NASA XHab Challenge

FDR

Inflatable/deployable airlock Structure

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To: Russell Smith

From: UVM XHAB TEAM

Date: 5/4/2015

Subject: Final Design Report

The UVM XHAB team has put together a comprehensive final design report containing an overview of our design process as well as testing and fabrication protocol. Inside you will find a complete break down of schedule, design overview, function analysis, and operations manual.

This project could not have been completed without the support from our mentors from the University of Vermont and the correspondents from NASA. Dr. Hitt, Dr. Houston, Dr. Dewoolkar, and Dr. Barnes met with us on a biweekly basis and were very helpful ensuring we were on schedule and offered us advice and assistance to the many problems that arose throughout this design process.

The NASA correspondents' continual support, positive attitude, and critical analysis of our design inspired us and kept us motivated throughout the process. Your availability to answer any and all questions in a critical fashion with involved answers and possible solutions was much appreciated. As students of engineering, thinking about space specific design is not something we get to do every day and your insight into the complicated process helped us solve our problems while also gaining appreciation for the complexity of NASA's designs. It also meant a lot to us that you took time of your busy schedule to drive all the way up here and see our final project. It was great experience being part of your team! Thank you.

Sincerely,

The University of Vermont XHAB Team

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A. Abstract

As part of NASA's XHAB initiative, the University of Vermont (UVM) student design team is contributing to this program with a novel approach concept that combines Space Race era concepts – inflatable space structures – with 21st century materials and technology: braided reinforce inflatable "air beams" and carbon composite structures. NASA's challenge for a team of senior engineering design students was to develop an "inflatable, habitable & deployable space airlock".

An airlock allows astronauts to preform extra vehicular activities (EVA) under space or extraterrestrial conditions; it is conceptually analogous to the role of a submarine airlock in an underwater environment. An extraterrestrial airlock must allow the controlled transit of people and/or material, between two environmental extremes. For example, the Quest Joint Airlock's function on the International Space Station (ISS) is to create an interface between the vacuum of space and the pressurized volume in the interior. An airlock module typically consists of two airtight doors that cannot be opened simultaneously. Astronauts enter through the station side door to access their EVA gear; including space suits, breathing apparatus, and other critical equipment. Once inside the airlock, an air system separate from that of the main station, allows pressure equalization with the outside environment. Egress outside the airlock is then conducted. Upon EVA completion, ingress is the reverse process as that of egressing from the airlock.

For any space mission planning, the payload mass and volume represent key design drivers. The designer seeks to minimize the complexity (and mass) of these system components; doing so reduces the required propellant mass budget and therefore launch vehicle requirements and cost. An airlock is an important component of any space habitat and its proper functioning is critical. Its design is subject to the overall goal of volume and mass minimization. Optimizing critical features associated with the airlock. Due to this, the major focus of the prototype airlock is structural design. By utilizing an inflatable airlock, a significant mass savings could be realized versus current metallic variants, as well as allowing the volume to be repurposed when not in sue as an airlock.

A circular array of sixteen high pressure air beams provides the necessary stiffness and strength on the assembly, which could be subjected to gravitational and dynamic loading; the articulation of the air beams allows for shape retention of the airlock during depressurization, and which has its own dedicated inflation system separate from that of the main airlock interior. Pressurized nitrogen gas provides for the articulation of the high load bearing air beams; specialized braided carbon fabric is used fo construct the air beams and which allows them to perform at elevated pressures. The airlock, with its associated air beam array, is contained via two lightweight endplates that allow for integration of the airlock with the spacecraft, and/or the space habitat, and the outside environment. Hatches are also integrated into the endplate sections facilitating egress and ingress operations. Additionally, the endplates serve the key function of containing and assisting in the retracting and folding of the inflatable sections during the inflation/deflation process; conceptually, the ship-side endplate will be recessed within the pressurized volume allowing the outer endplate to sit flush against the exterior wall section when retracted. Additional components in the design include the restraining fabric that keeps the air beam array in proper orientation, as well as bands stitched into the restraining fabric that assist in the controlled retraction and containment process. Concept diagrams of the prototype design appear in Figure 1.

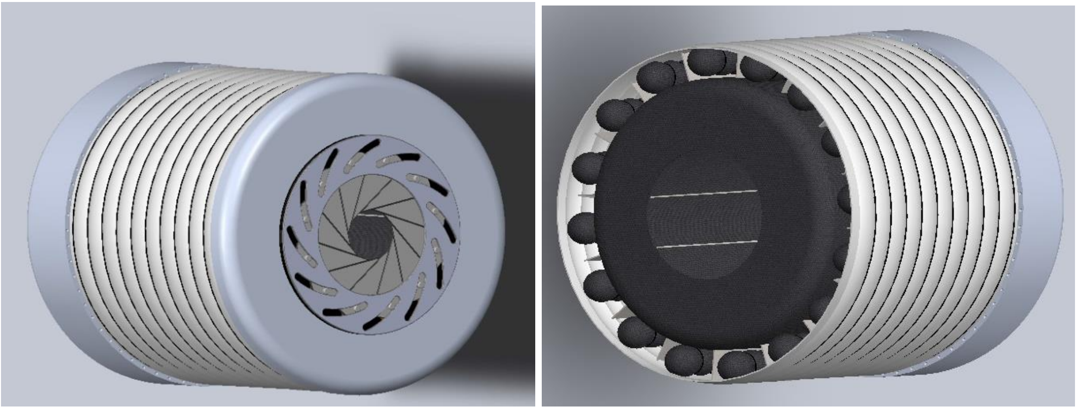


Figure 1 – Concept diagrams of the prototype design. (left) The full assembly of the inflatable airlock design; (right) Air beam array is shown within full assembly providing the structural rigidity of the airlock.

The UVM XHab team has constructed a 3:1 scale prototype of the outlined conceptual design. This scaled prototype will provide the means for the students and professors at UVM to conduct additional testing and analysis with inflatable space structures that will help determine key performance parameters. Examples include the reliable inflation and deflation of the airlock, packaging and folding of the fabric sections, as well as key stiffness and strength margin determinations.

The UVM School of Engineering, with continued NASA support could become one of the premier institutions for research into the use of inflatables for spacecraft and space habitat type applications.

B. Introduction

Inflatable space designs have focused mainly on inhabitable areas for astronauts to perform daily functions and they did not have a way for astronauts to leave the station. Little development has been made on inflatable airlock designs. Of the handful of airlock designs which have been developed, few have addressed the problem of structural rigidity. The importance of creating an rigid airlock device is seen in the use of the device. If it maintains shape, the materials be less likely to experience scuffs and scrapes during use, and the astronauts will be able to enter and exit the air-lock with little issues. This will increase the lifespan and use of the device.

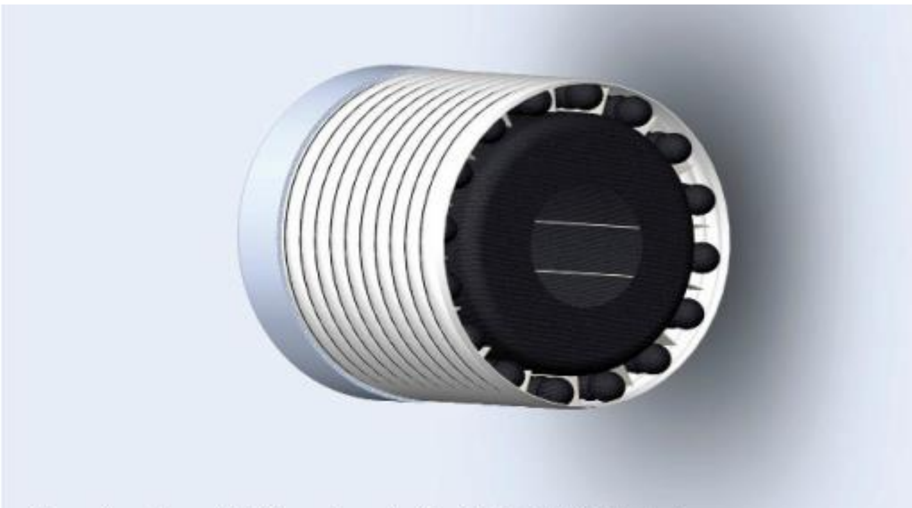
This airlock addresses rigidity of the airlock through the use of air beams. They sit in an array around the airlock. The full design is made originally with some inspiration from Bigalow's space capsule for material selection. There is a conceptual design of the airlock addressing many of the functions. This is drawn through Solidworks drafting. There is also a mock-up design to prove the folding and expanding concept. Folding fabric in a controlled manner at the scale required through automated machinery proves to be a difficult task. Also the conditions of a space environment add additional requirements for the solution to a collapsible foldable material.

