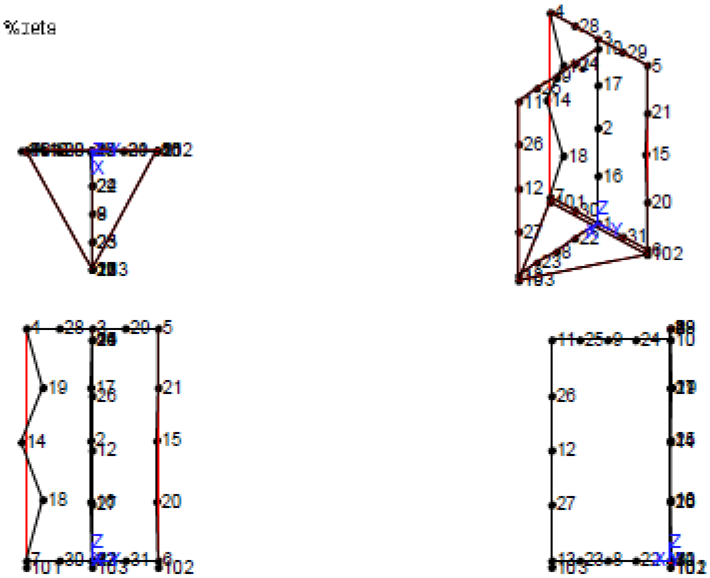
MSS_CMF&Geo.unv
Mode Nr : 17
48.643 Hz : 0.434 %zeta



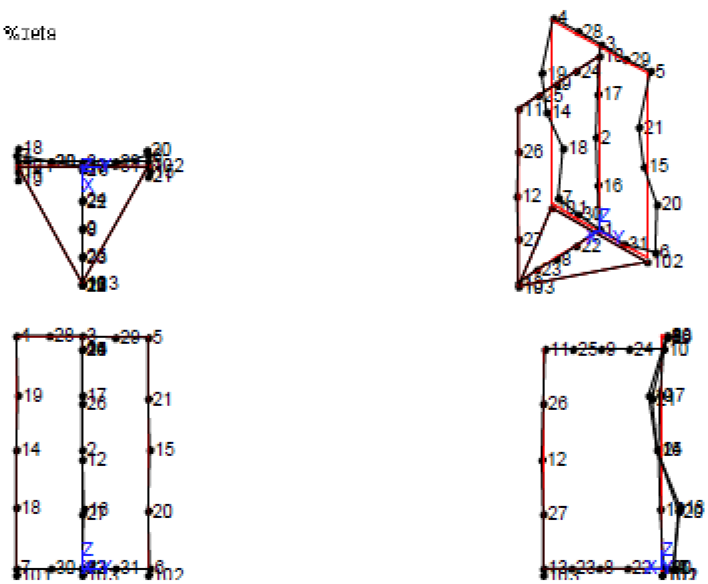
MSS_CMF&Geo.unv
Mode Nr : 18
50.810 Hz : 0.168 %zeta



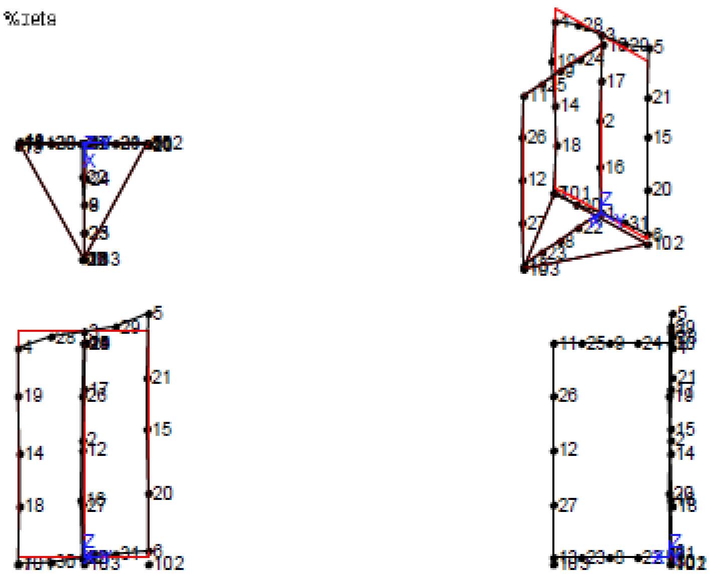
MSS_CMF&Geo.unv
Mode Nr : 19
51.461 Hz : 0.211 %zeta



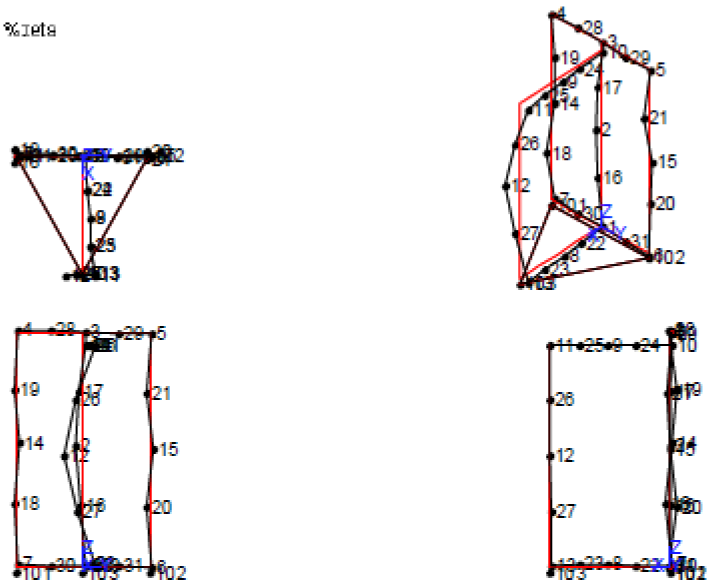
MSS_CMF&Geo.unv
Mode Nr : 20
55.029 Hz : 1.080 %zeta



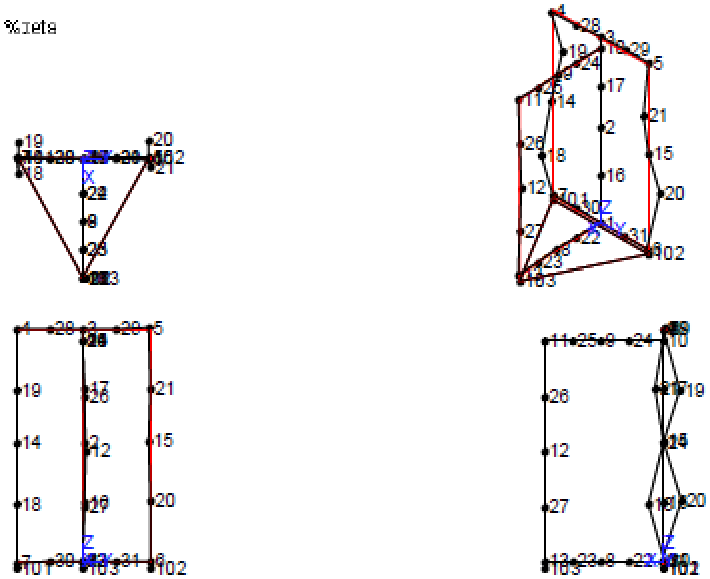
MSS_CMIF&Geo.unv
Mode Nr : 21
60.404 Hz : 0.770 %zeta



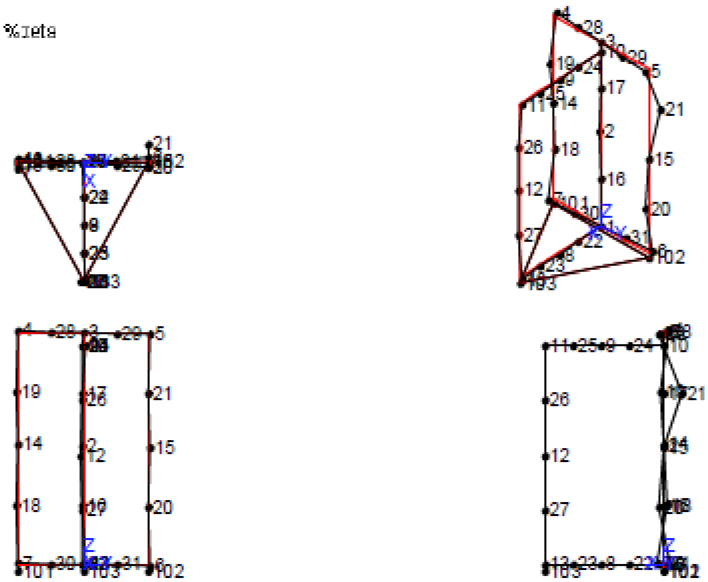
MSS_CMIF&Geo.unv
Mode Nr : 22
71.325 Hz : 0.228 %zeta



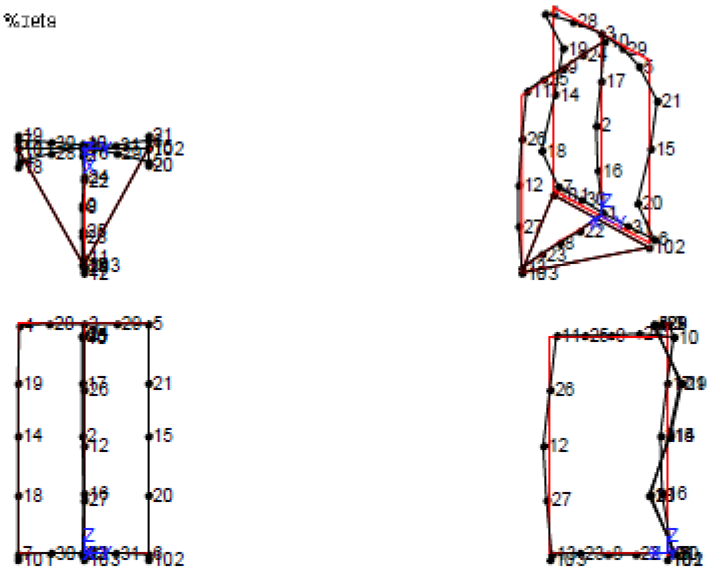
MSS_CMF&Geo.unv
Mode Nr : 23
72.632 Hz : 0.370 %zeta



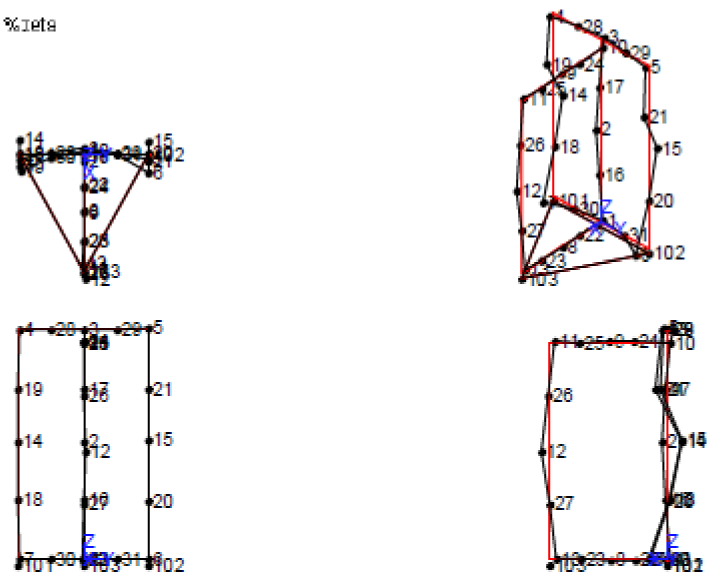
MSS_CMF&Geo.unv
Mode Nr : 24
73.109 Hz : 0.394 %zeta