C. Development of Problem Statement

The main objective of this project is for students to design a 3:1 scale, inflatable/deployable airlock structure with the ability to be deployed in a deep space, near asteroid environment. The airlock should have the same functionality as previous conventional, all metal airlocks, but weigh less than 3000 kg. The design will need to be deflated into a compact, self-contained assembly, with the ability to withstand launch and space travel conditions. After launch it must be able to be deployed on an asteroid. Once deployed, it will need to provide life support services for two fully suited astronauts, as well as provide convenient storage for staging activities. The structure needs to be durable in an adverse asteroid environment, withstand a pressure gradient of at least 34 psi, with no air leakage. The airlock will have to be able to resist space debris impact, shield against EM background radiation, and have redundancy/survivability (self-healing) characteristics. It will need to be reused, meaning it will need to be able to be packed and be re-deployed multiple times during a mission. It must also have a minimum lifespan of 5 years, during which full initial capabilities will have to be maintained. All components must adhere to a safety factor of four.

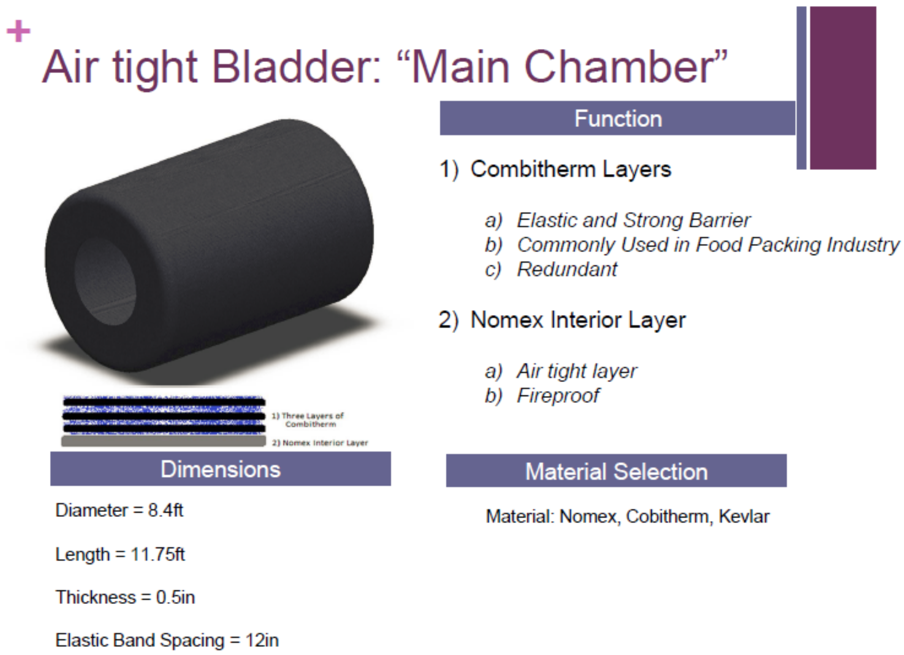
D. Design Overview

I. Conceptual Overview

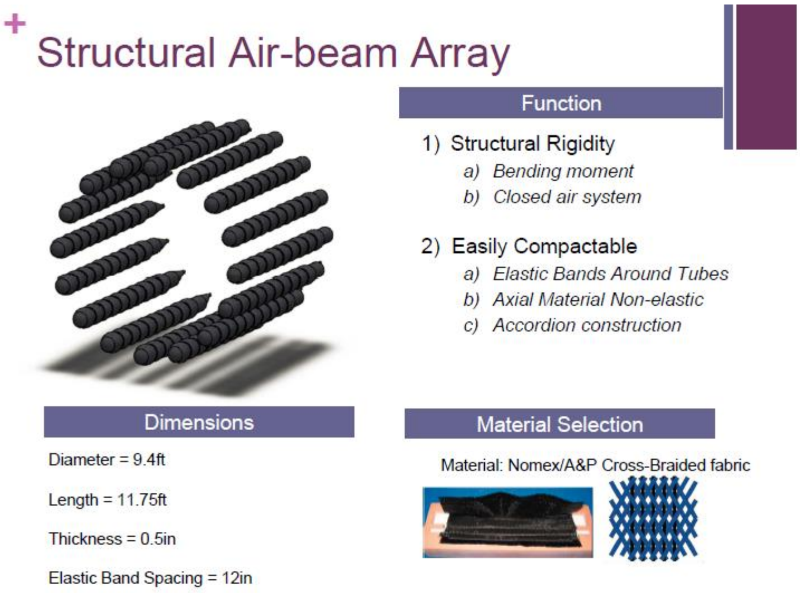


Shown (from the outside in) are the restraining fabric (white) with dark circumferential lines depicting elastic bands, 16 structural air beams, and airtight bladder (black). The light gray item at the back is the main endplate, which serves as a housing for the various components of the air lock en route and which also serves as the connecting point with a spaceship/space station in situ. Not shown is the front endplate.

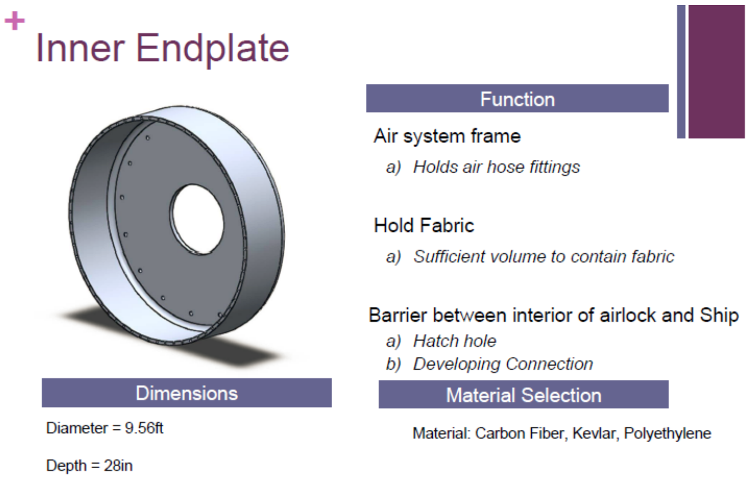
After a comprehensive analysis of different approaches to this problem, the team at the University of Vermont decided on a solution. The design would consist of three main components. First, an inflatable, airtight main chamber serves the purpose of the main airlock function, which is to provide all the current function of solid structure airlocks in use today.



The second major component is an inflatable array of air beams. This array provides the necessary structural integrity to the assembly, which would be subjected to gravitational and dynamic induced forces. It is inflated via an air system separate to that of the main chamber air system allowing for the structure to remain expanded while the main chamber is void of air during EVA missions. The air beams are supplied with high pressure nitrogen in varying degree depending on operating conditions. Through our analysis we have found that as pressure in the air beams is increased the force that can be applied to the structure before failure is greater. To achieve high pressures in inflatable members a specialized braided carbon fabric is used to construct the air beams.



The final major component consists of two lightweight solid structure endplates located on either end of the inflatable members. These endplates allow for integration of the airlock with a space station or ship, provide connection points for the fabrics of the inflatable members, and allow for the airtight doors to be constructed of solid materials. Their Most important function though, is to contain and assist in the retracting and folding of the inflatable sections during the retraction/deflation process. The ship side endplate will sit within the station or ship the airlock is attached to, allowing the outer endplate to sit flush against the exterior or the station or ship.



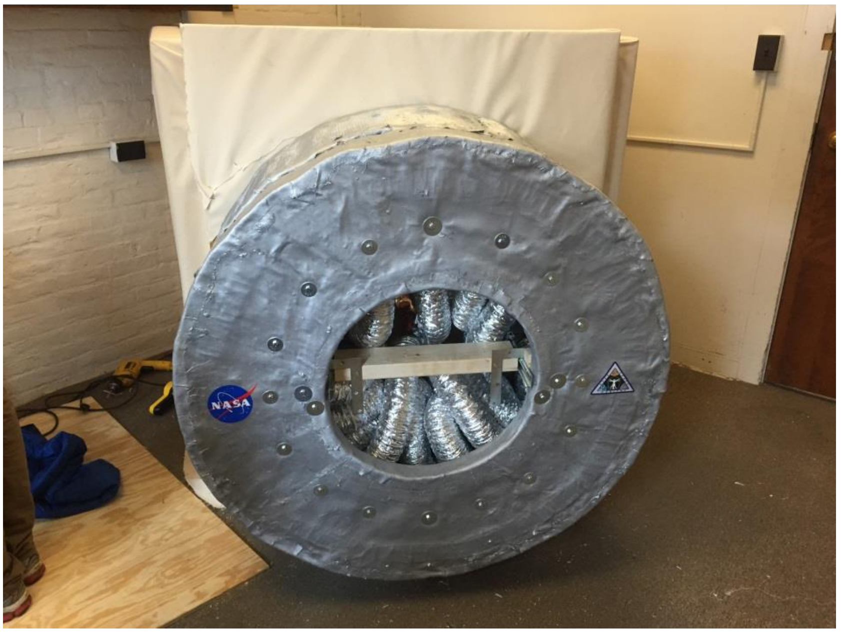
Other less important components include a restraining fabric, which keeps the air beam array in proper formation, and bands located on the restraining fabric which assists in the controlled folding process.

II. Demonstration Prototype Design Overview:

How can we test and prove the concepts behind our conceptual design? To do so we designed and built a 3 to 1 scale model of our airlock. What do we want to prove with this scale model? Carbon fiber woven fabric air beams are a known technology they have been tested extensively and are commercially used today. However when they are used today they are never deployed from a compact location. They are always laid out into the position they are to be used before pressurization. What we want to prove with our scale model is our ability to inflate the air beams from a compacted orientation as well as retract the same air beams in a neat and controlled matter back into the compacted containment.

Due to safety concerns we decided to use a different style of air system for our model. We elected to use an open air system powered by four blowers which will always be on and will not create a high pressure situation in our beams. This style of air system still allows us to achieve our testing goal.

To replicate our conceptual design we built two endplates by creating foam molds and laying and curing fiber glass over them.



For every four air beams there is a 250 CFM blower providing the flow.

We constructed a wooden frame behind the model airlock to represent what the airlock would look like attached to a station or ship.

To provide the force of retraction we mounted a 2,000b capable winch inside our main frame. This winch was connected to the outer plate. It also allowed for controlled inflation of the device. We could turn on the blowers and then slowly let out the winch to create a slow and even inflation of the device.

Due to the fact that we are trying to test our conceptual design under earth's gravity, we had to come up with a solution as to how we could keep the airlock static, and hold up the outer end plate during inflation. To do this we mounted industrial drawer sliders inside of the supporting frame discussed above. These drawer sliders were connected to the outer endplate as well as the winch. This solution ended up working extremely well and allowed us to focus on our testing concerning the folding of the air beam fabrics.

We constructed the model air beams out of vinyl sheeting. We chose this material because of cost reasons and that its thickness is represented of the thickness of the carbon fiber weave scaled down. We began testing these model beams inflation and compaction abilities. We found that there were lots of issues with our original methods. The use of the bands to create the accordion like folds in the beams caused pinch points where pressure would build, which on the real thing could cause a catastrophic failure. As well as an inability to properly fold during retraction, causing entanglement and twisting of the beams.

During some test inflations of the original air beams we noticed something. The flexible ductwork we used to transport the air from the blowers into the air beams had an interesting ability. No matter how you twisted them, pushed on them, bent them, you could never change the diameter along any point of the ductwork. They also had the ability to be neatly compacted. What gave them this capability was a weak spring interwoven in the duct fabric. We looked deeper into the design of these duct pieces and began drawing up redesigns of all of our inflatable members to have a thin widely spaced spring interwoven into the fabrics they we made out of. The only difference is that our springs acted in the opposite direction of the ones in the duct so as to always keep themselves under tension.

We wanted to test this new air beam design further. To do so we built 16 air beams out of 3 inch flexible duct work and integrated them with our airlock model. This allowed us to observe how they inflate from compacted orientation as well as how neatly they can compact themselves. Due to the fact that the springs in the duct work do not act in the direction that would always put them under tension they are not an exact match to the beams designed for the conceptual prototype, which means we can expect that their folding abilities will not be a precise.

After lots of testing we came to the conclusion that the spring integration will be our final design iteration. We went back to our conceptual design and applied what we learned from testing our model. After testing multiple folding methods with our 1:3 scale model we found that using the functionality of the springs inside the flexible ductwork could provide for a much neater and controlled folding method, due to this finding we have redesigned our air beams to include springs similar to that of the Duct work. The springs we have integrated into our air beams are relatively weak; they also act in the opposite direction of the ductwork air beams used on our model, so as to always be under tension instead of always trying to expand themselves.

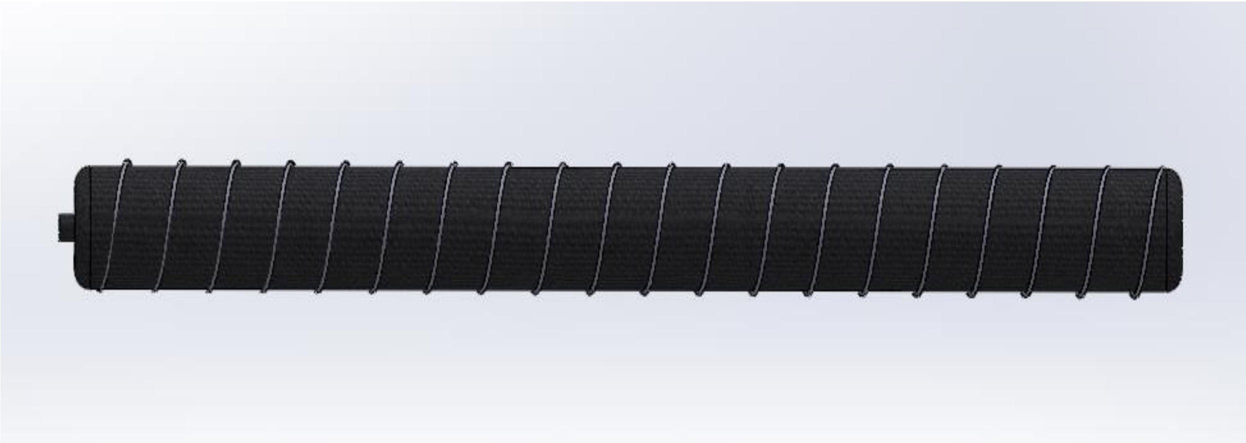


Image of Re-Designed Air Beam with spring integration (L= 12ft)

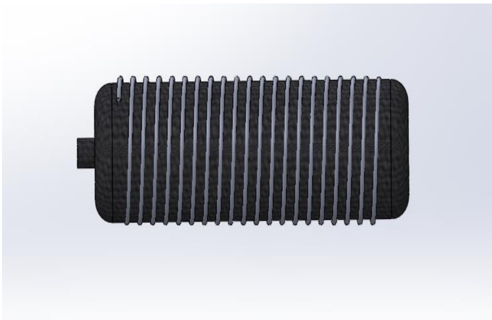


Image of Re-Designed Air Beam once compacted (Min L = 3.2ft)

Due to this redesign we have to go back a preform some further analysis on our airlock. We are hoping that not only will the spring integration allow for the neat expansion and folding of the air beams, but that it will also be able to replace our winch system. As seen in our winch force required analysis we found that as the working pressures we are expecting, a force of 75,000 lbf will be applied to the outer endplate. The winches that can restrain such a force require very large amounts of power as well as hydraulic systems. We want to avoid all of this due to the constraints that we have during a space flight mission. With analysis of the spring integration we will be able to specific a spring within the air beams as well as integrated with the restraining fabric and the main chamber that will be able to balance its spring constant and force that is balanced with the force applied by the pressures in the inflatable members.

E. Objective Analysis

Our initial objective, as outlined by the client, was to design an inflatable and deployable airlock for outer space. The driving idea of making the design as light as possible was implicit to the technology constraint (inflatables).

Space systems costs are extremely cost intensive due to the nature of the existing technology to orbit cargo. Also, financial aspects aside, the very technical feasibility of space missions depend on making the cargo meet stringent weight and dimensional limitations. Weight is a limitation of current propulsive technology. Dimensions, on the other hand, are limited by aerodynamics (diameter) and structure/stability (length).

The fact that the design is mostly made of inflatable structural members makes the current flight concept at most a third of the weight of the current technological solution in the ISS. On the other side, the fact that the current design is deployable, drastically reduces the length the module would occupy in rocket's fairing. As an example, our current design is 13 ft long when deployed, and only 3ft when collapsed. The current design occupies 18 ft. in a rocket's tandem payload.

Lastly, the fact that our design's technological basis has been proven over 60 years ago, coupled with current designs being evaluated, and the exponential leap in materials technology more than validates the feasibility of the core ideas behind our flight design.

F. Function Analysis

The PDR report presented the teams plan for a demonstration mock-up of the device. The purpose of the mock-up was to address the expanding and contracting of the device as it was an integral part of the inflatable air-lock solution. The plan was to create air-beams from a test fabric (polyvinyl-chloride) and create a testing station to test the collapsibility and expansion of the beams.

The test platform was made to prove how folding and expanding would function. It holds collapsible rails which moved in the x-direction only while gravity worked in the y-direction. The bulk of the test platform was made from lumber. The interior of the platform had for air-blowers attached to flex-ducting arranged to attach to the airlock.