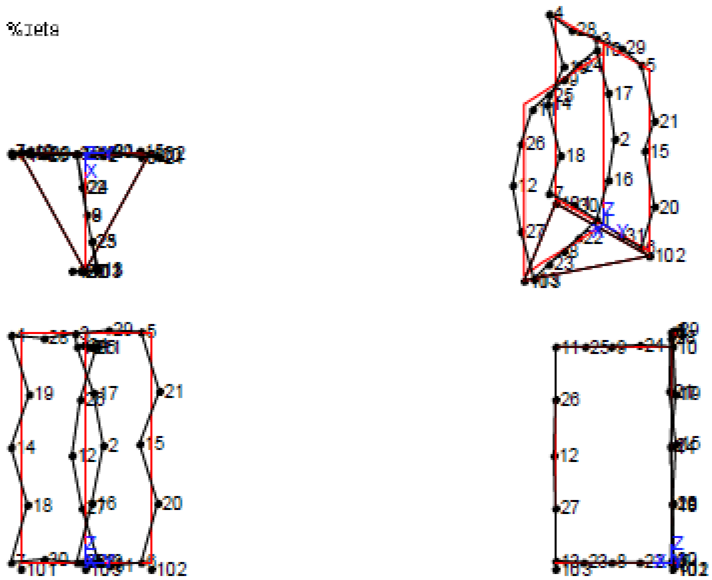
MSS_CMF&Geo.unv
Mode Nr : 25
77.959 Hz : 0.636 %zeta



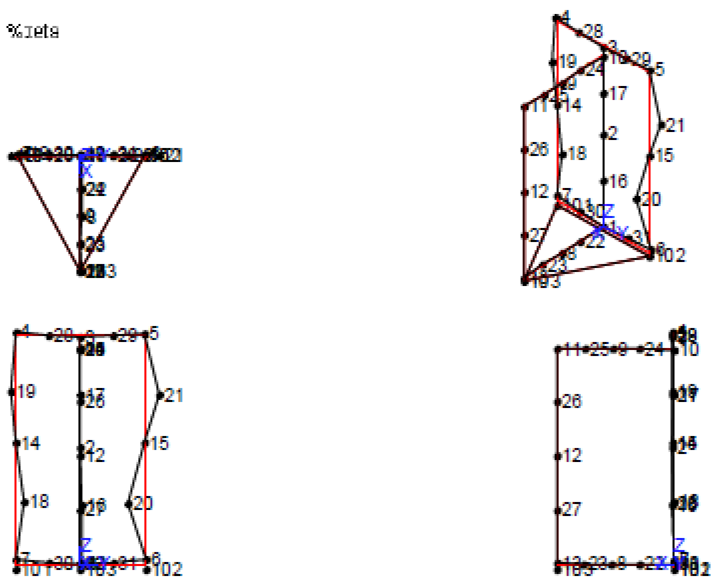
MSS_CMF&Geo.unv
Mode Nr : 26
79.680 Hz : 0.600 %zeta

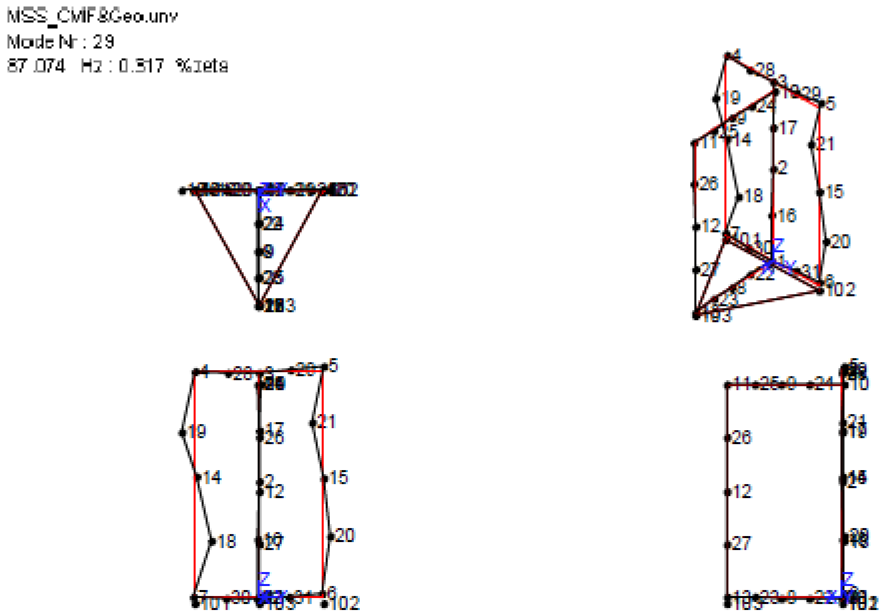


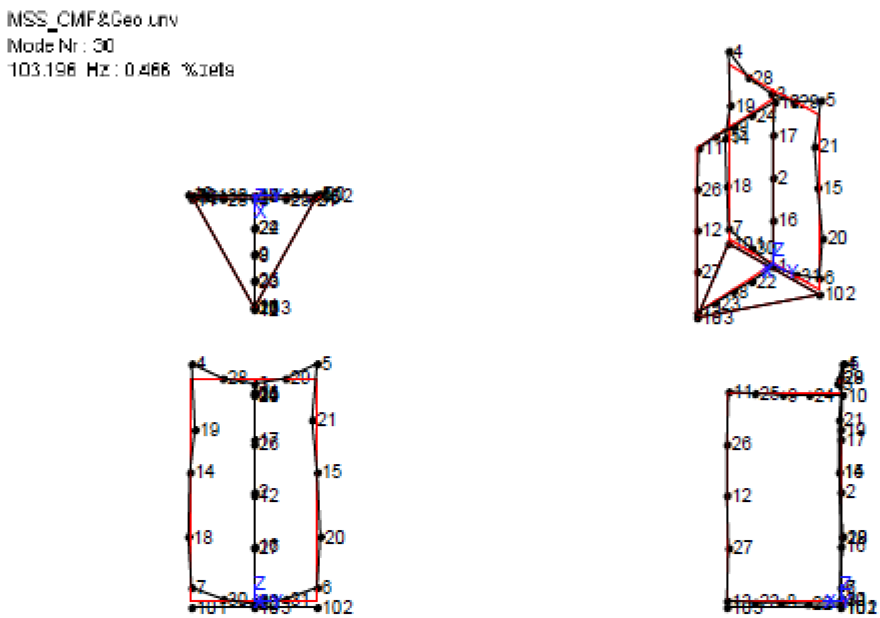
MSS_CMF&Geo.unv
Mode Nr : 27
83.653 Hz : 0.194 %zeta



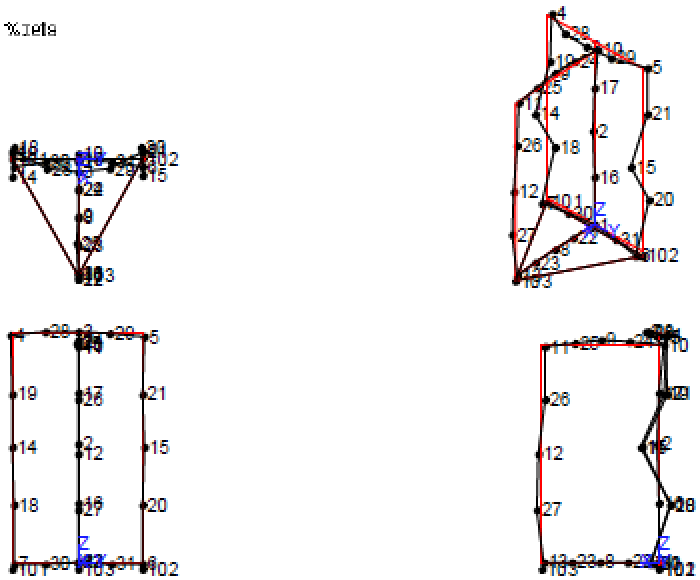
MSS_CMF&Geo.unv
Mode Nr : 28
84.933 Hz : 0.254 %zeta



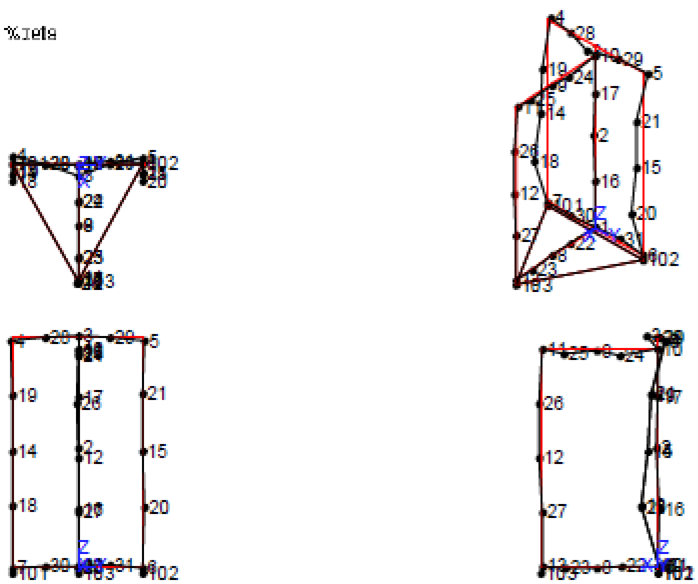

MSS_CMF&Geo.unv
Mode Nr : 29
87.074 Hz : 0.317 %zeta

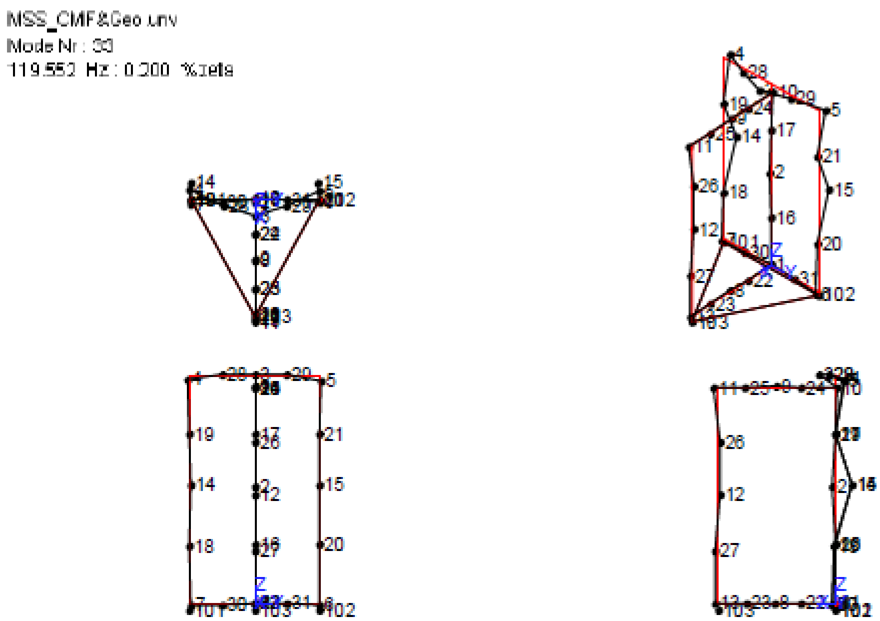

MSS_CMF&Geo.unv
Mode Nr : 30
103.196 Hz : 0.466 %zeta

MSS_CMF&Geo.unv
Mode Nr : 31
119.455 Hz : 0.325 %zeta



MSS_CMF&Geo.unv
Mode Nr : 32
119.551 Hz : 0.204 %zeta




MSS_CMF&Geo.unv
Mode Nr : 33
119.552 Hz : 0.200 %zeta

# Appendix J: NASA Review Item Discrepancy Forms

Clear Form

| | | |
|---|---|---|
| 1. TYPE OF REVIEW: PDR<br>2. PROJECT: NASA X-HAB Stowage System<br>3. DATE: 11/15/12 | **Review Item Discrepancy** | 4. RID NUMBER: RFA #: AC001<br>4a. INPUT FORM #: N/A<br>5. RELATED RIDS: N/A |
| 6. INITIATOR (Last, First): Carter, Anne<br>6b. PHONE: | 6a. EMAIL<br>7. ORGANIZATION: MSFC | 8. TEAM #/NAME: FP30 |

9. ITEM REVIEWED (Item, Revision, Title):
UAH Design Team - PDR Presentation

SEC/VOL: N/A    PART/ATT #: N/A
PAGE/SHEET: N/A    PARA./ZONE#: N/A

10. RID SUBJECT:
RFA Title: Proof of concept percentage

11. DISCREPANCY/PROBLEM:
The definition of proof of concept percentage was misunderstood at the beginning of this effort.

REQUIREMENTS DOC.: UAH Design Team Product Requirements Document    PARA: N/A

12. CONSEQUENCES IF NOT CORRECTED:
Poor understanding of proof of delivered design concept.

13. INITIATOR'S SUGGESTED CORRECTIVE ACTION (Optional):
Provide explicit information that ensures everyone has the same understanding.

14. DEVELOPER'S COMMENTS:
N/A

| COST IMPACT: | SCHEDULE IMPACT: | 14a: DEVELOPER'S SIGNATURE: |
|---|---|---|
| ○ YES ◉ No | ○ YES ◉ No | |

15. TEAM RECOMMENDATION:
◉ ACCEPTED ○ ACCEPTED PER REMARKS ○ WITHDRAWN ○ SUBMIT TO PREBOARD
○ ACCEPTED FOR STUDY ○ DISAPPROVED ○ COMBINED WITH:

REMARKS:
Clarification is needed for the definition of proof of concept percentage.

| 15a. ACTIONEE (Mail Code/Last, First): | 15b. SUSPENSE: | 15c. TEAM CAPTAIN SIGNATURE: |
|---|---|---|
| Bryson, Caroline | 12/2/12 | |

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| | | RID NUMBER: RFA #: AC001 | Page 2 |
|---|---|---|---|

16. PREBOARD RECOMMENDATION:

- (•) ACCEPTED
- ( ) ACCEPTED PER REMARKS
- ( ) WITHDRAWN
- ( ) SUBMIT TO BOARD
- ( ) ACCEPTED FOR STUDY
- ( ) DISAPPROVED
- ( ) COMBINED WITH:

REMARKS:

| 16a. ACTIONEE (Mail Code/Last, First): | 16b. SUSPENSE: | 16c. PREBOARD CHAIRPERSON SIGNATURE: | 16d. DATE: |
|---|---|---|---|
| | | | |

17. BOARD DISPOSITION:

- (•) ACCEPTED
- ( ) ACCEPTED PER REMARKS
- ( ) WITHDRAWN
- ( ) ACCEPTED FOR STUDY
- ( ) DISAPPROVED
- ( ) COMBINED WITH:

REMARKS:

| 17a. ACTIONEE (Mail Code/Last, First): | 17b. SUSPENSE: | 17c. BOARD CHAIRPERSON SIGNATURE: | 17d. DATE: |
|---|---|---|---|
| | | | |

## RID CLOSURE RECORD

18. IMPLEMENTATION:

Per UAH Design Team Product Requirements Document, Requirement 2.1.1.1, the allowed volume of the Deep Space Habitat (81.1"W x 81.125"H x 37.50"D) will be completely occupied by the delivered demonstration product. Three full stowage units, as shown in the CAD renderings of the PDR Presentation Slide 30, will be manufactured, delivered, and installed in the DSH at MSFC in May 2013. This will adequately account for and show the proof of concept percentage and allow for proper demonstration of the product.

19. CLOSED: ( ) YES (•) No

| 18a. INITIATOR APPROVAL: | 18b. DATE: | 18c. ACTIONEE APPROVAL: | 18d. DATE: |
|---|---|---|---|
| 18e. SYSTEM ENGINEER APPROVAL: | 18f. DATE | 18g. CLOSURE APPROVAL (Program) | 18h. DATE: |

Back of MSFC Form 3739 (Rev. August 2000) PDF

Clear Form

| | | |
|---|---|---|
| 1. TYPE OF REVIEW: PDR<br>2. PROJECT: NASA X-HAB Stowage System<br>3. DATE: 11/15/12 | **Review Item Discrepancy** | 4. RID NUMBER: RFA #: AC002<br>4a. INPUT FORM #: N/A<br>5. RELATED RIDS: N/A |

6. INITIATOR (Last, First): Carter, Anne — 6a. EMAIL:
6b. PHONE: — 7. ORGANIZATION: MSFC — 8. TEAM #/NAME: FP30

9. ITEM REVIEWED (Item, Revision, Title):
UAH Design Team - PDR Presentation

SEC/VOL: N/A — PART/ATT #: N/A
PAGE/SHEET: N/A — PARA./ZONE#: N/A

10. RID SUBJECT:
RFA Title: Use of 80/20 interface

11. DISCREPANCY/PROBLEM:
The rail system and the configuration of the 80/20 structure both allow for translation of components.
What was the thought process for choosing to use the rail system?

REQUIREMENTS DOC.: UAH Design Team Product Requirements Document — PARA: N/A

12. CONSEQUENCES IF NOT CORRECTED:
N/A

13. INITIATOR'S SUGGESTED CORRECTIVE ACTION (Optional):
Show how the rail system interfaces with 80/20.

14. DEVELOPER'S COMMENTS:
N/A

| COST IMPACT: | SCHEDULE IMPACT: | 14a: DEVELOPER'S SIGNATURE: |
|---|---|---|
| ○ YES ◉ No | ○ YES ◉ No | |

15. TEAM RECOMMENDATION:
○ ACCEPTED ◉ ACCEPTED PER REMARKS ○ WITHDRAWN ○ SUBMIT TO PREBOARD
○ ACCEPTED FOR STUDY ○ DISAPPROVED ○ COMBINED WITH:

REMARKS:
After further consideration and analysis of the preliminary track system presented at the PDR, the design team has made changes to the track system to be implemented in the design. The design will now implement the use of the existing 80/20 of the secondary structure.

| 15a. ACTIONEE (Mail Code/Last, First): | 15b. SUSPENSE: | 15c. TEAM CAPTAIN SIGNATURE: |
|---|---|---|
| Bryson, Caroline | 12/2/12 | |

MSFC Form 3739 (Rev. August 2000) PDF

| RID NUMBER: RFA #: AC002 | Page 2 |
|---|---|

16. PREBOARD RECOMMENDATION:

- ◯ ACCEPTED
- ⦿ ACCEPTED PER REMARKS
- ◯ WITHDRAWN
- ◯ SUBMIT TO BOARD
- ◯ ACCEPTED FOR STUDY
- ◯ DISAPPROVED
- ◯ COMBINED WITH:

REMARKS:

| 16a. ACTIONEE (Mail Code/Last, First): | 16b. SUSPENSE: | 16c. PREBOARD CHAIRPERSON SIGNATURE: | 16d. DATE: |
|---|---|---|---|

17. BOARD DISPOSITION:

- ◯ ACCEPTED
- ⦿ ACCEPTED PER REMARKS
- ◯ WITHDRAWN
- ◯ ACCEPTED FOR STUDY
- ◯ DISAPPROVED
- ◯ COMBINED WITH:

REMARKS:

| 17a. ACTIONEE (Mail Code/Last, First): | 17b. SUSPENSE: | 17c. BOARD CHAIRPERSON SIGNATURE: | 17d. DATE: |
|---|---|---|---|

## RID CLOSURE RECORD

18. IMPLEMENTATION:

The method for linear motion has been altered since the PDR to more effectively utilize the wide availability and adjustability of the 80/20 secondary structure. The team has decided to use existing rail interfaces designed specifically for heavy use on 80/20 based setups. The secondary 80/20 structure of the module will be the track on which the frames of the design will slide. The frames will be secured to the linear motion interface and will slide, using the secondary as a guide. A detailed CAD image dedicated to the track system interface and its application will be provided during the CDR and can also be sent prior to the CDR to any parties upon request.

19. CLOSED: ◯ YES ⦿ No

| 18a. INITIATOR APPROVAL: | 18b. DATE: | 18c. ACTIONEE APPROVAL: | 18d. DATE: |
|---|---|---|---|
| 18e. SYSTEM ENGINEER APPROVAL: | 18f. DATE | 18g. CLOSURE APPROVAL (Program) | 18h. DATE: |

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| 1. TYPE OF REVIEW: PDR | Review Item Discrepancy | 4. RID NUMBER: RFA #: AC003 |
|---|---|---|
| 2. PROJECT: NASA X-HAB Stowage System | | 4a. INPUT FORM #: N/A |
| 3. DATE: 11/16/12 | | 5. RELATED RIDS: N/A |

| | | |
|---|---|---|
| 6. INITIATOR (Last, First): Carter, Anne | 6a. EMAIL | |
| 6b. PHONE: | 7. ORGANIZATION: MSFC | 8. TEAM #/NAME: FP30 |

9. ITEM REVIEWED (Item, Revision, Title):
UAH Design Team - PDR Presentation

SEC/VOL: N/A PART/ATT #: N/A
PAGE/SHEET: N/A PARA./ZONE#: N/A

10. RID SUBJECT:
RFA Title: Risk definition

11. DISCREPANCY/PROBLEM:
List all safety hazards and provide rationale for how each was mitigated.

REQUIREMENTS DOC.: UAH Design Team Product Requirements Document PARA: N/A

12. CONSEQUENCES IF NOT CORRECTED:
All safety and risk concerns not understood.

13. INITIATOR'S SUGGESTED CORRECTIVE ACTION (Optional):
N/A

14. DEVELOPER'S COMMENTS:
N/A

| COST IMPACT: | SCHEDULE IMPACT: | 14a: DEVELOPER'S SIGNATURE: |
|---|---|---|
| ○ YES ◉ No | ○ YES ◉ No | |

15. TEAM RECOMMENDATION:
○ ACCEPTED ◉ ACCEPTED PER REMARKS ○ WITHDRAWN ○ SUBMIT TO PREBOARD
○ ACCEPTED FOR STUDY ○ DISAPPROVED ○ COMBINED WITH:

REMARKS:
More detail will be provided during the CDR concerning the risks associated with the design project as well as a complete description of how they will be mitigated.

| 15a. ACTIONEE (Mail Code/Last, First): | 15b. SUSPENSE: | 15c. TEAM CAPTAIN SIGNATURE: |
|---|---|---|
| Bryson, Caroline | 12/2/12 | |

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| | | RID NUMBER: RFA #: AC003 | Page 2 |
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16. PREBOARD RECOMMENDATION:

- ○ ACCEPTED
- ◉ ACCEPTED PER REMARKS
- ○ WITHDRAWN
- ○ SUBMIT TO BOARD
- ○ ACCEPTED FOR STUDY
- ○ DISAPPROVED
- ○ COMBINED WITH:

REMARKS:

| 16a. ACTIONEE (Mail Code/Last, First): | 16b. SUSPENSE: | 16c. PREBOARD CHAIRPERSON SIGNATURE: | 16d. DATE: |
|---|---|---|---|
| | | | |

17. BOARD DISPOSITION:

- ○ ACCEPTED
- ◉ ACCEPTED PER REMARKS
- ○ WITHDRAWN
- ○ ACCEPTED FOR STUDY
- ○ DISAPPROVED
- ○ COMBINED WITH:

REMARKS:

| 17a. ACTIONEE (Mail Code/Last, First): | 17b. SUSPENSE: | 17c. BOARD CHAIRPERSON SIGNATURE: | 17d. DATE: |
|---|---|---|---|
| | | | |

## RID CLOSURE RECORD

18. IMPLEMENTATION:

Per PDR slides 46 and 47, the design team has completed/performed a thorough risk assessment analysis and mitigation using Military Standard 882-B. All safety hazards are outlined and ranked with a hazard risk index number. The design team then mitigated the hazard, as listed in the chart, and ranked the risk with a new hazard risk index number. All risks scored at least 'Acceptable With Review' or 'Acceptable Without Review' by the standard. Further details of this process can be provided upon request. The CDR will contain a similar assessment of risks with further details outlined and mitigation processes.