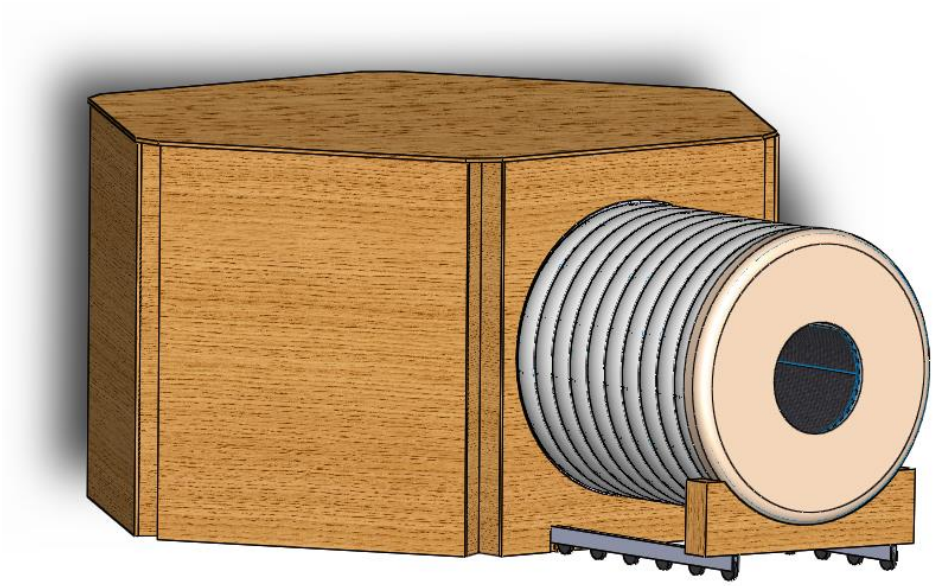


Figure : Test Platform

The team created an airlock which only consisted of endplates and the air-beams. The interior bladder and outer membrane were not included. During the PDR, we hoped to include these portions of the device, however discussed the necessity of having those sections and decided that solely making air-beams would save us time and money because we were building the device ourselves and those were complicated tasks which we would have to outsource.

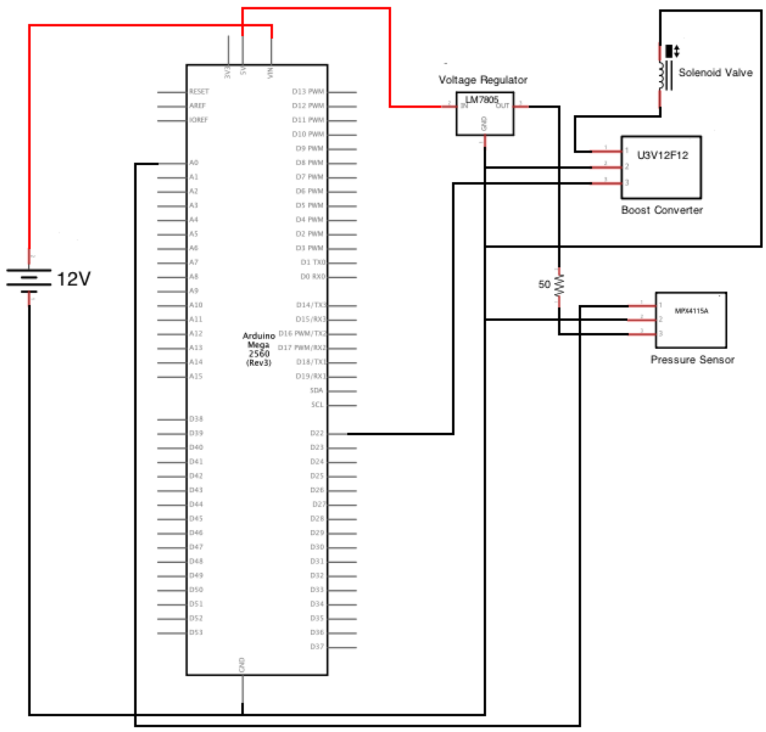


Figure 1: Electronic schematic of the pressurized feedback system in the air beam array for the flight concept

This circuit diagram represents the electrical components in each air beam. This circuit would be powered by the ship and the voltage will be stepped down to 12VDC using a voltage relay. Since we decided to us 12V as our input, there is a voltage regulator in place to ensure there is a constant 5V supply to the pressure sensor. The analog pin is constantly reading the output voltage of the pressure sensor. The boost converter is connected to a digital output pin so when the digital output is on the voltage is stepped up to 12V to open the electrical valve. As you can see in figure 1, we did not choose a specific electrical valve. This is because NASA gives a company certain specs and has the valves custom made. It is possible that the 40mA, from the digital output pin, will not be large enough current to open the valve. If this were the case an NPN transistor in a common-emitter configuration could be added and serve as a current amplifier. The reason an Arduino was chosen as the microcontroller was because our client stated we could choose the software and an Arduino had the exact amount of analog and digital pins needed to run the pressurized feedback system.

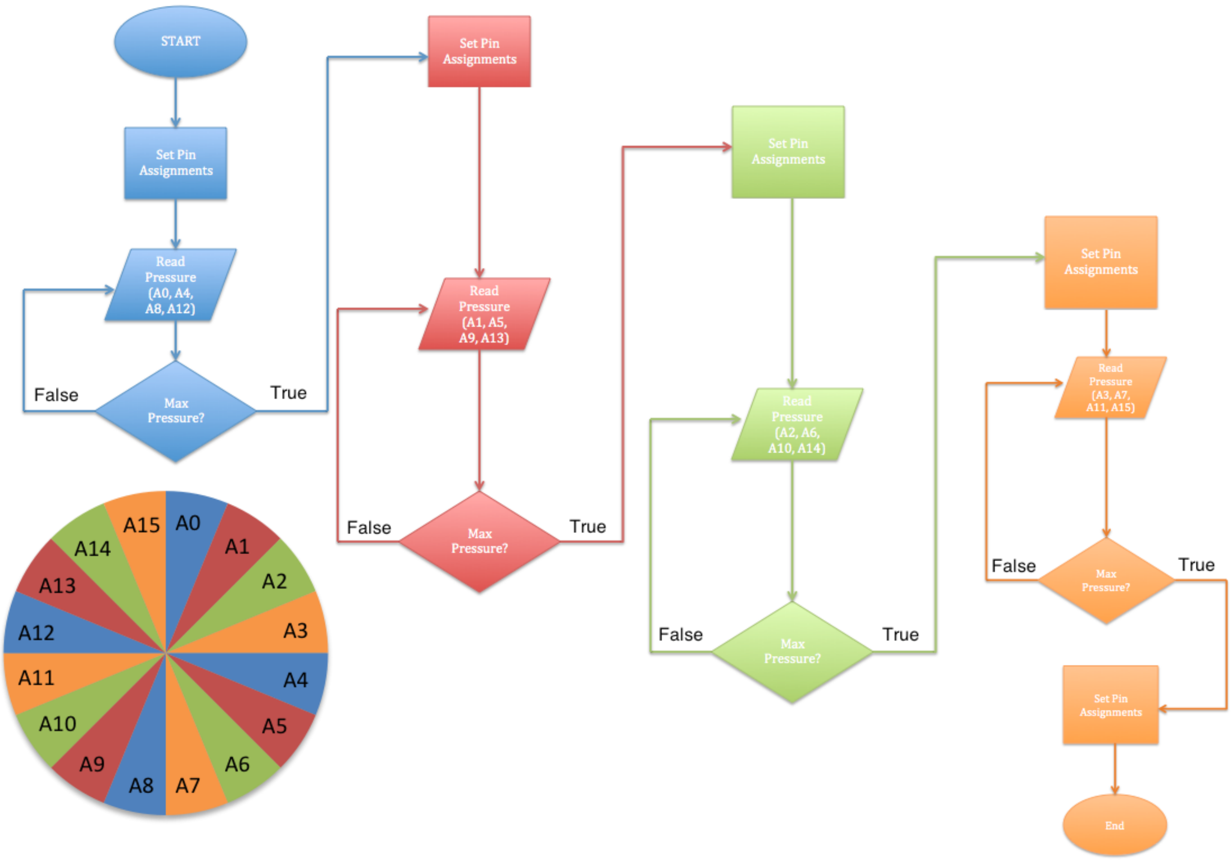


Figure 2: Software logic chart for the pressurized feedback system

The logic flow chart demonstrates how the program will work to operate the pressurized feedback system in figure 1. In the pie chart each sliver represents an air beam that also corresponds to the chart. First the program will set the pin assignments so that A0, A4, A8, A12 (blue slivers) are constantly checking the pressure. It will also set the corresponding will also be assigned and the output to open the valves. The system will continuously check the pressure until it reaches the maximum. Then the digital output pins will be set to low, closing the valves of the four air beams. Next it set the pin assignments in the next sequence of air beams and repeats this process until it's fully inflated. This program allows for a controlled inflation.