19. CLOSED: ○ YES ◉ No

| 18a. INITIATOR APPROVAL: | 18b. DATE: | 18c. ACTIONEE APPROVAL: | 18d. DATE: |
|---|---|---|---|
| 18e. SYSTEM ENGINEER APPROVAL: | 18f. DATE | 18g. CLOSURE APPROVAL (Program) | 18h. DATE: |

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|---|---|---|
| 1. TYPE OF REVIEW: PDR<br>2. PROJECT: NASA X-HAB Stowage System<br>3. DATE: 11/16/12 | **Review Item Discrepancy** | 4. RID NUMBER: RFA #: AC004<br>4a. INPUT FORM #: N/A<br>5. RELATED RIDS: N/A |
| 6. INITIATOR (Last, First): Carter, Anne<br>6b. PHONE: | 6a. EMAIL:<br>7. ORGANIZATION: MSFC | 8. TEAM #/NAME: FP30 |

9. ITEM REVIEWED (Item, Revision, Title):
UAH Design Team - PDR Presentation

SEC/VOL: N/A PART/ATT #: N/A
PAGE/SHEET: N/A PARA./ZONE#: N/A

10. RID SUBJECT:
RFA Title: Labeling

11. DISCREPANCY/PROBLEM:
Labeling is an important aspect of re-configurable stowage. Explain how labeling will aid in tracking stowage items, particularly non-standard and temporary stowage.

REQUIREMENTS DOC.: UAH Design Team Product Requirements Document PARA: N/A

12. CONSEQUENCES IF NOT CORRECTED:
N/A

13. INITIATOR'S SUGGESTED CORRECTIVE ACTION (Optional):
N/A

14. DEVELOPER'S COMMENTS:
N/A

| COST IMPACT: | SCHEDULE IMPACT: | 14a: DEVELOPER'S SIGNATURE: |
|---|---|---|
| ○ YES ◉ No | ○ YES ◉ No | |

15. TEAM RECOMMENDATION:
○ ACCEPTED ◉ ACCEPTED PER REMARKS ○ WITHDRAWN ○ SUBMIT TO PREBOARD
○ ACCEPTED FOR STUDY ○ DISAPPROVED ○ COMBINED WITH:

REMARKS
Per Level 1 Requirements Document (NASA) and the Product Requirements Document (UAH Design Team), labeling the delivered demonstration product is not required.

| 15a. ACTIONEE (Mail Code/Last, First): | 15b. SUSPENSE: | 15c. TEAM CAPTAIN SIGNATURE: |
|---|---|---|
| Bryson, Caroline | 12/2/12 | |

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|---|---|
| RID NUMBER: RFA #: AC004 | Page 2 |

16. PREBOARD RECOMMENDATION:

- ○ ACCEPTED
- ○ ACCEPTED FOR STUDY
- ◉ ACCEPTED PER REMARKS
- ○ DISAPPROVED
- ○ WITHDRAWN
- ○ COMBINED WITH:
- ○ SUBMIT TO BOARD

REMARKS:

| 16a. ACTIONEE (Mail Code/Last, First): | 16b. SUSPENSE: | 16c. PREBOARD CHAIRPERSON SIGNATURE: | 16d. DATE: |
|---|---|---|---|
| | | | |

17. BOARD DISPOSITION:

- ○ ACCEPTED
- ○ ACCEPTED FOR STUDY
- ◉ ACCEPTED PER REMARKS
- ○ DISAPPROVED
- ○ WITHDRAWN
- ○ COMBINED WITH:

REMARKS:

| 17a. ACTIONEE (Mail Code/Last, First): | 17b. SUSPENSE: | 17c. BOARD CHAIRPERSON SIGNATURE: | 17d. DATE: |
|---|---|---|---|
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## RID CLOSURE RECORD

18. IMPLEMENTATION:

In addition to the outlined Level 1 requirements specified by this project, the design team will give special consideration to labeling, as it is an important issue. The design team as a part of the Human Integration Design considerations, will address and provide many options for labeling of storage items and present these in our final report. Furthermore, the design team will label all user interfaces on the delivered product (e.g. Handles with 'Open' and 'Close' directions specified).

19. CLOSED: ○ YES ◉ No

| 18a. INITIATOR APPROVAL: | 18b. DATE: | 18c. ACTIONEE APPROVAL: | 18d. DATE: |
|---|---|---|---|
| 18e. SYSTEM ENGINEER APPROVAL: | 18f. DATE | 18g. CLOSURE APPROVAL (Program) | 18h. DATE: |

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|---|---|---|
| 1. TYPE OF REVIEW: PDR | **Review Item Discrepancy** | 4. RID NUMBER: RFA #: AC006 |
| 2. PROJECT: NASA X-HAB Stowage System | | 4a. INPUT FORM #: N/A |
| 3. DATE: 11/16/12 | | 5. RELATED RIDS: N/A |

6. INITIATOR (Last, First): Carter, Anne
6a. EMAIL:
6b. PHONE:
7. ORGANIZATION: MSFC
8. TEAM #/NAME: FP30

9. ITEM REVIEWED (Item, Revision, Title):
UAH Design Team - PDR Presentation

SEC/VOL: N/A
PART/ATT #: N/A
PAGE/SHEET: N/A
PARA./ZONE#: N/A

10. RID SUBJECT:
RFA Title: Gravity design items

11. DISCREPANCY/PROBLEM:
The design is being demonstrated on the ground and therefore may have components to compensate for earth's gravity. How will these design components be marked?

REQUIREMENTS DOC.: UAH Design Team Product Requirements Document
PARA: N/A

12. CONSEQUENCES IF NOT CORRECTED:
N/A

13. INITIATOR'S SUGGESTED CORRECTIVE ACTION (Optional):
Address how would not having these items might change the function of the design.

14. DEVELOPER'S COMMENTS:
N/A

| COST IMPACT: | SCHEDULE IMPACT: | 14a: DEVELOPER'S SIGNATURE: |
|---|---|---|
| ○ YES ◉ No | ○ YES ◉ No | |

15. TEAM RECOMMENDATION:
◉ ACCEPTED ○ ACCEPTED PER REMARKS ○ WITHDRAWN ○ SUBMIT TO PREBOARD
○ ACCEPTED FOR STUDY ○ DISAPPROVED ○ COMBINED WITH:

REMARKS:
N/A

| 15a. ACTIONEE (Mail Code/Last, First): | 15b. SUSPENSE: | 15c. TEAM CAPTAIN SIGNATURE: |
|---|---|---|
| Bryson, Caroline | 12/2/12 | |

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| | RID NUMBER: RFA #: AC006 | Page 2 |
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16. PREBOARD RECOMMENDATION:

◉ ACCEPTED ◯ ACCEPTED PER REMARKS ◯ WITHDRAWN ◯ SUBMIT TO BOARD
◯ ACCEPTED FOR STUDY ◯ DISAPPROVED ◯ COMBINED WITH:

REMARKS:

| 16a. ACTIONEE (Mail Code/Last, First): | 16b. SUSPENSE: | 16c. PREBOARD CHAIRPERSON SIGNATURE: | 16d. DATE: |
|---|---|---|---|
| | | | |

17. BOARD DISPOSITION:

◉ ACCEPTED ◯ ACCEPTED PER REMARKS ◯ WITHDRAWN
◯ ACCEPTED FOR STUDY ◯ DISAPPROVED ◯ COMBINED WITH:

REMARKS:

| 17a. ACTIONEE (Mail Code/Last, First): | 17b. SUSPENSE: | 17c. BOARD CHAIRPERSON SIGNATURE: | 17d. DATE: |
|---|---|---|---|
| | | | |

## RID CLOSURE RECORD

18. IMPLEMENTATION:

The design team has considered both "1G" and microgravity environments for demonstration and implementation. It has been concluded that the main variation in the design between both environments will be the bottom track system that interacts with the floor of the Deep Space Habitat. In "1G", for demonstration purposes, the track system will be replaced with wheels, allowing it to translate easily, showing the motion of the system. These design environment differences will be outlined in the CDR and final report.
Further considering how the design will behave in "1G", for demonstration of the system's ability to hold CTBs on its cloth shelving, the display CTBs currently utilized in the NASA MSFC DSH will be used. Due to weight limitations of the Velcro fasteners in "1G" CTBs will not be fully loaded with supplies for demonstration purposes. As with the current configuration, the CTBs used for demonstration will have lightweight stuffing in the place of supplies, this will allow the cloth shelving with Velcro fasteners to easily hold the CTBs and provide an accurate representation of how the system will hold mission supplies in microgravity environments. The system is not designed for loaded CTBs to be stored (attached) on the Velcro patches of the system in "1G". The loading and restraint of CTBs during launch will be similar to current methods utilized by NASA.

19. CLOSED: ◯ YES ◉ No

| 18a. INITIATOR APPROVAL: | 18b. DATE: | 18c. ACTIONEE APPROVAL: | 18d. DATE: |
|---|---|---|---|
| 18e. SYSTEM ENGINEER APPROVAL: | 18f. DATE | 18g. CLOSURE APPROVAL (Program) | 18h. DATE: |

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**Review Item Discrepancy**

1. TYPE OF REVIEW: PDR

2. PROJECT: NASA X-HAB Stowage System

3. DATE: 11/15/12

4. RID NUMBER: RFA #: JB-001

4a. INPUT FORM #: N/A

5. RELATED RIDS: N/A

6. INITIATOR (Last, First): Broyan, Jim

6a. EMAIL:

6b. PHONE:

7. ORGANIZATION: JSC

8. TEAM #/NAME:

9. ITEM REVIEWED (Item, Revision, Title):

UAH Design Team - PDR Presentation

SEC/VOL: N/A PART/ATT #: N/A

PAGE/SHEET: N/A PARA./ZONE#: N/A

10. RID SUBJECT:

RFA Title: Structural interface loads

11. DISCREPANCY/PROBLEM:

Need to define the magnitude and direction of loads that the stowage system will place on the 'vehicle' interfaces.

REQUIREMENTS DOC.: UAH Design Team Product Requirements Document PARA:

12. CONSEQUENCES IF NOT CORRECTED:

Poor understanding of the loads placed by the stowage system on the 'vehicle'

13. INITIATOR'S SUGGESTED CORRECTIVE ACTION (Optional):

In particular consider the following load cases:

- When shelves are loaded and retracted with expected launch loads.
- When shelves are loaded and fully extended.
- When shelves are loaded, fully extended, and have a vertical or horizontal crew kick load applied perpendicular to the axis of extension.

14. DEVELOPER'S COMMENTS:

This analysis would provide a better understanding of the system's loading and needs for material strength and integrity. However, the detail of the analysis would be outside of the scope of the project with the current time and resource constraints.

COST IMPACT: ○ YES ◉ No

SCHEDULE IMPACT: ○ YES ◉ No

14a: DEVELOPER'S SIGNATURE:

15. TEAM RECOMMENDATION:

○ ACCEPTED ◉ ACCEPTED PER REMARKS ○ WITHDRAWN ○ SUBMIT TO PREBOARD

○ ACCEPTED FOR STUDY ○ DISAPPROVED ○ COMBINED WITH:

REMARKS:

Further analysis will be completed on the system. The launch loads analysis will not be completed for this project.

15a. ACTIONEE (Mail Code/Last, First): Bryson, Caroline

15b. SUSPENSE: 12/2/12

15c. TEAM CAPTAIN SIGNATURE:

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| | | RID NUMBER: RFA #: JB-001 | Page 2 |
|---|---|---|---|

16. PREBOARD RECOMMENDATION:

- ◯ ACCEPTED
- ◉ ACCEPTED PER REMARKS
- ◯ WITHDRAWN
- ◯ SUBMIT TO BOARD
- ◯ ACCEPTED FOR STUDY
- ◯ DISAPPROVED
- ◯ COMBINED WITH:

REMARKS:

| 16a. ACTIONEE (Mail Code/Last, First): | 16b. SUSPENSE: | 16c. PREBOARD CHAIRPERSON SIGNATURE: | 16d. DATE: |
|---|---|---|---|
| | | | |

17. BOARD DISPOSITION:

- ◯ ACCEPTED
- ◉ ACCEPTED PER REMARKS
- ◯ WITHDRAWN
- ◯ ACCEPTED FOR STUDY
- ◯ DISAPPROVED
- ◯ COMBINED WITH:

REMARKS:

| 17a. ACTIONEE (Mail Code/Last, First): | 17b. SUSPENSE: | 17c. BOARD CHAIRPERSON SIGNATURE: | 17d. DATE: |
|---|---|---|---|
| | | | |

## RID CLOSURE RECORD

18. IMPLEMENTATION:

An analysis will be completed of the following configurations of the system:
• When shelves are loaded and fully extended.
• When shelves are loaded, fully extended, and have a vertical or horizontal crew kick load applied perpendicular to the axis of extension.

19. CLOSED: ◯ YES ◉ No

| 18a. INITIATOR APPROVAL: | 18b. DATE: | 18c. ACTIONEE APPROVAL: | 18d. DATE: |
|---|---|---|---|
| James Broyan/NASA/JSC | 11/26/2012 | | |
| 18e. SYSTEM ENGINEER APPROVAL: | 18f. DATE | 18g. CLOSURE APPROVAL (Program) | 18h. DATE: |
| | | | |

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**Review Item Discrepancy**

1. TYPE OF REVIEW: PDR

2. PROJECT: NASA X-HAB Stowage System

3. DATE: 11/16/12

4. RID NUMBER: RFA #: JB-002

4a. INPUT FORM #: N/A

5. RELATED RIDS: N/A

6. INITIATOR (Last, First): Broyan, Jim

6a. EMAIL:

6b. PHONE:

7. ORGANIZATION: JSC

8. TEAM #/NAME: N/A

9. ITEM REVIEWED (Item, Revision, Title): UAH Design Team - PDR Presentation

SEC/VOL: N/A PART/ATT #: N/A

PAGE/SHEET: N/A PARA./ZONE#: N/A

10. RID SUBJECT: RFA Title: Structural analysis of storage system

11. DISCREPANCY/PROBLEM:

The charts did not allow the analysis to be followed. Concern is that have not enough info provide to get agreement that how it is loaded if fully capturing the reasonable conditions. Need to provide additional structural analysis to ensure safety, enable sufficient fidelity of mass calculations, and enable results to be understood by others. Slide 39 shows a 0.52 deflection and is indicated to be acceptable. What is basis?? If it deflects this means more vertical space is consumed from stowage volume.

REQUIREMENTS DOC.: UAH Design Team Product Requirements Document PARA: N/A

12. CONSEQUENCES IF NOT CORRECTED:

N/A

13. INITIATOR'S SUGGESTED CORRECTIVE ACTION (Optional):

- Provide a list of analysis types (crew, launch, 1-g, bending, shear, axial) performed, how load is applied to part (figure or free body diagram), and loading assumptions.
- List out factor of safety, material properties, or model assumptions used.
- Show the resultant margin of safety and its location of some of the internal components. Also need to define load on slides.

14. DEVELOPER'S COMMENTS:

N/A

COST IMPACT: ○ YES ◉ No

SCHEDULE IMPACT: ○ YES ◉ No

14a: DEVELOPER'S SIGNATURE:

15. TEAM RECOMMENDATION:

○ ACCEPTED ◉ ACCEPTED PER REMARKS ○ WITHDRAWN ○ SUBMIT TO PREBOARD

○ ACCEPTED FOR STUDY ○ DISAPPROVED ○ COMBINED WITH:

REMARKS:

The finite element analysis for the PDR was completed only on the CAD models of the preliminary design, thus explaining the detail of the analysis. Further FEA will be performed on the completed models of the design, with the suggested recommendations to be implemented.

15a. ACTIONEE (Mail Code/Last, First): Bryson, Caroline

15b. SUSPENSE: 12/2/12

15c. TEAM CAPTAIN SIGNATURE:

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| | | RID NUMBER: RFA #: JB-002 | Page 2 |
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16. PREBOARD RECOMMENDATION:

- ◯ ACCEPTED
- ◯ ACCEPTED FOR STUDY
- ⦿ ACCEPTED PER REMARKS
- ◯ DISAPPROVED
- ◯ WITHDRAWN
- ◯ COMBINED WITH:
- ◯ SUBMIT TO BOARD

REMARKS:

| 16a. ACTIONEE (Mail Code/Last, First): | 16b. SUSPENSE: | 16c. PREBOARD CHAIRPERSON SIGNATURE: | 16d. DATE: |
|---|---|---|---|

17. BOARD DISPOSITION:

- ◯ ACCEPTED
- ◯ ACCEPTED FOR STUDY
- ⦿ ACCEPTED PER REMARKS
- ◯ DISAPPROVED
- ◯ WITHDRAWN
- ◯ COMBINED WITH:

REMARKS:

| 17a. ACTIONEE (Mail Code/Last, First): | 17b. SUSPENSE: | 17c. BOARD CHAIRPERSON SIGNATURE: | 17d. DATE: |
|---|---|---|---|

## RID CLOSURE RECORD

18. IMPLEMENTATION:

The design team has made further progress on the preliminary storage system design presented at the PDR. With all details involving fasteners, translation systems, materials, and the design complete, the finite element analysis of the design will be much more detailed. As outlined by the design team's capstone senior design course, the team will complete at least six (6) types of analysis and present the results at the CDR. The provided suggestions will be considered when completing the final analysis of the system. More clarification on loading, deflection, factor of safety, and material properties will be provided.

19. CLOSED: ◯ YES ⦿ No

| 18a. INITIATOR APPROVAL: | 18b. DATE: | 18c. ACTIONEE APPROVAL: | 18d. DATE: |
|---|---|---|---|
| 18e. SYSTEM ENGINEER APPROVAL: | 18f. DATE | 18g. CLOSURE APPROVAL (Program) | 18h. DATE: |

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|---|---|---|
| 1. TYPE OF REVIEW: PDR<br>2. PROJECT: NASA X-HAB Stowage System<br>3. DATE: 11/16/12 | **Review Item Discrepancy** | 4. RID NUMBER: RFA #: JB-003<br>4a. INPUT FORM #: N/A<br>5. RELATED RIDS: N/A |

6. INITIATOR (Last, First): Broyan, Jim
6a. EMAIL:
6b. PHONE:
7. ORGANIZATION: JSC
8. TEAM #/NAME: N/A

9. ITEM REVIEWED (Item, Revision, Title):

UAH Design Team - PDR Presentation

SEC/VOL: N/A    PART/ATT #: N/A

PAGE/SHEET: N/A    PARA./ZONE#: N/A

10. RID SUBJECT:

RFA Title: Slide and Restraint Mechanisms Not Defined

11. DISCREPANCY/PROBLEM:

Need to provide information on the type of slides. Define the expected force to pull out, how they are stopped (hard stop, bumper, or shock absorber). How will the crew react this load? (you may need additional foot or handholds), how are shelves restrained for launch loads, and on-orbit in closed position, (Note: ISS hardware typically has to resist a 0.3 g reboost load in any direction on-orbit).

REQUIREMENTS DOC.: UAH Design Team Product Requirements Document    PARA: N/A

12. CONSEQUENCES IF NOT CORRECTED:

N/A

13. INITIATOR'S SUGGESTED CORRECTIVE ACTION (Optional):

Provide a concept of operations to address a jammed shelf (slide failure, stowed CTB hangup on adjacent shelf...)
Does the shelf slide all the way out only or have intermediate stops?
Does the slide have a release that allows the shelf to be removed? If so, how do you prevent unintended separation or ensure engagement? (tip over safety issue in 1g)

14. DEVELOPER'S COMMENTS:

N/A

| COST IMPACT: | SCHEDULE IMPACT: | 14a: DEVELOPER'S SIGNATURE: |
|---|---|---|
| ○ YES ◉ No | ○ YES ◉ No | |

15. TEAM RECOMMENDATION:

○ ACCEPTED    ◉ ACCEPTED PER REMARKS    ○ WITHDRAWN    ○ SUBMIT TO PREBOARD
○ ACCEPTED FOR STUDY    ○ DISAPPROVED    ○ COMBINED WITH:

REMARKS:

Further details of the design, including slide and restraint mechanisms will be discussed during the CDR. A separate Concept of Operations for a jammed shelf will not be created. Instead, as required by the scope of the capstone senior design course, the failure mode will be examined using a fault tree analysis. Mitigation approaches will be considered and implemented to prevent any safety hazards associated with the design, including the tip over safety hazard in 1G.

| 15a. ACTIONEE (Mail Code/Last, First): | 15b. SUSPENSE: | 15c. TEAM CAPTAIN SIGNATURE: |
|---|---|---|
| Bryson, Caroline | 12/2/12 | |

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| | RID NUMBER: RFA #: JB-003 | Page 2 |

16. PREBOARD RECOMMENDATION:

○ ACCEPTED ◉ ACCEPTED PER REMARKS ○ WITHDRAWN ○ SUBMIT TO BOARD
○ ACCEPTED FOR STUDY ○ DISAPPROVED ○ COMBINED WITH:

REMARKS:

| 16a. ACTIONEE (Mail Code/Last, First): | 16b. SUSPENSE: | 16c. PREBOARD CHAIRPERSON SIGNATURE: | 16d. DATE: |
|---|---|---|---|
| | | | |

17. BOARD DISPOSITION:

○ ACCEPTED ◉ ACCEPTED PER REMARKS ○ WITHDRAWN
○ ACCEPTED FOR STUDY ○ DISAPPROVED ○ COMBINED WITH:

REMARKS:

| 17a. ACTIONEE (Mail Code/Last, First): | 17b. SUSPENSE: | 17c. BOARD CHAIRPERSON SIGNATURE: | 17d. DATE: |
|---|---|---|---|
| | | | |

## RID CLOSURE RECORD

18. IMPLEMENTATION:

N/A

19. CLOSED: ○ YES ◉ No

| 18a. INITIATOR APPROVAL: | 18b. DATE: | 18c. ACTIONEE APPROVAL: | 18d. DATE: |
|---|---|---|---|
| 18e. SYSTEM ENGINEER APPROVAL: | 18f. DATE | 18g. CLOSURE APPROVAL (Program) | 18h. DATE: |

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|---|---|---|
| 1. TYPE OF REVIEW: PDR<br>2. PROJECT:<br>NASA X-HAB Stowage System<br>3. DATE: 11/16/12 | **Review Item Discrepancy** | 4. RID NUMBER: RFA #: JB-004<br>4a. INPUT FORM # N/A<br>5. RELATED RIDS:<br>N/A |

6. INITIATOR (Last, First): Broyan, Jim
6a. EMAIL
6b. PHONE:
7. ORGANIZATION: JSC
8. TEAM #/NAME: N/A

9. ITEM REVIEWED (Item, Revision, Title):
UAH Design Team - PDR Presentation

SEC/VOL: N/A
PART/ATT #: N/A
PAGE/SHEET: N/A
PARA./ZONE#: N/A

10. RID SUBJECT:
RFA Title: Packaging/Use efficiency not defined

11. DISCREPANCY/PROBLEM:
Provide major parameters of performance so that packaging and use efficiency can be compared to other stowage systems (RSPs, RSRs, ZGSRs). Parameter suggestions include: estimated 0-g mass/unit (likely different than what you build for your prototype), accessible surface area/unit, number of CTBs/unit, est crew time to load/unload CTBs/unit.

REQUIREMENTS DOC.: UAH Design Team Product Requirements Document
PARA: N/A

12. CONSEQUENCES IF NOT CORRECTED:
N/A

13. INITIATOR'S SUGGESTED CORRECTIVE ACTION (Optional):
Provide major parameters of performance so that packaging and use efficiency can be compared to other stowage systems (RSPs, RSRs, ZGSRs). Parameter suggestions include: estimated 0-g mass/unit (likely different than what you build for your prototype), accessible surface area/unit, number of CTBs/unit, est crew time to load/unload CTBs/unit.