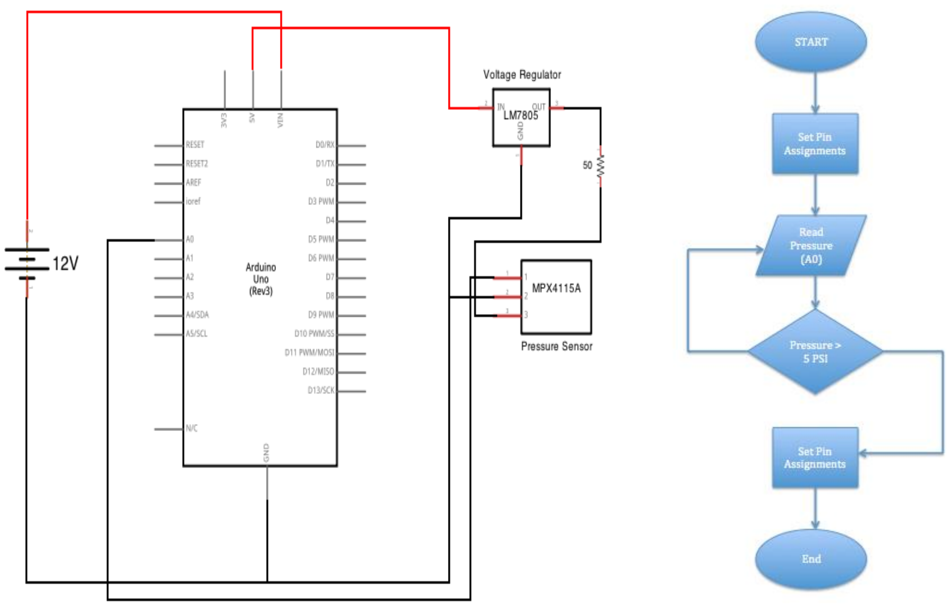


Figure 3: The winch system electronic schematic and software logic chart lock for our original prototype

This was our original design to control the winch system. Again as you can see in the circuit diagram it uses 12V to power the Arduino, a voltage regulator, and pressure sensor. With the help of Dr. Burns, we successfully used a voltage relay that stepped down the voltage from the outlet to 12VDC and powered the Arduino. The program would monitor the pressure and when it reached 5PSI it would give an alert (light or sound) to let the user know it was time to deploy the winch system. However when we changed our system design from a closed air system to an open air system it was no longer necessary to monitor pressure. If the grant to continue this project next year is approved, this can be applied to next year's design as there will be an emphasis on the pressurization. The winch system we did use in our mockup was the Superwinch UT3000 which used 12V and 10A.

We created a logic chart for the automation system however did no write the code because it is subject to change and was not necessary for structural testing. We found while building that creating the circuit and programming it would not serve as a practical purpose for our design. We did not believe NASA would use our code as a model and wanted to focus on creating a folding solution above making a user friendly mock-up at this stage in the air-locks development.

We were able to develop on the attachments of various membrane of the device in our conceptual design since the PDR. An array of fasteners was developed on the edges of the fabrics to create an airtight connection between the fabric and the endplates. We created a carbon fiber layer for the connection between the inner membrane and the endplate. This layer attaches to the inner membrane through an array of bolts and keeps an airtight seal in the portion of the airlock containing the astronaut's oxygen supply.

The winch system constructed in the mock-up served its purpose. The design was built on a rail system and did not need the balanced release our conceptual winch design will provide for the air-lock. The mock-up winch was able to demonstrate the functionality of the winches and showed that the air-lock can in fact be contracted by using winches. Further development is necessary to show that the winches can maneuver the device in an organized fashion through an automated sequence.

Changes were necessary for our design and further development in the conceptual design will be necessary to meet the safety standards of sending someone into space.

G. Design Details

Testing on the air-beams was possible and done extensively. The team was able to test a variety of beam designs and to develop a conceptual beam we would like to have made in the future.

The original air-beam design was a nomex fabric woven with another fabric and then the geometry was surrounded by elastic bands. The band's purpose was to help the folding of the materials. They generate a force to the fabric causing it to collapse on itself similar to a balloon deflating. This is necessary in space because there is not a pressure gradient which will cause fabrics to fold.

Figure : Air-beam Model 1 with Elastic Bands

To serve as a functioning deployment testing air-beam, the team decided to use PVC. This material is used extensively in inflatable structures on earth from bouncy castles to white water rafts. It is has a moderate thickness and would behave similarly to the nomex material, however does not handle high heat as well and costs significantly less. We bought the material and built all the air-beams for the test.

The team found that the PVC air-beams did not function in the test platform. The material was thick and did not fold or expand properly. Each beam was approximately 5 feet by 6 inch and made by two pieces of fabric sown together. When inflating, the air-beams did not create the necessary forces in the x-direction to move the endplate attached to the rails. We believe this was caused by the folding of the fabric and also we did not install a compressor into our system. When folding, the PVC air-beams were folding on themselves and got pinched by the endplates. They were not folding on themselves in the desired fashion and gravity was causing them to droop. The team decided to test more air-beam designs.

The team tried multiple stich patterns on the beams. Folding a singular fabric over itself was able to expand properly however folding it was difficult. Other stitching techniques like curved lines were tried however the materials continued to fold. The folding found was due to gravity.

The team found that gravity had a significant impact on the design platform and the weight of the PVC was causing issues. This was an unfortunate event because in space or on an asteroid gravity would not be a factor. One way to work around the influence of gravity would be to create a platform which stood vertically allowed the airlock to expand with gravity or to test underwater. Due to time constraints of the design, neither was possible and an alternative was necessary for testing.

Moving away from the PVC fabric seemed to be the most viable option and flex ducting proved to be a great substitute. The advantage to flex ducting is that it does not create pinch points when folding on itself. This allowed for more uniform expansion generate what we saw as more forces in the x-direction. The reason the flex ducting did not pinch itself is because there is a built in spring to it. This internal spring served as a great material guide for folding.

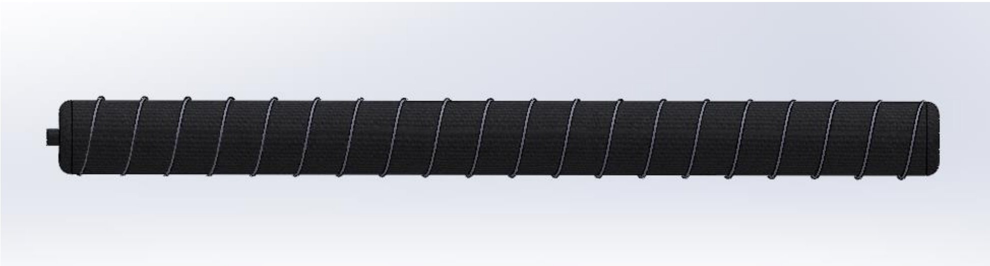


Figure : Air-beam Model 2 Expanded Spring

The second model of air beams made similar to flex ducting proved to expand properly and generated a strong lateral force in the x-direction. The beam however had difficulty folding after expanded. Further conceptual design was done to create a beam which was made from a spring with a smaller natural state which could expand to the desired size of the structure.

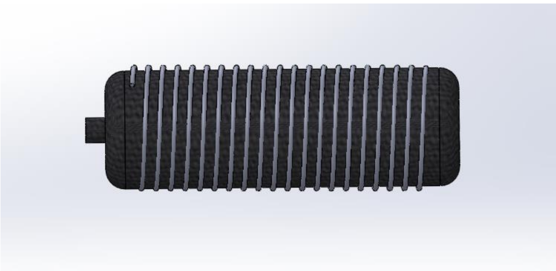


Figure : Air-beam Model 3 Closed Spring

The figure above showed a collapsed air-beam with the conceptual spring design. The hopes are to develop an actual model of this design in further design.

H. Analysis

In order to analysis the structure of the air-lock, we created a Solidworks analysis and did calculations. Our analysis is based on our theoretical stress values the structure will withstand during use. Further analysis will be done when the actual materials are used.