14. DEVELOPER'S COMMENTS:
N/A

| COST IMPACT: | SCHEDULE IMPACT: | 14a: DEVELOPER'S SIGNATURE: |
|---|---|---|
| ○ YES ⦿ No | ○ YES ⦿ No | |

15. TEAM RECOMMENDATION:
○ ACCEPTED ○ ACCEPTED PER REMARKS ○ WITHDRAWN ○ SUBMIT TO PREBOARD
○ ACCEPTED FOR STUDY ⦿ DISAPPROVED ○ COMBINED WITH:

REMARKS:
Per the results of the interviews conducted with stowage specialists, the comparison between the stowage capacity of existing designs and the UAH Design Team's proposed design has already been made. The comparison was discussed during the PDR. The design team's system will accommodate 56 single-sized CTBs, an improvement over the current stowage system maximum of 40 single-sized CTBs in the same allocated space.

| 15a. ACTIONEE (Mail Code/Last, First): | 15b. SUSPENSE: | 15c. TEAM CAPTAIN SIGNATURE: |
|---|---|---|
| Bryson, Caroline | 12/2/12 | |

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| | RID NUMBER: RFA #: JB-004 | Page 2 |
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16. PREBOARD RECOMMENDATION:

- ◯ ACCEPTED
- ◯ ACCEPTED PER REMARKS
- ◯ WITHDRAWN
- ◯ SUBMIT TO BOARD
- ◯ ACCEPTED FOR STUDY
- ⦿ DISAPPROVED
- ◯ COMBINED WITH:

REMARKS:

| 16a. ACTIONEE (Mail Code/Last, First): | 16b. SUSPENSE: | 16c. PREBOARD CHAIRPERSON SIGNATURE: | 16d. DATE: |
|---|---|---|---|

17. BOARD DISPOSITION:

- ◯ ACCEPTED
- ◯ ACCEPTED PER REMARKS
- ◯ WITHDRAWN
- ◯ ACCEPTED FOR STUDY
- ⦿ DISAPPROVED
- ◯ COMBINED WITH:

REMARKS:

| 17a. ACTIONEE (Mail Code/Last, First): | 17b. SUSPENSE: | 17c. BOARD CHAIRPERSON SIGNATURE: | 17d. DATE: |
|---|---|---|---|

## RID CLOSURE RECORD

18. IMPLEMENTATION:

As time permits during the CDR, a more detailed comparison between the design team's proposed system and the current stowage systems may be made. However, the design team does not have access to or intimate knowledge of detailed specifications of the current systems (RSPs, RSRs, ZGSRs). So, an accurate numerical comparison cannot be made. Anne Carter, with NASA MSFC, has made an action to research the aforementioned storage systems and provide the team with their respective dimensions, storage capabilities, and additional specifications. If the design team receives this information in time to implement considerations before the CDR, it will be done.

The proposed system provides equally easy access to all CTBs stored in the three units. This is apparent by referencing the design outlined at the PDR. The number of CTBs the proposed system will accommodate is outlined above in 'Remarks'. The design team does not have the resources to accurately estimate the following parameters of the current stowage systems: crew time to load/unload CTBs/unit, estimated 0-g mass/unit.

19. CLOSED: ◯ YES ⦿ No

| 18a. INITIATOR APPROVAL: | 18b. DATE: | 18c. ACTIONEE APPROVAL: | 18d. DATE: |
|---|---|---|---|
| 18e. SYSTEM ENGINEER APPROVAL: | 18f. DATE | 18g. CLOSURE APPROVAL (Program) | 18h. DATE: |

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| | | |
|---|---|---|
| 1. TYPE OF REVIEW: PDR<br>2. PROJECT: NASA X-HAB Stowage System<br>3. DATE: 11/16/12 | **Review Item Discrepancy** | 4. RID NUMBER: RFA #: JB-005<br>4a. INPUT FORM #: N/A<br>5. RELATED RIDS: N/A |

6. INITIATOR (Last, First): Broyan, Jim
6a. EMAIL:
6b. PHONE:
7. ORGANIZATION: JSC
8. TEAM #/NAME: N/A

9. ITEM REVIEWED (Item, Revision, Title):
UAH Design Team - PDR Presentation

SEC/VOL: N/A PART/ATT #: N/A
PAGE/SHEET: N/A PARA/ZONE#: N/A

10. RID SUBJECT:
RFA Title: Requirements verification

11. DISCREPANCY/PROBLEM:
Provide a summary table showing how your design met the major requirements. I.e. what features/functions met what requirements.

REQUIREMENTS DOC.: UAH Design Team Product Requirements Document PARA: N/A

12. CONSEQUENCES IF NOT CORRECTED:
N/A

13. INITIATOR'S SUGGESTED CORRECTIVE ACTION (Optional):
Also a suggestion, not a RFA, at CDR identify what risks exist to meeting your requirements. An example could be not sure the frame welding will not adversely distort the frame. Another suggestion is that difficult to predict the bearing friction and resultant crew pull out force. These could be a risk to ease of use.

14. DEVELOPER'S COMMENTS:
N/A

COST IMPACT: ○ YES ⦿ No
SCHEDULE IMPACT: ○ YES ⦿ No
14a: DEVELOPER'S SIGNATURE:

15. TEAM RECOMMENDATION:
○ ACCEPTED ○ ACCEPTED PER REMARKS ○ WITHDRAWN ○ SUBMIT TO PREBOARD
○ ACCEPTED FOR STUDY ⦿ DISAPPROVED ○ COMBINED WITH:

REMARKS:

15a. ACTIONEE (Mail Code/Last, First): Bryson, Caroline
15b. SUSPENSE: 12/2/12
15c. TEAM CAPTAIN SIGNATURE:

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| | RID NUMBER: RFA #: JB-005 | Page 2 |
|---|---|---|

16. PREBOARD RECOMMENDATION:

- ◯ ACCEPTED
- ◯ ACCEPTED FOR STUDY
- ◯ ACCEPTED PER REMARKS
- ⦿ DISAPPROVED
- ◯ WITHDRAWN
- ◯ COMBINED WITH:
- ◯ SUBMIT TO BOARD

REMARKS:

| 16a. ACTIONEE (Mail Code/Last, First): | 16b. SUSPENSE: | 16c. PREBOARD CHAIRPERSON SIGNATURE: | 16d. DATE: |
|---|---|---|---|

17. BOARD DISPOSITION:

- ◯ ACCEPTED
- ◯ ACCEPTED FOR STUDY
- ◯ ACCEPTED PER REMARKS
- ⦿ DISAPPROVED
- ◯ WITHDRAWN
- ◯ COMBINED WITH:

REMARKS:

| 17a. ACTIONEE (Mail Code/Last, First): | 17b. SUSPENSE: | 17c. BOARD CHAIRPERSON SIGNATURE: | 17d. DATE: |
|---|---|---|---|

## RID CLOSURE RECORD

18. IMPLEMENTATION:

As a part of the design team's senior capstone engineering course, the table referenced by the RFA in question, is not a required component for the PDR or CDR. However, the design team realizes the additional clarification and reinforcement of the design that a table such as this would provide. Due to this, a Product Design Specifications document has been created that outlines each customer and flow down requirement and states if the requirement has been met and if applicable, the reason it was not met. This document will be available to all parties post CDR through NASA Share Point.

Furthermore, a requirements matrix, like the one discussed in the RFA in question, is completed after the hardware is fabricated and tested in the second semester (January 2012-May 2013) of the capstone senior design course. This matrix will be available to all parties interested at this time.

19. CLOSED: ◯ YES ⦿ No

| 18a. INITIATOR APPROVAL: | 18b. DATE: | 18c. ACTIONEE APPROVAL: | 18d. DATE: |
|---|---|---|---|
| 18e. SYSTEM ENGINEER APPROVAL: | 18f. DATE | 18g. CLOSURE APPROVAL (Program) | 18h. DATE: |

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| | | |
|---|---|---|
| 1. TYPE OF REVIEW: PDR | **Review Item Discrepancy** | 4. RID NUMBER: RFA #: PSB001 |
| 2. PROJECT: NASA X-HAB Stowage System | | 4a. INPUT FORM #: N/A |
| 3. DATE: 11/15/2012 | | 5. RELATED RIDS: N/A |

6. INITIATOR (Last, First): Bookout, Paul
6a. EMAIL:
6b. PHONE:
7. ORGANIZATION: MSFC
8. TEAM #/NAME: DSH

9. ITEM REVIEWED (Item, Revision, Title):
UAH Design Team - PDR Presentation

SEC/VOL: N/A PART/ATT #: N/A
PAGE/SHEET: N/A PARA./ZONE#: N/A

10. RID SUBJECT:
RFA Title: Missing fire extinguisher port

11. DISCREPANCY/PROBLEM:
Level One Requirement 1.4.4 requires a fire extinguisher port.

REQUIREMENTS DOC.: UAH Design Team Product Requirements Document PARA: N/A

12. CONSEQUENCES IF NOT CORRECTED:
N/A

13. INITIATOR'S SUGGESTED CORRECTIVE ACTION (Optional):
Include in the CDR a design for a fire extinguisher port.

14. DEVELOPER'S COMMENTS:
The item is no longer a requirement of the project. It has been removed per verbal and written agreement with NASA Point of Contact Anne Carter.

| COST IMPACT: | SCHEDULE IMPACT: | 14a: DEVELOPER'S SIGNATURE: |
|---|---|---|
| ○ YES ⦿ No | ○ YES ⦿ No | |

15. TEAM RECOMMENDATION:
○ ACCEPTED ○ ACCEPTED PER REMARKS ○ WITHDRAWN ○ SUBMIT TO PREBOARD
○ ACCEPTED FOR STUDY ⦿ DISAPPROVED ○ COMBINED WITH:

REMARKS:

| 15a. ACTIONEE (Mail Code/Last, First): | 15b. SUSPENSE: | 15c. TEAM CAPTAIN SIGNATURE: |
|---|---|---|
| Bryson, Caroline | 12/02/2012 | |

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| | | RID NUMBER: RFA #: PSB001 | Page 2 |
|---|---|---|---|
| 16. PREBOARD RECOMMENDATION: ( ) ACCEPTED ( ) ACCEPTED FOR STUDY ( ) ACCEPTED PER REMARKS (•) DISAPPROVED ( ) WITHDRAWN ( ) COMBINED WITH: ( ) SUBMIT TO BOARD<br>REMARKS: | | | |
| 16a. ACTIONEE (Mail Code/Last, First): | 16b. SUSPENSE: | 16c. PREBOARD CHAIRPERSON SIGNATURE: | 16d. DATE: |
| 17. BOARD DISPOSITION: ( ) ACCEPTED ( ) ACCEPTED FOR STUDY ( ) ACCEPTED PER REMARKS (•) DISAPPROVED ( ) WITHDRAWN ( ) COMBINED WITH:<br>REMARKS: | | | |
| 17a. ACTIONEE (Mail Code/Last, First): | 17b. SUSPENSE: | 17c. BOARD CHAIRPERSON SIGNATURE: | 17d. DATE: |
| **RID CLOSURE RECORD** | | | |
| 18. IMPLEMENTATION:<br>Per Level One Requirement 1.4.4, the UAH design team is not responsible for fire safety considerations. Reference UAH X-HAB Level 1 Requirements 20 Aug 12.pdf, in Appendix A, Section 'Safety', the information regarding fire ports is for 'information only.' | | | 19. CLOSED: ( ) YES (•) No |
| 18a. INITIATOR APPROVAL: | 18b. DATE: | 18c. ACTIONEE APPROVAL: | 18d. DATE: |
| 18e. SYSTEM ENGINEER APPROVAL: | 18f. DATE | 18g. CLOSURE APPROVAL (Program) | 18h. DATE: |

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## Review Item Discrepancy

1. TYPE OF REVIEW: PDR

2. PROJECT: NASA X-HAB Stowage System

3. DATE: 11/15/2012

4. RID NUMBER: RFA #: PSB002

4a. INPUT FORM #: N/A

5. RELATED RIDS: N/A

6. INITIATOR (Last, First): Bookout, Paul

6a. EMAIL:

6b. PHONE:

7. ORGANIZATION: MSFC

8. TEAM #/NAME: DSH

9. ITEM REVIEWED (Item, Revision, Title): UAH Design Team - PDR Presentation

SEC/VOL: N/A  PART/ATT #: N/A

PAGE/SHEET: N/A  PARA./ZONE#: N/A

10. RID SUBJECT:

RFA Title: Missing Project Risks

11. DISCREPANCY/PROBLEM:

Missing Project Level Risks

REQUIREMENTS DOC.: UAH Design Team Product Requirements Document  PARA: N/A

12. CONSEQUENCES IF NOT CORRECTED:

N/A

13. INITIATOR'S SUGGESTED CORRECTIVE ACTION (Optional):

Include in your risk assessment project level risks, such as procurement of materials (referred to as "long lead items"), manufacturer availability, etc. Just as important as technical risks, project level risks can evaluate costs and push out schedule.

14. DEVELOPER'S COMMENTS:

The action is acknowledged and accepted. Program risks, project level risks, team risks, etc. will all be included in the Risk Assessment and Mitigation for the CDR.