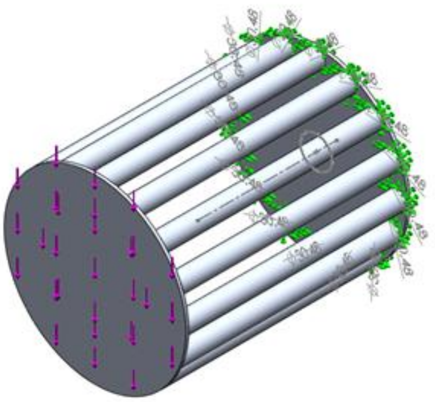
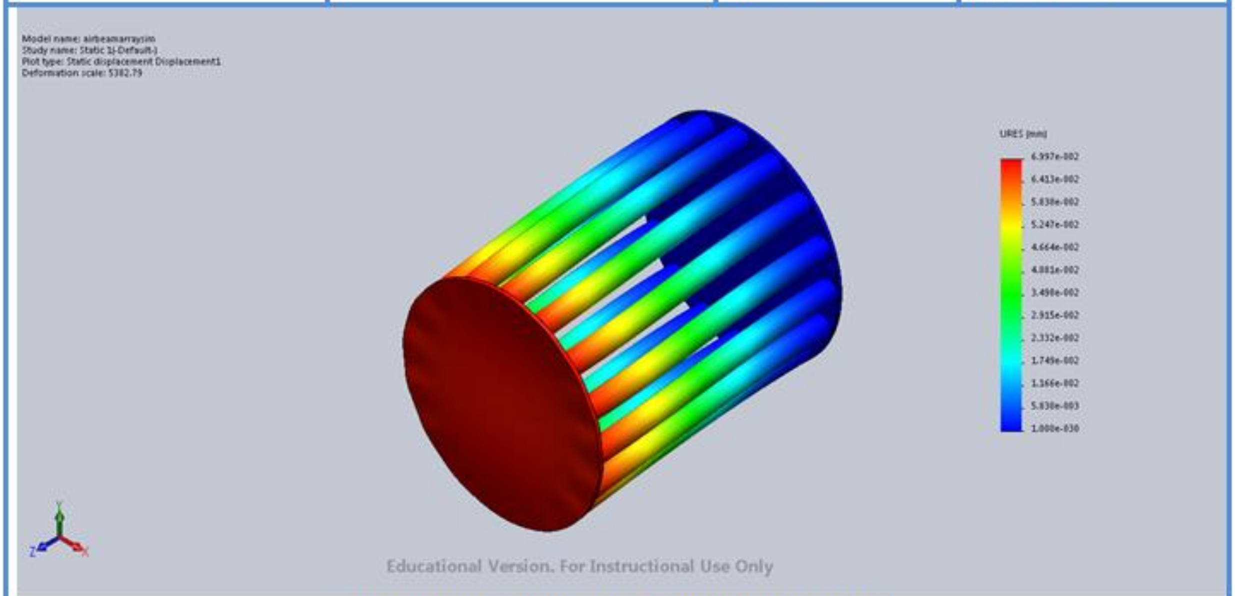


Figure : Test analysis attachments. (left) force (right) attachment

We decided to analyze the structure similar to a cantilever beam analysis. Our hopes were to see the pressure distribution along the beams to find what the week points would be.

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 29	0.0699653 mm Node: 15989

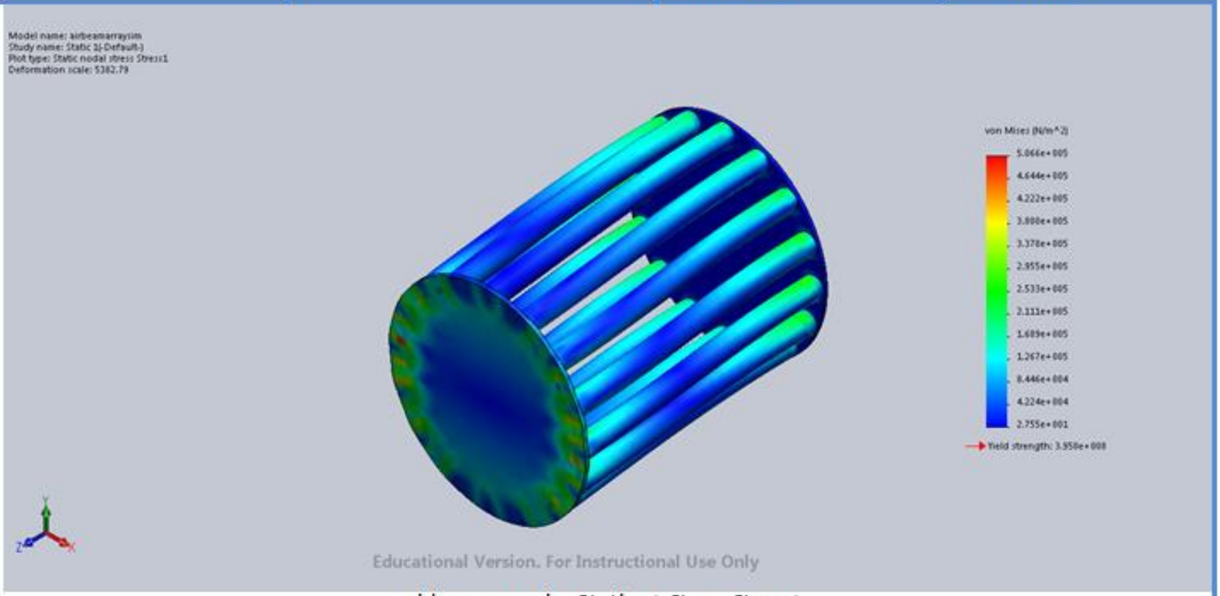


airbeamarraysim-Static 1-Displacement-Displacement1

Figure – Displacement Representation

As shown in the figure, the majority of disfiguration is at the detached portion of the beam. The beam remains more true to its original shape the closer to the shuttle you go.

Name	Type	Min	Max
Stress1	VON: von Mises Stress	27.5477 N/m^2 Node: 22484	506615 N/m^2 Node: 16076



airbeamarraysim-Static 1-Stress-Stress1

Figure : Stress Analysis of Structure

This figure shows the stress that the beams will be experience under a load at the end of the airlock. This shows that there are higher pressures along the connections of the airlock.

Force exerted on outer bulkhead: winch retraining force required calculation

To begin finding the retraining force required by the winches we must first find the area of the portions of the chamber and the air beams that will be acting on the outer bulkhead.

$$(1)\ Area = \pi r^2$$
$$(2)\ Area\ of\ main\ chamber\ bladder = \pi(54in)^2 = 9161in^2$$
$$(3)\ Area\ of\ air\ beam = \pi(12in)^2 = 452in^2$$

There are 16 airbeams in the structural array.

$$(4)\ Area\ of\ air\ beam\ array = 452in^2 * 16 = 7238in^2$$

The pressure inside the main chamber bladder is approximately 8.5 psi. We must find the force applied on this pressure on the outer bulk.

$$(5)\ Force\ applied = Pressure\ X\ Area$$
$$(6)\ Force\ applied = 8.5psi\ X\ 9161in^2 = 77{,}869\ lbf$$

The pressure inside the air beams will be relatively small this is due to the nature of expansion process and sequence. The winches will only be applying a retraining force during deployment and re-packing. Once the air lock is fully deployed the cross-woven fabric that the air beams and the main chamber bladder are made out of will be fully extended, and will be applying the retraining force required to stop further expansion. The deployment sequence essentially operates in such that the main chamber is fully inflated and expanded, and once that process is complete the air beams begin their inflation process. Due to the sequence the winches will not be required to apply any retraining force during the inflation of the air beams, as the main chamber bladder will be providing that force.

Once we complete conduct our prototype we will conduct tests to further understand how the force required by the winches changes during the deployment and re-packing processes. This will allow for more accurate calculations concerning the for flight concept design.

$$(7) Force\ applied(safety\ factor) = 8.5psi\ X\ 9161in^2 X\ 4 = \mathbf{300{,}000\ lbf}$$

Stress concentrated at winch connection point on outer bulkhead: optimization study of connection

Each winch will be applying 50,000 lbf during the deployment process. We need to identify the smallest diameter possible while adhering to the safety factor of 4 required to no failure to occur at the connection point. We will be assuming that a fatigue cycle analysis will be unnecessary due to the small number of expected cycles. Material for this study will be aluminum alloy 2024-T351 yield strength of 41 ksi.

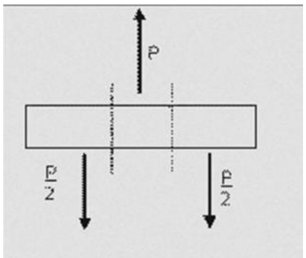


Figure 2: Force diagram of connection.

Deriving minimum area required from the shear stress

$$\tau = \frac{P}{A}$$

Where P = 200,000lbf and $\tau = 41ksi$

$$Minimum\ required\ area = \frac{200{,}000lbf}{41000psi}$$

$$Minimum\ required\ area = 4.88in^2$$

Due to the two point connection we divide the required area by 2.

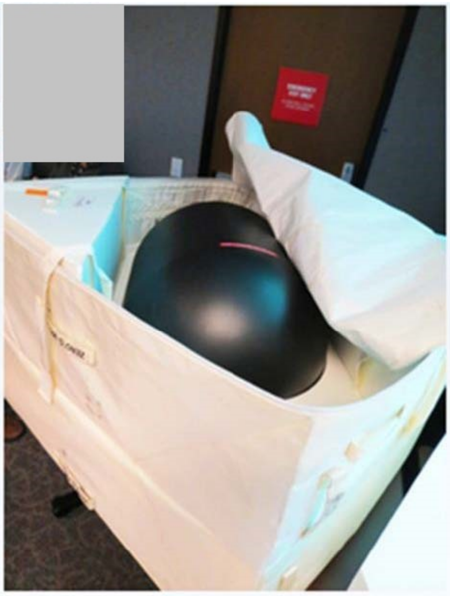
$$\boldsymbol{Minimum\ required\ area = 2.44in^2}$$

$$\boldsymbol{Diamter\ of\ connection\ joint = 1.76in}$$

Air system: study finding deployment sequences possible with given air supply.