COST IMPACT: (●) YES ( ) No

SCHEDULE IMPACT: (●) YES ( ) No

14a: DEVELOPER'S SIGNATURE:

15. TEAM RECOMMENDATION:

(●) ACCEPTED ( ) ACCEPTED PER REMARKS ( ) WITHDRAWN ( ) SUBMIT TO PREBOARD

( ) ACCEPTED FOR STUDY ( ) DISAPPROVED ( ) COMBINED WITH:

REMARKS:

15a. ACTIONEE (Mail Code/Last, First): Bryson, Caroline

15b. SUSPENSE: 12/02/2012

15c. TEAM CAPTAIN SIGNATURE:

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|---|---|---|
| | RID NUMBER: RFA #: PSB002 | Page 2 |

16. PREBOARD RECOMMENDATION:

◉ ACCEPTED ○ ACCEPTED PER REMARKS ○ WITHDRAWN ○ SUBMIT TO BOARD
○ ACCEPTED FOR STUDY ○ DISAPPROVED ○ COMBINED WITH:

REMARKS:

| 16a. ACTIONEE (Mail Code/Last, First): | 16b. SUSPENSE: | 16c. PREBOARD CHAIRPERSON SIGNATURE: | 16d. DATE: |
|---|---|---|---|
| | | | |

17. BOARD DISPOSITION:

◉ ACCEPTED ○ ACCEPTED PER REMARKS ○ WITHDRAWN
○ ACCEPTED FOR STUDY ○ DISAPPROVED ○ COMBINED WITH:

REMARKS:

| 17a. ACTIONEE (Mail Code/Last, First): | 17b. SUSPENSE: | 17c. BOARD CHAIRPERSON SIGNATURE: | 17d. DATE: |
|---|---|---|---|
| | | | |

## RID CLOSURE RECORD

18. IMPLEMENTATION:
Program, project level, and team risks will be included in the CDR Risk Assessment and Mitigation.

19. CLOSED: ○ YES ◉ No

| 18a. INITIATOR APPROVAL: | 18b. DATE: | 18c. ACTIONEE APPROVAL: | 18d. DATE: |
|---|---|---|---|
| 18e. SYSTEM ENGINEER APPROVAL: | 18f. DATE | 18g. CLOSURE APPROVAL (Program) | 18h. DATE: |

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|---|---|---|
| 1. TYPE OF REVIEW: PDR<br>2. PROJECT: NASA X-HAB Stowage System<br>3. DATE: 11/15/2012 | **Review Item Discrepancy** | 4. RID NUMBER: RFA #: PSB003<br>4a. INPUT FORM #: N/A<br>5. RELATED RIDS: N/A |

6. INITIATOR (Last, First): Bookout, Paul
6a. EMAIL
6b. PHONE:
7. ORGANIZATION: MSFC
8. TEAM #/NAME: DSH

9. ITEM REVIEWED (Item, Revision, Title):
UAH Design Team - PDR Presentation

SEC/VOL: N/A PART/ATT #: N/A
PAGE/SHEET: N/A PARA./ZONE#: N/A

10. RID SUBJECT:
RFA Title: Available volume not fully utilized.

11. DISCREPANCY/PROBLEM:
Volume is limited in the confined space of the module. To have an acceptable design, the stowage system must be able to utilize all the volume to its fullest capability.

REQUIREMENTS DOC.: UAH Design Team Product Requirements Document PARA: N/A

12. CONSEQUENCES IF NOT CORRECTED:
N/A

13. INITIATOR'S SUGGESTED CORRECTIVE ACTION (Optional):
Implement design that utilizes the volume behind the flat wall of the stowage system and the curved surface of the module wall.

14. DEVELOPER'S COMMENTS:
N/A

| COST IMPACT: | SCHEDULE IMPACT: | 14a: DEVELOPER'S SIGNATURE: |
|---|---|---|
| (●) YES ( ) No | ( ) YES (●) No | |

15. TEAM RECOMMENDATION:
( ) ACCEPTED (●) ACCEPTED PER REMARKS ( ) WITHDRAWN ( ) SUBMIT TO PREBOARD
( ) ACCEPTED FOR STUDY ( ) DISAPPROVED ( ) COMBINED WITH:

REMARKS:
Per original Level One Requirements document and Product Requirements Document, the UAH Design Team feels that we have effectively utilized the space allowed in the DSH (81.1" W X 81.125" H X 37.5" D). However, the team does realize necessity of using allocated space wisely. Per conversation with MSFC POC Dr. Paul Bookout on MSFC visit, the design team will consider various possibilities concerning appropriate use of space in curvature.

| 15a. ACTIONEE (Mail Code/Last, First): | 15b. SUSPENSE: | 15c. TEAM CAPTAIN SIGNATURE: |
|---|---|---|
| Bryson, Caroline | 12/02/2012 | |

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| | | RID NUMBER: RFA #: PSB003 | Page 2 |
|---|---|---|---|

16. PREBOARD RECOMMENDATION:

- ACCEPTED
- ACCEPTED FOR STUDY
- ◉ ACCEPTED PER REMARKS
- DISAPPROVED
- WITHDRAWN
- COMBINED WITH:
- SUBMIT TO BOARD

REMARKS:
The design team's manufactured stowage system product will not have rigid components that mimic the curvature of the module wall. The stowage system will have an open concept for back and overhead areas of the system and will allow for continuous and easy access to the curvature space as well as overhead space. The team proposes that the space be utilized for long duration storage of CTBs or items that will not be frequently accessed. The use of the extra space allowed by the curvature will be specifically addressed at the CDR.

| 16a. ACTIONEE (Mail Code/Last, First): | 16b. SUSPENSE: | 16c. PREBOARD CHAIRPERSON SIGNATURE: | 16d. DATE: |
|---|---|---|---|

17. BOARD DISPOSITION:

- ACCEPTED
- ACCEPTED FOR STUDY
- ◉ ACCEPTED PER REMARKS
- DISAPPROVED
- WITHDRAWN
- COMBINED WITH:

REMARKS:

| 17a. ACTIONEE (Mail Code/Last, First): | 17b. SUSPENSE: | 17c. BOARD CHAIRPERSON SIGNATURE: | 17d. DATE: |
|---|---|---|---|

## RID CLOSURE RECORD

18. IMPLEMENTATION:
The design team's manufactured stowage system product will not have rigid components that mimic the curvature of the module wall. The stowage system will have an open concept for back and overhead areas of the systemand will allow for continuous and easy access to the curvature space as well as overhead space. The team proposes that the space be utilized for long duration storage of CTBs or items that will not be frequently accessed.

19. CLOSED: YES ◉ No

| 18a. INITIATOR APPROVAL: | 18b. DATE: | 18c. ACTIONEE APPROVAL: | 18d. DATE: |
|---|---|---|---|
| 18e. SYSTEM ENGINEER APPROVAL: | 18f. DATE | 18g. CLOSURE APPROVAL (Program) | 18h. DATE: |

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|---|---|---|
| 1. TYPE OF REVIEW: CDR<br>2. PROJECT: NASA X-HAB Stowage System<br>3. DATE: 12/17/12 | **Review Item Discrepancy** | 4. RID NUMBER: N/A<br>4a. INPUT FORM #: N/A<br>5. RELATED RIDS: N/A |

6. INITIATOR (Last, First): Broyan, James L. 6a. EMAIL:
6b. PHONE: 7. ORGANIZATION: JSC 8. TEAM #/NAME: EC711

9. ITEM REVIEWED (Item, Revision, Title):
UAH Design Team - CDR Presentation

SEC/VOL: N/A PART/ATT.#: N/A
PAGE/SHEET: N/A PARA./ZONE#: N/A

10. RID SUBJECT:
E-mail Action 1: Points of rail attachment in the Unibearing

11. DISCREPANCY/PROBLEM:
The point(s) of rail attachment in the unibearing appears to be only in one top location. But there appears to be a unibearing structure on the bottom but no rail. How are loads reacted? It seems there would be a very significant moment on the unibearing from CTBs and the frame would deflect in the starboard and forward directions because the CG is out of plane with the unibearing.

REQUIREMENTS DOC.: UAH Design Team Project Requirements Document PARA: N/A

12. CONSEQUENCES IF NOT CORRECTED:

13. INITIATOR'S SUGGESTED CORRECTIVE ACTION (Optional):
Action: Idntify the range CG of the CTB loaded structure.

Action: Determine the reaction forces on the Unibearing (free body diagram).

14. DEVELOPER'S COMMENTS:
N/A

| COST IMPACT: | SCHEDULE IMPACT: | 14a: DEVELOPER'S SIGNATURE: |
|---|---|---|
| ○ YES ◉ No | ○ YES ◉ No | |

15. TEAM RECOMMENDATION:
○ ACCEPTED ○ ACCEPTED PER REMARKS ○ WITHDRAWN ○ SUBMIT TO PREBOARD
○ ACCEPTED FOR STUDY ◉ DISAPPROVED ○ COMBINED WITH:

REMARKS:
The design will have multiple points of attachment.

| 15a. ACTIONEE (Mail Code/Last, First): | 15b. SUSPENSE: | 15c. TEAM CAPTAIN SIGNATURE: |
|---|---|---|
| Bryson, Caroline | 1/13/13 | |

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| | | RID NUMBER: N/A | Page 2 |
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16. PREBOARD RECOMMENDATION:

- ○ ACCEPTED
- ○ ACCEPTED FOR STUDY
- ○ ACCEPTED PER REMARKS
- ◉ DISAPPROVED
- ○ WITHDRAWN
- ○ COMBINED WITH:
- ○ SUBMIT TO BOARD

REMARKS:

| 16a. ACTIONEE (Mail Code/Last, First): | 16b. SUSPENSE: | 16c. PREBOARD CHAIRPERSON SIGNATURE: | 16d. DATE: |
|---|---|---|---|

17. BOARD DISPOSITION:

- ○ ACCEPTED
- ○ ACCEPTED FOR STUDY
- ○ ACCEPTED PER REMARKS
- ◉ DISAPPROVED
- ○ WITHDRAWN
- ○ COMBINED WITH:

REMARKS:

| 17a. ACTIONEE (Mail Code/Last, First): | 17b. SUSPENSE: | 17c. BOARD CHAIRPERSON SIGNATURE: | 17d. DATE: |
|---|---|---|---|

## RID CLOSURE RECORD

18. IMPLEMENTATION:

The designed stowage system will utilize multiple points of attachment (4 total) via Unibearings on the top and bottom of each of the 3 frames. In the theoretical design (Zero G), there are Unibearings on the bottom of each frame which attach to the existing 80/20 track system in the DSH. In actuality, the delivered demonstration product will utilize wheels on the bottom for easy translation in 1G and the top will still use the Unibearing connected to the 80/20 track system. After extensive research, technical calculations, and Finite Element Analysis, the design team feels certain that the design presented at the CDR will provide for little to no bending moment due to the multiple points of attachment on the top and bottom of each frame. The design team will be performing further, more detailed, finite element analysis throughout this school semester which will be presented at the upcoming Progress Checkpoints. The aforementioned FEA will include load directions labeled.

19. CLOSED: ○ YES ◉ No

| 18a. INITIATOR APPROVAL: | 18b. DATE: | 18c. ACTIONEE APPROVAL: | 18d. DATE: |
|---|---|---|---|
| 18e. SYSTEM ENGINEER APPROVAL: | 18f. DATE | 18g. CLOSURE APPROVAL (Program) | 18h. DATE: |

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|---|---|---|
| 1. TYPE OF REVIEW: CDR<br>2. PROJECT: NASA X-HAB Stowage System<br>3. DATE: 12/17/12 | **Review Item Discrepancy** | 4. RID NUMBER: N/A<br>4a. INPUT FORM #: N/A<br>5. RELATED RIDS: N/A |

6. INITIATOR (Last, First): Broyan, James L. 6a. EMAIL:

6b. PHONE: 7. ORGANIZATION: JSC 8. TEAM #/NAME: EC711

9. ITEM REVIEWED (Item, Revision, Title):

UAH Design Team - CDR Presentation

SEC/VOL: N/A PART/ATT.#: N/A

PAGE/SHEET: N/A PARA./ZONE#: N/A

10. RID SUBJECT:

E-mail Action 2: Structural analysis of the track

11. DISCREPANCY/PROBLEM:

The structural analysis of the track appears to only consider shear forces. The track will also see very sizeable bending moments. The track is also only supporting 200lbs uniformly distributed. Each track supports 16 or 32 CTBs. Each CTB can weigh up to 60 lbs 960-1920 lbs. The weight the full CTBs needs to be included. The load is NOT uniformly distributed. It appears as nearly point loads in the unibearing contact points. Additionally the entire rail is a cantilever beam.