The air provide to the air lock comes from four high pressure gas tanks pressurized to

6,000 psi



A NORS tank seen in its packing for flight. The tanks are filled with nitrogen or oxygen at 6,000 pounds psi and are used to refill the gaseous nitrogen and oxygen systems on the International Space Station.

Image Credit: NASA

Figure #1: 6,000 psi gas tanks for station & airlock air supply

According to the article released by NASA these tanks are 36 inches long and have a diameter of 21 inches.

$$Volume\ of\ supply\ tank = \pi r^2 l = \pi(10.5in)^2(36in) = 12{,}468.9in^3$$

$$Volume\ required\ to\ fill\ main\ chamber\ bladder = \pi(54in)^2(144in) = 1{,}319{,}167in^2$$

$$Volume\ required\ to\ sixteen\ air\ beams = \pi(12in)^2(144in)(16) = 1{,}042{,}305in^2$$

Using the given volumes and the air pressures we want to find out how much volume of air we have available when the air inside the high pressure tank is reduced to the working pressure of 8.5psi.

We will assume ideal gas conditions.

$$PV = nRT$$

Where P = pressure, V = volume, n = mols, R = ideal gas constant, T = Temperature. We will assume temperature remains constant.

$$\frac{P_1V_1}{n_1RT_1} = \frac{P_2V_2}{n_2RT_2}$$

This is a closed system so we know that n remains constant. This simplifies to.

$$P_1V_1 = P_2V_2$$

We are looking for V_2.

$$V_2 = \frac{P_1V_1}{P_2}$$

$$V_2 = \frac{(6{,}000psi)(12{,}468.9in^3)}{(8.5psi)}$$

$$V_2 = 8{,}801{,}576in^3$$

What this means is that for each of the four tanks at 6,000 psi we will have a usable volume of air of $8{,}801{,}576in^3$ at 8.5psi. Giving us a total of $\mathbf{35,206,305in^3}$ of usable air from all four tanks.

$$Total\ volume\ avaible\ from\ air\ supply = \mathbf{35,206,305in^3}$$

We now calculate how many deployment cycles this allows the airlock to have on a single mission.

$$Required\ volume\ per\ deployment\ cycle = 2{,}361{,}472in^2$$

$$Deployment\ cycles\ per\ mission = \frac{Total\ volume\ avaible\ from\ air\ supply}{Required\ volume\ per\ deployment\ cycle}$$

$$Deployment\ cycles\ per\ mission = \frac{35{,}206{,}305in^3}{2{,}361{,}472in^2} = 14.9\ cycles$$

$$\mathbf{Deployment\ cycles\ per\ mission = 14\ Cycles}$$

I. Test Results

So far, our test results have been obtained from a mockup, which renders conclusions not as relatable to an actual prototype. However, our results will allow the next iteration of this program to make more educated choices when designing a test article, be it a better engineered mock-up, or even an prototype.

Also, aside from results related to the mock-up design, we achieved important goals for a project of this complexity. The thorough research of existing literature on inflatable space structures and its enabling technology will allow next year's XHAB team to concentrate on realizing more concrete ideas, instead of having to prove their feasibility.

Also, an initial contact with the company that manufactures the enabling technology for our design was made. Unfortunately, although the initial exchange of messages with this company was fluent and promising, they ceased communications without a reason. Even after several attempts to contact them, neither response, nor acknowledgement of receipt was received. We believe that this may be due to a problem with commercial interests on their part, as this company has been involved in a similar project with NASA. We hope that, in the future, our client will intercede on behalf of the XHAB team, so as to secure technical cooperation. This is a necessary step to building a prototype in the future.

As regards the mock-up, a sizeable list of conclusions was obtained. Again, we are confident that this initial iteration of the XHAB program will greatly improve the results of next year's team.

The folding sequence worked as expected, the only observation being that the force exerted by the open flow air-beams was marginally sufficient, and delivered very suddenly.

The winch worked as expected, helping in the retraction process, and was especially useful in containing the force exerted by the air-beams, which would otherwise deploy violently.

The air-beams did not entangle, but they did spread around in an unorderly way. If an inner fake airtight bladder was in place, it would have probably helped to keep the air-beams from clustering in the centerline of the assembly.

As regards the air-beams themselves, a first attempt was made at fabricating them out of PVC fabric. This proved to be problematic, because the weight of the fabric would be high enough cause wrinkles along id when folded. The wrinkles would, in turn, significantly increase the air-induced forces necessary to deploy them, to the point of not being possible to expand the assembly.

A decision was made to use small diameter commercial HVAC tubes. These tubes where considerably lighter per unit length when compared to the PVC fabric air-beams. Also, these tubes had a reinforcing wire that was embedded into the tube in a spiral. This reinforcing prevented the tube from wrinkling.

In the case that future teams were to go for an all fabric system, it would be highly desirable to have at least a single working example of an air-beam with the high quality fabric intended for use in the flight concept. This would allow making extensive, designing validating testing on the enabling technology. In the case that a team was able to procure at least three air-beams, it would even be possible to do without the roller support for the assembly.

Continuing with the air-beams, if a future attempt was made at making them out of fabric, it would be highly recommendable to permanently attach the air-beams at both ends to a circular fabric ring. This ring would, in turn, be attached to the endplates by means of bolts and washers, in a similar way to the flight concept.

Although the testing of a scaled airtight bladder itself would not be of much insight, it would help model the interaction with the air-beams, both with the bladder inflated and deflated. The bladder, of course, need not to have hatches install, as it would not offer any useful information regarding the design. The hatches, however, could be taken into account by inserting similarly heavy objects, scaled in dimension and weight to the flight concept.

The design of the endplates is a further necessary improvement. Our team's attempt at fabricating these out of fiberglass did not meet the expectations. It would be highly desirable to try and improve the quality of the endplates. If a second or third attempt at this was met with success, it would be worth trying to go for carbon fiber, honeycomb construction. The price of this technology is nowadays within the budgetary constraints of the program.

As regards the air system itself, it was concluded that in a future it should be attempted to go to a constant pressure system. Such a system would offer a much precise control of the deploying sequence and speed. It would also be representative of the flight concept, which of course uses a closed air system. It would also make the implementation of control software easier, as each individual tube's pressure could be monitored, and would represent a feedback variable for such software.

Software control would be another obvious step in the next attempt. We think that, given more manpower, a set of rules could be developed to control the deployment sequence. Control signals to relays could be sent to valves to open and close, to pressurize or deflate the air-beams. Gas pressure sensors could, in turn, provide feedback to control the aforementioned delivery of gas to air-beams. Another conditional variable that would further refine the deployment sequence would be a position sensor. Such a system could be a triad of cheap range finders that would monitor the parallelism of the outer endplate. If the outer endplate was not completely vertical, it would imply that the air-beams are, for example, not being pressurized at the same speed, or that one or more is leaking air.

J. Conclusion

Through our conceptual design we were able to meet all of our major design objectives presented us by NASA. We were able to come up with a new novel inflation mechanism to allow for the deployment of our air lock design. Through past literature and our analysis we were able to adhere to the safety factor of four given to us, we were also able to prove the function of our device in a zero gravitational acceleration environment. We were able to show how we can provide a slow and control deployment and retraction through our original winch design which ended up being scrapped due to the weight and power constraints it presents. We were then able to adjust our design after this failure to our spring interwoven method, which presents multiple improvements on our original design. This was a very ambitious project. Conceptually designing a fully function air lock device is an extremely large problem to tackle. Some of the failures of our design are that it is not extremely detailed. It is such a large problem that it can be hard to exactly nail down what section should be focused on. We chose to keep our focus towards the structural side of the device, as that was where our real innovative ideas were located. This led to decreased details in the electrical systems and the small intricacies of the air system. Our air system is a very basic layout, not nearly as detailed as a real flight capable system would be. The major lacking section of the air system is the feedback controls system. We essentially only have the logical plan for the system laid. It needs to be much more developed.

K. User's Manual

Inflating the Airlock

1) First engage airflow into the main chamber of the airlock
    a. The microcontroller will begin reading the pressure in the main chamber of the airlock. Once the main airlock chamber reaches 5 psi the winch system begins to release allowing for the expansion of the structure to begin.
        i. If the winch system feedback system were to fail, there are controls that allow user to engage the winches.
    b. When the main airlock chamber is fully inflated to 8.5 psi the air beam array begins inflation by the process of the pressurized feedback system explained above on page (whatever page number it winds up being).
        i. If beams fail to inflate by the microcontroller the user will be able to do so manually.

Performing Extravehicular Activities (EVA)

1) Astronauts suit up near the ship side hatch for EVA (extravehicular activities)
2) The main chamber air bleeds off to the outside surroundings in a controlled manner using the feedback sensor network
3) The astronauts exit the airlock
4) The astronauts enter the airlock post EVA
5) The outer hatch locks
6) The main chamber is slowly depressurized according to current campout protocol. This continues until the pressure reaches 8.5 psi
7) The airlock is tested for breathable composition
8) Once the air is deemed breathable, astronauts remove gear, and enter the ship

Deflating the Airlock

1) User initiates deflation sequence.
    a. First the air beams deflate and the air bleeds off in a controlled manner. This is accomplished again by using a microcontroller and a feedback sensor network described before.

i. If the array does fail, the user will be able to manually open the valves to depressurize the air beam array.

b. After the air beams are full deflated the main chamber begins to depressurize by the use of the microcontroller and feedback network.

c. When the main airlock chamber reaches 5 psi, the winch system begins to retract until the airlock is returned to its original compact size.

L. Budget

System	Budgeted funds
Bladder material & construction	
Air equipment	
Bulk head fiber glass	
Electrical system	
Test frame	
Emergency fund	
Total	

Figure : Original Budget Estimate

The original plan was to order high powered air compressors and make the bladders from space like materials. We soon discovered the danger involved in building a high pressure device and that buying materials for space purposes would cost much more than our budget allowed. We redesigned the mock-up to test our questioned portion of the design and decreased the cost.

M. Cost of Materials

System	Spent as of 4/30/15
Bladder material & construction	
Air equipment	
Bulk head fiber glass	
Electrical system	
Test frame	
Emergency fund	
Total	

Figure : Spending on Project

N. Schedule

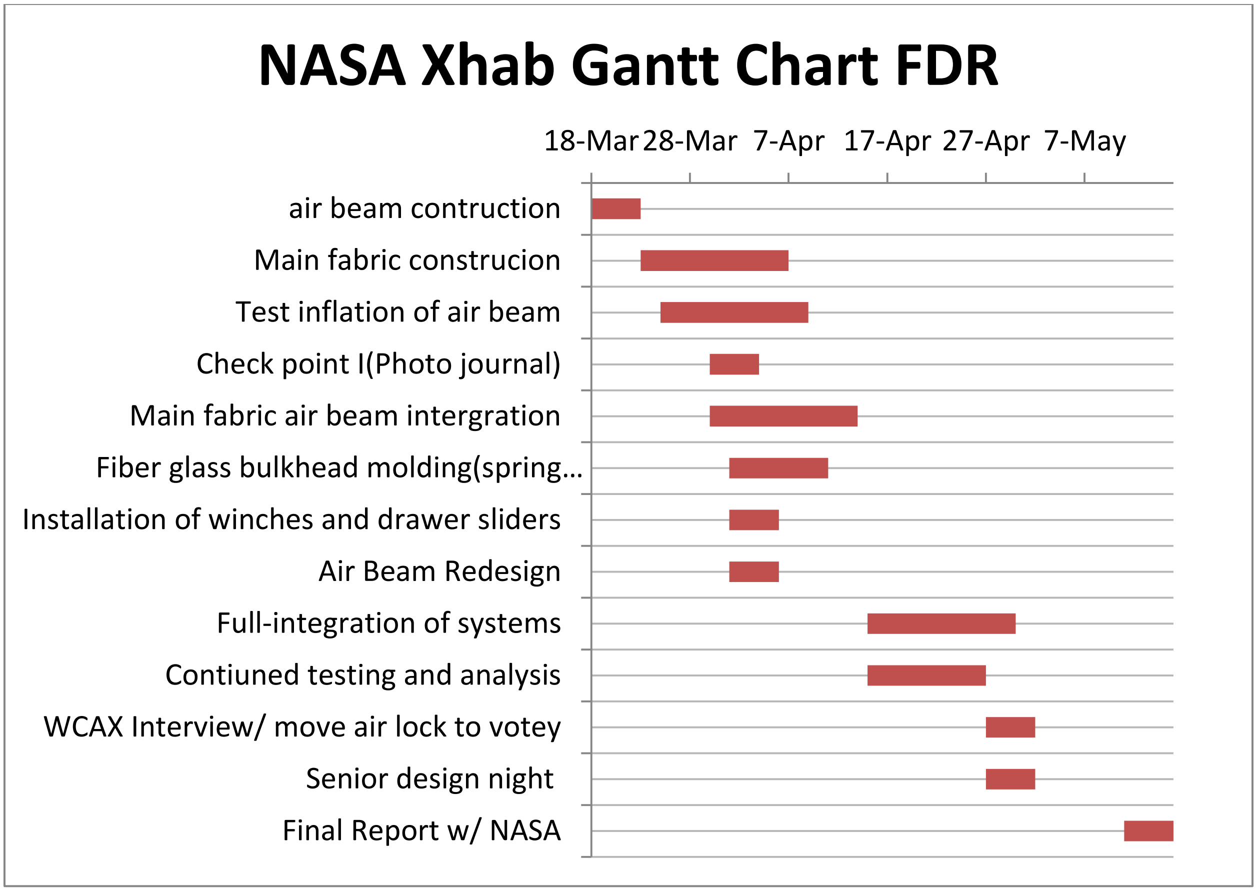
NASA Xhab Challenge Overview Schedule			
Task	**Start Date**	**Durration(days)**	**End Date**
Final Equipment Purchase	13-Feb	12	16-Feb
Air system layout	13-Feb	15	1-Mar
design software automation of air system/winch contrc	13-Feb	45	1-Apr
Support frame construction	13-Feb	15	1-Mar
Air system support frame integration	15-Feb	15	1-Mar
Fiber glass bulkhead molding(spring break work)	1-Mar	10	10-Mar
Check point I (Video)(spring break work)	1-Mar	5	10-Mar
Installation of winches and rollers to frame	10-Mar	5	15-Mar
air beam contruction	10-Mar	5	15-Mar
Main fabric construcion	15-Mar	15	1-Apr
Test inflation of air beam	15-Mar	15	1-Apr
Main fabric air beam intergration	15-Mar	15	1-Apr
Full-integration of systems	1-Apr	15	15-Apr
Check point II (Progress shown to NASA)	1-Apr	15	15-Apr
Contiuned testing and analysis	15-Apr	12	27-Apr
Senior design night	27-Apr	5	1-May
Final Report w/ NASA	11-May	5	15-May

Schedule as of PDR, December 2014

Task	Start Date	Durration(days)
air beam contruction	18-Mar	5
Main fabric construcion	23-Mar	15
Test inflation of air beam	25-Mar	15
Check point I(Photo journal)	30-Mar	5
Main fabric air beam intergration	30-Mar	15
Fiber glass bulkhead molding(spring break work)	1-Apr	10
Installation of winches and drawer sliders	1-Apr	5
Air Beam Redesign	1-Apr	5
Full-integration of systems	15-Apr	15
Contiuned testing and analysis	15-Apr	12
WCAX Interview/ move air lock to votey	27-Apr	5
Senior design night	27-Apr	5
Final Report w/ NASA	11-May	5

Final Schedule, May 2015

The Major differences between the PDR schedule and FDR schedule are that the design of the model was changed. During the PDR we were still under the impression that we would be designing a 1:1 scale model, however at the beginning of the spring semester we made a decision with NASA advisement to scale down our demonstration model. This changed lots of items in our design as well as the timing when things would actually be built. We ended up getting rather behind schedule, completing almost all of the fabrication work in early and mid-April. After we completed the first iteration of our model we found through testing that our first air beam design was not going to work. We went back to the drawing board to try to find a solution, which we did, however this meant that we did not have a successful demonstration of the model until the 3rd week in April.



Final Gantt char of actual fabrication schedule completed

O. Test Plans

The inflatable air-lock is still in development. Further design will be necessary for tests to prove useful. Since we conceived a design for the model, each individual part will need to be developed and tests with the proper materials. This test plan is for the actual parts of the design.

DYNAMIC LOADS
Astronauts w/ EVA suits entering\egressing airlock, carrying 20 kg of equipment\samples, as well as performing usual activities: donning of EVA suit, walking, falling down, etc.
Testing of max dynamic load & likely resonating scenarios.

STATIC LOADS
Yearlong deployment of the system, with max load at end of cantilever.
Testing of max (fail) load on cantilever.

TEMPERATURE CYCLES
Year long testing of deployed airlock in the desert (extreme temp. gradient).
Several, individual, tests on extreme temperature environments (north pole, “furnace”, etc.).

DEBRIS/MMOD IMPACT
Testing projectiles of different caliber, speed, shape and incidence angle on outer layer.
Scuff and puncture test on inner scuff resistant layer & bladder

EM RADIATION
Combination of small scale testing of sample materials.
Use of test data to fine-tune computer simulations.

FAIL MODES
Devise fail mode scenarios for: In-transit-packed; docking\first deployment; pack up; progressive loss of integrity by projectile impact, collision, fire or loss of pressurizing capabilities.

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