REQUIREMENTS DOC.: UAH Design Team Project Requirements Document PARA: N/A

12. CONSEQUENCES IF NOT CORRECTED:

13. INITIATOR'S SUGGESTED CORRECTIVE ACTION (Optional):

Include the weight of CTBs in the stress analysis. Note, 60lbs in the max load of a CTB they may weigh less. So that can contribute to CG from being off center. Include combined loads on the rail (shear, bending, and the crew load) when the unit is pulled out. Stress analysis of the unibearing element is needed. What is the material? Stress analysis of the floor' of each unit is required to make sure it can support the CTBs.

14. DEVELOPER'S COMMENTS:

N/A

| COST IMPACT: | SCHEDULE IMPACT: | 14a: DEVELOPER'S SIGNATURE: |
|---|---|---|
| ○ YES ◉ No | ○ YES ◉ No | |

15. TEAM RECOMMENDATION:

○ ACCEPTED ○ ACCEPTED PER REMARKS ○ WITHDRAWN ○ SUBMIT TO PREBOARD

○ ACCEPTED FOR STUDY ◉ DISAPPROVED ○ COMBINED WITH:

REMARKS:

The stowage system is not designed to be fully loaded in 1G (pre-launch) environments.

| 15a. ACTIONEE (Mail Code/Last, First): | 15b. SUSPENSE: | 15c. TEAM CAPTAIN SIGNATURE: |
|---|---|---|
| Bryson, Caroline | 1/13/13 | |

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| 16. PREBOARD RECOMMENDATION: | | RID NUMBER: N/A | Page 2 |
|---|---|---|---|
| ○ ACCEPTED ○ ACCEPTED FOR STUDY | ○ ACCEPTED PER REMARKS ⦿ DISAPPROVED | ○ WITHDRAWN ○ COMBINED WITH: | ○ SUBMIT TO BOARD |
| REMARKS: | | | |
| 16a. ACTIONEE (Mail Code/Last, First): | 16b. SUSPENSE: | 16c. PREBOARD CHAIRPERSON SIGNATURE: | 16d. DATE: |

| 17. BOARD DISPOSITION: | | | |
|---|---|---|---|
| ○ ACCEPTED ○ ACCEPTED FOR STUDY | ○ ACCEPTED PER REMARKS ⦿ DISAPPROVED | ○ WITHDRAWN ○ COMBINED WITH: | |
| REMARKS: | | | |
| 17a. ACTIONEE (Mail Code/Last, First): | 17b. SUSPENSE: | 17c. BOARD CHAIRPERSON SIGNATURE: | 17d. DATE: |

## RID CLOSURE RECORD

18. IMPLEMENTATION:

Per verbal agreement with NASA POC Anne Carter, the designed stowage system is not meant to be loaded in 1G (pre-launch) environments. The CTBs will be placed on the floor of the DSH in between each stowage unit and strapped securely using NASA's current methods of launch preparation. Once the DSH has reached deep space (Zero G environment) each of the rack systems can be loaded with CTBs. In the Zero G environment, the system will have minimal to no weight, so the design team will not complete FEA with CTB weight included. The design team did perform analysis with Solid Edge ST4 in order to determine a weight of the stowage system (see CDR presentation). For Unibearing material and specifications see the link on CDR slide 80. (UHMW-PE Unibearing)

The three produced stowage units will not have closed "floors" on the bottom of the units. As shown in the design, additional space is provided between CTBs and external walls of the system. The design team does not plan for the CTBs to rest on the floor of the DSH during operation. During launch, however, the floor of the DSH will need to withstand the weight of the CTBs. This structural analysis is out of the scope of the NASA X-HAB stowage system project's original solicitation.

19. CLOSED: ○ YES ⦿ No

| 18a. INITIATOR APPROVAL: | 18b. DATE: | 18c. ACTIONEE APPROVAL: | 18d. DATE: |
|---|---|---|---|
| 18e. SYSTEM ENGINEER APPROVAL: | 18f. DATE | 18g. CLOSURE APPROVAL (Program) | 18h. DATE: |

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Clear Form

| | | |
|---|---|---|
| 1. TYPE OF REVIEW: CDR | **Review Item Discrepancy** | 4. RID NUMBER: N/A |
| 2. PROJECT: NASA X-HAB Stowage System | | 4a. INPUT FORM #: N/A |
| 3. DATE: 12/17/12 | | 5. RELATED RIDS: N/A |

6. INITIATOR (Last, First): Broyan, James L.
6a. EMAIL:
6b. PHONE:
7. ORGANIZATION: JSC
8. TEAM #/NAME: EC711

9. ITEM REVIEWED (Item, Revision, Title):
UAH Design Team - CDR Presentation

SEC/VOL: N/A
PART/ATT.#: N/A
PAGE/SHEET: N/A
PARA./ZONE#: N/A

10. RID SUBJECT:
E-mail Action 3: Kick Load for ISS

11. DISCREPANCY/PROBLEM:
Kick load for ISS is 125 lbs any direction. The load needs to be transmitted through the frame, to the unibearing, and to the rail support. The analysis only appears to look at the frame and the frame seems to be fixed at its ends.

REQUIREMENTS DOC.: UAH Design Team Project Requirements Document
PARA: N/A

12. CONSEQUENCES IF NOT CORRECTED:

13. INITIATOR'S SUGGESTED CORRECTIVE ACTION (Optional):
Include the reaction of the kickload through the frame unibearing and rail.

14. DEVELOPER'S COMMENTS:
N/A

COST IMPACT: ○ YES ⦿ No
SCHEDULE IMPACT: ○ YES ⦿ No
14a: DEVELOPER'S SIGNATURE:

15. TEAM RECOMMENDATION:
⦿ ACCEPTED ○ ACCEPTED PER REMARKS ○ WITHDRAWN ○ SUBMIT TO PREBOARD
○ ACCEPTED FOR STUDY ○ DISAPPROVED ○ COMBINED WITH:

REMARKS:

15a. ACTIONEE (Mail Code/Last, First): Bryson, Caroline
15b. SUSPENSE: 1/13/13
15c. TEAM CAPTAIN SIGNATURE:

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| | | RID NUMBER: N/A | Page 2 |
|---|---|---|---|

16. PREBOARD RECOMMENDATION:

- (●) ACCEPTED
- ( ) ACCEPTED PER REMARKS
- ( ) WITHDRAWN
- ( ) SUBMIT TO BOARD
- ( ) ACCEPTED FOR STUDY
- ( ) DISAPPROVED
- ( ) COMBINED WITH:

REMARKS:

| 16a. ACTIONEE (Mail Code/Last, First): | 16b. SUSPENSE: | 16c. PREBOARD CHAIRPERSON SIGNATURE: | 16d. DATE: |
|---|---|---|---|

17. BOARD DISPOSITION:

- (●) ACCEPTED
- ( ) ACCEPTED PER REMARKS
- ( ) WITHDRAWN
- ( ) ACCEPTED FOR STUDY
- ( ) DISAPPROVED
- ( ) COMBINED WITH:

REMARKS:

| 17a. ACTIONEE (Mail Code/Last, First): | 17b. SUSPENSE: | 17c. BOARD CHAIRPERSON SIGNATURE: | 17d. DATE: |
|---|---|---|---|

## RID CLOSURE RECORD

18. IMPLEMENTATION:

The design team's FEA Specialist will research kick loadings further and implement findings in the updated FEA presented in the upcoming Progress Checkpoints.

19. CLOSED: ( ) YES (●) No

| 18a. INITIATOR APPROVAL: | 18b. DATE: | 18c. ACTIONEE APPROVAL: | 18d. DATE: |
|---|---|---|---|
| 18e. SYSTEM ENGINEER APPROVAL: | 18f. DATE | 18g. CLOSURE APPROVAL (Program) | 18h. DATE: |

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Clear Form

| | | |
|---|---|---|
| 1. TYPE OF REVIEW: CDR<br>2. PROJECT: NASA X-HAB Stowage System<br>3. DATE: 12/17/12 | **Review Item Discrepancy** | 4. RID NUMBER: N/A<br>4a. INPUT FORM #: N/A<br>5. RELATED RIDS: N/A |

6. INITIATOR (Last, First): Broyan, James L. 6a. EMAIL:
6b. PHONE: 7. ORGANIZATION: JSC 8. TEAM #/NAME: EC711

9. ITEM REVIEWED (Item, Revision, Title):
UAH Design Team - CDR Presentation

SEC/VOL: N/A PART/ATT.#: N/A
PAGE/SHEET: N/A PARA./ZONE#: N/A

10. RID SUBJECT:
E-mail Action 4: FTA

11. DISCREPANCY/PROBLEM:
Slide 57 Fault Tree. Included on every fault tree should be 'improper design'. It can be the design loads were incorrect, the operation was not properly understood, design flaw (typically stress concentrations in structures), unforeseen interferences, ICD issues

REQUIREMENTS DOC.: UAH Design Team Project Requirements Document PARA: N/A

12. CONSEQUENCES IF NOT CORRECTED:

13. INITIATOR'S SUGGESTED CORRECTIVE ACTION (Optional):

14. DEVELOPER'S COMMENTS:
N/A

| COST IMPACT: | SCHEDULE IMPACT: | 14a: DEVELOPER'S SIGNATURE: |
|---|---|---|
| ○ YES ⦿ No | ○ YES ⦿ No | |

15. TEAM RECOMMENDATION:
⦿ ACCEPTED ○ ACCEPTED PER REMARKS ○ WITHDRAWN ○ SUBMIT TO PREBOARD
○ ACCEPTED FOR STUDY ○ DISAPPROVED ○ COMBINED WITH:

REMARKS:

| 15a. ACTIONEE (Mail Code/Last, First): | 15b. SUSPENSE: | 15c. TEAM CAPTAIN SIGNATURE: |
|---|---|---|
| Bryson, Caroline | 1/13/13 | |

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| | | RID NUMBER: N/A | Page 2 |
|---|---|---|---|
| 16. PREBOARD RECOMMENDATION:<br>(•) ACCEPTED ( ) ACCEPTED PER REMARKS ( ) WITHDRAWN ( ) SUBMIT TO BOARD<br>( ) ACCEPTED FOR STUDY ( ) DISAPPROVED ( ) COMBINED WITH:<br>REMARKS: | | | |
| 16a. ACTIONEE (Mail Code/Last, First): | 16b. SUSPENSE: | 16c. PREBOARD CHAIRPERSON SIGNATURE: | 16d. DATE: |
| 17. BOARD DISPOSITION:<br>(•) ACCEPTED ( ) ACCEPTED PER REMARKS ( ) WITHDRAWN<br>( ) ACCEPTED FOR STUDY ( ) DISAPPROVED ( ) COMBINED WITH:<br>REMARKS: | | | |
| 17a. ACTIONEE (Mail Code/Last, First): | 17b. SUSPENSE: | 17c. BOARD CHAIRPERSON SIGNATURE: | 17d. DATE: |

## RID CLOSURE RECORD

| | | | |
|---|---|---|---|
| 18. IMPLEMENTATION:<br>The design team will update the Fault Tree Analysis per the initiators requested actions and present the completed FTAs at the upcoming Progress Checkpoint. | | | |
| | | 19. CLOSED: ( ) YES (•) No | |
| 18a. INITIATOR APPROVAL: | 18b. DATE: | 18c. ACTIONEE APPROVAL: | 18d. DATE: |
| 18e. SYSTEM ENGINEER APPROVAL: | 18f. DATE | 18g. CLOSURE APPROVAL (Program) | 18h. DATE: |

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